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FIRE SAFETY OF EARLY CHILDHOOD CENTRES IN HIGH RISE BUILDINGS IN AUSTRALIA

FINAL REPORT

Prepared for:	Australian Building Codes Board
Prepared by:	RED Fire Engineers Pty Ltd
Report No:	JA18-00224
Revision:	Final (Rev 1)
Date:	22 February 2019

Document History

Revision	Date	Document control		
Draft	9/11/2018	Issue:	For client comment	
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Final (Rev 1)	22/02/2019	Issue:	For approval incorporating ABCB comments	
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Executive Summary

The research objectives of this study are to investigate whether the current fire safety related Deemed-to-Satisfy Provisions of the NCC Volume One (hereinafter referred to as NCC) provides an acceptable level of fire and life safety to the occupants in Early Childhood Centres when the Early Childhood Centres are located above ground level, i.e. level 1 and above.

The hypothesis is that the presence of Early Childhood Centres above ground level in Low-Rise and High-Rise buildings that adopt the current NCC DtS Provisions increases the risk of occupant fire and life safety outside the tolerable levels.

The research compares the fire and life safety risk level of occupants in Early Childhood Centres located on an upper level in low-rise and high-rise buildings against:

- the acceptable risk level in the ABCB draft Tolerable Risk Handbook (absolute risk measure)
- an Early Childhood Centre located on the ground level (relative risk measure)

The acceptable individual risk for an Early Childhood Centre is 3.39×10^{-7} year^{-1} on fire and life safety in the draft ABCB draft Tolerable Risk Handbook which has been used as a benchmark for this study. The benchmark for the Individual Risk is an outcome in the form of fatalities. However, it should be noted that the measure for Individual Risk is not the same as the expected number of fatalities per year.

The acceptable societal risk for an Early Childhood Centre on fire life safety in the draft ABCB draft Tolerable Risk Handbook is provided in Table 1.

Table 1: Acceptable societal risk in the draft ABCB Tolerable Risk Handbook

Fatalities (N)	Acceptable frequency (F)
N=1	3.00×10^{-6}
N=10	3.24×10^{-7}
N=100	1.58×10^{-8}
N=1000	1.00×10^{-12}

In this study, harm is defined as a fatality. It is common practice to only quantify the number of fatalities in quantitative risk analyses. However, there are common correlations between fatalities and injuries. The harm measure therefore implicitly considers injuries.

The research has considered various design cases. Each design case has a different building height, and the location of Early Childhood Centres also varies within the building. The design cases, along with the associated fire safety measures that are prescribed for these buildings in the DtS Provisions, are as described in Table 2.

Table 2: Design cases for evaluation

Design case	Number of storeys/ height	ECC location	Fire-isolated stairs	Smoke detection	Sprinklers	Stair pressurisation	Zone smoke control system
#1	1 (Base Case)	Level 0 (i.e. ground level)	N/A	No	No	N/A	N/A
#2 & 3[1]	2 – less than 25 m effective height	Level 1	No	No	No	No	No
#4	8 – less than 25 m effective height	Level 7	Yes	Yes	No	No	No
#5	9 – over 25 m effective height	Level 8	Yes	No	Yes	Yes	Yes

Furthermore, the results of the research indicate that there are two distinct cases that affect the form of evacuation (and thus egress times) from an Early Childhood Centre:

- Type A – Children can't self-egress. Staff will have to carry the children to a place of safety.
- Type B – Children can self-egress. Staff will assist children in an evacuation.

Therefore, our study has also quantified the risk associated with both Type A and Type B evacuation scenarios.

[1] Design case #2 is a two storey building with an Early Childhood Centre occupying both floors. Design case #3 is an Early Childhood Centre located above a Class 9b library on ground floor.

The study indicates that none of the design cases (including an Early Childhood Centre on ground level) meets the acceptable individual risk as specified in the draft ABCB Tolerable Risk Handbook. The estimated absolute individual risks and the ratio between the estimated absolute individual risks and the acceptable individual risk (expressed as percentage of acceptable risk in the tables) are shown in Table 3 and Table 4.

Table 3: Individual Risk vs Acceptable Risk – Type A evacuation

Design Case	Individual Risk	% of Acceptable Risk
#1	5.58E-04 $year^{-1}$	164656 %
#2	3.61E-03 $year^{-1}$	1064299 %
#3	7.22E-03 $year^{-1}$	2128597 %
#4	8.65E-03 $year^{-1}$	2552619 %
#5	7.05E-04 $year^{-1}$	208109 %

Table 4: Individual Risk vs Acceptable Risk – Type B evacuation

Design Case	Individual Risk	% of Acceptable Risk
#1	5.58E-04 $year^{-1}$	164656 %
#2	5.10E-03 $year^{-1}$	1505290 %
#3	8.71E-03 $year^{-1}$	2569589 %
#4	5.32E-03 $year^{-1}$	1568691 %
#5	3.59E-04 $year^{-1}$	105875 %

The main contributor to the acceptable risk being exceeded is the frequency of fire starts in buildings as well as a large proportion of the scenarios in the Quantitative Risk Assessment (QRA) leading to fatalities. The probability of a fire causing a fatality must be 6.1×10^{-5} or lower to meet the acceptable risk. Such a small probability of a fire causing a fatality is probably not feasible to achieve, even with numerous independent and highly reliable fire safety measures such as sprinklers, smoke detectors, and other active and passive fire protection systems.

A sensitivity study on the frequency of fire starts has concluded that the model and data used for calculating the frequency of fire starts in the study is reasonable and does not provide an over-estimation of the risk level. There is a general lack of data for frequency of fire starts related to only Early Childhood Centres. Typically, Early Childhood Centres are lumped together with other categories of use (e.g. libraries, theatres, cinemas, public halls, places of worship, schools, nightclubs, sports stadia etc.) under BCA classification 9b Assembly Building which leads to an uncertainty regarding the actual frequency of fire starts in Early Childhood Centres. We have not been able to determine that the frequency of fire starts has been overestimated by reviewing statistics related to the most common sources of ignition. However, due to the uncertainty acknowledged, we have carried out a sensitivity analysis where the frequency of fire starts is decreased by one order of magnitude (i.e. multiplied by 10^{-1}) and increased by one order of magnitude (i.e. multiplied by 10). The sensitivity analysis on frequency of fire starts shows that all design cases (including an Early Childhood Centre on ground level) still exceed the acceptable individual risk stipulated in the draft ABCB Tolerable Risk Handbook.

Societal risk, expressed in the form of FN-curves, was estimated for all design cases. It should be noted that only the consequences associated with the occupants in Early Childhood Centres have been incorporated into the societal risk estimates, rather than the entire building which is typically the norm. This is due to the scope of this project. In all design cases (including an Early Childhood Centre on ground level), the tolerable risk criteria expressed in Table 1 are exceeded continuously throughout the full spectrum of consequences (see for example Figure 1). The lowest societal risk in this study relates to Design Case #5 for Type B evacuation which is illustrated in Figure 1. A sensitivity study on the frequency of fire starts was also included for the societal risk estimates and the pattern is identical to that of the individual risk. As can be seen in Figure 1, even at the lower bound of this sensitivity study, the estimated societal risk exceeds the acceptable societal risk throughout the full spectrum of consequences.

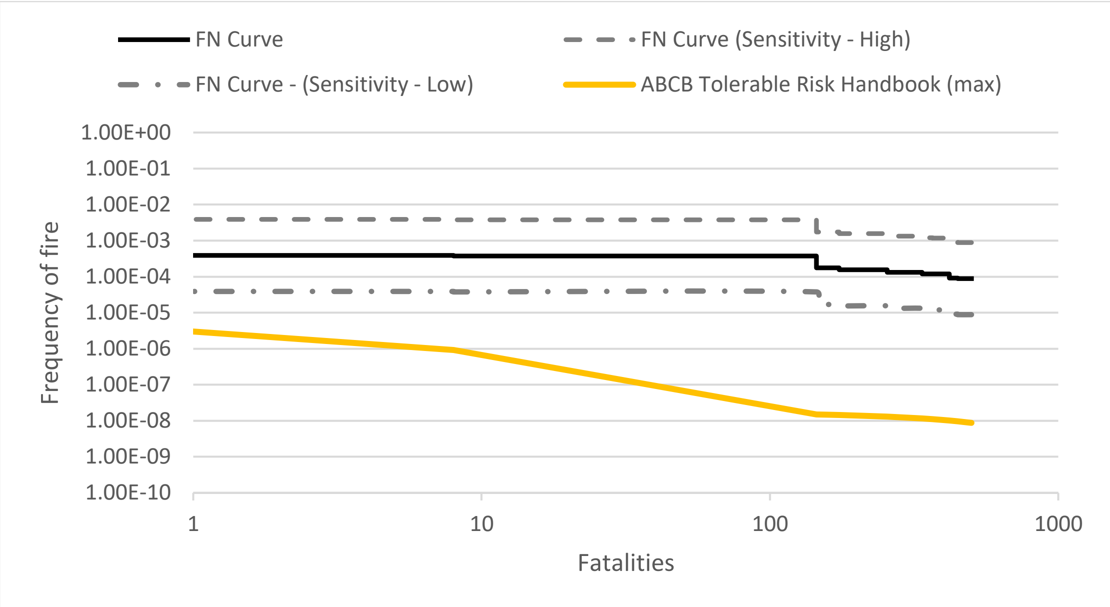

Figure 1: FN-curve for Design Case #5 – Type B evacuation

An alternative means of measuring risk is to benchmark it against a design that is considered to be acceptable to form a Relative Risk measure. This may aid in decision making where uncertainties on the validity of absolute risk measures exist. Using Design Case #1, an Early Childhood Centre located on ground level (DtS Solution) as the benchmark for what can be considered an acceptable risk, it has been demonstrated that all Early Childhood Centres located above ground level are associated with an unacceptable relative risk. The Relative Risks for Type A and Type B evacuations are shown in Table 5.

The exception is for design case #5 in an Early Childhood Centre with Type B evacuation where the relative risk was predicted to be 0.6. However, the risk model includes assumptions that would lead to a higher risk in reality compared to the results predicted by the model. The sensitivity analysis also shows that the results is quite sensitive to certain parameters. Therefore, the results in Table 5 should be interpreted as none of the design cases 2 to 5 are associated with an acceptable risk using the estimated absolute risk level of an Early Childhood Centre located on ground level as the benchmark.

Table 5: Relative Risk – Type A and Type B evacuations

Design Case	Relative Risk Type A	Relative Risk Type B
#1	1.0	1.0
#2	6.5	9.1
#3	12.9	15.6
#4	15.5	9.5
#5	1.3	0.6

Based on the results of this study, it is recommended that the NCC is amended to require the following additional DtS Provisions where an Early Childhood Centre is located above ground level:

- An automatic sprinkler system in accordance with AS 2118.1 including a building occupant warning system (AS 1670.1) or an emergency warning and intercom systems (AS 1670.4) as appropriate is provided throughout the entire building. Sprinklers are recommended to be quick response heads; concealed and flush type sprinkler heads shall not be used even when the heat sensitive elements of these sprinklers are classified as fast response.

- The Early Childhood Centre is to be separated into a minimum of two fire compartments with a minimum FRL of (120)/120/120 with horizontal egress being provided between the two compartments. All of the occupants in the fire compartment with the largest size must be able to be accommodated in the smallest fire compartment, whilst the smallest fire compartment is assumed to be fully occupied as per Table D1.13 of the NCC.

- At least two horizontal exits shall be provided between two fire compartments that the Early Childhood Centre is divided into. The horizontal exits shall be located at least 9 m from each other.

The study has explicitly evaluated the proposed recommendations using the QRA methodology. The results indicate that none of the design cases meet the acceptable individual or societal risk even with these measures implemented. The relative risks for the recommendations have been calculated against Design Case #1 (Early Childhood Centre located on ground level, the DtS Solution). It should be noted that Design Case #1 does not include any of the recommended additional measures proposed for Early Childhood Centres above ground.

The relative risks for the design cases with the additional safety measures implemented are provided in Table 6. In almost all of the design cases, the relative risk is half or less than that of an Early Childhood Centres located on ground level. The exception is for Design Case #3 for Type A evacuation where the fire compartmentation was found to not have a significant impact according to the simulation results.

A detailed analysis shows that two of the fire scenarios providing the largest impact on the results are within the order of a few seconds away from having a consequence of zero fatality. Assuming a zero consequence for these two scenarios results in the relative risks presented in Table 7. We are of the opinion that this is within the bounds of the uncertainty of the model and is more consistent with the overall risk reduction impact as a result of the risk reducing measures proposed.

Table 6: Relative Risks with recommended safety measures

Design Case	Relative Risk (Type A)	Relative Risk (Type B)
#2	0.48	0.05
#3	0.96	0.11
#4	0.34	0.28
#5	0.28	0.21

Table 7: Relative Risks with recommended safety measures (modified)

Design Case	Relative Risk (Type A)	Relative Risk (Type B)
#2	0.48	0.05
#3	0.16	0.11
#4	0.34	0.28
#5	0.28	0.21

Table 7 demonstrates that by implementing the proposed additional safety measures, the Early Childhood Centres located above ground level are associated with a similar or lower risk compared to an Early Childhood Centre located on ground level. Accounting for the uncertainties involved (e.g. egress and fire modelling, counter-flows from fire brigade and other building occupants, lack of reliable data, frequency of fire, reliability of fire safety systems), we are of the opinion that all of the proposed fire safety measures should be included in a future revision of the NCC to ensure that the fire and life safety risks to which occupants in Early Childhood Centres above ground level are exposed are acceptable.

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Abbreviations and Definitions

Abbreviation/Term	Description
ABCB	Australian Building Codes Board
ACT	Australian Capital Territory
BMF	Building Ministers forum
CFD	Computational Fluid Dynamics
Class 2 to Class 9 buildings	As defined in the NCC
ECC	Early Childcare Centre (as defined in the NCC)
IFEG	International Fire Engineering Guidelines 2005
NCC	National Construction Code 2016 Volume One (incorporating Amendment #1) Building Code of Australia Class 2 to Class 9 Buildings
NFPA	National Fire Protection Association
NSW	New South Wales
NT	Northern Territory
NZBC	New Zealand Building Code
QLD	Queensland
QRA	Quantitative Risk Assessment
SA	South Australia
TAS	Tasmania
VIC	Victoria
WA	Western Australia

1 Introduction

1.1 Background

1.1.1 The way we live in cities has been changing rapidly over the past few years, with early trends towards high-rise working being followed by trends in high-rise living, schools and child care centres. With these trends come the potential for new hazards that are not easily captured by fire statistics. These hazards may or may not be accounted for or even thought of by building designers.

1.1.2 The dominant occupant characteristics in Early Childhood Centres are the number and age of the children who generally do not understand fire alarms, fire hazards, and require assistance to evacuate.

1.1.3 Not only are children more vulnerable to fire and smoke, they take longer to evacuate than adults. Children may also slow down evacuation if they share their escape route with other building users. Evacuation of children may also require significant resources from attending fire fighters, who may be unaware of the presence of a childcare centre on the top floor of a shopping centre, for example.

1.1.4 The BMF has directed the ABCB to investigate and report on whether the code is adequate, or to propose changes to the code. As a result, the ABCB is carrying out a detailed investigation into the fire safety of children particularly in early childhood centres in high rise buildings as part of the Holistic Review of Fire Safety (HRFS) Project.

1.1.5 Although this is not indicated explicitly in the NCC, early childhood centres located on higher levels other than the ground floor are not covered by the NCC. This is revealed in the Guide to the NCC.

1.1.6 Section E2.3 of the NCC states that "Additional smoke hazard management measures may be necessary due to the— (a) special characteristics of the building; or (b) special function or use of the building; or (c) special type or quantity of materials stored, displayed or used in a building; or (d) special mix of classifications within a building or fire compartment, which are not addressed in Tables E2.2a and E2.2b."The Guide to the NCC Volume One Amendment 1 states that "E2.3 may be applicable in situation where a child care centre is located above ground floor level or within a commercial building. Safety of children is paramount. They will need assistance to evacuate. As egress arrangements depart from providing exits direct to a road or open space, (usually provided at ground floor level) so does the potential for things to go wrong. The NCC does not specifically address child care centres at other than the ground floor."

1.1.7 Despite this guidance, the NCC does not prohibit Early Childhood Centres above ground floor, nor does it specify Deemed-to-Satisfy requirements for this situation.

1.1.8 The NCC is a constantly evolving code that needs to be updated to account for new and unique building uses, and risks arising from these. Building practitioners also need guidance from the ABCB and NCC about these trends. In turn, the ABCB has sought expertise from experienced fire safety engineers who can provide the background necessary to examine the code in detail, and if appropriate provide technical support to changing the code.

1.1.9 RED Fire Engineers has been engaged by the ABCB to:

1. Review/confirm the adequacy of the current fire safety Performance Requirements and Deemed-to-Satisfy (DtS) Provisions of the NCC with regard to children in Early Childhood Centres in high rise buildings in Australia.

2. Compare the current NCC provisions against international requirements of similar countries.

3. Review Commonwealth, State and Territory and other jurisdictional body administrative and operational procedures and guidance information as to its impact on the safety of children within Early Childhood Centres in NCC compliant buildings.

1.2 Report Applicability

1.2.1 This report is for the use by ABCB to determine whether the current NCC requirements on Early Childhood Centres provide an adequate level of fire and life safety for the occupants in the Early Childhood Centres when the Early Childhood Centres are located above Ground level.

1.2.2 The opinions in this report do not represent the opinions of ABCB or Australian Government.

1.2.3 The findings and opinions expressed within this report are based on the conditions encountered and/or the information reasonably available at the date of issue of this document, and are applicable only to the detailed circumstances envisaged herein.

1.3 Assumptions and limitations

1.3.1 This report is based on the information and instructions contained in the:

- Approach to Market for the provision of an assessment of the fire safety of Early Childhood Centres in NCC high rise buildings, Reference Number ABCB RA/1-2018, published by the Commonwealth of Australia represented by ABCB,
- the study "NCC Early Childhood Centres Review" undertaken by Ove Arup Pty Ltd for ABCB, and
- the draft ABCB draft Tolerable Risk Handbook provided to RED Fire Engineers Pty Ltd.

1.3.2 This report is also based on the publications and literature related to childcare safety that are in the public domain which RED Fire Engineers Pty Ltd reviewed.

1.3.3 The fire engineering assessment and conclusions drawn in this report are limited to fire and life safety of occupants in Early Childhood Centres which is consistent with the objectives of the NCC. Property and content protection, insurer's requirements, environmental impact as a result of fire, business continuity, maintaining corporate image etc. have not been considered in this report.

1.3.4 The study is limited to the Deemed-to-Satisfy Provisions that are applicable to Early Childhood Centres in the current version of the NCC only, and have not considered potential Performance Solutions that may be formulated for such Centres.

1.3.5 Limitations affecting the assessments are presented in the relevant section throughout this report.

1.4 Applicable Legislation

1.4.1 The NCC is an initiative of the Council of Australian Governments developed to incorporate all on-site construction requirements into a single code, and is produced and maintained by the ABCB on behalf of the Australian Government and each State and Territory government.

1.4.2 The NCC is a uniform set of technical provisions for the design and construction of buildings and other structures, and plumbing and drainage systems throughout Australia. It allows for variations in climate and geological or geographic conditions.

1.4.3 Each State and Territory in Australia is responsible for enacting and enforcing building control legislation. In general buildings are required to comply with the National Construction Code (NCC) series. Volume One of the NCC is the Building Code of Australia for Class 2 to Class 9 buildings.

1.4.4 Early Childhood Centre (ECC) is defined in section A1.1 of the NCC as any premises or part thereof providing or intending to provide a centre-based education and care service within the meaning of the Education and Care Services National Law Act 2010 (Vic), the Education and Care Services National Regulations and centre-based services that are licensed or approved under State and Territory children's services law, but excludes education and care primarily provided to school aged children in outside school hours settings.

1.4.5 Under the Victoria Education and Care Services National Law Act 2010, Education and Care Service means any service providing or intended to provide education and care on a regular basis to children under 13 years of age other than—

(a) a school providing full-time education to children, including children attending in the year before grade 1 but not including a preschool program delivered in a school or a preschool that is registered as a school; or

(b) a preschool program delivered in a school if—

(i) the program is delivered in a class or classes where a full-time education program is also being delivered to school children; and

(ii) the program is being delivered to fewer than 6 children in the school; or

(c) a personal arrangement; or

(d) a service principally conducted to provide instruction in a particular activity; or

(e) a service providing education and care to patients in a hospital or patients of a medical or therapeutic care service; or

(f) care provided under a child protection law of a participating jurisdiction; or

(g) a prescribed class of disability service; or

(h) a service of a prescribed class.

1.4.6 Under the NCC, a building part that contains an Early Childhood Centre is classified as Class 9b Assembly Building.

1.4.7 The NCC provides a set of prescriptive DtS Provisions. The DtS Provisions are defined within the NCC as building solutions deemed to comply with the Performance Requirements of the NCC.

1.4.8 Deviations from the DtS Provisions are an acceptable option to comply with the NCC if the Performance Requirements of the NCC are met. The alternative method to demonstrate compliance is called a 'Performance Solution' (formerly known as an 'Alternative Solution').

1.4.9 The assessment of a Performance Solution can be undertaken using a variety of methods. These are defined in Clause A0.5 of the NCC. One or more, or a combination of these methods are adopted to determine whether the Performance Solution complies with the Performance Requirements of the NCC. The relevant Performance Requirements are determined in accordance with Clause A0.7 of the NCC. Compliance with Performance Requirements is undertaken in accordance with A0.2 of the NCC.

2 Overview of Research

2.1 Research Objectives

2.1.1 The research objectives are to investigate whether the current fire safety Deemed-to-Satisfy Provisions of the NCC provides an acceptable level of fire and life safety to the occupants in Early Childhood Centres when the Centres are located above ground level.

2.2 Hypothesis

2.2.1 That the presence of Early Childhood Centres above ground level in Low-Rise and High-Rise buildings that adopt the current NCC DtS Provisions increases the fire and life safety risk of occupants outside tolerable risk levels.

2.3 Benchmark

2.3.1 The research compares the fire and life safety risk level of occupants in Early Childhood Centres located on an upper level in low-rise and high-rise buildings against

- Tolerable risk level in the draft ABCB Tolerable Risk Handbook, and
- an Early Childhood Centre located on the ground level only.

2.3.2 The research considers various design cases. Each design case has a different building height, and the locations of Early Childhood Centres also vary within the building. The design cases, along with the associated fire safety measures that are prescribed for these buildings in the DtS Provisions are as described in Table 8. The assumed use of the design cases is explained by Table 9.

Table 8: Design cases for evaluation

Design case	Number of storeys/ height	ECC location	Fire-isolated stairs	Smoke detection	Sprinklers	Stair pressuri sation	Zone smoke control system
#1	1 (Base Case)	Level 0 (i.e. ground level)	N/A	No	No	N/A	N/A
#2 & 3	2 – less than 25 m effective height	Level 1	No	No - See Note 1	No	No	No
#4	8 – less than 25 m effective height	Level 7	Yes	Yes	No	No	No
#5	9 – over 25 m effective height	Level 8	Yes	No – See Note 2	Yes	Yes	Yes

Note 1 – Building is assumed to not have a centralised HVAC system with smoke detectors that would include a building occupant warning system.

Note 2 – Building must have a zone smoke control system which is activated by smoke detectors as per AS/NZS 1668.1:2015. This requires smoke detectors in circulation spaces (i.e. not full coverage), rooms that have a dimension of 15 m or more in any direction on plan and rooms that open directly into fire-isolated pressurised exit paths, see Clause 7.5.2.2 in AS 1670.1:2015.

Table 9: Use of different floor levels for each design case

Floor Level	Design Case #1 (Base Case)	Design Case #2	Design Case #3	Design Case #4	Design Case #5
Level 0	ECC	Library (Note 1)	ECC	Class 6	Class 6
Level 1	N/A	ECC	ECC	Class 6	Class 6
Level 2	N/A	N/A	N/A	Class 5	Class 5
Level 3	N/A	N/A	N/A	Class 5	Class 5
Level 4	N/A	N/A	N/A	Class 5	Class 5
Level 5	N/A	N/A	N/A	Class 5	Class 5
Level 6	N/A	N/A	N/A	Class 5	Class 5
Level 7	N/A	N/A	N/A	ECC	Class 5
Level 8	N/A	N/A	N/A	N/A	ECC

Note 1 – Class 9b use other than Early Childhood Centre

2.3.3 The research is focussed on buildings that adopt the NCC DtS Provisions. It does not consider buildings that incorporate Performance Solutions.

2.4 Overview of this research report

2.4.1 This report contains the following sections:

- Literature review including a review of Australian State and Territory requirements, plus NCC requirements
- Principal building and occupant characteristics including hypothetical Early Childhood Centre design
- Establish risk assessment framework and level of acceptable risk (QRA)
- Establish sub-models for consequence modelling incl. input data
- Results including a sensitivity analysis
- Discussion
- Conclusions and Recommendations

3 Literature Review

3.1 Prior Research

Arup Report 086241-00 Fire Safety Provisions Relating to Early Childhood Centres Located on Upper Levels of Multi-storey Buildings

3.1.1 This draft Arup report dated 12/006/2007 provided a review of the fire safety provisions for early childhood centres in the NCC that was current at the time of preparing such report. It is understood that this draft was never finalised.

3.1.2 The Arup report revealed that all States in Australia have made provisions of the fire and life safety requirements for early childhood centres. However, very few of these contain any specific requirements for centres located above ground level.

3.1.3 The draft report also stated that the Commonwealth Government introduced the National Quality Assurance (QA) standards in 1994 and the QA system details 7 quality areas of operational and administrative requirements for centres to comply with. However, these quality areas do not relate to childcare centre design and do not contain any conditions for fire and life safety.

3.1.4 An international review undertaken by Arup indicated that it is not commonplace for regulatory requirements to limit facilities for childcare to be located above ground level. However, some countries have identified the diminished provisions for life safety when an Early Childhood Centre is located in a multi-storey building, and the provision of a fire detection system and development of an emergency evacuation plan is common.

3.1.5 ABCB has advised that the Arup report was not finalised.

3.2 State and Territory-based accreditation of Early Childhood Centres

3.2.1 Most states and territories regulate the provision of Early Childhood Centres under a scheme known as the National Quality Framework (NQF). The framework covers any service providing or intending to provide education and care on a regular basis to children under the age of 13 years. This includes family day care services, long day care services, outside school hours care services and preschools (kindergartens). Services must meet the requirements set out in the framework.

3.2.2 The NQF includes:

- National Law and National Regulations
- National Quality Standard
- assessment and quality rating process
- national learning frameworks

3.2.3 The National Law sets a national standard for children's education and care across Australia, and the National Regulations support the National Law by providing detail on a range of operational requirements for an education and care service.

3.2.4 The seven areas covered by the National Quality Standard are educational program and practice; children's health and safety; physical environment; staffing arrangements; relationships with children; collaborative partnerships with families and communities; and leadership and service management.

3.2.5 The NQF also sets out the minimum educator to child ratio requirements for children's education and care services (see Table 10). Educators must be working directly with children to be counted in the educator to child ratios.

Table 10: Minimum prescribed educator to child ratios (adopted from https://www.acecqa.gov.au/nqf/educator-to-child-ratios)

Age of children	Minimum educator-to-child ratio	Applies
Birth to 24 months	1:4	All states and territories (Some declared approved services in Queensland have approval to operate at 1:5 until January 2020)
Over 24 months and less than 36 months	1:5	All states and territories excluding VIC
	1:4	VIC
Over 36 months up to and including preschool age	1:11	ACT, NT, ALD, VIC
	1:10	NSW
	1:10 for centre-based services other than a preschool 1:10 for disadvantaged preschools 1:11 for preschools other than a disadvantaged preschool	SA
	1:10 2:25 for children attending a preschool program	TAS
	1:10	WA
Over preschool age	1:15	NT, QLD, SA, TAS, VIC
	1:15	NSW - applies 1 October 2018
	1:11	ACT
	1:13 (or 1:10 if kindergarten children are in attendance)	WA

3.2.6 In the case of Victoria, Queensland, Tasmania and at least parts of NSW, Early Childhood Centres are required to be accredited or licensed. The accreditation/licensing process involves preparation of an Emergency Evacuation Plan. Such a plan would cover aspects such as the following:

- In the event of a fire the evacuation strategy will be based on a 'defend in place strategy' using portions of the outdoor areas as holding areas, where the children will be mustered before evacuation. The size of the refuge areas is to be determined based on the maximum occupancy (staff plus children) multiplied by 0.5 m² per person, or the size of evacuation cots.
- In order to ensure that the holding areas are free from obstructions no fixed playground equipment, garden beds, furniture or the like is to be fitted in the refuge areas. This will be maintained as an Essential Service.
- During evacuation, babies are mustered at a place of relative safety. Once mustered, babies in cots will be wheeled to the top of the stairs where they will be transferred into portable evacuation cots or evacuation sleds, to be carried down the stairs by staff. The portable cots should be stored next to each stair entrance and staff should be trained in their use. One staff member should remain with the babies at all times until they have all been evacuated from the building.
- The model of portable evacuation cot should be Buscot 'BabEvac' or similar. The model of sled should be 'Med Sled Infant' from Evacuation Chairs Australia or similar.

3.2.7 For the purpose of this research it is assumed that:

- Early Childhood Centres comply with State/Territory accreditation requirements, and
- There are no specific fire safety provisions arising from these requirements over and above compliance with the National Construction Code.

3.2.8 The second point above is a conservative assumption as even the most basic emergency response plan will improve the safety of occupants.

3.3 Building Code of Australia review

Building Code of Australia Class 2 to Class 9 Buildings 2016 Amendment 1 (NCC)

3.3.1 The NCC, under Clause A1.1, classifies early childhood centre building as a Class 9b Assembly building. There are only a few general safety and fire safety requirements in the DtS Provisions that specifically apply to early childhood centres, and are summarised below.

Provision for Escape

3.3.2 Under Clause D1.2(d) for Class 9 buildings, in addition to any horizontal exit, not less than 2 exits must be provided from each storey in a Class 9b building used as an early childhood centre.

3.3.3 Under Clause D1.4(c), the requirement on exit travel distance for a Class 9 building is that no point on a floor must be more than 20 m from an exit, or a point from which travel in different directions to 2 exits is available, in which case the maximum distance to one of those exits must not exceed 40 m. The longer travel distance of up to 60 m permitted for Assembly buildings under sub-clause (f) is not allowed for Early Childhood Centres.

3.3.4 Under Clause D1.11(a)(ii), horizontal exits must not be counted as required exits in a Class 9b building used as an early childhood centre.

3.3.5 Under Clause D2.21(b)(iii), the requirement on the provision to open a door in a required exit, forming part of a required exit or in the path of travel to a required exit without a key by a single hand downward action on a single device or a single hand pushing action on a single device does not apply to early childhood centres on the condition that:

- such door can be immediately unlocked by operating a fail-safe control switch, not contained within a protective enclosure, to actuate a device to unlock the door, or

- by hand by a person or persons, specifically nominated by the owner, properly instructed as to the duties and responsibilities involved and available at all times when the building is lawfully occupied so that persons in the building or part may immediately escape if there is a fire.

3.3.6 Under Clause D2.24, a window opening must be provided with protection, if the floor below the window is 2 m or more above the surface beneath in a Class 9b early childhood centre. This Clause is intended to limit the risk of falls during general occupation, and is therefore not directly related to building fire safety.

3.3.7 Under the Tasmania NCC Appendix, TAS Part H122 specifies the following fire safety related Performance Requirement and Deemed-to-Satisfy Provision.

PERFORMANCE REQUIREMENTS

TAS H122 P2

An early childhood centre and school age care facility, must to the degree necessary, have sufficient space and facilities to ensure a healthy, safe and comfortable environment for children, staff and parents including—

(a) sanitary facilities; and

(b) nappy changing facilities; and

(c) laundry facilities; and

(d) food preparation facilities; and

(e) reception, administration and staff facilities; and

(f) storage facilities; and

(g) suitable—

  (i) floor surfaces; and

  (ii) lighting and ventilation; and

  (iii) fire safety provisions; and

  (iv) windows and glazing; and

  (v) heating and cooling.

DEEMED-TO-SATISFY PROVISIONS

TAS H122.0 Application of Part

This Part applies to early childhood centres and school age care facilities approved under the Education and Care Services National Law (Application) Act 2011 or licensed under the Child Care Act 2001.

TAS H122.1 Deemed-to-Satisfy Provisions

(b) Performance Requirement Tas H122 P2 is satisfied by complying with the relevant provisions of the Early Childhood Centre and School Age Care Facilities Code [SACFC].

3.3.8 The SACFC Clause B1.9 lists the requirements for fire safety in Early Childhood Centres in Tasmania. They must be provided with: "

(a) An automatic fire detection system in accordance with Tas EP1.7, Tas E1.0 and Tas E1.101; or

(b) a smoke alarm system in accordance with Clause 3 of Specification E2.2a where the premises is –

(i) only one storey; and

(ii) the floor area of the storey is not more than 500 m^2; and

(c) required exits in accordance with D1.2; and

(d) portable fire extinguishers in accordance with E1.6."

3.3.9 In summary, the NCC as it applies in Tasmania is the only part that prescribes additional fire safety measures for Early Childhood Centres in Australia.

3.3.10 For the purpose of this study TAS H122.0 and .1 are not considered further.

New Zealand Building Code

3.3.11 The New Zealand Building Act 2004 establishes the New Zealand Building Regulations 2015. The Regulations call up the New Zealand Building Code as the main compliance document.

3.3.12 As stated on the New Zealand Ministry of Business, Innovation and Employment website[2]:

"*there are six Building Code clauses related to protecting people in and around buildings, limiting fire spread and helping firefighting and rescue.*

Supporting them are two Verification Methods and seven Acceptable Solutions, based on the occupant activity in all or part of a building.

Each clause has an objective (see C1), and there may be specific products and determinations under each clause. However, most guidance applies to all of the clauses and most requirements cross over a number of other Building Code clauses, including structure and access."

2 https://www.building.govt.nz/building-code-compliance/c-protection-from-fire/ (accessed 5 September 2018).

3.3.13 The six Building Code fire safety clauses referred to above are broadly similar to NCC Performance Requirements in Parts C, D1 and D2, and E of the NCC Volume 1.

3.3.14 The Acceptable Solutions to the NZBC are analogous to the DtS Provisions in the NCC.

3.3.15 A building design may demonstrate compliance either by adopting with the Acceptable Solutions to the NZBC, or as an Alternative Solution that complies with the NZBC fire safety Clauses.

3.3.16 The different building occupant classes, and associated Acceptable Solutions, are as follows:

Table 11: NZBC Occupant classes and associated Acceptable Solutions

Risk Group	Abbreviation	Acceptable Solution	Current Version
Buildings with Sleeping (residential) and Outbuildings	SH	C/AS1	Amendment 4, January 2017
Buildings with Sleeping (non-institutional)	SM	C/AS2	Amendment 4, January 2017
Buildings Where Care or Detention is Provided	SI	C/AS3	Amendment 4, January 2017
Buildings with Public Access and Educational Facilities	**CA**	**C/AS4**	**Amendment 4, January 2017**
Buildings with Business, Commercial and Low Level Storage	WB	C/AS5	Amendment 4, January 2017
Buildings with High Level Storage and Other High Risk Purposes	WS	C/AS6	Amendment 4, January 2017
Buildings with Vehicle Storage and Parking	VP	C/AS7	Amendment 4, January 2017

3.3.17 Early Childhood Centre is a specifically defined term in the NZBC Acceptable Solutions. It means:

> "*premises used regularly for the education or care of 3 or more children (not being children of the persons providing the education or care, or children enrolled at a school being provided with education or care before or after school) under the age of six—*
>
> *a) by the day or part of a day; but*
>
> *b) not for any continuous period of more than seven days.*
>
> *ECC does not include home based early childhood services*."

3.3.18 Parts of buildings that contain Early Childhood Centres are classified as 'Risk Group CA', which are 'Public access and educational facilities', and hence C/AS4 applies if an Acceptable Solution is being used.

3.3.19 Where a building contains multiple uses, the Acceptable Solutions each describe what features and requirements need to be applied throughout a building or to other dependant parts. An Early Childhood Centre in a building with Business or Commercial/low-level storage (Risk Group WB) would need to incorporate the most onerous measures from both acceptable solutions.

3.3.20 C/AS4 prescribes general requirements for public/educational buildings such as fire safety systems, fire compartmentation and structural stability during fire, separation from adjacent buildings, and means of escape. The precise features selected depend largely on the building height.

3.3.21 Acceptable Solution C4/AS1 does not apply to buildings that contain:

- Atriums
- Intermediate floors, other than limited area intermediate floors
- Stadiums where tiered seating is provided for more than 2000 people or where the primary access for more than 100 people is above the level of the playing surface,
- Buildings more than 20 storeys high, or
- 'Hazardous substances' (i.e. dangerous goods).

3.3.22 Furthermore, C4/AS1 states "*<u>Other than where specifically required for early childhood centres</u>, this Acceptable Solution allows for an 'all out' evacuation strategy only and does not provide features that would allow for delayed evacuation strategies*." This is an indication that not only does the NZBC specifically address Early Childhood Centres, it also considers the complexities involved in evacuating such facilities.

3.3.23 The New Zealand Education (Early Childhood Services) Regulations 2008 are referenced in C4/AS1. RED Fire Engineers have not reviewed the Education Regulations in detail, except to note that Schedule 2 to the Regulations sets minimum adult-child ratios and staffing levels for different types of facility. These ratios/staffing levels are adopted as the occupant numbers in Early Childhood Centres under C4/AS1. Occupant numbers in turn influence the requirements prescribed in C4/AS1.

3.3.24 In addition to the general requirements of C4/AS1 for education/public access buildings, C4/AS1 Clauses 2.2.1 and 2.2.2 contain specific requirements for Early Childhood centres. These are summarised below:

- Alarm systems must be connected to the fire brigade
- In single storey early childhood centres, dedicated sleeping areas shall be protected with supplementary smoke detectors. The alarm system and any smoke detection system shall comply with NZS 4512.
- Where the escape height of the early childhood centre is greater than 2.0 m, a Type 7 [sprinkler system and smoke detection and occupant warning] alarm system shall be installed throughout the building.
- If the early childhood centre is located in a multi-storey building other than the ground floor at least two separate places of safety shall be provided.

> Each place of safety shall be separated with fire separations designed to the property [fire] rating and have direct access to a safe path [fire isolated exit] or final exit."

BBR, Sweden

3.3.25 The Swedish building code (BBR) includes several classifications of use depending on:

- the knowledge of the building and available egress options
- the ability for occupants to self-egress
- the occupants can be expected to be sleeping
- the building being subjected to a high risk of fire and where a fire may develop and spread rapidly.

3.3.26 The above considerations are used to divide the different types of uses into six classifications under BBR; Class 1 to Class 6. Under each class, there may be sub-classifications (e.g. 3B).

3.3.27 Class 5A includes pre-school use. The Swedish Academy's Dictionary (SAOL) defines pre-school as "a facility incorporating pedagogic functions for children under the age which allows them to be in school"[3]. Early childhood care buildings would fall within this definition.

3.3.28 Other uses within Class 5 are for example hospitals, prisons, aged care facilities, etc.

3.3.29 The BBR includes four different building classifications (Br0, Br1, Br2, Br3) where Br3 requires the lowest level of protection. This may loosely be compared to Type of Construction under the NCC. The classification of the building will govern such things as the minimum requirement for fire rated construction. Br0 applies to buildings deemed to be high risk and have no Deemed-to-Satisfy Provisions. The design of such a building requires a full quantitative risk assessment.

3.3.30 The following applies to building classifications incorporating Class 5A under BBR:

- Single storey building may be Br3
- Two-storey building shall be no less than Br1
- Buildings over 16 storeys are Br0

3.3.31 At least two independent exits are required from an ECCs. More may be required depending on the number of occupants and the travel distances.

3.3.32 For ECCs only operable during daytime, only smoke alarms are prescribed. If the ECC is operable during night time as well, then it is prescribed with an automatic smoke detection and alarm system.

[3] Original (in Swedish): Lokal med pedagogisk verksamhet för barn under skolåldern

3.3.33 Fire compartmentation of ECCs is required to have a minimum FRL of (60)/60/60 for building classification Br1 and minimum FRL of (30)/30/30 for building classifications Br2 and Br3. For Br0, the required FRL must be determined analytically.

3.3.34 For ECCs, fire compartmentation is required as follows:

- Fire compartments shall contain a maximum of two departments or functional units.
- Rooms or functional units intended for sleeping occupants during night time shall be located in individual fire compartments.

3.3.35 The maximum permitted size of a fire compartments is 1250 m^2. Fire compartments shall be organized in sections of 2500 m^2 unless an automatic smoke detection and alarm system or a sprinkler system is provided which allows the sections to have a greater area. Sections shall be divided by fire walls.

NFPA 101 Life Safety Code

3.3.36 The National Fire Protection Association (NFPA) Standard 101 (2018 edition) groups child day-care occupancies together with adult day-care occupancies, day-care homes, kindergarten classes that are incidental to a child day-care occupancy, and nursery schools under the classification of Day-Care Occupancy.

3.3.37 Below is a brief summary of fire protection requirements in NFPA 101 for child day-care occupancies.

3.3.38 Construction type limitation (adopted from Table 16.1.6.1 of NFPA 101):

Construction Type	Sprinklered[b]	Stories in Height[a]: One Story Below[c]	1	2	3–4	>4 but Not High-Rise	High-Rise
I (442)	Yes	X	X	X	X	X	X
	No	NP	X	X	X	NP	NP
I (332)	Yes	X	X	X	X	X	X
	No	NP	X	X	X	NP	NP
II (222)	Yes	X	X	X	X	X	X
	No	NP	X	X	X	NP	NP
II (111)	Yes	X	X	X	X	X	NP
	No	NP	X	NP	NP	NP	NP
II (000)	Yes	X	X	X	X	NP	NP
	No	NP	X	NP	NP	NP	NP
III (211)	Yes	X	X	X	X	NP	NP
	No	NP	X	NP	NP	NP	NP
III (200)	Yes	NP	X	X	NP	NP	NP
	No	NP	X	NP	NP	NP	NP
IV (2HH)	Yes	X	X	X	NP	NP	NP
	No	NP	X	NP	NP	NP	NP
V (111)	Yes	X	X	X	X	NP	NP
	No	NP	X	NP	NP	NP	NP
V (000)	Yes	NP	X	X	NP	NP	NP
	No	NP	X	NP	NP	NP	NP

Figure 2: Table 16.1.6.1 of NFPA 101

Notes:

The three Arabic numerals in parentheses following the Roman numeral under Construction Type indicate the fire resistance of the exterior bearing walls, structural frame, and floor, respectively, in hours.

X: Permitted. NP: Not Permitted.

a. The stories in height are counted starting with the level of exit discharge and ending with the highest occupiable storey containing the occupancy considered.
b. Sprinklered throughout by an approved, supervised automatic system in accordance with the NFPA 13, NFPA 13D or NFPA 13R Standard as appropriate.
c. One storey below the level of exit discharge.

Where day-care occupancies with clients who are 24 months or less in age or who are incapable of self-preservation, are located one or more storeys above the level of exit discharge, or where day-care occupancies are located two or more storeys above the level of exit discharge, smoke partitions shall be provided to divide such stories into not less than two compartments. The smoke partitions shall be constructed with Section 8.4 of NFPA 101 but shall not be required to have a fire resistance rating.

3.3.39 Means of Egress Requirements:

Means of egress shall be in accordance with Chapter 7 and section 16.2 of NFPA 101. The requirements therein refer to door hardware; door operation; door latches and door locking mechanism; stairs; smokeproof enclosures; horizontal exits; ramps; exit passageways; fire escape ladders; alternating tread devices; areas of refuge; capacity, number, arrangement, and illumination of means of egress; travel distance to exits; discharge from exits; emergency lighting; signage; and special means of egress features.

The special means of egress features require every room or space normally subject to client occupancy, other than bathrooms, shall have not less than one outside window for emergency rescue unless the building is protected throughout by an approved, supervised sprinkler system or where the room or space has a door leading directly to an exit or directly to the outside of the building.

3.3.40 Protection from Fire Hazards:

The following rooms and spaces are required to be separated from the remainder of the building by fire barriers having a minimum 1-hour fire resistance rating or protection of such rooms by automatic extinguishing systems.

- Boiler and furnace rooms
- Rooms or spaces for the storage of combustible supplies, hazardous materials or flammable or combustible liquids in quantities deemed hazardous by the authority having jurisdiction
- Janitor closets.

The following rooms and spaces are required to be separated from the remainder of the building by fire barriers having a minimum 1-hour fire resistance rating and protection of such rooms by automatic extinguishing systems.

- Laundries
- Maintenance shops, including woodworking and painting areas
- Rooms or spaces used for processing or use of combustible supplies deemed hazardous by the authority having jurisdiction
- Rooms or spaces used for processing or use of hazardous materials or flammable or combustible liquids in quantities deemed hazardous by recognized standards

3.3.41 Interior Finish:

Interior wall and ceiling finish materials shall be Class A (a flame spread index of 0-25 and a smoke developed index of 0-450) in stairways, corridors and lobbies; in all other occupied areas, interior wall and ceiling finish shall be Class A or Class B (a flame spread index of 26-75 and a smoke developed index of 0-450). The classification of these finish materials shall be based on test results from ASTM E84, Standard Test Method for Surface Burning Characteristics of Building Materials, or ANSI/UL 723, Standard for Test for Surface Burning Characteristics of Building Materials.

Interior floor finish in exit enclosures and exit access corridors and spaces not separated from them by walls shall be not less than Class II. Other interior floor finishes shall comply with ASTM D 2859, Standard Test Method for Ignition Characteristics of Finished Textile Floor Covering Materials, or shall have a minimum critical radiant flux of 1.0 kW/m^2, as applicable. Class I interior floor finish shall have a critical radiant flux of not less than 4.5 kW/m^2, and Class II interior floor finish shall have a critical radiant flux of not less than 2.2 kW/m^2 but less than 4.5 kW/m^2, based on the test results from NFPA 253, Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source, or ASTM E 648, Standard Test Method for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source.

3.3.42 Detection, Alarm, and Communications Systems:

A smoke detection and fire alarm system that is installed, tested, and maintained in accordance with NFPA 70 and NFPA 72 shall be provided. Detectors shall be installed on each storey in front of the doors to the stairways and in the corridors of all floors occupied by the day-care occupancy, and installed in lounges, recreation areas and sleeping rooms in the day-care occupancy. Initiation of the required fire alarm system shall be by manual means and by operation of any required smoke detectors and required sprinkler systems. The fire alarm system shall be arranged to transmit the alarm automatically to the municipal fire department and fire brigade.

3.3.43 Extinguishment Requirements:

Buildings with unprotected openings in accordance with Clause 8.6.6 of NFPA 101 (i.e. unenclosed floor openings forming a communicating space between floor levels subject to various conditions in the Clause) shall be protected throughout by an approved, supervised automatic sprinkler system in accordance with NFPA 13, NFPA 13D or NFPA 13R as appropriate.

Every interior corridor shall be constructed of walls having not less than 1-hour fire resistance rating, unless otherwise permitted by any of the following:

(1) Corridor protection shall not be required where all spaces normally subject to client occupancy have not less than one door opening directly to the outside or to an exterior exit access balcony or corridor in accordance with Clause 7.5.3 of NFPA 101.

(2) In buildings protected throughout by an approved, supervised automatic sprinkler system in accordance with Section 9.7, corridor walls shall not be required to be rated, provided that such walls form smoke partitions in accordance with Section 8.4 of NFPA 101.

(3) Where the corridor ceiling is an assembly having a 1-hour fire resistance rating where tested as a wall, the corridor walls shall be permitted to terminate at the corridor ceiling.

(4) Lavatories shall not be required to be separated from corridors, provided that they are separated from all other spaces by walls having not less than a 1-hour fire resistance rating in accordance with Section 8.3 of NFPA 101.

(5) Lavatories shall not be required to be separated from corridors, provided that both of the following criteria are met:

    (a) The building is protected throughout by an approved, supervised automatic sprinkler system in accordance with Section 9.7 of NFPA 101.

    (b) The walls separating the lavatory from other rooms form smoke partitions in accordance with Section 8.4 of NFPA 101.

3.3.44 Special Provisions:

Limited access buildings and underground buildings shall comply with Section 11.7 of NFPA 101 that calls for a sprinkler system and a smoke venting system.

High-rise buildings that house day-care occupancies on floors more than 75 ft (23 m) above the lowest level of fire department vehicle access shall comply with Section 11.8 of NFPA 101 that calls for a sprinkler system, a fire detection and alarm system that is connected to the fire brigade, two-way telephone communication service for the fire brigade, emergency lighting and standby power, an emergency command centre for use by the fire brigade, stairway video monitoring, as well as fire resisting construction.

3.4 Summary – Comparison between NCC and similar building codes

3.4.1 The NCC prescribes only a few egress-related provisions that are specifically applied to early childhood centres, with no additional requirements on fire resistance and fire protection services. Other fire safety measures that are required for Class 9b Assembly Buildings also apply to early childhood centres.

3.4.2 The New Zealand Building Code includes specific provisions that apply to Early Childhood Centres from relatively low 'escape heights.' These provisions include sprinklers and smoke detection throughout, plus multiple fire separated 'places of safety' with independent escape routes.

3.4.3 The Swedish building code includes a range of smoke alarms/detection and fire separations, plus at least two independent escape routes from Early Childhood Centres.

3.4.4 The Life Safety Code, NFPA 101, in the USA includes specific provisions that apply to child day-care occupancies located in low rise as well as high rise buildings. The basic requirements include a fire alarm system that is connected directly to the fire brigade, a sprinkler system, a smoke detection and fire alarm system, fire separation from other fire hazards, and the interior wall and ceiling finish materials shall be Class A in exits and path of travel to exits, and be Class A or Class B in other occupied areas.

4 Principal Building and Dominant Occupant Characteristics

4.1 Design Cases – Principal Building Characteristics

4.1.1 The quantification of risk requires input parameters that dictates a specific or several specific geometries of ECCs are evaluated. We have selected five buildings each with different numbers of storeys above ground that are prescribed with different sets of fire safety measures under the NCC DtS Provisions. In this report, we refer to these buildings as *design cases*.

4.1.2 The different design cases for which the fire and life safety risk will be quantified are summarised in Table 12. This table also contains a summary of fire safety measures prescribed in the DtS Provisions of the NCC. An explanation of our interpretation of the DtS Provisions follows from Section 4.1.4. 'Level 0' is the level corresponding to ground level. Table 13 provides a description of the use of all other levels in the building. Our design cases do not account for any variations from the NCC DtS Provisions, nor do they account for the Tasmanian Appendix Clauses H122.0 and .1.

4.1.3 The ECC is located on the topmost storey in each design case. The reasoning behind this placement is that:

- it produces the longest travel distances from the Early Childhood Centre to reach the outside, and
- it is a reasonable assumption as ECCs often require outdoor play areas which are easier to accommodate on the topmost storey of a building compared to a floor in the middle of the building, because the roofs may be used as the outdoor play areas.

Table 12: Design cases for evaluation

Design case	Storeys/ height	ECC location	Fire-isolated stairs	Smoke detection	Sprinklers	Stair pressuri sation	Zone smoke control systems
#1	1 (Base Case)	Level 0	N/A	No	No	N/A	N/A
#2 & 3	2 – less than 25 m effective height	Level 1	No	No - See Note 1	No	No	No
#4	8 – less than 25 m effective height	Level 7	Yes	Yes	No	No	No
#5	9 – over 25 m effective height	Level 8	Yes	No – See Note 2	Yes	Yes	Yes

Note 1 – Building is assumed to not have a centralised HVAC system with smoke detectors that would include a building occupant warning system.

Note 2 – Building must have a zone smoke control system which is activated by smoke detectors as per AS/NZS 1668.1:2015. This requires smoke detectors in circulation spaces (i.e. not full coverage), rooms that have a dimension of 15 m or more in any direction on plan and rooms that open directly into fire-isolated pressurised exit paths, see Clause 7.5.2.2 in AS 1670.1:2015.

Table 13: Use of different floor levels for each design case

Floor Level	Design Case #1 (Base Case)	Design Case #2	Design Case #3	Design Case #4	Design Case #5
Level 0	ECC	Library (Note 1)	ECC	Class 6	Class 6
Level 1	N/A	ECC	ECC	Class 6	Class 6
Level 2	N/A	N/A	N/A	Class 5	Class 5
Level 3	N/A	N/A	N/A	Class 5	Class 5
Level 4	N/A	N/A	N/A	Class 5	Class 5
Level 5	N/A	N/A	N/A	Class 5	Class 5
Level 6	N/A	N/A	N/A	Class 5	Class 5
Level 7	N/A	N/A	N/A	ECC	Class 5
Level 8	N/A	N/A	N/A	N/A	ECC

Note 1 – Class 9b use other than Early Childhood Centre

DtS Provisions for design cases – major safety systems/barriers

4.1.4 NCC Clause D1.3 prescribes that in buildings containing classifications 5, 6 and 9b, fire-isolated exits are required in stairs connecting three storeys or more. Variations using Clause D1.3(iii)(A) or (B) have not been explicitly evaluated.

4.1.5 In buildings over 25 m in effective height, NCC Clause E1.5 prescribes an automatic sprinkler system and NCC Clause E2.2a prescribes a pressurisation system to any stair that serves a level above 25 m effective height. For a Class 9b ECC located in a building over 25 m in effective height, it is also prescribed with a zone smoke control system.

4.1.6 In a building less than 25 m in effective height but with more than three storeys, Table E2.2a in the NCC prescribes that a building containing classifications 5, 6 and 9b must be provided with one of the following fire safety measures:

- An automatic smoke detection and alarm system
- A stair pressurisation system
- A zone smoke control system
- An automatic sprinkler system

4.1.7 We have assumed that such a building is most likely to be provided with an automatic smoke detection and alarm system. This is the least expensive and technically complex system to install.

4.1.8 For buildings containing classifications 5, 6 and 9b and a rise in storeys of only two, no smoke hazard management measures (e.g. smoke detection, pressurisation or smoke control or sprinkler systems) is prescribed under Table E2.2a of the NCC.

4.2 Design Cases – Hypothetical building design

4.2.1 This section provides information on the characteristics of the assumed building layouts.

Floor geometry/layout - ECC

4.2.2 A general floor layout has been created for a hypothetical ECC as shown in Figure 3. The floor layout was created based on our general understanding of the different room uses required within an ECC and the distribution between play areas, sleep areas and ancillary uses such as storage, laundry and kitchens. Such understanding is based on our involvement in ECC projects in Victoria, NSW and Queensland.

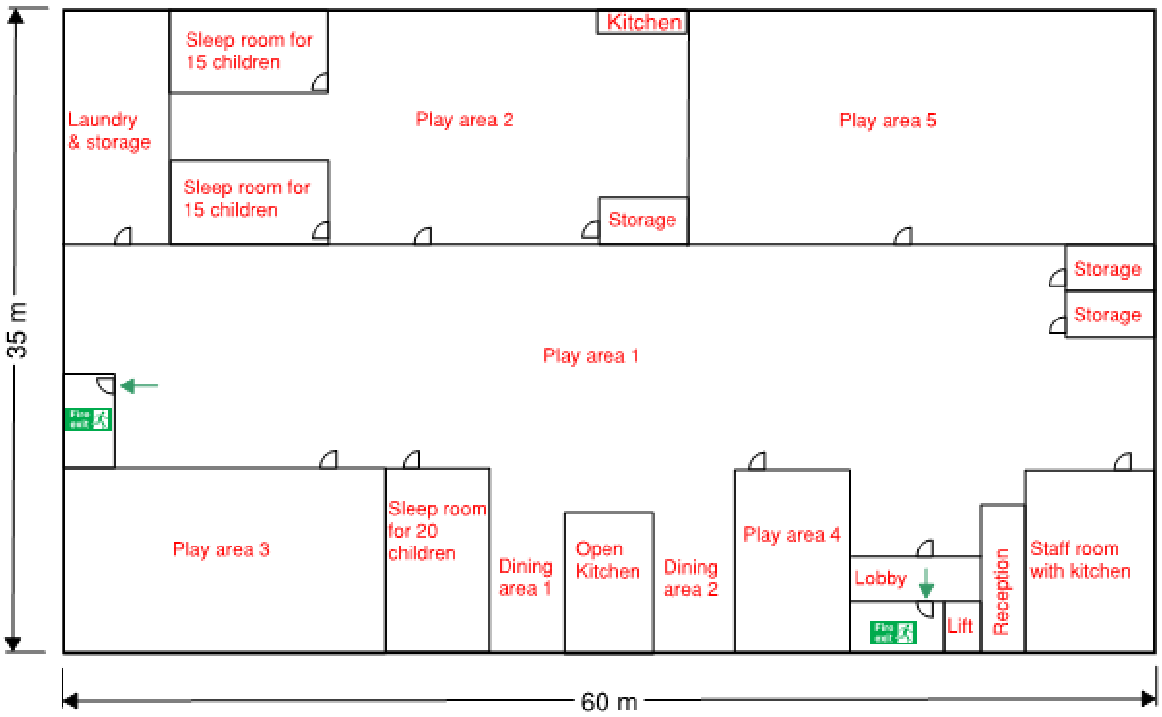

Figure 3: Hypothetical floor plan of ECC

4.2.3 The floor area of the ECC is approximately 2,070 m^2. The area designated for children (i.e. play and sleep areas) has a total floor area of approximately 1,830 m^2. The total floor area is within the fire compartment area and volume limitations in the NCC (Clause C2.2). The validity of this assumption of size was justified through a review of the projects RED Fire Engineers have been involved in. The floor areas (per storey) for these projects are shown in Figure 4.

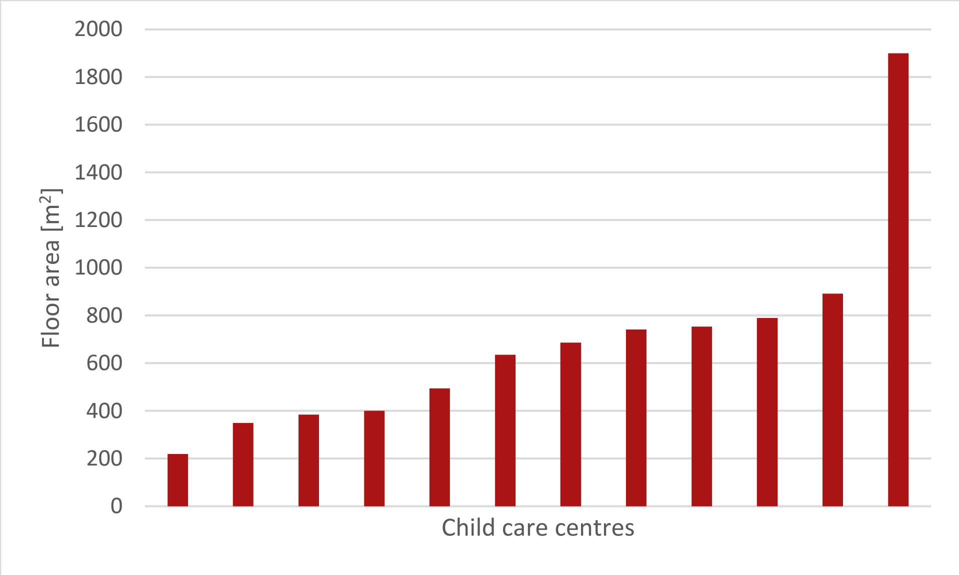

Figure 4: Distribution of floor areas for ECCs

4.2.4 According to the SA Early Childhood Facilities Design Standards and Guidelines (SA, 2016), as well as the NSW draft Childcare Planning Guideline (NSW, 2017), a minimum of 3.25 m² per child of unencumbered space (usable floor area which is directly for children's use) is required to be provided. This area excludes circulation/passageways, fixed joinery toilets, kitchen, administration space etc. Under the above-mentioned guidelines, a maximum of 563 children would be permitted in the hypothetical ECC.

4.2.5 The internal ceiling height has been assumed to be 2.4 m in accordance with DtS Provision F3.1.

Occupant load in the ECC

4.2.6 The total occupant load in the ECC has been determined using Table D1.13 of the NCC. This table states that in an Early Childcare Centre it can be assumed to have one person for every four square metres of floor area. Allowing for a small reduction of space in accordance with D1.13(a)(i) and (ii), the resulting area is approximately 2,000 m^2. This would allow a total of 500 occupants in the ECC.

4.2.7 The National Quality Framework prescribes the minimum educator (staff)-to-child ratios for centre-based ECCs as per Table 10. Only staff working directly with the children may be counted towards the minimum prescribed number of staff.

4.2.8 The staff-to-child ratio is an important factor affecting the level of safety in an ECC as the staff will be required to manually evacuate or lead children to safety. As described in Section 4.3, children aged 36 months or older can generally walk down stairs and egress under supervision of staff. On the contrary, children under 24 months of age often need to be carried or some other major assistance in order to egress.

4.2.9 The age bracket 24 to 36 months is therefore of particular interest as it may contain wholly children that cannot self-egress and need to be carried or wholly of children that can self-egress under supervision of staff or a mix thereof. For children that can self-egress under the supervision of staff, the younger the child, the slower the walking speed. We are therefore of the opinion that the staff-to-child ratio of particular interest is 1:5 as this is perceived to achieve the longest egress times and therefore highest consequences.

4.2.10 A ratio of 1:5 has been assumed in the ECC which results in 416 children and 84 staff.

Egress design from the ECC

4.2.11 D1.2 of the NCC requires that a Class 9b used as an ECC must have access to at least two exits. Two exits have been assumed for the design as it is the minimum requirement for the NCC DtS Provisions.

4.2.12 The two exits in the hypothetical ECC are indicated by green arrows and the following symbol Fire exit in Figure 3. In Design Case #1, this represents an exit directly to the outside. In all other cases, the exits are either the top of an open stair or the entry into a fire-isolated stair depending on the rise in storeys of the building (see Table 12).

4.2.13 The two exits have been provided with a total exit width that adopts Clause D1.6 of the NCC. D1.6(d)(ii) prescribes that a storey with 500 occupants shall have a total of 4.0 m exit width on aggregate. In design cases where stairs are used for egress, each stair is assumed to be 2.0 m wide. Doorways in a path of egress (leading directly to the outside or to a stair) are assumed to be 1.75 m wide in accordance with NCC Clause D1.6(f)(iii).

4.2.14 The travel distances within the ECC are to be within the limits prescribed in NCC Clauses D1.4 and D1.5. The maximum distance of travel to a point of choice is less than 20 m from all parts of the floor plate and the closest exit is within 40 m as per NCC Clause D1.4(c). The exits are located more than 9 m apart and the exits are located less than 60 m apart when measured through the point of choice as per NCC Clause D1.5. This is illustrated in Figure 5. The average travel distance to an exit within the ECC is approximately 20.4 m.

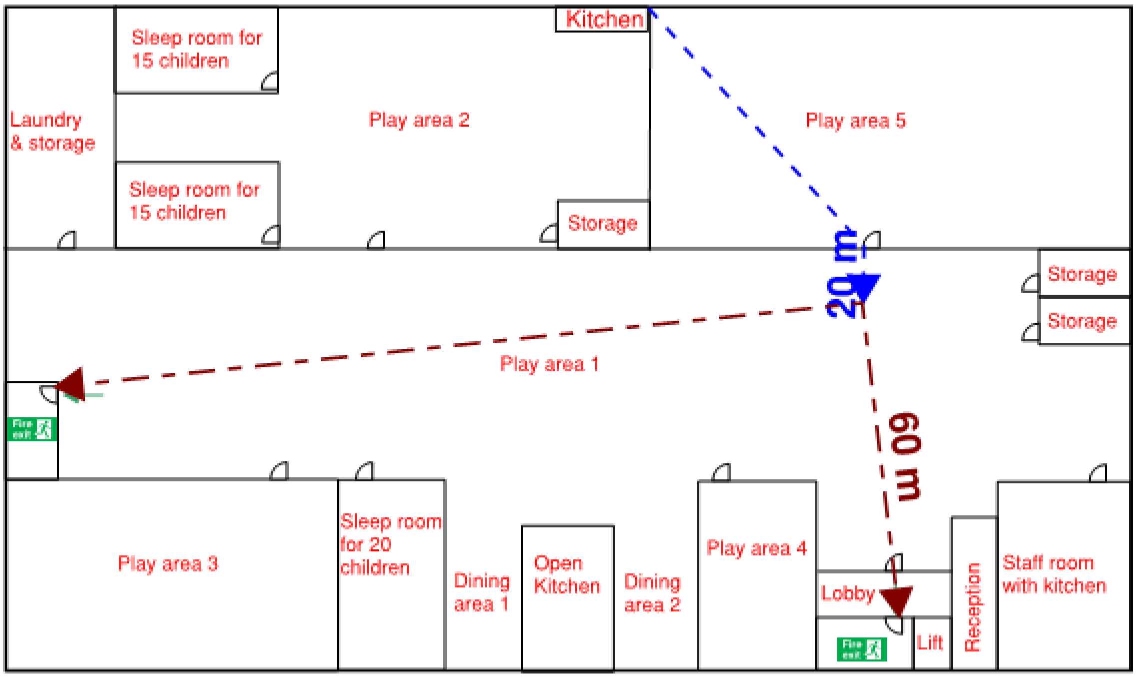

Figure 5: Travel distance to a point of choice and between exits

Other storeys – Design Case 2

4.2.15 Design case 2 evaluates a two storey building with an ECC on the topmost storey and a Class 9b library on the ground floor level. The ECC floor is assumed to be identical to the hypothetical floor layout in Figure 3. Because both storeys are Class 9b, the stairs are permitted to be open stairs under Clause D1.3(b)(iii) of the NCC.

Other storeys – Design Case 3

4.2.16 Design case 3 evaluates a two storey ECC. Each floor is assumed to be identical to the hypothetical floor layout in Figure 3. In this design, the stairs are permitted to be open stairs under Clause D1.3(b)(iii) of the NCC.

Other storeys – all other design cases

4.2.17 For all other design cases, Table 13 provides a description of the assumed use. However, no floor layout is provided for these levels. The reason for this is that the consequences on the occupants from a fire on these levels is outside the scope of this study. The NCC does not restrict the uses on the other storeys (provided that the Performance Requirements of the NCC are met) which allows an infinite complexity in the combinations of use of the storeys not used as an ECC.

4.2.18 In design cases 4 and 5, the lower levels have been assumed to be of commercial use (Class 6) and office use on the levels above (Class 5). We have chosen these uses as this is a common occurrence in mixed-use buildings incorporating ECCs in our experience.

4.2.19 The only effect the assumption of use on the other storeys has on the quantitative risk assessment (QRA) is the frequency of fire occurrence calculated for those floors, see Section 5.4.

4.3 Occupant Characteristics - Characteristics of children and staff

4.3.1 Different age groups of children require different types of evacuation. Children less than 24 months of age will require to be carried or require major assistance whilst egressing and walking down stairs (Larusdottir, et al., 2014).

4.3.2 Children aged 36 months or older generally don't require any assistance walking down stairs (Larusdottir, et al., 2014). The age span 24 months to 36 months represents a transitional phase where, on average, children increase their capabilities from not being able to egress to being able to egress under the instruction of adults (staff).

4.3.3 If children are not able to walk down stairs, then the evacuation of an ECC will be fully reliant on staff carrying the children to a place of safety. The time for evacuation will therefore depend on the number of staff and children (including the ratio between staff and children), preparation time for staff to commence evacuation, a member's or staff's capability of carrying children, travel speeds of staff carrying children, travel speeds of staff walking up stairs and staff fatigue.

4.3.4 Where children are able to walk down stairs, the staff will instruct and lead children down the stairs. The time for evacuation will therefore depend on the number of staff and children, preparation time for staff to commence evacuation, the staff-to-child ratio required for an evacuating group, walking speeds for children walking down stairs, and if necessary, time for staff walking back to the ECC to evacuate more groups.

4.3.5 Based on the above, two distinct cases have been analysed:

- Type A – Children can't self-egress. Staff will have to carry the children to a place of safety.
- Type B – Children can self-egress. Staff will assist children in an evacuation.

4.3.6 We have assumed that the occupant characteristics (e.g. walking speed) correspond to adult females. This is supported by statistics which indicated that in 2017 approximately 90 % of the workforce in preschool education were women (WGEA, 2018).

Type A – Staff carry children

4.3.7 When staff are carrying children, the evacuation speeds of children is not relevant. The behaviour of children also becomes less of importance as the staff do not need compliance from the child in order for evacuation to occur.

4.3.8 As the NCC does not require any fire safety measure (e.g. evacuation cots or slings) to aid the evacuation of children who are unable to self-egress, children have been assumed to be carried by staff. It is assumed that each member of staff is able to carry two children during an emergency situation (evacuation).

4.3.9 There is limited data available for walking speeds (both horizontally and down stairs) for staff carrying children. At the time of preparing this report, the only data that we have found in the public domain is that presented by Burton (2018), as shown in Table 14.

4.3.10 In designs where staff are evacuating children and the total number of staff are not sufficient to evacuate all children immediately, staff will have to first carry the children they initially have picked up and carry them to a place of safety and then return to the ECC to pick up more children. In such a situation, the walking speed up stairs is of importance. The available data suggests a walking speed of approximately 0.5 m/s for women (Norén, et al., 2014).

4.3.11 The walking speeds assumed in the analysis as well as in the sensitivity study are described in Section 0.

Table 14: Walking speeds for staff

Description	Walking speeds	Reference
Staff carrying children up to 24 months	Horizontal – 0.8 – 1.1 m/s Down stairs – 0.31 – 0.55 m/s	(Burton, 2018)
Staff walking up stairs (without children)	Up stairs – Approx. 0.5 m/s(1)	(Norén, et al., 2014)

[1] Assumes a majority of women (see Section 4.3.6) and buildings less than 25 storeys.

4.3.12 When staff are carrying children, and not all children can be carried out at once by all staff, some staff will have to remain in the ECC to guard the remaining children and some staff will have to be placed at the exit (e.g. discharge point to the outside of a fire-isolated stair). We have assumed that 10 % of staff are not actively egressing with children in the event of a fire. These staff are assumed to egress when the last of the children can be picked up and carried to a place of safety.

Type B – Children self-egress under staff guidance

4.3.13 When children are assumed to self-egress under the guidance of staff, the walking speed of the children and flow through exits (e.g. stairs) will determine the overall time for the movement phase.

4.3.14 As described in Section 4.3.2, children over 36 months can generally be assumed to be able to self-egress under supervision of staff. As children become more able to move at a higher speed both horizontally and down stairs with age, the slowest walking speeds will be at the time the child is able to traverse the stair. Because of this, the walking speed data collected is for children around 36 months of age as it constitutes the worst credible case scenario.

4.3.15 There is limited data available for walking speeds (both horizontally and down stairs) for children. At the time of preparing this report, the only data that are in the public domain and available to us are that presented by Burton (2018), and the experimental studies by (Larusdottir et al., 2014) and (Kholshchevnikov et al., 2012) as shown in Table 14.

Table 15: Walking speeds for children

Age	Walking speeds	Reference
24 - 36 months	Horizontal – 0.61 m/s Down stairs – 0.33 m/s	(Burton, 2018)
6 - 24 months	Horizontal – 0.60 m/s (average)	(Larusdottir, et al., 2014)
24 - 72 months	Horizontal – 0.84 m/s (average)	
Unknown (6 - 72 months)	Down stairs – 0.13 -0 58 m/s	
36 – 48 months	Horizontal – 0.78 m/s	(Kholshchevnikov, et al., 2012)
48 – 60 months	Horizontal – 0.85 m/s Down stairs – 0.66 m/s	
60 – 84 months	Horizontal – 0.86 m/s Down stairs – 0.74 m/s	

4.3.16 We have not been able to find any research data purely on flow rates through doorways and stairs for children, but flow rates as a function of person density.

4.3.17 Furthermore, the relevance of any available data on flows is questioned since children egressing under supervision of staff is very different to adult people egressing. Adult people will organise themselves within the available space through the width of a doorway or through a stair. However, children will need to be managed to move continuously and together as a unit. In our experience in Australia, this is often achieved by staff instructing a group of children to hold to a rope or rings connected to a rope or by holding hands, see example in Figure 6. A member of staff leading the group and typically a member of staff follows behind the group of children.

4.3.18 Instead of creating a flow generated through a stair, the flow of children (and staff) will depend on the walking speed of the slowest child and the spacing between each child (as can be seen in Figure 6). Based on our experience, the distance between each child is approximately 0.5 m. This is the distance that has been assumed in the analysis with the sensitivity analysis varying this parameter as per Section 0.

Figure 6: Example of children egressing

4.3.19 For adults egressing through narrow egress pathways with changes in directions (e.g. stairs), the width is directly correlated to the flow of people. This has to do with adults organising themselves to fill up the space available and therefore automatically optimising the flow allowed by the width.

4.3.20 Egress with children is different and the self-optimisation does not occur as children does not naturally organise themselves in such a way. Therefore, an increase in width of a stair is therefore not necessarily correlated to an increase in flow of children. Even in a wide stair, children may organise themselves in such a way that it would block another group that would attempt to egress in parallel along the stair. It is also anticipated that children will take the shortest path available around corners, especially when being linked up (e.g. as can be seen in Figure 6). This would effectively block another group from egressing past the first group.

4.3.21 For the purposes of the analysis, the stair width is therefore assumed to not affect the flow of egressing children in a Type B design case.

5 Quantitative Risk Assessment Methodology

5.1 Defining risk

5.1.1 The definition of risk is taken from the draft ABCB draft Tolerable Risk Handbook as "*Risk is a measure of human injury (harm), environmental damage or economic loss in terms of incident likelihood and the magnitude of injury, damage or loss.*" Mathematically risk is therefore expressed as:

$$\boldsymbol{R} = \boldsymbol{F_f} \cdot \boldsymbol{C} \qquad \text{Equation 1}$$

where

R risk [year^{-1}]
F_f fire start frequency [year^{-1}]
C harm [-]

5.1.2 In this study, harm is defined as a fatality. Any person exposed to untenable conditions (see Section 7.3.2) is assumed to become a fatality. It is common practice to only quantify the number of fatalities in QRAs. However, there are common correlations between fatalities and injuries. The harm measure therefore implicitly considers injuries.

5.1.3 Individual Risk is defined in the draft ABCB draft Tolerable Risk Handbook as "*the frequency at which an individual may be expected to sustain a given level of harm from the realisation of a specified hazard*". The draft ABCB draft Tolerable Risk Handbook does not provide a mathematical relationship for calculating individual risk.

5.1.4 Individual Risk criteria can be categorised into three categories:

- Average Individual Risk – This is typically calculated using historical data and calculated as: IR = Number of fatalities per year / Number of people exposed to the risk source.
- Location Specific Individual Risk – This is defined as the annual probability of a hypothetical person located in the same location for an entire year becoming a fatality.
- Person Specific Individual Risk - This is identical to the Location Specific Individual Risk but the hypothetical person is not assumed to be located at a single location. The Person Specific Individual Risk is therefore the sum of all the location specific individual risks to which a hypothetical person is exposed to at multiple locations.

5.1.5 Because this study is related to the risk of a specific location (inside an ECC), a Location Specific Individual Risk has been adopted for this study. The Individual Risk is calculated as per Equation 2:

$$\boldsymbol{IR} = \sum_{\boldsymbol{i}}^{\boldsymbol{n}} \boldsymbol{F_i}(\boldsymbol{C_i} \geq \mathbf{1}) \qquad \text{Equation 2}$$

where

IR Individual Risk [year^{-1}]
F_i frequency of scenario i provided that $C_i \geq 1$ [year^{-1}]
C fatalities associated with scenario i [-]
n total number of scenarios [-]

5.1.6 Societal Risk is calculated and presented in the form of FN-curves. An FN-curve is a graph with the frequency on the y-axis and consequence on the x-axis. The FN-curve illustrates the cumulative frequency (F) of scenarios that lead to a consequence equal to or higher than the number of fatalities (N).

5.2 Limitations and assumptions

5.2.1 The QRA estimates only the Individual Risk and Societal Risk within the ECC. The risk to other occupants located in the building does not form part of this study and is therefore not reported.

5.2.2 The QRA assumes a 24/7 occupation of the ECCs. These child care centres exist and the NCC does not explicitly restrict such use. We therefore are of the opinion that this is a prudent assumption.

5.3 Event Tree Analysis

5.3.1 We have used an Event Tree Analysis (ETA) approach to:

- Produce a list of relevant design fire scenarios,
- Calculate the frequency of each design fire scenario

5.3.2 ETAs have been created for all the five design cases (Table 8).

5.3.3 The ETA assumes that fire ignition has occurred. The frequency of such ignition events is estimated using the method presented in Section 5.4.

5.3.4 Furthermore, the ETA is used to characterise the design fire scenario based on the following:

- Fire Location in the Building – Is the fire located in the ECC or elsewhere in the building (if applicable)
- Fire Location in the ECC – Where in the ECC has the fire occurred?
- Fire Development – Does the fire develop into a flaming fire? What is the growth rate of the fire?
- Safety Barriers – Do the active and passive fire safety barriers (e.g. sprinklers, smoke detection, fire-isolated stairs) operate as intended?

5.3.5 The ETA produces a number of design fire scenarios. Each such scenario is associated with a certain fire development, fire location and set of safety systems operating and/or failing. See Figure 7 to Figure 11 for the event trees developed for a fire occurring inside the ECCs for design cases 1 to 5.

5.3.6 Consequence modelling (see Section 7) is used to determine the number of fatalities associated with each design fire scenario.

5.3.7 Once the frequency and consequence are known for each design fire scenario, the Individual Risk is calculated using Equation 2.

Events – Location of fire

5.3.8 The location of the fire will determine the immediate threats to an ECC. If the fire is located within the ECC, then smoke and heat may after a time period cause untenable conditions within the fire compartment the ECC is located. If the fire occurs on a level below the ECC (applies to design cases with more than one level), then a fire on another level may compromise the egress routes for the ECC.

5.3.9 Based on the above, for each design case the following fire locations will be analysed:

- On the storey containing the ECC, and
- All levels below the storey containing the ECC (if applicable).

5.3.10 Where applicable, the frequency of fire on levels below the ECC has been lumped together. The reason for this is described in Section 7.1. Ultimately, the frequency of all egress routes being blocked by a fire on levels below the ECC has been used in the Event Tree analysis.

5.3.11 On the storey containing the ECC, two categories of fire locations have been evaluated; a fire in "Main Play Area 1" (see Figure 3) and a fire in the other adjacent areas. The background to this is that Main Play Area 1 must be passed by any egressing occupant. Therefore, when untenable conditions occur in Main Play Area 1, all remaining occupants in Main Play Area 1 and all adjacent rooms are assumed to be fatalities. In the event that a fire occurs in one of the adjacent spaces, the time until untenable conditions occur in Main Play Area 1 is delayed as smoke filling of the adjacent space occurs first before smoke spills into Main Play Area 1.

5.3.12 The probability of fire location in the Main play area 1 has been calculated using the following expression:

$$\boldsymbol{P}_{\boldsymbol{play\ area}} = \frac{\boldsymbol{A}_{\boldsymbol{play\ area}}}{\boldsymbol{A}_{\boldsymbol{f}}} \qquad \text{Equation 3}$$

where

$P_{play\ area}$	probability of fire located in main play area [%]
A_f	total floor area [m^2]
$A_{play\ area}$	floor area of Main play area 1 [m^2]

5.3.13 The probability of a fire in any other location other than Main play area 1 has been calculated as $\boldsymbol{1 - P}_{\boldsymbol{play\ area}}$.

Events – Fire Development

5.3.14 Fires often start as smouldering fires that may transition to flaming fires. In turn, if the fuel and ventilation conditions are favourable, then a fire may flashover and become a fully developed fire at which point all combustible materials in the compartment of fire origin become involved in the fire.

5.3.15 Smouldering fires are excluded from this study. Smoke detection systems capable of detecting a fire in the smouldering phase are not prescribed in the NCC Clause E2.2a. This is true even for high-rise buildings over 25 m effective height, see Table 8. Even if a building has a zone smoke control system or a stair pressurisation system, not all rooms will have to be monitored. Therefore, we are of the opinion that smouldering fires can go undetected in a DtS building over 25 m effective height.

5.3.16 Fully developed fires pose immediate threats to the life safety of occupants. A fire reaching a fully developed phase has at some stage been a flaming fire. Flaming fires may pose an immediate threat to occupants near the fire, and eventually the smoke produced by the flaming fire may cause untenable conditions along the escape routes.

5.3.17 The proportion of fires reaching the different stages of fire development is summarised for Australian apartment buildings (Class 2) in Table 16 (Apte, et al., 2005). As the data is for single dwellings, the data likely include a majority of non-sprinklered buildings. Therefore, the data is assumed to be related to non-sprinklered buildings.

Table 16: Proportion of fires reaching a certain stage of fire development in Australian apartment buildings

Smouldering fire	Non-flashover fire (flaming)	Flashover fire
24.5 %	60.0 %	15.5 %

5.3.18 Whilst the data in Table 16 relate to apartment buildings, similar sources of ignition and combustible materials are likely to be found in an ECC compared to a typical apartment. Therefore, the proportion of fires only reaching a smouldering state is assumed to be applicable to ECCs. This results in 24.5 % of ignitions that are assumed to only lead to a smouldering fire, the remaining 75.5 % of ignitions lead to at least a flaming fire scenario. This assumption is also applied to the cases where fires are located in Class 9b libraries, Class 5 offices and Class 6 retails. This assumption has been accepted and adopted in previous QRAs for ABCB (FPAA, 2017).

Events – Design Fires and Fire Growth

5.3.19 The rate at which a fire increases its heat release rate will have a major effect on the time of onset of untenable conditions within a specific fire compartment. It is therefore of importance to probabilistically differentiate between different fire growth rates in a risk assessment.

5.3.20 Fire growth rate of time-squared fires is defined as per Equation 4 (Karlsson & Quintiere, 2000):

$$\alpha = \frac{\dot{Q}}{t^2} \qquad \text{Equation 4}$$

where

$\dot{Q}$	heat release rate [kW]
α	fire growth rate coefficient [kW/s^2]
t	time from ignition [s]

5.3.21 We have reviewed data collected on fire growth rates in the studies by Holborn et. al. (2004), Nilsson et al. (2014) and Bengtson & Ramachandran (1994). The data from Nilsson et al. is for commercial buildings and thus not applicable to this project. The data from Bengtson & Ramachandran is for railway properties, public car parks, road tunnels and power stations and thus also not applicable to this project. Holborn's data (16 fires) was collected for the category of schools which contained everything from "infant, primary and secondary" schools. This is interpreted as containing child care centres. The limited data suggests that the distribution of fire growth rates may be skewed. We have therefore also included the category of "Public buildings" in the relevant data extracted from Holborn et al. The fire growth rate distribution from Holborn et al. for these categories are reproduced in Table 17.

5.3.22 The Holborn et al. study classifies the time-squared fire growth rate as a range from very slow to ultra fast. The classification is based on defined intervals by Holborn et al. The assumed values for slow, medium and fast are the average fire growth rate reported for these categories. The very slow growth rate is the upper bound of the open-ended interval.

5.3.23 The assumed distribution of fire growth rates for ECCs and in the Class 9b library is summarised in Table 17.

Table 17: Fire growth data and assumed ECC distribution

Occupancy type	Very slow $\alpha = 0.000412$	Slow $\alpha = 0.003503$	Medium $\alpha = 0.016485$	Fast $\alpha = 0.065938$	Ultra fast $\alpha = 0.1055$
Schools	6	9	0	1	0
Public buildings	2	6	1	1	0
Total (assumed)	**8 (30.8%)**	**15 (57.7%)**	**1 (3.8%)**	**2 (7.7%)**	**0 (0 %)**

5.3.24 We note that the Society of Fire Safety has produced a Practice Note for derivation of design fires (SFS, 2012). The recommended fire growth rates for the types of uses in the Practice Note which are relevant to the study are summarised in Table 18.

Table 18 Design fire growth rate

Building occupancy	Fire t-squared growth (kW/s²)
Child care centre	Fast (0.047)
Library	Fast (0.047)

5.3.25 The fire growth rates suggested in the Society of Fire Safety Practice Note (Table 18) can be concluded to be the upper percentile growth rates which is typical for deterministic assessments. Given no ultrafast fires were found in Holborn's study, this supports the use of the fire growth rate data from Holborn et al. in our probabilistic assessment.

Events – Fire Safety Systems

5.3.26 Sprinkler systems: A study of historical data has demonstrated that sprinklers in Australia are associated with high reliabilities (Maryatt, 1988). The study shows that the reliability spread across different types of occupancies are nearly 100 %. However, that does not account for the efficacy of the sprinkler in controlling the fire. In an analysis of successful sprinkler control of fires in the U.S., the probability for successful sprinkler control of the fire across the different building types is noted as 92 % which has been adopted for the QRA (Hall, 2010).

5.3.27 Smoke detection and alarm systems: Published Document 7974 Part 7 suggests a reliability of 90 % for commercial smoke detection systems (BSI, 2003). This value has been used for the probability of smoke detection and alarm system activation in the QRA.

5.3.28 Stair pressurisation systems: Stair pressurisation system reliabilities were studied as part of an FCRC study (Zhao, 1998). It was found that the stair pressurisation system was associated with varying reliability based on a range of different factors. This finding is confirmed by a New Zealand study (Gravestock, 2008). Based on these studies and engineering judgement, a reliability of 35 % has been adopted for the QRA.

5.3.29 Zone smoke control systems: Zone smoke control systems have been assessed as providing no impact on the life safety for the occupants in the ECC and is therefore omitted. A thorough justification of this is provided in Section 7.2.

5.3.30 Fire-isolated stairs and associated self-closing fire doors. This factor relates to the probability of a fire-isolated stair with its associated self-closing fire door being compromised by smoke or a fire. The reliability of fire rated barriers, excluding fire doors, is largely dependent on their inherent fire resistance, details and quality of construction, and protection of penetrations. Fire-isolated stairs are typically constructed of masonry/concrete elements. For the purpose of this risk analysis, it is assumed that the structure has been properly designed to withstand the anticipated structural load and a total burnout of the compartment in fire. Thus, the reliability of such barriers is considered to be affected by the service penetrations only. The reliability of penetration seals was estimated to be 88% with the lower bound and upper bound values being 60% and 95% respectively (Hui, 2009). With respect to self-closing fire doors, their reliability data were gathered from four sources, i.e. 82% (FM Global), 58.9% (CIGNA Property and Casualty Loss Control), 86.6% (Dusing, Buchanan and Elms) and 82% (Scarff) (Milke, 2014). For the purpose of this QRA, the reliability of self-closing fire doors has been considered to be the average of the four values above, i.e. 77%, with the lower bound and upper bound values being 59% and 87% respectively.

5.3.31 The event probabilities discussed in the above sections are summarised in Table 19 for use in the event tree analyses. The sensitivity analysis values presented for smoke detection and alarm systems, sprinklers and stair pressurisation systems in Table 19 were that used in the ABCB VM Calibration Study (FPAA, 2017).

Table 19: Assumed event probabilities. Values for sensitivity analysis in brackets.

Event	Reliability
Smoke detection and alarm system activation	0.90 [0.80]
Sprinklers	0.92 [0.85, 0.95]
Stair pressurisation system	0.35 [0.20]
Fire-isolated stairs and associated self-closing fire doors (fire resistant construction)	0.77 [0.59, 0.87]

Event Trees

5.3.32 In Figure 7 to Figure 11 the Event Trees for each design case (as per Table 12 and Table 13) are presented. The Event Trees are unique for every Design case as they depend on the number of storeys, occupancies and the technical systems installed. They account for the different types of design fires (growth rates, flaming or smouldering fire) and fire locations. The frequency and consequence have been evaluated for each end event of the design fire scenarios presented in these Event Trees.

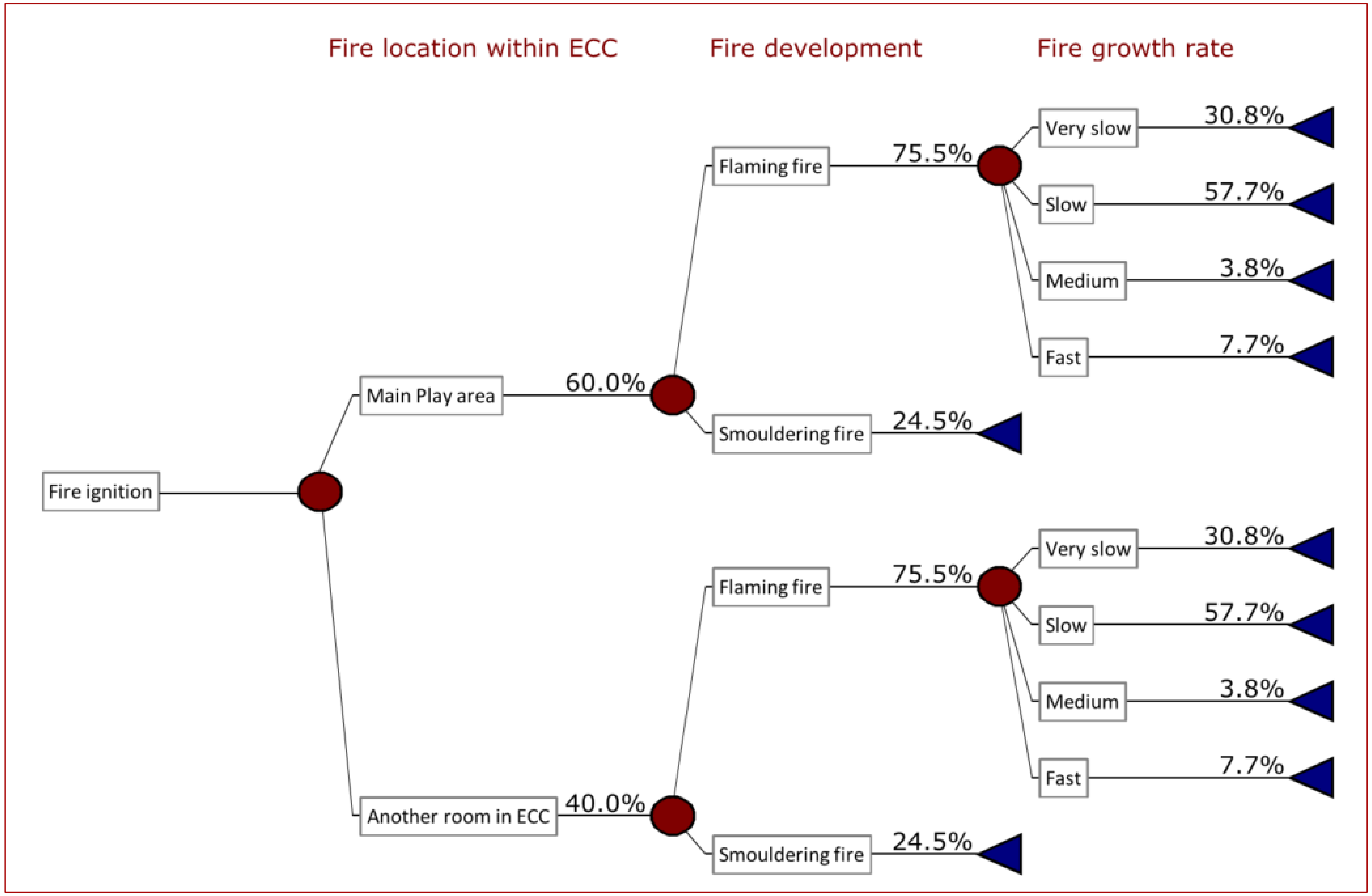

Figure 7: Event tree for Design Case #1 given that a fire has occurred

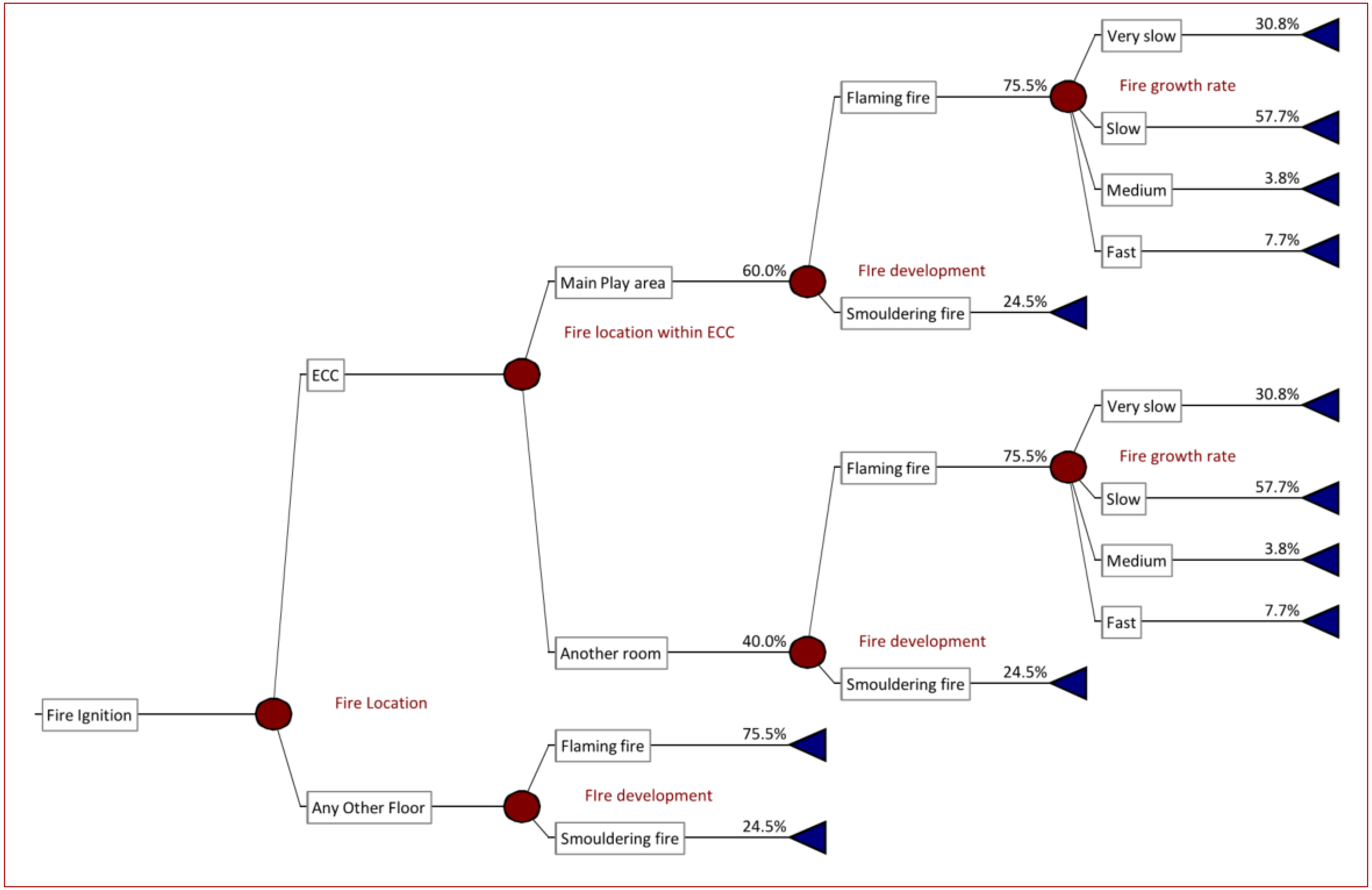

Figure 8: Event tree for Design Case #2 given that a fire has occurred

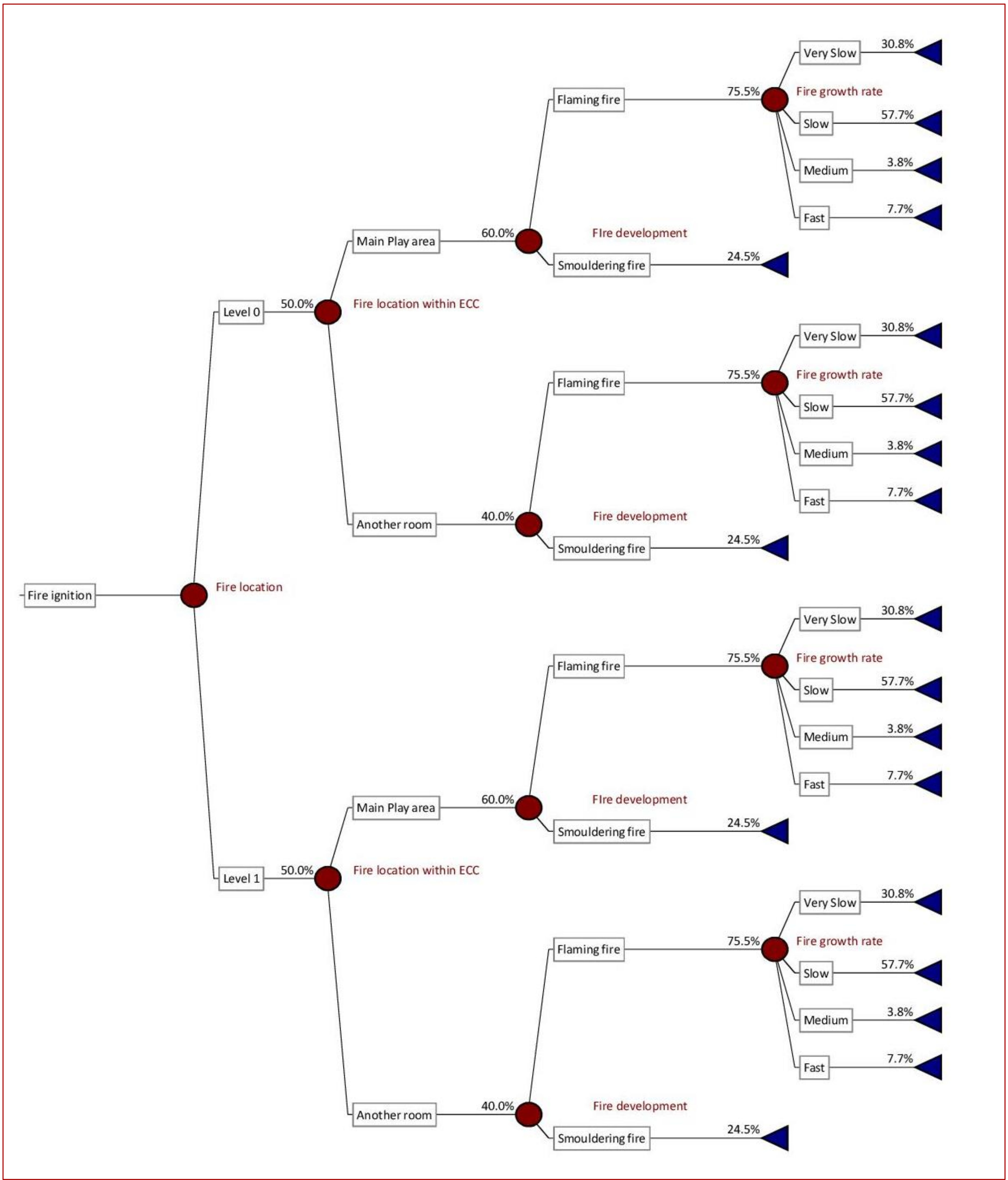

Figure 9: Event tree for Design Case #3 given that a fire has occurred

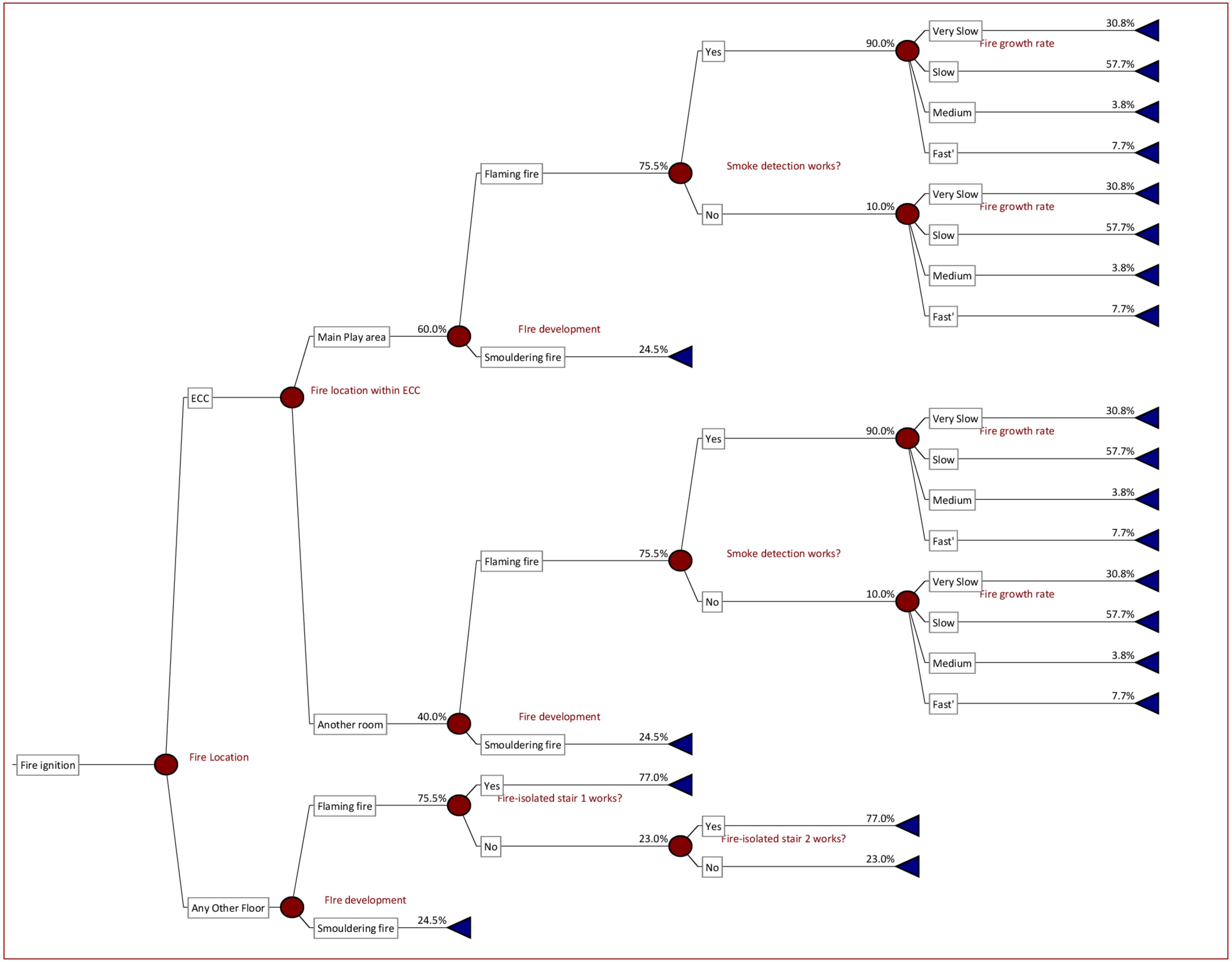

Figure 10: Event tree for Design Case #4 given that a fire has occurred

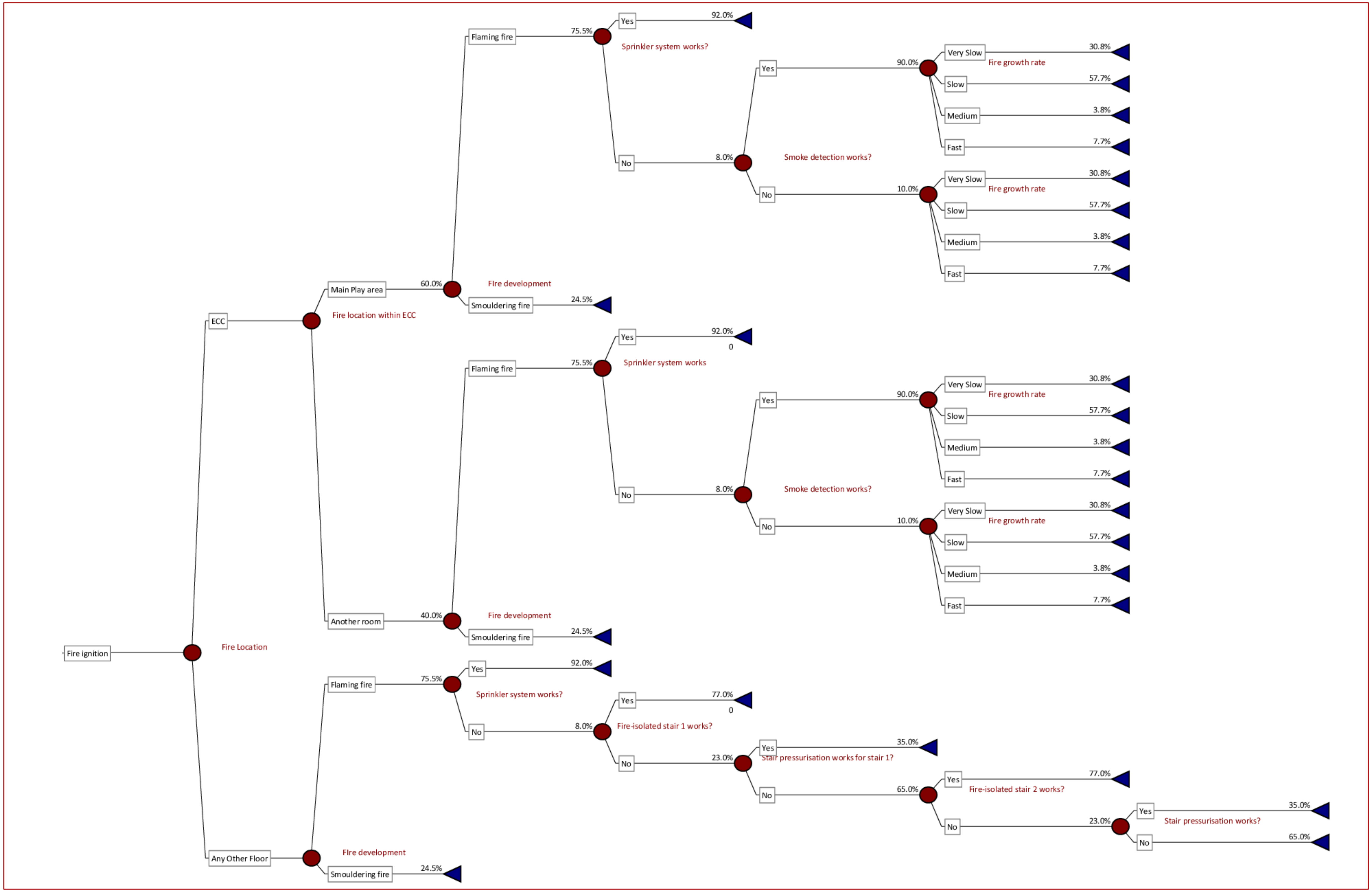

Figure 11: Event tree for Design Case #5 given that a fire has occurred

5.4 Frequency of fire

5.4.1 We are not aware of any studies that provide empirical correlations of the frequency of fire start to the size and use of the building in Australia, apart from the frequency of fire starts in residential apartments, units, flats as well as in commercial properties estimated in the Warren Centre project in 1989 (Warren Centre, 1989). Because the data relates to residential uses, the data is not applicable to this study. Therefore, overseas data from Finland has been used to predict the frequency of fire start based on floor areas and the type of use (Tillander, 2004). We consider it an appropriate approximation as Finland is a western country with similar ignition sources and combustible materials in their buildings compared to Australia. The assumption has previously been accepted and adopted in a previous QRA for ABCB (FPAA, 2017).

5.4.2 The model by Tillander estimates the frequency of fire ignition per unit floor area per annum by using Equation 5.

$$\boldsymbol{F_B}'' = \boldsymbol{a} \cdot \boldsymbol{A_f}^{\boldsymbol{b}} + \boldsymbol{c} \cdot \boldsymbol{A_f}^{\boldsymbol{d}} \qquad \text{Equation 5}$$

where

F_B''	ignition frequency per m² per annum [year^{-1}m^{-2}]
A_f	floor area [m^2]
a, b, c, d	occupancy characteristic coefficients (see Table 20) [-]

Table 20: Occupancy dependent coefficients (Tillander, 2004)

Occupancy	a	b	c	d
Commercial	7×10^{-5}	-0.65	6×10^{-6}	-0.05
Office	0.056	-2.00	3×10^{-6}	-0.05
Assembly	0.003	-1.14	2×10^{-6}	-0.05
Institutional care	0.0002	-0.61	5×10^{-6}	-0.05

5.4.3 The frequency of fire ignition per unit floor area per annum (F_B'') has been calculated using Equation 5 for this QRA. Occupancy characteristics have been selected as appropriate from Table 20.

5.4.4 Note that this frequency is the frequency of ignition per unit area and must be multiplied again by the total area of the building to calculate the total ignition frequency of the building:

$$\boldsymbol{F_f} = \boldsymbol{F_B}'' \cdot \boldsymbol{A_f} \qquad \text{Equation 6}$$

where

F_f	fire start frequency [year^{-1}]

5.5 Acceptable risk

5.5.1 The acceptable risk for the purpose of this QRA is that proposed in the draft ABCB Tolerable Risk Handbook. The Handbook classifies a Class 9b Early Child Care as a Building Class Group 3 (BCG 3) which includes Class 9b assembly buildings, Class 6 retail/commercial and Class 7a carparks. The individual risk applicable is for consequences in the form of fatalities.

5.5.2 The acceptable individual risk for building fires as per the Handbook is presented in Table 21.

Table 21: Acceptable individual risk

Building Class Group	Benchmark Safety Hazard Individual risk for fire
Building Class Group 3	3.39×10^{-7} year^{-1}

5.5.3 The acceptable societal risk for an ECC for fire and life safety in the draft ABCB draft Tolerable Risk Handbook is provided in Table 22.

Table 22: Acceptable societal risk

Fatalities (N)	Acceptable frequency (F)
N=1	3.00×10^{-6}
N=10	3.24×10^{-7}
N=100	1.58×10^{-8}
N=1000	1.00×10^{-12}

5.6 Risk Presentation

5.6.1 Presentation of the risk includes percentage of acceptable risk which is calculated as per Equation 7.

$$\boldsymbol{P = \frac{IR}{IR_a} \cdot 100} \qquad \text{Equation 7}$$

where

P Percentage of the acceptable risk [%]
IR Estimated Individual Risk [year^{-1}]
IR_a Acceptable Individual Risk [year^{-1}]

5.6.2 Presentation of risk in the form of Relative Risk has also been included. The base case is design case 1 (Deemed-to-Satisfy) which will be given a Relative Risk of 1.0. The Relative Risk of the other design cases is calculated as per Equation 8.

$$\boldsymbol{RR_i = \frac{IR_i}{IR_{DC1}}} \qquad \text{Equation 8}$$

where

RR_i Relative Risk for design case *i* [-]

IR_i Individual Risk for design case *i* [$year^{-1}$]

IR_{DC1} Individual Risk for design case 1 [$year^{-1}$]

5.6.3 Societal risks are presented in the form of FN-curves.

6 Egress modelling

6.1 Introduction

6.1.1 We are not aware of any empirical correlations that may accurately predict the time to evacuate an ECC. The mathematical models presented in this section is based on the authors' observations of evacuation drills in Australian ECCs, as well as from reviewing reports presenting such data.

6.2 Assumptions and limitations

Staff not actively evacuating children in Type A evacuation

6.2.1 In Type A evacuation, not all children will be able to be carried simultaneously by the staff available in the ECC due to the staff-to-child ratios. Therefore, some staff will have to wait with the children to not leave the children unattended. Some staff will also have to be positioned at the place of relative safety to tend these children. We are not aware of any studies that have investigated the ratio of staff that actively evacuate children to staff that tend children in the ECC and at the place of relative safety. In this assessment, we have assumed that 10 % of the staff are not actively partaking in the evacuation of children until the last of the children has been carried out.

Queuing in Type A evacuation

6.2.2 In Type A evacuation, staff will carry children to a place of relative safety. In the hypothetical design, the occupant load results in 84 staff (see section 4.2.10). As described in section 6.2.1, not all members of staff will be actively evacuating children in Type A evacuation. The building has two exits each with an unobstructed width of 2.0 m. The individual differences in travel speed (up and down stairs as well as horizontally), behaviour of the children and attending to each individual child's needs will create differences in the time when staff will pick up children to evacuate them. These factors combined will result in that the overall egress time will be governed by the travel speed of staff and not queuing at exits which occurs when higher occupant loads try to enter the same exit simultaneously.

6.2.3 Despite the reasoning above, a Pathfinder model was created to determine if the flows through doorways or the walking speed down the stairs will govern the flow rate of occupants (Thunderhead Engineering, 2012). The input parameters were as follows:

- Occupants shoulder width was assumed to be 0.75 m (assumes woman carrying two children).
- Single exit with 1.75 m wide doorway and 2.0 m stair.
- Walking speeds down the stairs as per Table 25.
- Doorway flows calculated by Pathfinder steering algorithm.
- All staff using the same single exit.

6.2.4 The Pathfinder simulation demonstrated that the walking speed down the stairs governed the travel time rather than queuing to enter the stairs or down stairs. Queuing to enter stairs or within the stairs has therefore not been considered in Type A evacuation.

6.2.5 Note that the assessment using Pathfinder (as described in Sections 6.2.3 and 6.2.4) was utilised to justify the overall egress model created for Type A evacuation. Pathfinder was not used to quantify the movement/queuing times for the egress analyses that were used to calculate the fire and life safety risk in this report.

Queuing in Type B evacuation

6.2.6 As described in sections 4.3.16 to 4.3.21, we are not aware of any data for door or stair flows for children queuing. Based on observations, we are of the opinion that it is the walking speed of the slowest child and the separation distances between children that govern the flow through the stair.

6.2.7 We also do not believe it is feasible to evacuate more than one group of children in parallel in stairs as described in these sections. These assumptions have been used in the egress modelling. The exception is design case #1 where horizontal evacuation directly to the outside can occur. We have assumed that two rows of children will be able to evacuate (under the guidance of staff) through a 1.75 m wide door. This assumption is also applied to horizontal evacuation between fire compartments for Type B evacuation applied in the analysis of recommended fire safety measures in Appendix A.

Places of relative safety

6.2.8 This section includes methods to calculate the egress time to a *place of relative safety.*

6.2.9 A *place of relative safety* is defined as follows:

- For design case #1 - A door leading directly to the outside.
- For design cases #2 and 3 with open stairs (non-fire-isolated stairs) -
    a. When the fire is located on Level 1 – The open stair.
    b. When the fire is located on Level 0 – A door leading directly to the outside.
- For design cases #4 and 5 with fire-isolated stairs - The fire-isolated stair.
- For the analysis of recommended additional fire safety measures where horizontal fire compartmentation is provided (see Appendix A) – The fire compartment adjacent to the fire-affected compartment.

Floor-to-floor heights and stair design

6.2.10 For design cases with more than one storey, the travel distances within the stair govern the egress times within the stairs. In the assessments, the height between the top of the floor slab and the top of the floor slab above has been assumed to be 2.8 m.

6.2.11 The stairs have been designed to meet the DtS Provisions for riser and going dimensions. The risers (13 in total) are assumed to be 115 mm each and the goings (12 in total) are assumed to be 355 mm each. This leads to the walking distance (along the threads) being approximately 4.5 m from landing to landing and thus approximately 9.0 m per storey.

Counter-flows in the stairs from fire brigade personnel

6.2.12 The egress modelling has not included any effects from counter-flows from fire brigade personnel carrying out fire fighting activities. We have excluded this from the study as the effect on the egress is unknown. However, the effect is likely to be negative in terms of evacuating ECCs. The effect will predominantly affect medium to high rise buildings with significant times required to evacuate the ECC. The actual risk to ECCs such as design cases #4 and 5 are expected to be higher than that predicted in this study.

Egress from other storeys affecting the egress from the ECC

6.2.13 In design cases 4 and 5, the fire-isolated exits are very likely to be used by not only the ECC but also occupants on the other storeys in the building. The influx of occupants from the other storeys will negatively impact the time for evacuating an ECC with both Type A and Type B evacuations.

6.2.14 The uses in buildings are not regulated by the NCC DtS Provisions and there is an infinite complexity in the combinations of uses (and therefore occupant loads and pre-movement times) on these storeys. We have therefore excluded any impact on the egress times of the ECC from other storeys. The actual risk to ECCs such as design cases #4 and 5 are expected to be higher than that predicted in this study.

6.3 Time for egress of occupants

6.3.1 The time required for egress to a *place of relative safety* for the occupants in an ECC is described by Equation 9:

$$\boldsymbol{t_e = t_a + t_{pre} + t_m} \qquad \text{Equation 9}$$

where

t_e	RSET to reach a place of relative safety [s]
t_a	time to staff becoming aware of fire – cues or alarm system [s]
t_{pre}	pre-movement time for staff and children to commence evacuation [s]
t_m	movement time for staff and children to a place of relative safety [s]

6.3.2 For the prediction of the time for egress of occupants, two distinctly different occupant groups are assessed; Type A (staff carrying children) and Type B (children self-egressing under supervision of staff). For the two different occupant groups, the movement time will depend on different variables. Therefore, the movement phase for each of these occupant groups has been treated separately.

6.3.3 The alarm time is identical regardless of Type A or Type B evacuation.

6.3.4 The pre-movement time has been assumed to be identical regardless of Type A or Type B evacuation. For Type A, the pre-movement time will include preparing children for evacuation which could include putting on appropriate clothes, collecting some toys (or other comforting objects), etc. For Type B, the pre-movement time will include preparing children for evacuation which could include putting on appropriate clothes, retrieving any objects used to assist the movement of children (e.g. daisy chain rope), arranging children in groups, etc. We are not aware of any studies quantifying the pre-movement time for ECCs including any differentiation between Type A and Type B evacuation. The pre-movement time is therefore assumed to be identical in Type A and Type B evacuations.

Alarm time – Smoke Detection System

6.3.5 The activation time of the smoke detection system was predicted by using the zone model, CFAST, developed by the National Institute of Standards and Technology, USA. The smoke detector was set to activate at 10 % obscuration/m, which was a conservative estimate of the activation time for smoke detectors on the Australian market complying with the relevant Australian Standards.

Alarm time - Manual detection of fire

6.3.6 Occupants were assumed to become aware of the fire when smoke layer has descended 5 % of the total ceiling height (Eaton, 1991) provided that an occupant was present inside such a room. The occupants that will detect such a fire are assumed to be staff. We do not consider very young children to be capable of detecting a fire and raise an alarm.

6.3.7 When a member of staff has detected a fire as per section 6.3.6 above, additional time will be required to manually raise the alarm within the ECC. We are not aware of any studies that have investigated the time required to perform such an action. We have assumed that the time required is 30 s.

Pre-movement time

6.3.8 As noted in section 6.3.4, we are not aware of any studies quantifying the pre-movement time in ECCs, apart from the experimental study by (Kholshchevnikov et al., 2012) in a pre-school education institution environment in the city of Moscow and the Moscow region where teachers would have to put outdoor clothing on the children during the cold period of the year to prevent hypothermia. The pre-movement times reported in this study are 0.6 min in summer, 5 min in spring and autumn, and 7.5 min in winter if outdoor clothes are donned or 1.1 min in winter if blankets are used to wrap the children.

6.3.9 Determination of the pre-movement time has been carried out in accordance with Published Document 7974-6 - Human factors: Life safety strategies – Occupant evacuation, behaviour and condition (BSI, 2004). The method of PD 7974-6 allows the pre-movement time, expressed as the 1st and 99th percentile values, of different types of uses to be quantified based on four factors; classification of use (e.g. hotel, office), alarm system, level of management and building complexity.

6.3.10 PD 7974-6 does not include explicit categorisation of ECCs. However, we consider Category A (awake and familiar, e.g. office) to most accurately correspond to an ECC. The reasoning is that staff are to be awake and they are familiar with the building as it is their place of work. We have therefore assumed that the pre-movement times for Category A are applicable to an ECC.

6.3.11 In Table 23, the different design cases for the hypothetical buildings assessed are summarised along with their predicted 1st and 99th percentile values for pre-movement times by PD 7974-6. It should be noted that for occupancies without a Building Occupant Warning System, the Alarm System is categorised as A2 as our egress model explicitly considers the additional time for a member of staff to raise an alarm within the ECC.

Table 23: PD 7974-6 classification of design cases

Design case (see Table 12)	Alarm system (A)	Building Complexity (B)	Management Level (M)	1st percentile	99th percentile
#1	A2	B1	M1	30 s	90 s
#2	A2	B2	M1		
#3	A2	B2	M1		
#4	A1	B2	M1		
#5	A1	B2	M1		

6.3.12 In a Type A evacuations, where staff will have to carry children, the influence of queuing at an exit on the total time for egress is negligible as discussed in 6.2.4. Therefore, the overall total time for egress will depend on when the last few members of staff begin moving, i.e. the 99th percentile values. Therefore, in Type A evacuations, the 99th percentile value has been assumed for the assessment.

6.3.13 In Type B evacuations, where children will self-egress under directions of staff, the influence of the children’s walking speed will govern the overall time for egress. This is because as soon as a group of children have started to move down stairs, this will govern the overall flow of occupants down the stairs, see section 6.2.6. Therefore, in Type B evacuations, the 1st percentile pre-movement time will govern the overall time for egress.

6.3.14 The assumed pre-movement times for the assessments based on the reasoning above are shown in Table 24, and are in general agreement with that in the Moscow study discussed in section 6.3.8.

Table 24: Assumed pre-movement times

Design case	Type A	Type B
#1 – 5	90 s	30 s

Movement time – Type A evacuations

6.3.15 In Type A evacuations, staff will have to carry children to a place of relative safety. The movement phase will involve the following steps:

(1) Pick up children.
(2) Carry the children to the final exit (the outside). In design cases 2-5, this involves travelling down stairs.
(3) Leave the children with staff at the final exit.
(4) If not all children are evacuated in one go – Travel back to the ECC. In design cases 2-5, this involves travelling up stairs. Repeat procedure from step (1).

6.3.16 A mathematical model has been created to calculate the number of occupants in the ECC at a given time after the movement phase of the evacuation begins. The model relies on the following inputs:

- Walking speeds as per Table 25.
- Travel distances to an exit (i.e. the outside or a stair).
- Where applicable, travel distances in the stair (i.e. along the treads and landings). The number of storeys therefore affects the travel distances.

6.3.17 A result of the movement time model for Type A evacuations is that staff actively evacuating children will exit and re-enter the ECC during an evacuation.

6.3.18 The mathematical model has been used to predict the number of occupants in the ECC when untenable conditions occur.

6.3.19 An example of the number of occupants in the ECC as a function of time is provided in Figure 12, for Design Case #5.

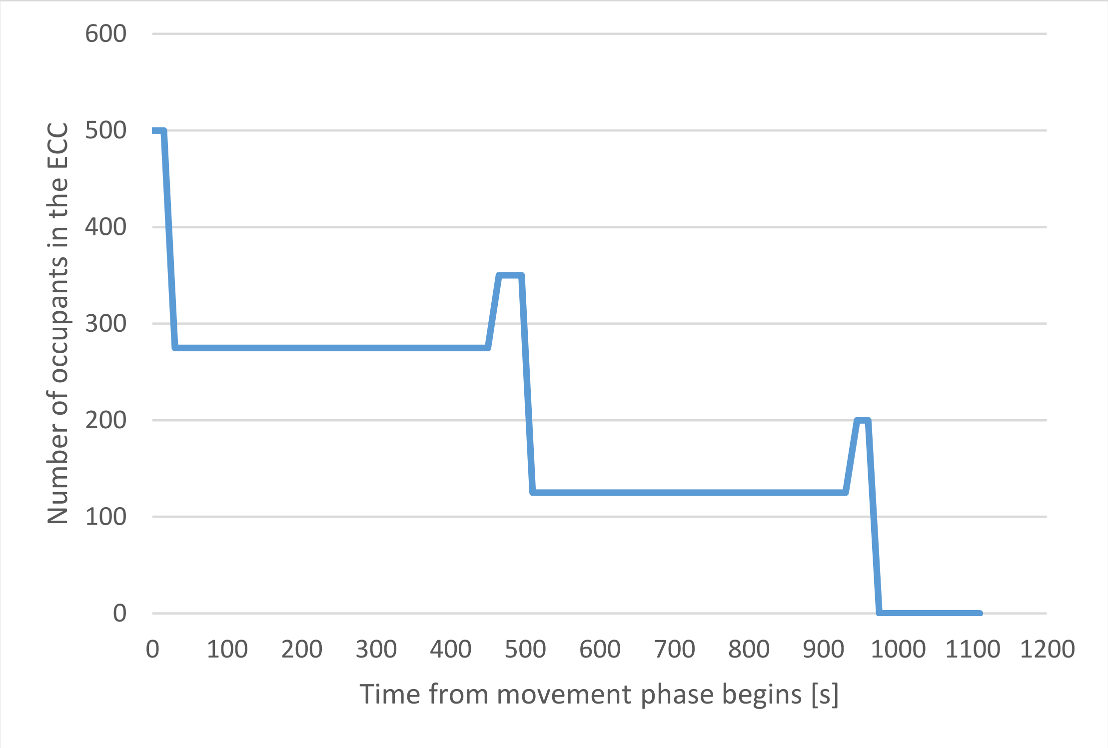

Figure 12: Movement time in Design Case #5

Movement time – Type B evacuation

6.3.20 In Type B evacuations, children will self-egress under the supervision of staff to a place of relative safety. The movement phase will involve the children moving from their starting point to a place of relative safety under the supervision and guidance of staff. Staff are therefore assumed to be divided up between the groups of children.

6.3.21 A mathematical model has been created to calculate the number of occupants in the ECC at a given time after the movement phase of the evacuation begins. The model relies on the following inputs:

- Walking speeds for children as per Table 26.
- Travel distances to an exit (i.e. the outside or a stair).
- Where applicable, travel distances in the stair (i.e. along the treads and landings). The number of storeys therefore affects the travel distances.
- The distance between each egressing child.

6.3.22 Walking speeds for staff are irrelevant for Type B evacuations as the time for evacuation will be governed by the children's walking speeds.

6.3.23 The mathematical model has been used to predict the number of occupants in the ECC when untenable conditions occur.

6.3.24 An example of the number of occupants in the ECC as a function of time is provided in Figure 13 for Design Case #5.

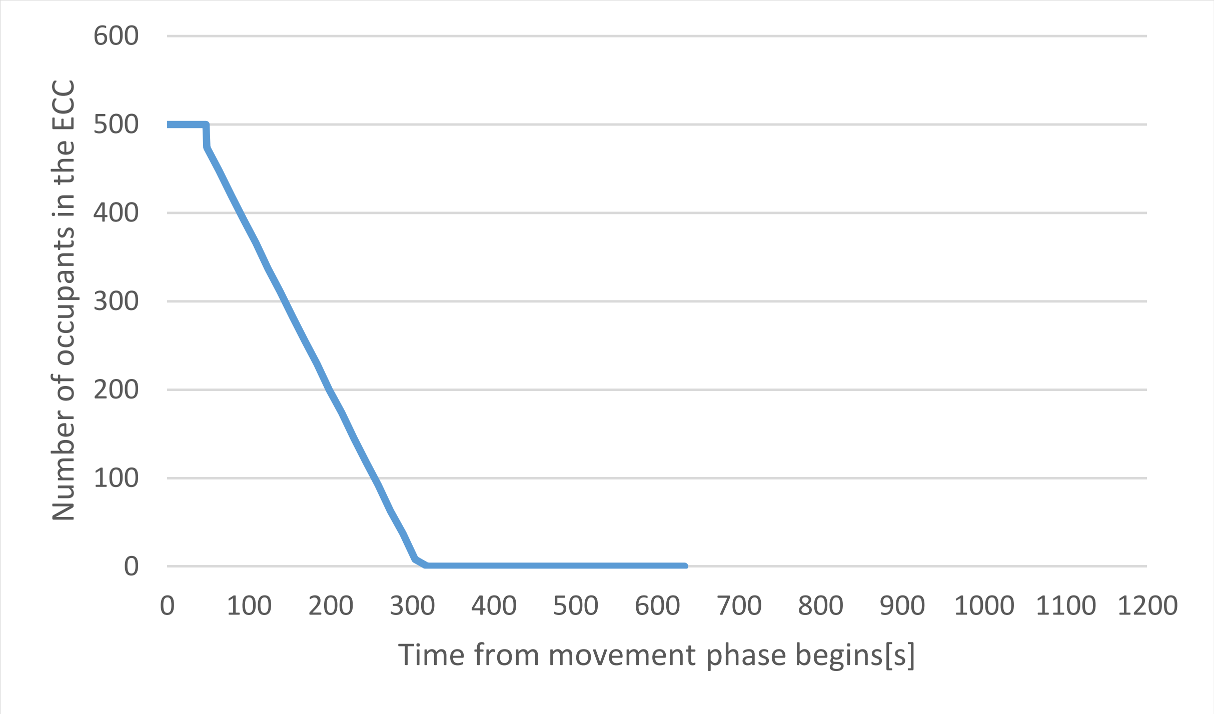

Figure 13: Movement time in Design Case #5

6.4 Inputs

6.4.1 This section contains input data used in the egress modelling.

Table 25: Walking speeds for staff

Description	Situation	Walking speed [m/s]
Staff carrying children up to 24 months	Horizontal walking	0.95
	Walking down stairs	0.43
Staff walking up stairs (without children)	Walking up stairs	0.5

Table 26: Walking speeds for children

Age	Situation	Walking speed [m/s]
24 - 36 months	Horizontal	0.61
	Down stairs	0.33

7 Consequence assessment

7.1 Introduction

7.1.1 The intention of this section is to describe how the consequences (number of fatalities) have been estimated for the different fire scenarios.

7.1.2 The QRA addresses fire scenarios occurring both in the ECC and elsewhere in the building. The threat to life from a fire in an ECC is very different from a fire elsewhere in the building. Therefore, two types of fire scenarios are required to be assessed separately using different methods.

7.1.3 A fire occurring in the ECC means toxic smoke and hot gases can directly affect the occupants in the ECC. The method applied is therefore modelling of the environment in the ECC from a fire. The method is explained in detail in section 7.3.

7.1.4 In design case #2, no fire separation is required between the ECC on Level 1 and the Class 9b Library on Level 0. However, we assume that such a design would involve a separation using toughened glass (see 7.2.8). The method in section 7.3 is used to predict glass breakage and the onset of untenable conditions.

7.1.5 When a fire occurs elsewhere in the building, the main threat to the occupants in the ECC is having the fire-isolated stairs (exits) compromised by the fire. The method applied to assess this scenario is a semi-probabilistic assessment of compromised egress routes. The method is explained in detail in section 7.4.

7.2 Assumptions

Zone smoke control systems

7.2.1 Zone smoke control systems provide a "sandwich pressurisation" of the fire-affected floor. Under AS/NZS 1668.1:2015, this is achieved by relieving air from the fire-affected compartment and providing pressurisation with outdoor air to the non-fire-affected compartments. The intent is to achieve a pressure differential between 20 and 80 Pascals between the fire-affected compartment and other non-fire-affected compartments when tested in fire mode (without the effects of a fire).

7.2.2 The intent of a zone smoke control system is to mitigate smoke migration from the fire-affected floor to other floors through cracks and small openings in floors as well as unpressurised shafts which is a risk to life safety remote from the fire-affected compartment (Klote & Milke, 2002).

7.2.3 A zone smoke control system is not designed to provide tenability in the fire-affected compartment (Klote, et al., 2012). This fact is supported by observing that AS/NZS 1668.1:2015 does not set a minimum required exhaust capacity for the relief air from the fire-affected compartment. The relief air could therefore in theory be infinitesimally small as long as the pressure differential is achieved by the zone smoke control system is achieved.

7.2.4 In the hypothetical building, the pressure differential is assumed to be created by the pressurisation of non-fire-affected compartments and the relief from the fire-affected compartment contributing a negligible amount to the pressure differential. Because of this, the modelling of untenable conditions in the ECC (Section 7.3) has not accounted for any smoke exhaust.

7.2.5 In the event that a fire occurs on a level other than the ECC in the hypothetical building, and the zone smoke control system fails to operate, a pressure differential is not achieved between the fire-affected and non-fire-affected compartments. However, we assumed that the building has been constructed in full accordance with the DtS Provisions of the NCC. These provisions require that penetrations through floors are appropriately sealed to prevent the spread of fire and smoke (as per C3.15) and shafts are either sealed at the floor (closed shafts as per C3.15) or provided with an appropriate fire rating (open shafts as per Specification C1.1). Therefore, in a DtS building, smoke migration through the floor is very unlikely.

7.2.6 Furthermore, the only hypothetical design case provided with a zone smoke control system is design case #5. This building is also provided with an automatic sprinkler system. The successful operation of a sprinkler system will serve as an effective means of smoke control as the buoyancy of smoke and pressure build up from the fire is reduced at the time of activation. The simultaneous failure of the zone smoke control system and the sprinkler system is a very unlikely event.

7.2.7 Because of the above, failure of the zone smoke control system when a fire occurs on a storey other than the ECC is assumed to have no impact on the fire and life safety of the occupants in the ECC for the purposes of this study.

Special consideration for Design Case #2

7.2.8 For Design Case #2 (see Table 13), it is assumed that a tenancy barrier is provided between the Class 9b library and the open stairs serving the ECC. It is assumed that this is a glass barrier constructed with toughened glass. A 6 mm toughened glass barrier may shatter at temperatures of approximately 350 °C (Xie, et al., 2008) and this has been assumed to occur in the present study. Once such a barrier fails, the stair will be compromised. The time until this occurs will be determined using the upper smoke layer temperature in the compartment adjacent the exits predicted by using CFAST (Section 7.3).

Special consideration for Design Case #3

7.2.9 For Design Case #3 (see Table 13), it has been assumed that no smoke will travel between the floors via the open stairs in the CFAST model. The rationale for this is to determine conservatively when the onset of untenable conditions occurs on the ground level. Once untenable conditions are present on the ground level, it is assumed that the untenable conditions also occur simultaneously in the open stairs.

Sprinklered fires

7.2.10 In fire scenarios where sprinklers activate, the consequence is assumed to be nil. This is based on research that demonstrates that whilst the visibility may become less than 10 m in a sprinklered fire due to the downward thrust of the sprinkler spray, the toxicity and temperature of the gases generated by the fire is expected to be low (Williams, et al., 2005). Therefore, occupants are allowed an almost infinite time to egress to a place of safety. Statistics also demonstrate that the risk of becoming a fatality in a sprinkler controlled fire is very low (Maryatt, 1988; Thomas, 2002).

7.3 Method to determine ASET – Fire in ECC or Class 9b Library

7.3.1 CFAST version 7 has been used to simulate the effects on the environment from a fire within the fire affected compartment (Peacock, et al., 2017). CFAST is a two-zone model that can predict life safety related parameters such as upper and lower smoke layer temperatures, smoke layer interface heights, visibilities and radiant heat fluxes in the fire-affected compartment and the adjoining compartments.

Tenability criteria

7.3.2 The tenability criteria are based on the Society of Fire Safety (SFS) Practice Note for Tenability Criteria in Building Fires and cover the following criteria:

- Temperature
- Level of visibility
- Level of toxicity

7.3.3 The acceptable levels depend on whether the modelled smoke layer height is above or below staff head-height (taken as 2.1 m). These parameters are taken from the SFS Practice Note (SFS, 2014).

Table 27: Tenability criteria

Parameter	Criteria 1: Smoke layer above 2.1 m	Criteria 2: Smoke layer below 2.1 m
Upper layer temperature	Not to exceed 200 °C	Not to exceed 60 °C
Lower layer temperature	Not to exceed 60 °C	Not to exceed 60 °C
Radiant heat	Not to exceed 2.5 kW/m^2 at 2.1 m above floor level.	Not to exceed 2.5 kW/m^2 at 2.1 m above floor level.
Visibility	-	Visibility not to fall below: 10 m
Toxicity	-	Toxicity is conservatively estimated by considering whether visibility is maintained.

7.3.4 The tenability criteria in Table 27 results are applicable to both staff (adults) and children as the general guidelines for toxicity from gases generated in fires are developed from vulnerable sub-populations such as elderly and people (incl. children) that are asthmatic (Purser & McAllister, 2016).

Design Fires inputs summary

7.3.5 The design fires have been developed in accordance with Society of Fire Safety Practice Note for Design Fires (SFS, 2012).

7.3.6 Four different design fire growth rates (Very Slow to Fast) presented in Table 17 have been used in the QRA.

7.3.7 The heat of combustion has been assumed to be 14.8 MJ/kg. This represents a mix of cellulosic and plastic materials. The soot yield has been set to 0.10 g/g. The radiative fraction has been set to 0.3, which is reasonable for flaming fires (Karlsson & Quintiere, 2000).

7.3.8 The peak HRR has been set to 20 MW. The peak HRR was set to this value to ensure that a fire would not reach the peak HRR prior to the onset of untenable conditions (see Table 35). This is in line with the Society of Fire Safety Practice Note for Design Fires which does not define a peak HRR (SFS, 2012).

7.3.9 The design fire characteristics are summarised in Table 28 to Table 31 below.

Table 28: Characteristics of Design Fire Scenario "Very Slow"

Design Fire Characteristics	
Peak HRR	20 MW
Fire Growth	0.412 W/s^2
Heat of combustion	14.8 MJ/kg
Yields	Smoke: y_s=0.10 g/g
Radiative fraction	0.3

Table 29: Characteristics of Design Fire Scenario "Slow"

Design Fire Characteristics	
Peak HRR	20 MW
Fire Growth	3.503 W/s^2
Heat of combustion	14.8 MJ/kg
Yields	Smoke: y_s=0.10 g/g
Radiative fraction	0.3

Table 30: Characteristics of Design Fire Scenario "Medium"

Design Fire Characteristics	
Peak HRR	20 MW
Fire Growth	1.6485 W/s^2
Heat of combustion	14.8 MJ/kg
Yields	Smoke: y_s=0.10 g/g
Radiative fraction	0.3

Table 31: Characteristics of Design Fire Scenario "Fast"

Design Fire Characteristics	
Peak HRR	20 MW
Fire Growth	6.5938 W/s^2
Heat of combustion	14.8 MJ/kg
Yields	Smoke: y_s=0.10 g/g
Radiative fraction	0.3

CFAST Model

7.3.10 A 3D rendering of the CFAST models for a fire located in Play Area 1 and Play Area 5 are shown in Figure 14 and Figure 15 respectively. Table 32 summarises the main input to the CFAST model.

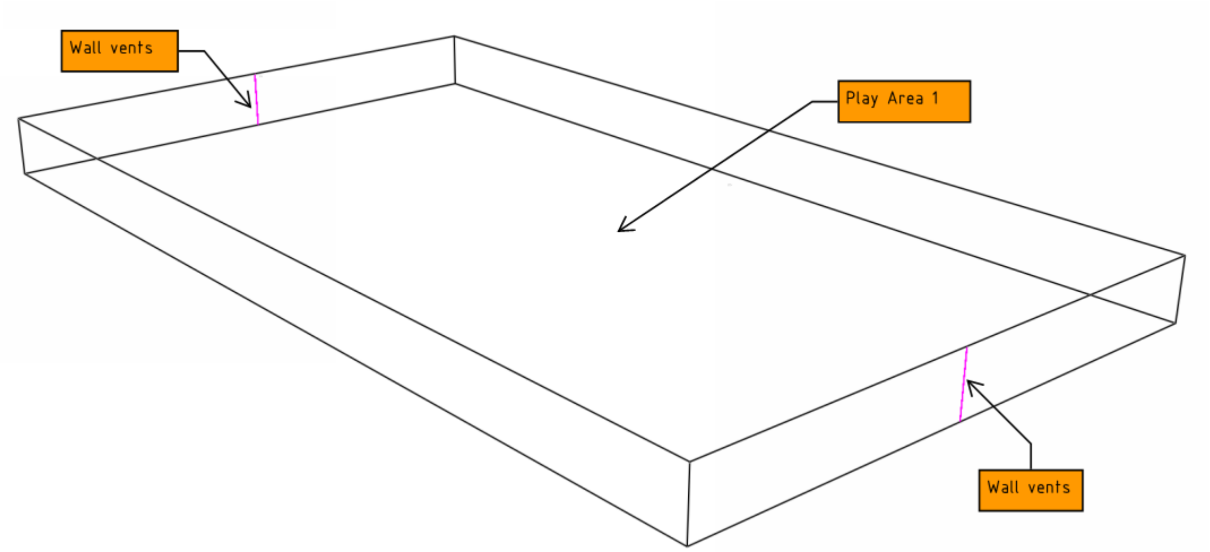

Figure 14: 3D rendering of the CFAST modelling for a fire in Play Area 1 (Note: Wall vents have been introduced to mimic building leakage and provide oxygen to enter the model for combustion as well as to avoid the build up of back pressure, not for smoke venting)

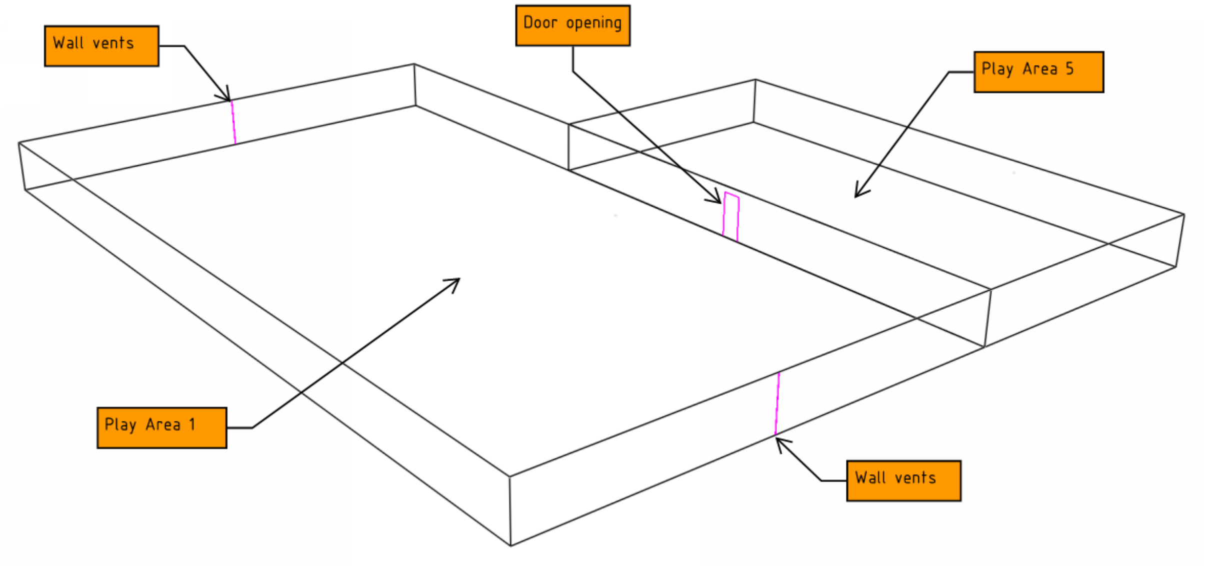

Figure 15: 3D rendering of the CFAST modelling for a fire in Play Area 5 (Note: Wall vents have been introduced to provide oxygen for combustion as well as to avoid the build up of back pressure, not for smoke venting)

Table 32: Main input parameters used for modelling untenable conditions

General / Domain Parameters	
Material Properties	Ceiling and Walls: Gypsum Plaster Floor: Concrete
Gypsum Plaster Properties	Conductivity: 0.00017 kW/(m°C) Specific Heat: 0.84 kJ/(kg°C) Density: 1440 kg/m^3 Thickness: 0.016 m
Concrete Properties	Conductivity: 0.0011 kW/(m°C) Specific Heat: 0.88 kJ/(kg°C) Density: 2100 kg/m^3 Thickness: 0.25 m
Play Area 1 Size	39.6 m (W) x 22.4 m (D) x 2.4 m (H)
Play Area 5 Size	25.7 m (W) x 12.8 m (D) x 2.4 m (H)
Wall Vents in Play Area 1	0.01 m (W) x 2.4 m (H)
Door opening	0.9 m (W) x 2.1 m (H)
Fire locations	Centrally located at floor level.
Scenario Parameters	
Ambient temperature	20°C
Fire Safety System / Device Parameters	
Smoke Detectors Activation Obscuration	10 %/m

Results – Untenable conditions

7.3.11 Results from the CFAST simulations of the design fires presented in Table 28 to Table 31 are shown in Table 33 (fire assumed to be located in Play Area 1) Table 34 (areas adjacent to Play Area 1 as modelled by a fire in Play Area 5). The upper and lower smoke layer temperatures, smoke layer interface height and upper and lower visibilities within the compartments are estimated by using the CFAST model.

Table 33: Observations from CFAST modelling for a fire located in Play Area 1

Observation	Very Slow	Slow	Medium	Fast
Upper layer temperature above 200°C	>1200 s	>1200 s	>1200 s	389 s
Lower layer temperature above 60°C	>1200 s	1064 s	607 s	369 s
Smoke layer height below 2.1 m	469 s	291 s	197 s	142 s
Upper layer visibility below 10 m	254 s	54 s	14 s	30 s
Lower layer visibility below 10 m	>1200 s	>1200 s	>1200 s	>1200 s

Table 34: Observations from CFAST modelling for a fire located in Play Area 5

Observation	Very Slow	Slow	Medium	Fast
Conditions in Play Area 1				
Upper layer temperature above 200°C	>1200 s	>1200 s	>1200 s	>1200 s
Lower layer temperature above 60°C	>1200 s	>1200 s	>1200 s	>1200 s
Smoke layer height below 2.1 m	1039 s	615 s	409 s	279 s
Upper layer visibility below 10 m	572 s	364 s	183 s	129 s
Lower layer visibility below 10 m	>1200 s	>1200 s	>1200 s	>1200 s
Conditions in Play Area 5				
Upper layer temperature above 200°C	>1200 s	>1200 s	>1200 s	>1200
Lower layer temperature above 60°C	>1200 s	895 s	511 s	326 s
Smoke layer height below 2.1 m	246 s	157 s	107 s	83 s
Upper layer visibility below 10 m	243 s	53 s	37 s	7 s
Lower layer visibility below 10 m	>1200 s	741 s	484 s	326 s

7.3.12 The time of onset of untenable conditions in Play Area 1 for each fire growth rate and fire location is summarised in Table 35.

Table 35: Time of onset of untenable conditions in Play Area 1

Fire Location	Very Slow	Slow	Medium	Fast
Play Area 1	469 s	291 s	197 s	142 s
Play Area 5	1039 s	615 s	409 s	279 s

Results – Time to reach 350 °C

7.3.13 CFAST has also been used to predict the time when the upper smoke layer reaches 350 °C. This corresponds to the temperature at which toughened glass is expected to fail. This only relates to design case #2, see 7.2.8.

7.3.14 The input parameters for the CFAST model have been varied slightly from the assessment of untenable conditions to suit the analysis output. These are summarised in Table 36.

Table 36: Main input parameters used for temperature analysis

General / Domain Parameters	
Material Properties	Ceiling and Walls: Gypsum Plaster Floor: Concrete
Gypsum Plaster Properties	Conductivity: 0.00017 kW/(m°C) Specific Heat: 0.84 kJ/(kg°C) Density: 1440 kg/m^3 Thickness: 0.016 m
Concrete Properties	Conductivity: 0.0011 kW/(m°C) Specific Heat: 0.88 kJ/(kg°C) Density: 2100 kg/m^3 Thickness: 0.25 m
Play Area 1 Size	39.6 m (W) x 22.4 m (D) x 2.4 m (H)
Play Area 5 Size	25.7 m (W) x 12.8 m (D) x 2.4 m (H)
Wall Vents in Play Area 1	2.0 m (W) x 2.0 m (H) **Note: Vent sizes were adjusted for the fire to growth to reach 350°C**
Wall Vents in Play Area 5	FS0 to FS2: 2.0 m (W) x 2.0 m (H) FS3 to FS4: 1.5 m (W) x 2.0 m (H) **Note: Vent sizes were adjusted for the fire to growth to reach 350°C. The width of the vents for FS3 and FS4 were smaller than FS0 to FS2 and were found that the time to reach 350°C was quicker.**
Door opening	0.9 m (W) x 2.1 m (H)
Fire locations	Centrally located at floor level.
Scenario Parameters	
Ambient temperature	20°C

7.3.15 The time to reach temperature 350°C in the upper smoke layer for each fire growth rate is summarised in Table 37.

Table 37: Time to reach temperature 350°C in the upper smoke layer

Fire Location	Very Slow	Slow	Medium	Fast
Play Area 1	>1200 s	>1200 s	737 s	414 s
Play Area 5	>1200 s	>1200 s	>1200 s	>1200 s

Quantification of consequences

7.3.16 For each of the design fire scenarios in the Event Tree Analysis related to a fire in an ECC (see Figure 7 to Figure 11), the number of occupants remaining in the ECC once untenable conditions occur (see Table 35) were considered to be fatalities.

7.3.17 For design fire scenarios in the Event Tree Analysis related to a fire in the library (design case #2), the number of occupants remaining in the ECC once the library reaches 350°C in the upper smoke layer (see Table 37) were considered to be fatalities.

Results – detection of smoke

7.3.18 The times for activation of a smoke detection system (if present) and manual detection of fire are summarised in Table 38 and Table 39.

Table 38: Detection time for a fire located in Play Area 1

	Very Slow	Slow	Medium	Fast
Smoke layer height below 5% of the ceiling height	249 s	158 s	109 s	85 s
Smoke detector activation	133 s	81 s	56 s	47 s

Table 39: Detection time for a fire located in Play Area 5

	Very Slow	Slow	Medium	Fast
Smoke layer height below 5% of the ceiling height	124 s	76 s	52 s	44 s
Smoke detector activation	63 s	38 s	27 s	23 s

7.4 Method to determine consequence – Fire elsewhere in the building compromising fire-isolated stairs

7.4.1 In design cases where the fire is not directly occurring within the ECC and instead is located on a level below the ECC, and where the building incorporates fire-isolated stairs, the fire-isolated stairs may become compromised by smoke. This would result in the occupants not being able to egress and therefore may become incapacitated by smoke.

7.4.2 The likelihood of a fire-isolated exit being compromised depends on the fire protection systems installed.

Assumptions regarding consequences

7.4.3 In an event that the fire-rated construction (walls and self-closing doors) operates as intended, the stair is assumed to not be compromised.

7.4.4 In the event of an installed sprinkler system activating, it is assumed that no smoke spread to the stair occurs. The rationale behind this assumption is that the rate of temperature increase in the fire-affected compartment will immediately turn negative upon sprinkler activation and the smoke produced will be limited or the fire completely suppressed. The risk posed from a sprinkler controlled fire is therefore considered negligible.

7.4.5 In the event that sprinklers are not installed or sprinkler system failure occurs, smoke control systems may still prevent smoke spread to the stair. In the event that a door to a fire-isolated stair fails to close but a stair pressurisation system operates as intended, it is assumed that the stair is not compromised. This is supported by the design parameters in AS/NZS 1668.1:2015 which requires an airflow speed of at least 1.0 m/s through the door(s) to the fire-affected compartment, the door(s) to the fire compartment(s) directly above or below the floor of the fire-affected fire compartment, with the final discharge door(s) open.

7.4.6 Zone smoke control systems are designed to minimise the smoke migration between floors through cracks in the floor and through unpressurised shafts (Klote & Milke, 2002). However, zone smoke control systems do not directly affect the risk of fire-isolated stairs being compromised by smoke. Therefore, for the purposes of determining if the fire-isolated stairs have become compromised, the zone smoke control system is assumed to have no impact.

7.4.7 A summary of the assumed consequences of a stair failure is presented in Table 40. The events are modelled in the Event Trees (see Figure 10 and Figure 11) along with the component failure probabilities as per Table 19.

Table 40: Failure of components and associated consequence on the egress stair

Failure of the…				
Fire-isolated stair self-closing door	**Sprinklers**	**Stair pressurisation system**	**Zone smoke control system**	**Stair compromised?**
No	Irrelevant	Irrelevant	Irrelevant	No
Yes	No	Irrelevant	Irrelevant	No
Yes	Yes	Yes	Irrelevant	Yes
Yes	Yes	No	Irrelevant	No

Quantification of consequence

7.4.8 In the event that all of the exits become compromised, the consequence is assumed to be the incapacitation of the total remaining occupant load of the ECC.

8 Results

8.1 Individual Risk

Type A Evacuation – Staff carrying children

8.1.1 Table 41 presents the Individual Risk for design cases 1 to 5 assuming a Type A evacuation. It also presents the percentage of acceptable risk (see Equation 7) for ECCs. Table 41 also contains the Relative Risk (see Equation 8) for each design case.

Table 41: Individual Risk vs Acceptable Risk

Design Case	Individual Risk	Relative Risk	% of Acceptable Risk
#1	5.58E-04	1.0	164656%
#2	3.61E-03	6.5	1064299%
#3	7.22E-03	12.9	2128597%
#4	8.65E-03	15.5	2552619%
#5	7.05E-04	1.3	208109%

Type B Evacuation – Children self-egressing under supervision of staff

8.1.2 Table 42 presents the Individual Risk, Relative Risk and percentage of acceptable risk for design cases 1 to 5 assuming a Type B evacuation.

Table 42: Individual Risk vs Acceptable Risk

Design Case	Individual Risk	Relative Risk	% of Acceptable Risk
#1	5.58E-04	1.0	164656%
#2	5.10E-03	9.1	1505290%
#3	8.71E-03	15.6	2569589%
#4	5.32E-03	9.5	1568691%
#5	3.59E-04	0.6	105875%

8.2 Societal risk

Type A Evacuation – Staff carrying children

8.2.1 The FN-curves for Type A evacuations are presented in Figure 16 to Figure 20 below. The acceptable risk as per Section 5.5 is shown as 'ABCB draft Tolerable Risk Handbook (max)' in the FN-curves. Each figure also includes a sensitivity analysis with regards to the frequency of fire starts. This is illustrated using one curve being an order of magnitude (x 10^1) increased frequency of fire denoted 'Sensitivity – High' and one curve being an order of magnitude (x 10^{-1}) decreased frequency of fire denoted 'Sensitivity – Low'.

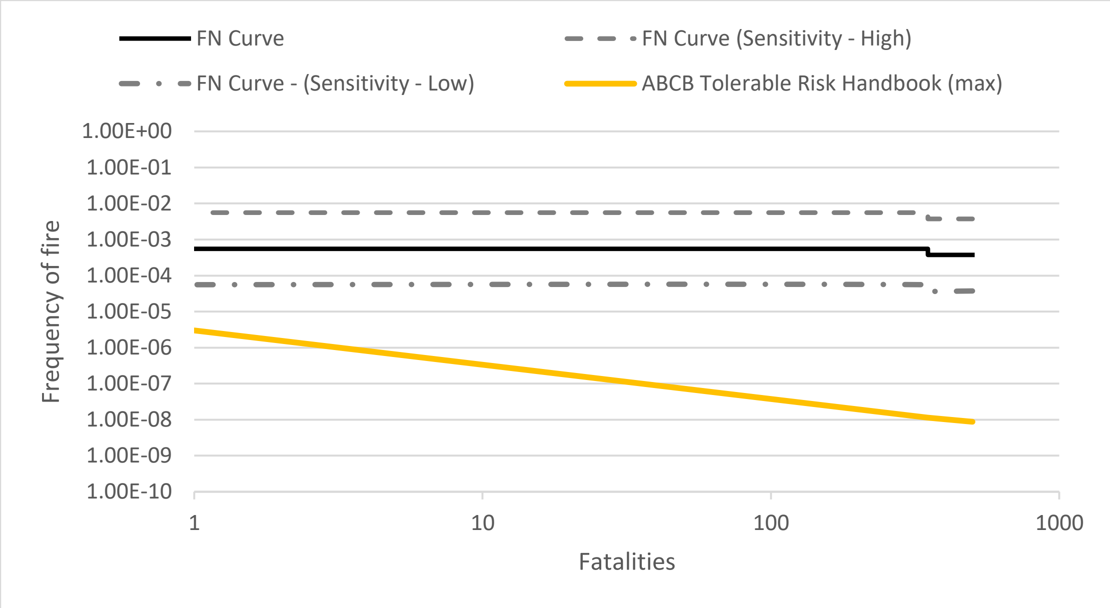

Figure 16: FN-curve for Design Case #1 (Type A evacuation)

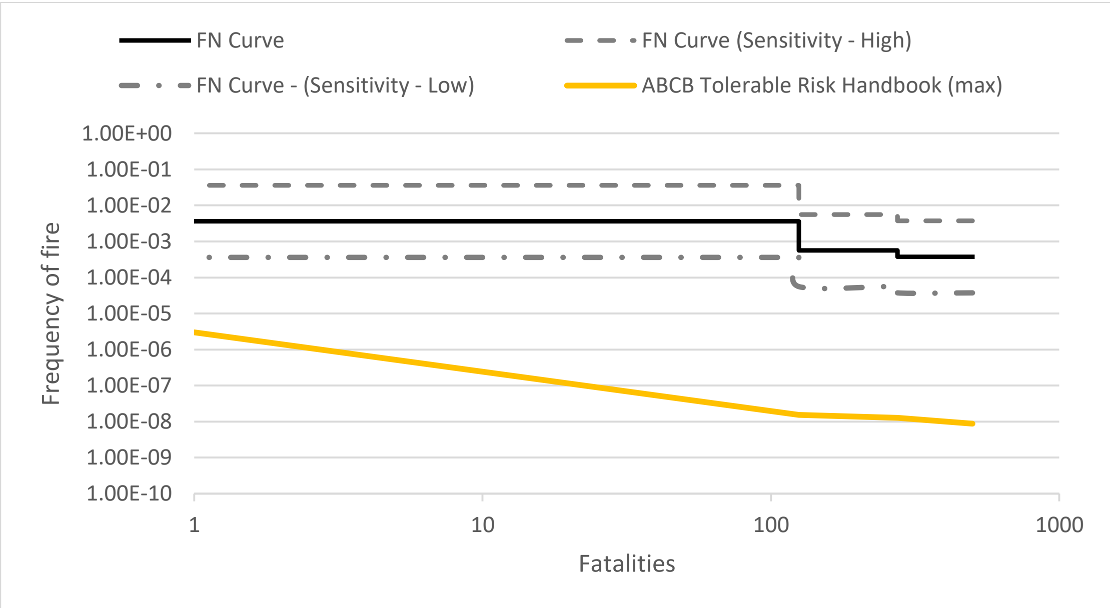

Figure 17: FN-curve for Design Case #2 (Type A evacuation)

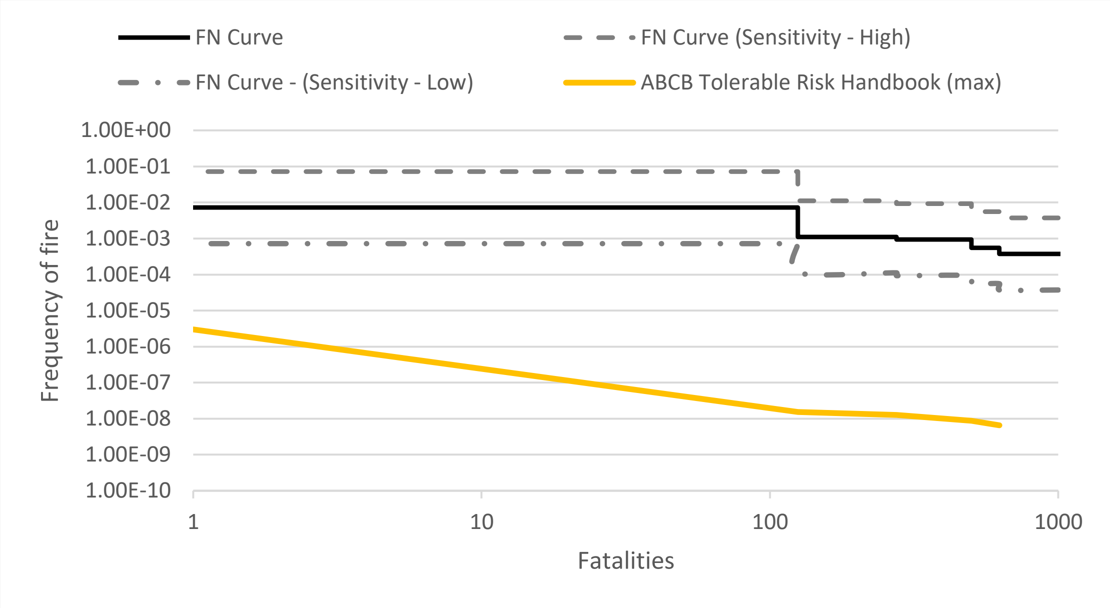

Figure 18: FN-curve for Design Case #3 (Type A evacuation)

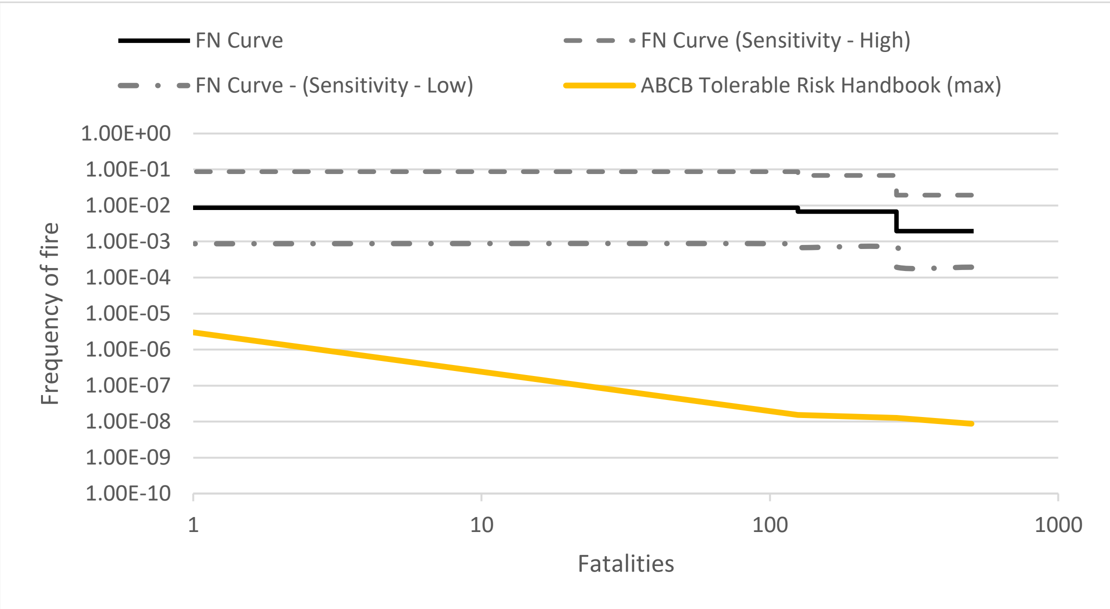

Figure 19: FN-curve for Design Case #4 (Type A evacuation)

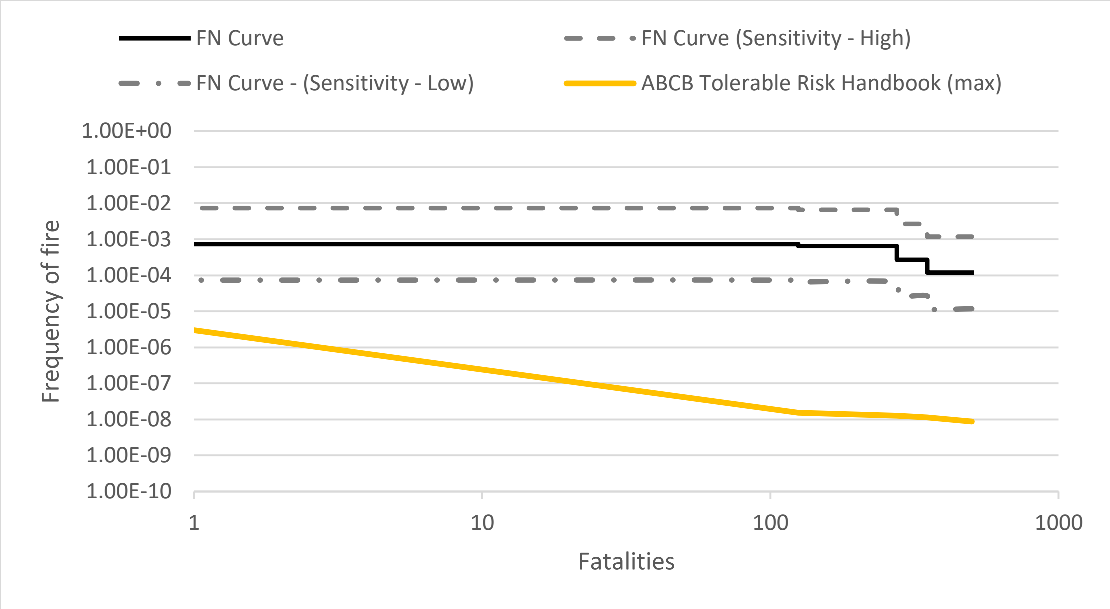

Figure 20: FN-curve for Design Case #5 (Type A evacuation)

Type B Evacuation – Children self-egressing under supervision of staff

8.2.2 The FN-curves for Type B evacuations are presented in Figure 21 to Figure 25 below. The acceptable risk as per Section 5.5 is shown as 'ABCB draft Tolerable Risk Handbook (max)' in the FN-curves. Each figure also includes a sensitivity analysis with regards to the frequency of fire. This is illustrated using one curve being an order of magnitude (x 10^{1}) increased frequency of fire denoted 'Sensitivity – High' and one curve being an order of magnitude (x 10^{-1}) decreased frequency of fire denoted 'Sensitivity – Low'.

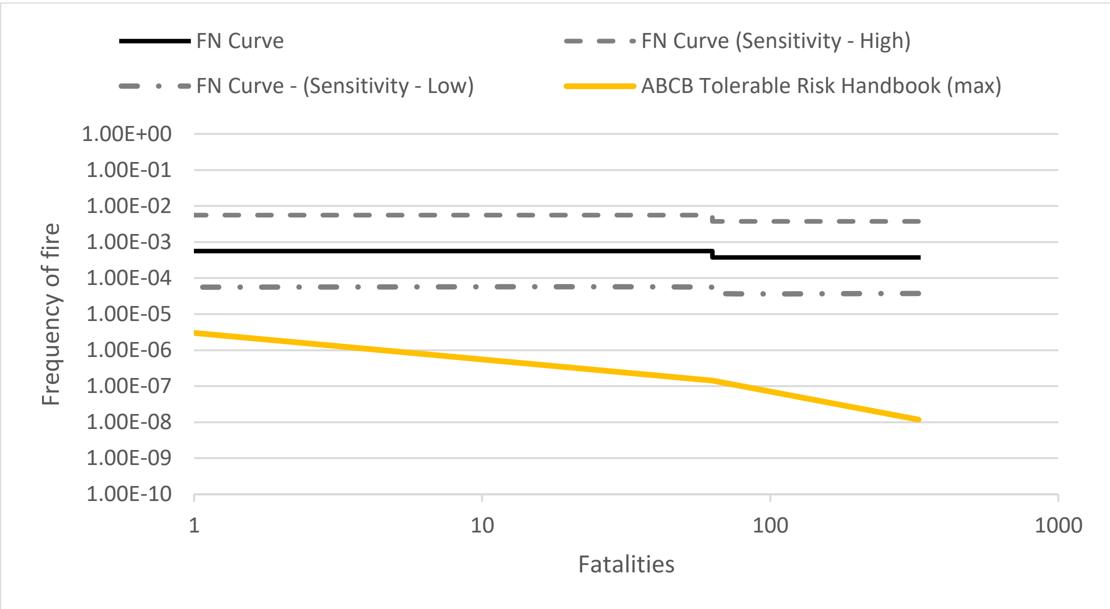

Figure 21: FN-curve for Design Case #1 (Type B evacuation)

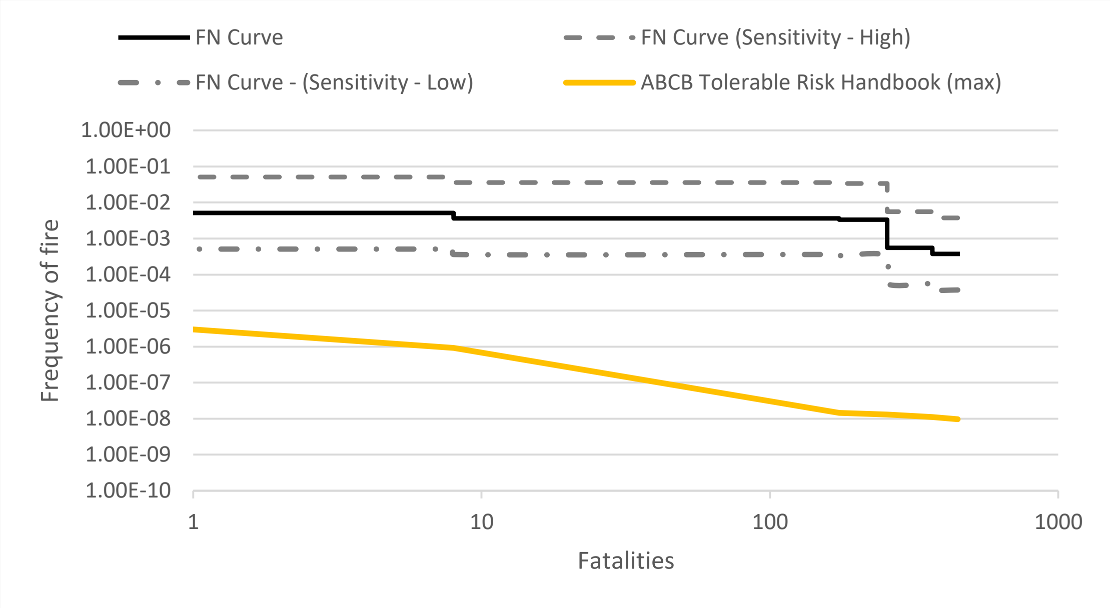

Figure 22: FN-curve for Design Case #2 (Type B evacuation)

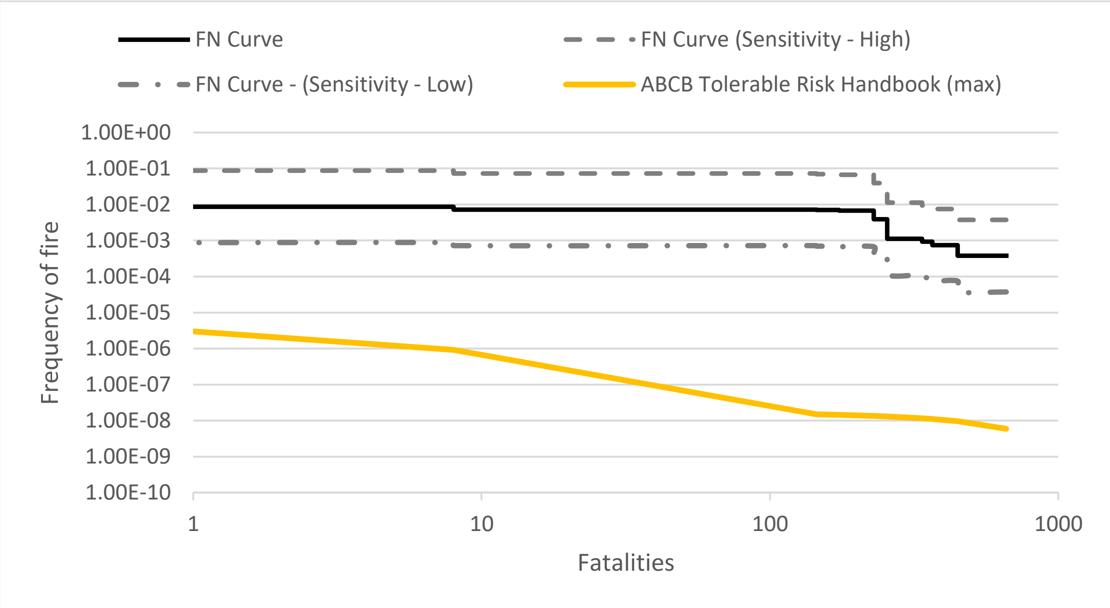

Figure 23: FN-curve for Design Case #3 (Type B evacuation)

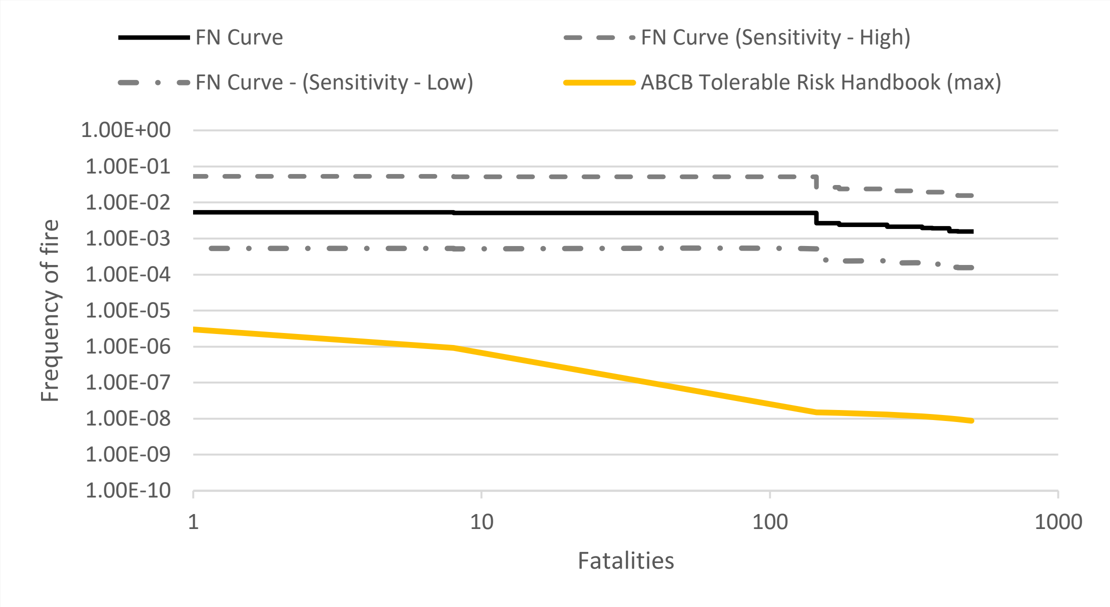

Figure 24: FN-curve for Design Case #4 (Type B evacuation)

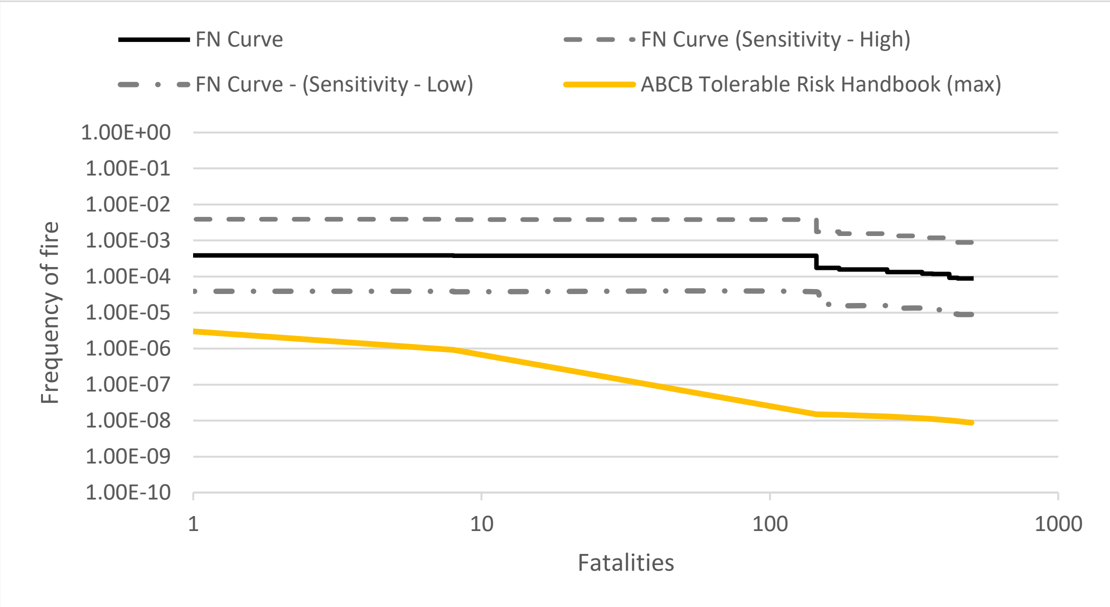

Figure 25: FN-curve for Design Case #5 (Type B evacuation)

9 Sensitivity analysis

9.1.1 The intent of the sensitivity analysis is to evaluate the overall impact on the calculated risk based on the uncertainty of the input values for the different parameters used in the assessment.

9.2 Fire frequency

9.2.1 A sensitivity study has been carried out by analysing other sources of ignition frequency data sources:

- BSI PD 7974-7. The frequency of ignition for ECCs has been assumed to be covered by the 'Public assembly' category. Values are obtained from Table A.3 in the Published Document.
- BSI PD 7974-7. The frequency of ignition is assumed to be described by Equation (1) in the report and the ECCs covered by the ''School' category. Values are obtained from Table A.1 in the Published Document.
- Microeconomic reform: Fire Regulation, 1991. The frequency of ignition for ECCs has been assumed to be covered by the 'Shop, Store, Office' category.

9.2.2 A comparison of the ignition frequency as a function of floor area from the three data sources above with that predicted by using the Tillander method (as per Section 5.4) is provided in Figure 26.

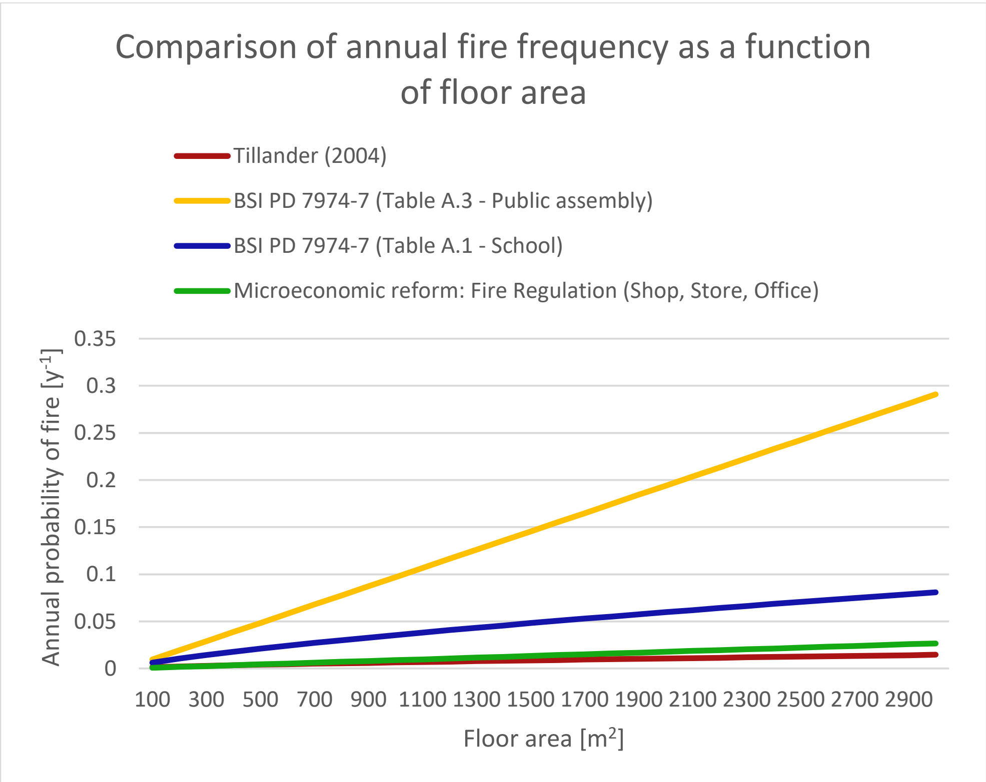

Figure 26: Comparison of ignition frequencies predicted by different methods

9.2.3 Because the BSI PD 7974-7 'Public assembly' source is significantly higher than the remainder of the other data sources/models, a separate chart without this data source is provided in Figure 27.

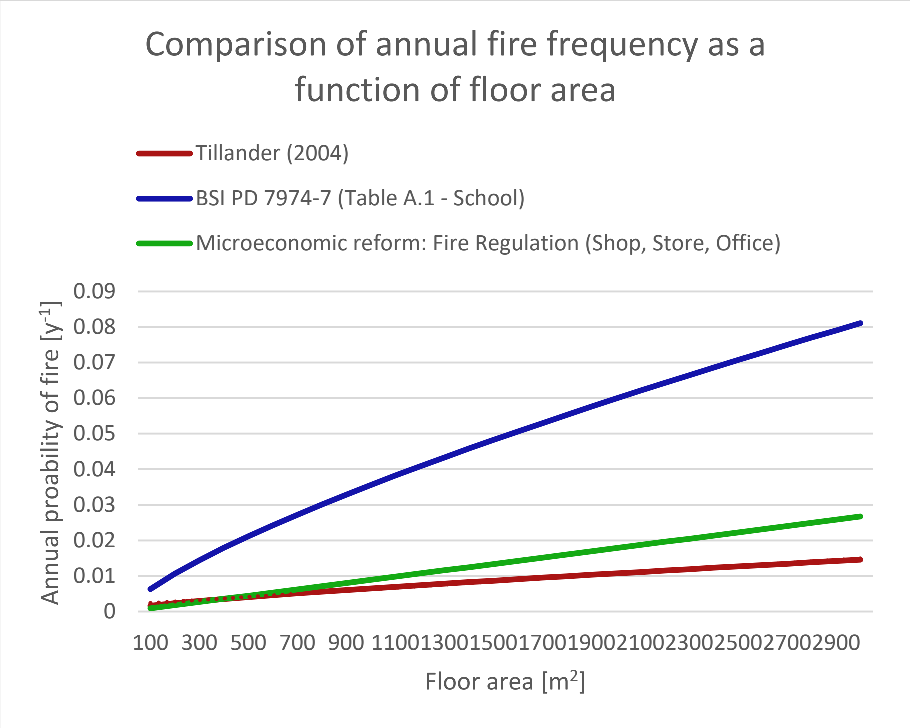

Figure 27: Comparison of ignition frequencies (without BSI PD 7974-7 'Public assembly')

9.2.4 Figure 26 and Figure 27 demonstrate that the frequency of fire does vary depending on the source of data. Therefore, we are of the opinion that a reasonable assumption is that the frequency of fire may vary by an order of magnitude. In Table 43 and Table 44, the resulting individual risk using a frequency of fire an order of magnitude less is shown.

Table 43: Sensitivity analysis using 10^{-1} lower fire frequency – Type A evacuation

Design Case	Individual Risk	New Individual Risk	% of Acceptable Risk
#1	5.58E-04	5.58E-05	16466%
#2	3.61E-03	3.61E-04	106430%
#3	7.22E-03	7.22E-04	212860%
#4	8.65E-03	8.65E-04	255262%
#5	7.05E-04	7.05E-05	21696%

Table 44: Sensitivity analysis using 10^{-1} lower fire frequency – Type B evacuation

Design Case	Individual Risk	New Individual Risk	% of Acceptable Risk
#1	5.58E-04	5.58E-05	16466%
#2	5.10E-03	5.10E-04	150529%
#3	8.71E-03	8.71E-04	256959%
#4	5.32E-03	5.32E-04	156869%
#5	3.59E-04	3.59E-05	11473%

9.2.5 Sensitivity analysis on the effect of frequency of fire starts on societal risk has been provided in Section 0.

9.3 Egress modelling

Pre-movement times in Type A evacuation

9.3.1 The assumed value in the assessment is 90 s. The sensitivity analysis evaluates an upper range of 120 s and a lower range of 60 s.

Table 45: Sensitivity analysis using a value of 120 s pre-movement time

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	3.36E-03	502%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.75E-03	1%
#5	7.05E-04	7.05E-04	0%

Table 46: Sensitivity analysis using a value of 60 s pre-movement time

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Pre-movement times in Type B evacuation

9.3.2 The assumed value in the assessment is 30 s. The sensitivity analysis evaluates an upper range of 60 s and a lower range of 0 s.

Table 47: Sensitivity analysis using a value of 60 s pre-movement time

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	1.02E-02	17%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	3.59E-04	0%

Table 48: Sensitivity analysis using a value of 0 s pre-movement time

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	3.74E-04	-33%
#2	5.10E-03	3.61E-03	-29%
#3	8.71E-03	7.22E-03	-17%
#4	5.32E-03	5.17E-03	-3%
#5	3.59E-04	3.47E-04	-3%

Time for staff to manually raise alarm

9.3.3 The assumed value in the assessment is 30 s. The sensitivity analysis evaluates an upper range of 60 s.

Table 49: Sensitivity analysis using a value of 60 s alarm time (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 50: Sensitivity analysis using a value of 60 s alarm time (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	3.59E-04	0%

Horizontal walking speed, child (only applicable to Type B evacuation)

9.3.4 The assumed value in the assessment is 0.61 m/s. The sensitivity analysis evaluates an upper range of 0.67 (+10 %) and a lower range of 0.55 (-10 %).

Table 51: Sensitivity analysis using a value of 0.67 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	3.61E-03	-29%
#3	8.71E-03	7.22E-03	-17%
#4	5.32E-03	5.17E-03	-3%
#5	3.59E-04	3.47E-04	-3%

Table 52: Sensitivity analysis using a value of 0.55 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	1.02E-02	17%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	3.59E-04	0%

Walking speed down stairs, child (only applicable to Type B evacuation)

9.3.5 The assumed value in the assessment is 0.33 m/s. The sensitivity analysis evaluates an upper range of 0.36 (+10 %) and a lower range of 0.30 (-10 %).

Table 53: Sensitivity analysis using a value of 0.36 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	3.61E-03	-29%
#3	8.71E-03	7.22E-03	-17%
#4	5.32E-03	5.17E-03	-3%
#5	3.59E-04	3.47E-04	-3%

Table 54: Sensitivity analysis using a value of 0.30 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	1.02E-02	17%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	3.59E-04	0%

Walking speed horizontally, staff carrying children (only applicable to Type A evacuation)

9.3.6 The assumed value in the assessment is 0.95 m/s. The sensitivity analysis evaluates an upper range of 1.10 m/s and a lower range of 0.80 m/s.

Table 55: Sensitivity analysis using a value of 1.10 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 56: Sensitivity analysis using a value of 0.80 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.75E-03	1%
#5	7.05E-04	7.05E-04	0%

Walking speed horizontally, staff without children (only applicable to Type A evacuation)

9.3.7 The assumed value in the assessment is 1.24 m/s. The sensitivity analysis evaluates an upper range of 1.36 m/s (+10 %) and a lower range of 1.12 m/s (-10 %).

Table 57: Sensitivity analysis using a value of 1.36 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 58: Sensitivity analysis using a value of 1.12 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Walking speed down stairs, staff carrying children (only applicable to Type A evacuation)

9.3.8 The assumed value in the assessment is 0.43 m/s. The sensitivity analysis evaluates an upper range of 0.55 m/s and a lower range of 0.31 m/s.

Table 59: Sensitivity analysis using a value of 0.55 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	6.34E-04	-10%

Table 60: Sensitivity analysis using a value of 0.31 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	9.65E-03	12%
#5	7.05E-04	7.05E-04	0%

Walking speed up stairs, staff without children (only applicable to Type A evacuation)

9.3.9 The assumed value in the assessment is 0.50 m/s. The sensitivity analysis evaluates an upper range of 0.55 m/s (+10 %) and a lower range of 0.45 m/s (-10 %).

Table 61: Sensitivity analysis using a value of 0.55 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 62: Sensitivity analysis using a value of 0.45 m/s walking speed

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.75E-03	1%
#5	7.05E-04	7.05E-04	0%

One-dimensional space taken up from a child queuing (only Type B evacuation)

9.3.10 The assumed value in the assessment is 0.50 m. The sensitivity analysis evaluates an upper range of 0.6 m and a lower range of 0.4 m.

Table 63: Sensitivity analysis using a value of 0.6 m space taken up from queuing

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.36E-03	5%
#3	8.71E-03	1.03E-02	19%
#4	5.32E-03	5.44E-03	2%
#5	3.59E-04	3.69E-04	3%

Table 64: Sensitivity analysis using a value of 0.4 m space taken up from queuing

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	3.74E-04	-33%
#2	5.10E-03	3.61E-03	-29%
#3	8.71E-03	7.22E-03	-17%
#4	5.32E-03	5.17E-03	-3%
#5	3.59E-04	3.47E-04	-3%

Percentage of staff actively evacuating children (only Type A evacuation)

9.3.11 The assumed value in the assessment is 90 %. The sensitivity analysis evaluates an upper range of 95 % and a lower range of 85 %.

Table 65: Sensitivity analysis using a value of 95 % active staff

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 66: Sensitivity analysis using a value of 85 % active staff

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Average travel distance in ECC

9.3.12 The assumed value in the assessment is 20.4 m. The sensitivity analysis evaluates an upper range of 25 m and a lower range of 15 m.

Table 67: Sensitivity analysis using a value of 25 m travel distance (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 68: Sensitivity analysis using a value of 25 m travel distance (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	1.02E-02	17%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	3.59E-04	0%

Table 69: Sensitivity analysis using a value of 15 m travel distance (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 70: Sensitivity analysis using a value of 15 m travel distance (Type B)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	3.59E-04	0%

Number of children that can be carried by staff (only applicable to Type A)

9.3.13 The assumed value in the assessment is 2. The sensitivity analysis evaluates a lower range of 1.5 (average).

Table 71: Sensitivity analysis using a value of 1.5 children per staff

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	3.36E-03	502%
#2	3.61E-03	5.36E-03	48%
#3	7.22E-03	1.05E-02	45%
#4	8.65E-03	9.65E-03	12%
#5	7.05E-04	7.05E-04	0%

9.4 Fire safety systems

Smoke detection system reliability

9.4.1 The assumed value in the assessment is 90 %. The sensitivity analysis evaluates a lower range of 80 %.

Table 72: Sensitivity analysis using a value of 80 % smoke detection system reliability (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.05E-04	0%

Table 73: Sensitivity analysis using a value of 80 % smoke detection system reliability (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	5.47E-03	3%
#5	3.59E-04	3.71E-04	3%

Sprinkler system reliability

9.4.2 The assumed value in the assessment is 92 %. The sensitivity analysis evaluates an upper range of 95 % and a lower range of 85 %.

Table 74: Sensitivity analysis using a value of 95 % sprinkler system reliability (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	4.41E-04	-37%

Table 75: Sensitivity analysis using a value of 95 % sprinkler system reliability (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	2.24E-04	-37%

Table 76: Sensitivity analysis using a value of 85 % sprinkler system reliability (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	1.32E-03	88%

Table 77: Sensitivity analysis using a value of 85 % sprinkler system reliability (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	6.73E-04	88%

Stair pressurisation system reliability

9.4.3 The assumed value in the assessment is 35 %. The sensitivity analysis evaluates a lower range of 20 %.

Table 78: Sensitivity analysis using a value of 20 % stair pressurisation system reliability (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	8.65E-03	0%
#5	7.05E-04	7.36E-04	4%

Table 79: Sensitivity analysis using a value of 20 % stair pressurisation system reliability (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	5.32E-03	0%
#5	3.59E-04	3.89E-04	8%

Reliability of fire-isolated stairs and associated self-closing fire doors

9.4.4 The assumed value in the assessment is 77 %. The sensitivity analysis evaluates an upper range of 87 % and a lower range of 59 %.

Table 80: Sensitivity analysis using a value of 87 % fire stair with fire door reliability (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	7.59E-03	-12%
#5	7.05E-04	6.66E-04	-6%

Table 81: Sensitivity analysis using a value of 87 % fire stair with fire door reliability (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	4.26E-03	-20%
#5	3.59E-04	3.19E-04	-11%

Table 82: Sensitivity analysis using a value of 59 % fire stair with fire door reliability (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	3.61E-03	3.61E-03	0%
#3	7.22E-03	7.22E-03	0%
#4	8.65E-03	1.21E-02	39%
#5	7.05E-04	8.32E-04	18%

Table 83: Sensitivity analysis using a value of 59 % fire stair with fire door reliability (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	5.58E-04	0%
#2	5.10E-03	5.10E-03	0%
#3	8.71E-03	8.71E-03	0%
#4	5.32E-03	8.72E-03	64%
#5	3.59E-04	4.86E-04	35%

9.5 Fire development

Fire growth rate

9.5.1 The assumed values in the assessment is as per Table 17. The sensitivity analysis evaluates a distribution with predominantly higher growth rates and a distribution with predominantly lower growth rates (as per Table 84).

Table 84: Fire growth rate distribution for sensitivity analysis

Occupancy type	Very slow $\alpha = 0.000412$	Slow $\alpha = 0.003503$	Medium $\alpha = 0.016485$	Fast $\alpha = 0.065938$
Higher than base case	15 %	50 %	20 %	15 %
Lower than base case	40 %	50 %	10 %	0 %

Table 85: Sensitivity analysis using higher growth rates (Type A evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	1.70E-03	204%
#2	3.61E-03	4.61E-03	28%
#3	7.22E-03	9.22E-03	28%
#4	8.65E-03	9.16E-03	6%
#5	7.05E-04	7.05E-04	0%

Table 86: Sensitivity analysis using higher growth rates (Type B evacuation)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	1.70E-03	204%
#2	5.10E-03	5.34E-03	5%
#3	8.71E-03	9.95E-03	14%
#4	5.32E-03	6.24E-03	17%
#5	3.59E-04	4.33E-04	21%

Table 87: Sensitivity analysis using lower growth rates (Type A)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	4.85E-04	-13%
#2	3.61E-03	2.91E-03	-19%
#3	7.22E-03	5.82E-03	-19%
#4	8.65E-03	8.36E-03	-3%
#5	7.05E-04	7.05E-04	0%

Table 88: Sensitivity analysis using lower growth rates (Type B)

Design Case	Base Case Individual Risk	New Individual Risk	% change
#1	5.58E-04	4.85E-04	-13%
#2	5.10E-03	4.85E-03	-5%
#3	8.71E-03	7.77E-03	-11%
#4	5.32E-03	4.67E-03	-12%
#5	3.59E-04	3.07E-04	-15%

Flaming vs smouldering fires

9.5.2 The probability of flaming fires is directly proportional to the Individual Risk. Therefore, no sensitivity analysis has been carried out.

9.6 Summary – Individual Risk

9.6.1 The sensitivity analysis has demonstrated that the results are more sensitive to certain input parameters than others. This section provides a summary of the main conclusions from the sensitivity analyses. This section excludes a commentary of frequency of fire since a change of frequency of fire results in a directly proportional increase or reduction of risk.

9.6.2 Major contributors are defined as parameters which produce a change of more than ± 10 % in the calculated Individual Risk when the sensitivity values are applied.

Type A evacuation

9.6.3 The main major contributors to the calculated risk are the following parameters:

- Pre-movement time (however, it only affects the result for design case #1 where it has a major impact).
- Number of children that can be carried by a member of staff.
- Sprinkler system reliability (only applies to design case #5).
- Reliability of fire-isolated stairs and associated self-closing fire doors (only applies to design cases #4 and 5).
- Fire growth rate distribution (except for the IR for design case #5 which is independent from this parameter).

9.6.4 For design case #1, the change in pre-movement time causes a 500 % increase in individual risk. This is due to the low number of design fire scenarios evaluated for a design case #1 building as the number of safety systems affecting the fire development and egress from the building. The change in pre-movement time causes another (relatively probable scenario) to cause fatalities and this therefore has a major impact on the result.

9.6.5 The number of children that staff can carry have a major impact in low rise buildings (design cases #1-3) but a drastically decreased impact in high-rise buildings (design cases #4-5). This is explained by the increasing time for return trips between the outside and the ECC in high-rise buildings which causes a majority of the fires occurring within the ECC to produce fatalities. The analysed sensitivity value therefore does not generate any impact on the high-rise buildings.

9.6.6 In design case #5 where sprinklers are present, the reliability of the sprinkler system plays a major role in the calculated individual risk.

9.6.7 In design cases #4 and 5 which are provided with fire-isolated stairs, the reliability of the fire-isolated stair has a major impact on the individual risk. This demonstrates that for high-rise buildings, the risk contribution from exits being compromised compared to the risk of being exposed to untenable conditions becomes more pronounced. The increase in risk in design case #5 is less than that in design case #4 which is explained by the provision of sprinklers and stair pressurisation system which limit the likelihood of the stair being compromised by smoke.

9.6.8 The distribution of fire growth rates plays a major role in the calculated risk, especially for the design case #1 (+204 % when using higher growth rates). The effects become less pronounced with the increasing height of the building which is expected.

9.6.9 One interesting aspect is that individual walking speeds of staff (horizontally, down and up stairs, with and without children) have no major impact on the result.

9.6.10 Smoke detection systems did not contribute to any changes in individual risk.

Type B evacuation

9.6.11 The main major contributors to the calculated risk are the following parameters:

- Pre-movement time.
- Horizontal walking speed for child.
- Walking speed down stairs for child.
- One-dimensional space taken up from a child queuing.
- Average travel distance within the ECC (only for design case #3).
- Sprinkler system reliability (only applies to design case #5).
- Stair pressurisation system reliability (only applies to design case #5).

- Reliability of fire-isolated stairs and associated self-closing fire doors (only applies to design cases #4 and 5).
- Fire growth rate distribution (except for the IR for design case #5 which is independent from this parameter).

9.6.12 An increase in pre-movement time causes an increase in risk for design case #3, but other scenarios are unaffected. The decrease in the pre-movement time reduces the risk for all scenarios but the impact decreases with height of the building. This is expected as the impact of the pre-movement time should become less important with taller buildings that have longer movement times.

9.6.13 An increase in walking speed for the slowest child (both horizontally and down stairs) has a major impact on design cases #2 and 3. It is expected that this is the case for design case #1 as well, however due to the low number of design fire scenarios for design case #1, the change does not affect any of the evaluated design fire scenarios to such an extent that it provides additional safety when calculated by the model. The effects of the walking speeds become less pronounced with increased height of the building which is expected as the walking speeds should become less important with increasing height.

9.6.14 The one-dimensional space taken up from a child queuing exhibits similar effects on the result as walking speeds with greater impact in low-rise buildings and only a small effect for high rise buildings (design cases #4 and 5).

9.6.15 Increasing the average walking distance in the ECC to 25 m causes a single increase in risk of 17 % for design case #3. All other cases are unaffected by this parameter.

9.6.16 Similar to Type A evacuation, the sprinkler system exhibits a major impact on the individual risk in design case #5. The stair pressurisation system also provides for a substantial increase of the individual risk in the event of a lower reliability.

9.6.17 Also similar to Type A evacuation, the reliability of the fire-isolated stair has a major impact on the individual risk. The effect on the risk is greater compared to a Type A evacuation because the portion of risk contribution from fires on storeys other than the ECC is greater in Type B evacuation compared to Type A evacuation.

9.6.18 The distribution of fire growth rates plays a major role in the calculated risk, especially for the design case #1 (+204 % when using higher growth rates). The effects become less pronounced with the increasing height of the building which is expected.

9.7 Societal risk

9.7.1 The sensitivity analyses carried out in Sections 9.3, 9.4 and 9.5 also provide an insight into the impact on societal risk. Where minor variability in the input parameters results in minor variability in the result, this would also apply to the societal risk.

9.7.2 Design Case #5 is associated with the lowest overall risk out of all of the design cases with ECCs located above ground level. The predominant driver for this is the automatic sprinkler system which results in a large risk reduction. This is demonstrated by the large impact on the individual risk from variation in the sprinkler system reliability. We have therefore selected Design Case #5 with an improved sprinkler system reliability (95 % as per Section 9.4.2) to demonstrate that even with the lowest overall risk predicted in the QRA, the acceptable societal risk level in the draft ABCB draft Tolerable Risk Handbook is grossly exceeded. Type B evacuation is assumed as it produces a lower risk compared to Type A evacuation.

9.7.3 The FN-curve for Design Case #5 (Type B) with an improved reliability for the sprinkler system of 95 % is illustrated in Figure 28. In the same figure, the original FN curve for Design Case #5 (Type B) as well as the sensitivity analysis (as per Section 0) with regards to the frequency of fire are provided for comparison.

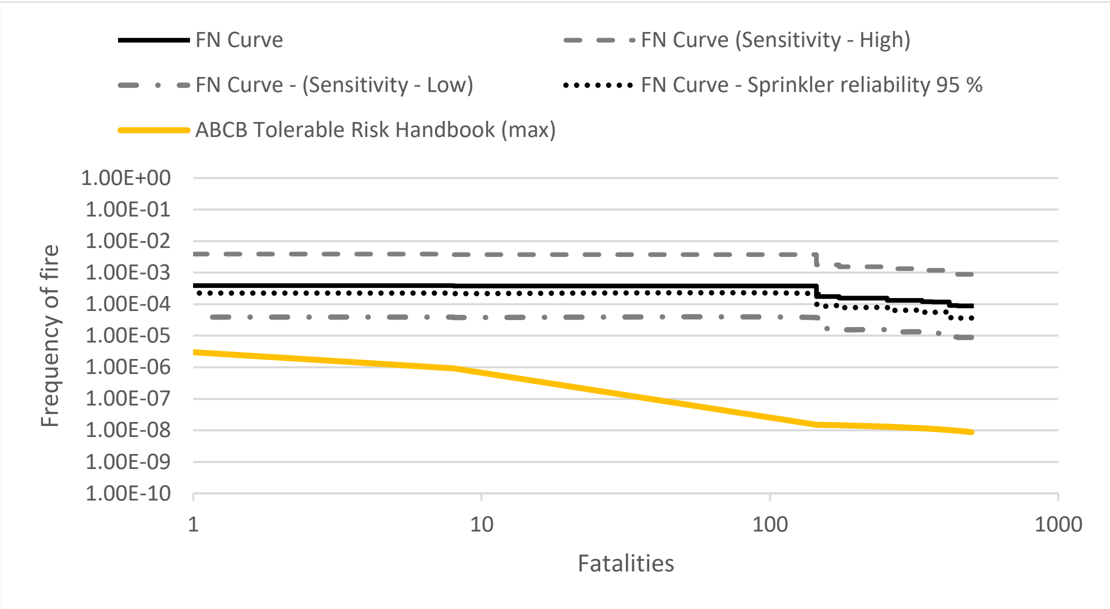

Figure 28: Sensitivity analysis of the societal risk (Design Case #5, Type B evacuation)

10 Discussion

10.1 Fire start frequency

10.1.1 An analysis of Figure 26 and Figure 27 suggests a few conclusions can be drawn. The first conclusion is that the ignition frequency used in the QRA is not different from other data sources/models by multiple orders of magnitude and as such the ignition frequency assumed is not unreasonable.

10.1.2 The second conclusion is that within the interval of 400 – 3,000 m^2 floor areas, the model and data by Tillander produces the lowest ignition frequency out of all of the available models/data sources. This means that the assumed ignition frequency is not contributing to an overestimation of the ignition frequency or risk in this report compared to other ignition sources.

10.1.3 The third conclusion is that the model and data by Tillander produces an R^2-value of 0.996 when fit with a linear regression model. This means that for ECCs, the increase in ignition frequency increases linearly with floor area. Therefore, the assumed floor area for the hypothetical building design used does not have an overall contribution to the result in terms of risk. A reduction in floor area would produce a proportional reduction of ignition frequency.

10.1.4 Using the method by Tillander (see Section 5.4), the ignition frequency in ECCs with a floor area of 2000 m^2 is estimated to be 5.36E-06 per m^2 per year. For a 2,000 m^2 ECC, this results in a fire frequency of 1.07E-02 per year or one fire every 93 years. We are of the opinion that this is not an unreasonable fire frequency.

10.1.5 The sensitivity analysis demonstrated that even with an order of magnitude variability in the fire frequency, it does not result in the ABCB Tolerable Risk Level for individual risk being met (see Table 43 and Table 44). The sensitivity analysis of societal risk has also demonstrated that the acceptable societal risk levels are exceeded regardless of input parameters, see Figure 28. The impact of fire frequency outweighs the impact of other input parameters (e.g. sprinkler reliability). Therefore, the absolute risk results are therefore not sensitive to the frequency of fire igntion.

10.2 Egress modelling

10.2.1 The modelling of an evacuation from an Early Child Care centre is difficult. There are no established models to calculate the time for egress from an ECC and the models produced within this study are based on the studies of evacuation of ECCs and the literature reviewed in preparing this report. As the egress model plays an important role in the estimation of the number of fatalities, it is recommended that further research into egress from ECCs is carried out and that the results of this study (in terms of egress times) are validated and possibly updated if found to be not representative of realistic egress times from an ECC.

10.2.2 This study has also shown that there is a lack of data for egress modelling parameters such as walking speeds (horizontally and down stairs), flows through doorways and stairs for staff carrying children and for children self-egressing under the supervision of staff. Of notable uncertainty is the walking speeds of staff carrying children, both horizontal movement and down stairs as this was obtained from a single source of information in the form of a seminar presentation by Burton (2018). Whilst walking speeds was found to only have minor contributions to the individual risk for Type A evacuations, this has a major impact in Type B evacuations. In the event that the models used are not representative of realistic egress times (as per 10.2.1), then it is also possible that the walking speeds play a greater role in terms of the overall time for egress. This is currently unknown.

10.2.3 In Type B evacuations, the walking speeds for children down stairs is also likely to depend on the availability of handrails for children. It is unclear in the presented data if such measures are provided for the stairs where the data was collected.

10.2.4 There is also a lack of pre-movement time data for ECCs. Therefore, this study has relied on the methodology in 'Published Document 7974-6 - Human factors: Life safety strategies – Occupant evacuation, behaviour and condition' to determine the pre-movement time in the ECC (BSI, 2004). It should be noted that PD 7974-6 does not explicitly provide data for ECCs and the value used in this study has therefore been approximated by the pre-movement times for an occupancy with awake occupants that are familiar with the layouts and the exits. Having said that, we would expect the actual pre-movement times for an ECC could be longer than predicted by PD 7974-6 as additional times will be required to prepare the children for evacuation which is expected to take longer than in a building with awake adult occupants that are familiar with the layouts and the exits. This would likely contribute to a higher risk than this study has calculated. It is recommended that further research into pre-movement times in ECCs are carried out and that the results of this study (in terms of pre-movement times) are validated and possibly updated if found to be not representative of realistic pre-movement times in an ECC.

10.2.5 This study has evaluated two distinctly different cases of evacuation; staff carrying children (Type A) and children self-egressing under the supervision of staff (Type B). Type A and Type B evacuations can be viewed as the extremes at either end of a spectrum of possible modes of evacuating children within an ECC. Therefore, we recommend that the individual risks estimated in this study are treated as an interval between the values calculated for Type A and for Type B evacuations. In reality, there is often a mix of children who will have to be carried and who can self-egress under the supervision of staff present in an ECC. Therefore, the risk for such a facility should lie within the bounds of such interval.

10.3 Consequence modelling

Sprinklers

10.3.1 Where sprinklers are provided and the design fire scenario assumes that the system operates successfully, a consequence of zero fatalities has been assumed. The statistics support this assumption for occupancies with occupants that can be awake during the occupation of the building. In an ECC, children may be asleep but staff are expected to be awake. We are therefore of the opinion that it is unlikely that any fatalities will occur in sprinkler-protected ECCs when the sprinkler system operates as designed.

10.3.2 In the event of fatalities occurring in a scenario where sprinklers activate (e.g. a shielded fire), this would have a major impact on the calculated individual risk. Evaluating such design fire scenarios will involve complex heat release rate from the fire in the ECC. The soot/CO yields from the fire will also become affected and it is likely that the toxicity of the gases play a greater role compared to an unsprinklered fire. Fire engineering modelling tools (such as FDS) do not yet contain sub-models that can accurately predict the CO production for such fires and CO yield data for shielded fires are lacking. In addition, recent research indicates that in repeatable large scale fire tests, the measurements of CO showed a large variation, and calculation of the dose of CO for toxicity analysis would need to consider a maximum error of 500% (Melcher, et al., 2016). It is therefore considered beyond the scope of this study to quantify the effects of such a scenario.

Fires in the ECC

10.3.3 Consequences in the ECC has been assumed to equate to the number of people that remain in the ECC when untenable conditions occur. In all of the simulated design fire scenarios to determine untenable conditions, the combination of the smoke layer interface height descending below 2.1 m and the visibility in the upper layer being less than 10 m determines the time of onset of untenable conditions have been used.

10.3.4 In reality, occupants may be able to evacuate in visibilities lower than 10 m. For example, the first edition of Fire Engineering Guidelines suggested a visibility of 5 m is acceptable in small rooms (FCRC, 1996). This tenability criterion is also currently used in the Swedish analytical framework for performance-based fire safety design (Boverket, 2011). If the visibility was allowed to be 5 m instead of 10 m, the calculated risk would have been lower.

10.3.5 However, in an ECC the staff will have to coordinate the evacuation of children (Type B evacuation) or find and carry children to a place of relative safety (Type A evacuation). It is therefore anticipated that a low smoke layer interface height and a visibility below 10 m will cause significant difficulties in egressing children. It is therefore deemed appropriate to use 10 m visibility as one of the tenability criteria.

10.3.6 An alternative approach to determine the time of onset of untenable conditions is using the Fractional Effective Dose (FED) method developed by Purser (Purser & McAllister, 2016). The method predicts incapacitation of an occupant from exposure to CO, CO_2 and heat. As stated above, recent research indicates that measurement of CO concentration in repeatable fire tests showed a large variation with a maximum error of 500% (Melcher, et al., 2016). Thus, it is not sensible to predict the CO levels within an enclosure by numerical modelling because there is not a definitive benchmark to verify such numerical model. Further modelling validation should be carried out before the FED method is to be used.

10.3.7 The fire growth rate plays an important role in predicting the time of onset of untenable conditions. The fire growth distribution data used in this study was collected in the UK which we consider having similar ignition sources and fuel load to that in Australia. However, the data collected was for schools including ECCs, rather than ECCs alone. We have also used the data collected for public assembly buildings to create an average distribution of fire growth rates. Due to the low number of fires contained in the statistics, even with the two data sets combined, the impact of each fire is large in terms of percentage (3.7 %). It is anticipated that the distribution is skewed in the distribution of 'Medium' and 'Fast' growth rates due to the low number of fires in these categories (1 and 2 respectively). It is recommended that further research is carried out on the fire growth rates in ECCs to validate the assumptions made in this study.

10.3.8 The determination of time of onset of untenable conditions have been carried out using CFAST which is a two-zone model. The two-zone model concept is based on a uniform upper smoke layer being assumed for each of the compartments in the geometrical model. As the compartments increase in size, the validity of this assumption decreases. In reality, untenable conditions will occur earlier than predicted near the fire and later than predicted far from the fire compared to the simulation results using the two-zone model. One method to more accurately predict the time of onset of untenable conditions would be to use CFD modelling (e.g. Fire Dynamics Simulator). However, the time frame allowed for this study eliminated the potential to use such tool. If further studies are undertaken, we recommend that sufficient time is allowed to use such tools to quantify the consequences in an ECC.

10.4 Calculation of Risk

10.4.1 The Individual Risk estimated in this study is a Location Specific Individual Risk. Whilst the ABCB draft Tolerable Risk Handbook does not explicitly specify that it provides tolerable risk criteria for Location Specific Individual Risk, this appears to be the most consistent with the wording in the ABCB draft Tolerable Risk Handbook which refers to a "subject building" being a specific location.

10.4.2 Using a Location Specific Individual Risk, we have not considered the likelihood of the ECC being occupied at the time of the fire. If this is implicitly considered in ABCB Tolerable Risk Handbook, then the results should be updated to reflect this.

10.4.3 The calculation of Individual Risk is dependent on the number of design fire scenarios evaluated for each design case. For the low-rise buildings, where the DtS Provisions of the NCC requires very few fire protection systems or barriers, the number of possible outcomes (design fire scenarios) are few. The effect of this on the Individual Risk is evidenced by the major impact a single design fire scenario can have on the calculated Individual Risk. For example, consider the sensitivity analysis for pre-movement time in a Type A evacuation and in design case 1 (see Table 45). The change in pre-movement time from 90 seconds to 120 seconds causes another design fire scenario to generate fatalities. In turn, this causes the Individual Risk to increase by over 500 %.

10.4.4 For the design cases with more fire safety systems and barriers (design cases #4 and 5), the overall frequency attributed to each design fire scenario is less. This produces a more nuanced risk for the building compared to the low-rise buildings which can be said to produce a more discrete distribution of risk.

10.4.5 Design case #4 is associated with the highest risk in Type A and the design case #3 is associated with the highest risk in Type B evacuations. This is expected as increased height above ground leads to longer evacuation times and an increased probability of fires on levels below the ECC compromising the egress routes. Design case #4 is also not provided with an automatic sprinkler system nor with a stair pressurisation system under the NCC DtS Provisions which contribute to major increases in level of safety, predominately from the absence of a sprinkler system. The provision of a smoke detection system and fire-isolated stairs has a greater impact in Type B evacuation and reduces the risk in design case #4 compared to design case #3 whereas for Type A evacuation the trend is opposite due to the long egress times.

10.5 Assumptions

Counter-flow from fire brigade intervention and egress from other floors

10.5.1 The egress model does not account for counter-flows from an attending fire brigade. The model also doesn't account for other occupants entering the exits (stairs) on levels below the ECC. The complexities of such interactions are considered beyond the scope of this study. However, the risk predicted has been underestimated because of this aspect not being accounted for in the models. We anticipate that the impact increases with building height as the influx of other occupants in the building increases with height as well as the time to evacuate the building (including the ECC). This should be considered in conjunction with the conclusions in this study. Once a better understanding of these effects (counter-flow and influx) have on the evacuation of an ECC has been developed, such concepts can be incorporated into a QRA. However, this may require the hypothetical buildings also to have specified use on levels not being an ECC in order to reduce the number of potential permutations in occupancies for the QRA. Whilst a revised QRA may provide more accurate predictions of the estimated risk, we expect that the revised risk will be higher than the predicted results in this study. As the results already suggest that the risks are unacceptably high (see Section 11), the benefit of such an updated QRA may be minor.

24/7 occupation of ECCs

10.5.2 The QRA implicitly assumes that the ECCs are occupied 24 hours a day and 7 days a week. We are of the opinion that this represents a small portion of ECCs currently and that the risk is therefore not representative of most ECCs.

11 Conclusions and Recommendations

11.1 Acceptable Risk

11.1.1 The study indicates that none of the design cases meet the acceptable risk level as specified in the draft ABCB Tolerable Risk Handbook.

11.1.2 For Type A evacuations, the lowest risk is produced by Design Case #1 followed by Design Case #5 (sprinkler-protected high-rise building). The highest risk is associated with Design Case #4.

11.1.3 Design Case #1 (i.e. fire in a single storey childcare building designed in accordance with the NCC DtS Provisions) exceeds the acceptable individual risk level by a factor of 1,647.

11.1.4 Design Case #4 exceeds the acceptable individual risk level by a factor of 25,526. This represents a seven-storey building without sprinklers or stair pressurisation system, designed in accordance with the NCC DtS Provisions.

11.1.5 The estimated societal risk levels far exceed the acceptable societal risk curves in the draft ABCB Tolerable Risk Handbook.

11.1.6 The main contributor to the acceptable risk level being exceeded is the frequency of fire in buildings. For example, in the hypothetical design case #5, the frequency of fire start is predicted to be 5.39×10^{-2} per year. To meet the acceptance risk level, the probability of a fire causing a fatality must be 6.1×10^{-5} or lower. Such a small probability of a fire causing a fatality is probably not feasible to achieve, even with numerous independent and highly reliable fire safety measures such as sprinklers, smoke detectors, and other active and passive systems. The sensitivity analysis for fire frequency in Section 9.2 and the associated discussion in Section 10.1 concluded that the ABCB's acceptable risk levels are not met even with a reasonable variation of the frequency of fire starts.

11.2 Relative Risk

11.2.1 We have quantified the Relative Risk for all of the design cases to compare the risk of design cases (#2-5) with design case #1 (base case).

11.2.2 The Relative Risks for Type A and Type B evacuations are shown in Table 89. Using Design Case #1 as the benchmark, it has been demonstrated that ECCs located above ground are associated with an unacceptable risk level.

11.2.3 The exception is for design case #5 in an ECC with Type B evacuation where the relative risk is predicted to be 0.6. However, the egress model does not account for counter-flows from fire fighters or from occupants on other storeys entering the fire-isolated stairs. In reality this will slow down the evacuation and the risk is therefore greater than what is predicted in this study.

11.2.4 The sensitivity study has also shown that parameters where uncertainty exists can have a major impact on the result. The results should therefore be interpreted with care and the reader should use caution in interpreting this as a design equally safe as design case #1. Whilst design case #5 for Type B predicts a Relative Risk of 0.6, the simplifying assumptions (e.g. no counter-flow and influx flow on lower levels) and limitations together with the large variation suggests that the real relative risk may well be above 1.0.

Table 89: Relative Risk – Type A and Type B evacuations

Design Case	Relative Risk (Type A)	Relative Risk (Type B)
#1	1.0	1.0
#2	6.5	9.1
#3	12.9	15.6
#4	15.5	9.5
#5	1.3	0.6

11.2.5 Our conclusion is therefore that none of the designs with an ECC above ground level produce a sufficiently low risk level to be permitted under the current DtS Provisions.

11.3 Recommendations for ECCs located above ground level

11.3.1 Based on the results from this study, it is recommended that the NCC is amended to require the following additional DtS Provisions where an Early Childhood Centre is located above ground level:

- An automatic sprinkler system in accordance with AS 2118.1 including a building occupant warning system (AS 1670.1) or an emergency warning and intercom systems (AS 1670.4) as appropriate is provided throughout the entire building. Sprinklers are recommended to be quick response heads; concealed and flush type sprinkler heads shall not be used despite their heat sensitive elements are classified as fast response.

- The Early Childhood Centre is to be separated into a minimum of two fire compartments with a minimum FRL of (120)/120/120 with horizontal egress being provided between the two compartments. All of the occupants in the fire compartment with the largest size must be able to be accommodated in the smallest fire compartment, whilst the smallest fire compartment is assumed to be fully occupied as per Table D1.13 of the NCC.

- At least two horizontal exits shall be provided between two fire compartments that the Early Childhood Centre is divided into. The horizontal exits shall be located at least 9 m from each other.

11.3.2 The effects of the recommended measures were quantified using the QRA methodology contained within this report. Details are provided in Appendix A.

11.3.3 The relative risks for the design cases with the additional recommended safety measures implemented are provided in Table 90. In almost all of the design cases, the relative risk is half or less than that of an Early Childhood Centres located on ground level. The exception is for Design Case #3 for Type A evacuation where the fire compartmentation was found to not have a significant impact according to the simulation results.

11.3.4 A detailed analysis shows that two of the fire scenarios providing the largest impact on the results are within the order of a few seconds away from having a consequence of zero fatality. Assuming a zero consequence for these two scenarios results in the relative risks presented in Table 91. We are of the opinion that this is within the bounds of the uncertainty of the model and is more consistent with the overall risk reduction impact as a result of the risk reducing measures proposed.

Table 90: Relative Risks with recommended safety measures

Design Case	Relative Risk (Type A evacuation)	Relative Risk (Type B evacuation)
#2	0.48	0.05
#3	0.96	0.11
#4	0.34	0.28
#5	0.28	0.21

Table 91: Relative Risks with recommended safety measures (modified)

Design Case	Relative Risk (Type A evacuation)	Relative Risk (Type B evacuation)
#2	0.48	0.05
#3	0.16	0.11
#4	0.34	0.28
#5	0.28	0.21

11.3.5 Table 91 demonstrates that by implementing the proposed additional safety measures, the Early Childhood Centres located above ground are associated with a similar or lower risk compared to an Early Childhood Centre located on ground level. Accounting for the uncertainties involved (e.g. egress and fire modelling, counter-flows from fire brigade and other building occupants, lack of reliable data, frequency of fire, reliability of fire safety systems), we are of the opinion that all of the proposed fire safety measures should be included in a future revision of the NCC to ensure that the fire and life safety risks to which occupants in Early Childhood Centres above ground level are exposed are acceptable.

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Appendix A. Analysis of recommended changes to the NCC

A.1 Introduction

A.1.1 The conclusions in Section 11 has demonstrated that the risk associated with ECCs located on levels above ground is significantly increased compared to ECCs located on ground level. The risk is also exceeding the tolerable risk criteria proposed by the ABCB.

A.1.2 This Appendix outlines the engineering basis for the recommended changes to the NCC made in Section 11.3. The recommendations are as follows:

1. An automatic sprinkler system in accordance with AS 2118.1 including a building occupant warning system (AS 1670.1) or an emergency warning and intercom systems (AS 1670.4) as appropriate is provided throughout the entire building. Sprinklers are recommended to be quick response heads; concealed and flush type sprinkler heads shall not be used despite their heat sensitive elements are classified as fast response.
2. The Early Childhood Centre is to be separated into a minimum of two fire compartments with a minimum FRL of (120)/120/120 with horizontal egress being provided between the two compartments. All of the occupants in the fire compartment with the largest size must be able to be accommodated in the smallest fire compartment, whilst the smallest fire compartment is assumed to be fully occupied as per Table D1.13 of the NCC.
3. At least two horizontal exits shall be provided between two fire compartments that the Early Childhood Centre is divided into. The horizontal exits shall be located at least 9 m from each other.

A.2 Recommendation #1 – Automatic sprinkler system in low and medium rise buildings

A.2.1 The recommendation is to provide an automatic sprinkler system in accordance with the relevant edition of AS 2118.1 including a Building Occupant Warning System (AS 1670.1) or an Emergency Warning and Intercom Systems (AS 1670.4) as appropriate in all buildings containing ECCs above ground level. Sprinklers are recommended to be fast response heads.

A.2.2 Results are presented below in relative risk for design cases provided with sprinkler systems. Design case 1 is not included as no changes are proposed for this case (it is the basis for comparison). Design case is already prescribed with sprinklers and is therefore not included in the comparison.

Table 92: Relative Risk – Type A and Type B

Design Case	Relative Risk (Type A)	Relative Risk (Type B)
#2	0.52	0.73
#3	1.03	1.21
#4	1.24	0.76

A.3 Recommendation #2 and #3 – Fire compartmentation within ECCs

A.3.1 The recommendation is to require all ECCs to be separated into a minimum of two fire compartments with horizontal egress being provided between the fire compartments. This would allow a staged evacuation procedure, whereby staff can quickly move all children horizontally to a place of relative safety before moving them down stairs.

Hypothetical building design

A.3.2 The recommendation has been evaluated against the hypothetical building design presented in Section 4.2. The building design has been provided with a centrally located internal wall achieving an FRL of (120)/120/120 separating the floor plate into two similar sized fire compartments which is illustrated in Figure 29. At minimum of two horizontal exits between the fire compartments shall be provided and the exits shall be separated a minimum of 9 m (as prescribed for distances between alternative exits under Clause D1.5 of the NCC DtS Provisions).

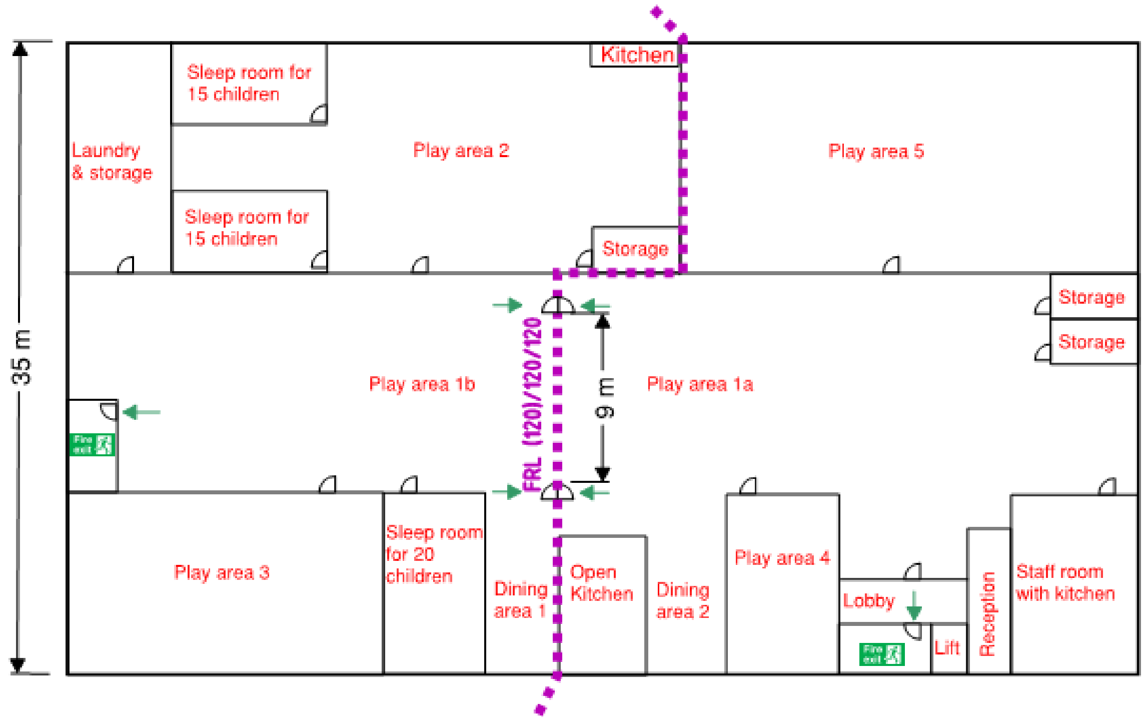

Figure 29: Hypothetical floor plan of ECC with fire compartmentation

A.3.3 The assumption made in this analysis is that each fire compartment is identical in the number of occupants housed and the floor area size (i.e. 1000 m^2 each).

CFAST modelling

A.3.4 The methodology described in Section 7.3 was applied to one of the identical 1000 m^2 fire compartments above.

A.3.5 The results relevant to the analysis are provided in Table 93 and Table 94.

Table 93: Observations from CFAST modelling for a fire located in Play Area 1a

Observation	Very Slow	Slow	Medium	Fast
Time to untenable conditions (ASET)	417 s	260 s	177 s	130 s
Time to upper layer reaching 350 °C	> 1200 s	> 1200 s	730 s	412 s
Manual detection time (5% of ceiling height)	210 s	141 s	90 s	73 s
Smoke detector activation time	114 s	69 s	48 s	40 s

Table 94: Observations from CFAST modelling for a fire located in Play Area 5

Observation	Very Slow	Slow	Medium	Fast
Time to untenable conditions in Play Area 1a (ASET)	979 s	581 s	387 s	264 s
Time to upper layer reaching 350 °C	> 1200 s	> 1200 s	> 1200 s	> 1200 s
Manual detection time (5% of ceiling height)	128 s	73 s	51 s	42 s
Smoke detector activation time	63 s	38 s	27 s	23 s

Results

A.3.6 Results are presented below in relative risk for design cases provided with fire compartmentation. Design case 1 is not included as no changes are proposed for this case (it is the basis for comparison). Design case is already prescribed with sprinklers and is therefore not included in the comparison.

Table 95: Relative Risk – Type A and Type B

Design Case	Relative Risk (Type A)	Relative Risk (Type B)
#2	6.0	0.67
#3	12.0	1.34
#4	4.3	3.5
#5	0.28	0.21

A.4 Recommendation #1 & #2 – Combined effects

A.4.1 In Table 96 below, the combined effects of fire compartmentation and sprinklers are presented in terms of relative risk. Design case 1 is not included as no changes are proposed for this case (it is the basis for comparison). Design case is already prescribed with sprinklers and is therefore not included in the comparison.

Table 96: Relative Risk – Type A and Type B

Design Case	Relative Risk (Type A)	Relative Risk (Type B)
#2	0.48	0.05
#3	0.96	0.11
#4	0.34	0.28