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OVERVIEW AND OBSERVATIONS FROM PRIMARY SCHOOL CASE STUDIES

Introduction

Fire-safety case studies using Quantitative Risk Assessment (QRA) approaches have been undertaken on a single-storey primary school building and a five-storey building with a primary school located on Levels 1 to 5 with a café and entertainment venue on the ground level.

The studies were undertaken to illustrate the application of the quantitative risk based criteria defined in the July 2020 draft of Part A8 of NCC 2022 but with the modifications described in the following section.

This case study simulated the involvement of a fire safety engineer from the schematic design phase providing opportunities for an effective design to be developed.

The case studies demonstrated that it was possible to successfully apply the criteria and that the quantitative risk assessment approach successfully identified potential vulnerabilities in the initially proposed designs and facilitated the identification of options for mitigation measures. Notwithstanding this a number of observations were made regarding opportunities for improving the specified metrics in the draft Part A8 of the NCC 2022 and are outlined within this overview which incorporates a series of recommendations.

Initial Review of July 2020 draft of Part A8 of the National Construction Code (NCC)

Modifications to 1 July draft of Section A8 of the NCC

An initial review of the proposed quantitative risk based criteria and the following modifications were made (which are indicated in Appendix B in red text with the deletions indicated as “strikethrough” text).

- to the note at the end of section A8.2 of the draft to clarify the treatment of designs with risk levels between the upper and lower tolerable limits.
- to clause A8.3(a) to clarify the application of the clause.
- to modify the first dot point of the definition of withstand. The definition relates specifically to the A8.3 spread of fire criteria. The dot point 1 criteria in the 1 July draft were duplications of requirements that are inherently addressed in the risk to life criteria and did not provide a quantitative limit for the spread of fire over the external façade of a building. The original 5m spread of fire limit above an opening was therefore reinstated but a note cross-referencing the need to consider the extent and velocity of fire spread under the proposed clause A8.2 criteria in addition to A8.3 was added for clarity.

Recommendation 1 The proposed changes are made to the July draft of Part A8

Addition of Tenability Criteria

The A8.2 criteria refer to the risk of exposure to untenable conditions, but untenable conditions are not defined. Therefore in Appendix B Section B2 the tenability criteria used for the case studies were defined. The primary tenability criteria for the designs were based on a fractional effective dose (FED) of 0.3 with respect to thermal exposure and exposure to CO in conjunction with simple criteria relating to occurrence of a fully developed fire and collapse and were identified as Level 3 criteria. These were compared to criteria based predominantly on visibility which were defined as Level 1 criteria) The high sensitivity of outcomes to selected tenability criteria was demonstrated and therefore it is important that the tenability criteria are defined, and the tolerable risk limits are consistent with the selected tenability criteria.

Recommendation 2 Tenability criteria should be prescribed and if necessary proposed risk levels modified so that they are consistent with the selected tenability criteria.

Treatment of Disproportionate Collapse

Disproportionate collapse due to fire is not a metric within the proposed Part A8 NCC requirements and is currently addressed in NCC Part B. The design of buildings to resist disproportionate collapse can have a significant impact with respect to overall structural adequacy under severe fire conditions and will therefore be indirectly addressed when determining individual and societal risks. A metric could be added if it is desired to explicitly address disproportionate collapse due to severe fire conditions or if retained in Part B guidance can should be provided on the treatment of performance under fire conditions.

Recommendation 3. There should be a clear indication if disproportionate collapse should be explicitly addressed with respect to fire or indirectly through life safety metrics and appropriate guidance should be provided.

Application of the Quantitative Risk Assessment Approach

A general quantitative risk assessment approach was adopted as shown in Figure A.

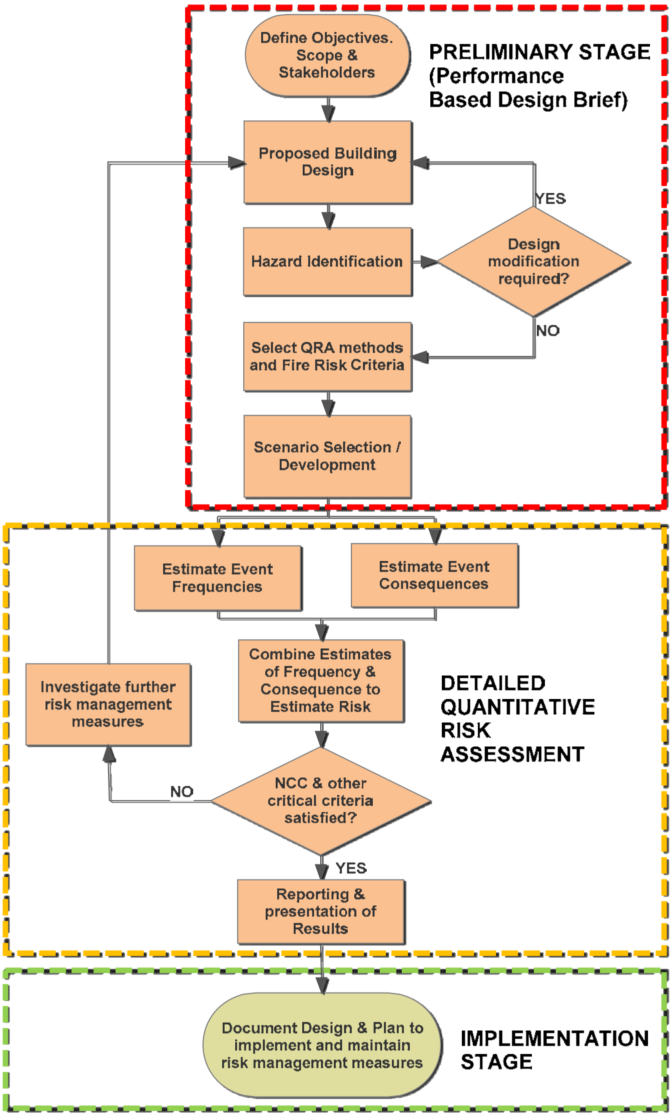


Figure A Overview of QRA Process

The processes forming part of the Performance Based Define Brief (PBDB) stage are shown and the continuation of the process through the implementation phase and building life is also included to highlight the importance of implementing the findings of the report

The determination of compliance with the NCC individual and societal risk criteria can require a comparative assessment if the lower risk criteria are not satisfied as shown in Figure B

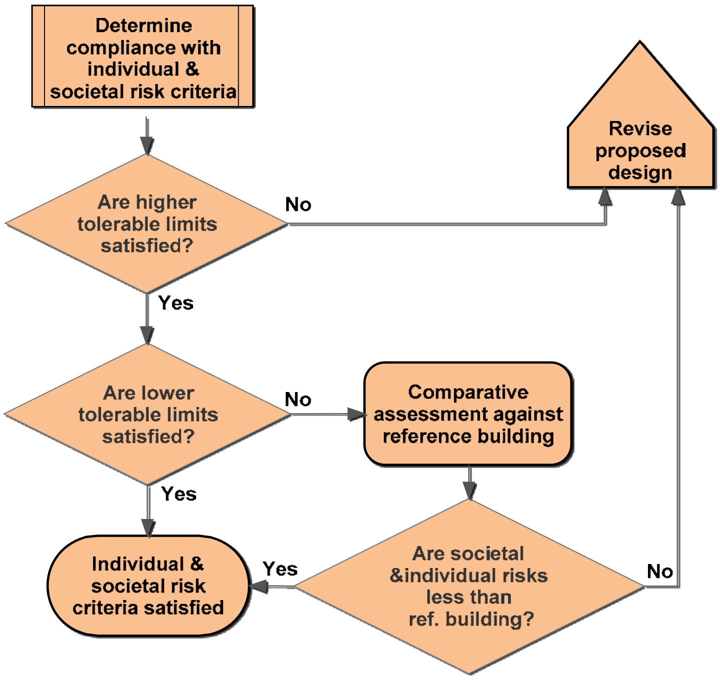


Figure B Determination of Compliance with Individual and Societal Risk Criteria

Overview of Case Study Buildings and Fire Safety Strategies

Basic Design and Layout

Two case studies were presented relating to primary schools.

Case study 1 was a typical single storey primary school complying with the NCC 2019 DTS provisions. The majority of existing primary schools in Australia comprise one or two-storey buildings and therefore this was considered to represent a useful study to benchmark or “calibrate” the proposed risk metrics and to develop an appropriate reference building for comparison with case study 2.

Case study 2 was a five storey mixed use building housing a primary school (levels 1-4) with a Class 6 (café) and Class 9b entertainment venue at ground level (effective building height below 25m) which was treated as a performance solution. The design used the NCC 2019 DTS provisions as the starting point for the design but with the design options permitted by the DTS provisions selected on the basis of the application of fire safety engineering principles. Additional measures were also incorporated, to address additional drivers and constraints identified during the equivalent of the Performance-based Design Brief (PBDB) process and where appropriate achieve compliance with the proposed metrics

A typical sized primary school was assumed for both case studies providing accommodation for a maximum of 420 students from Prep to year 6 (i.e. seven-year groups) and two streams per year group with a maximum class size of 30. This is slightly larger than the average primary school size of 360 students but is not an extreme case.

The schematic designs for both case studies were developed using a modular approach with the same general format of learning areas to enable the comparative study to focus on matters relating to the height of the building. Within these constraints the ancillary areas were adjusted where necessary to provide workable building layouts as shown in Figure C (single storey building) and Figure D (5-storey building)

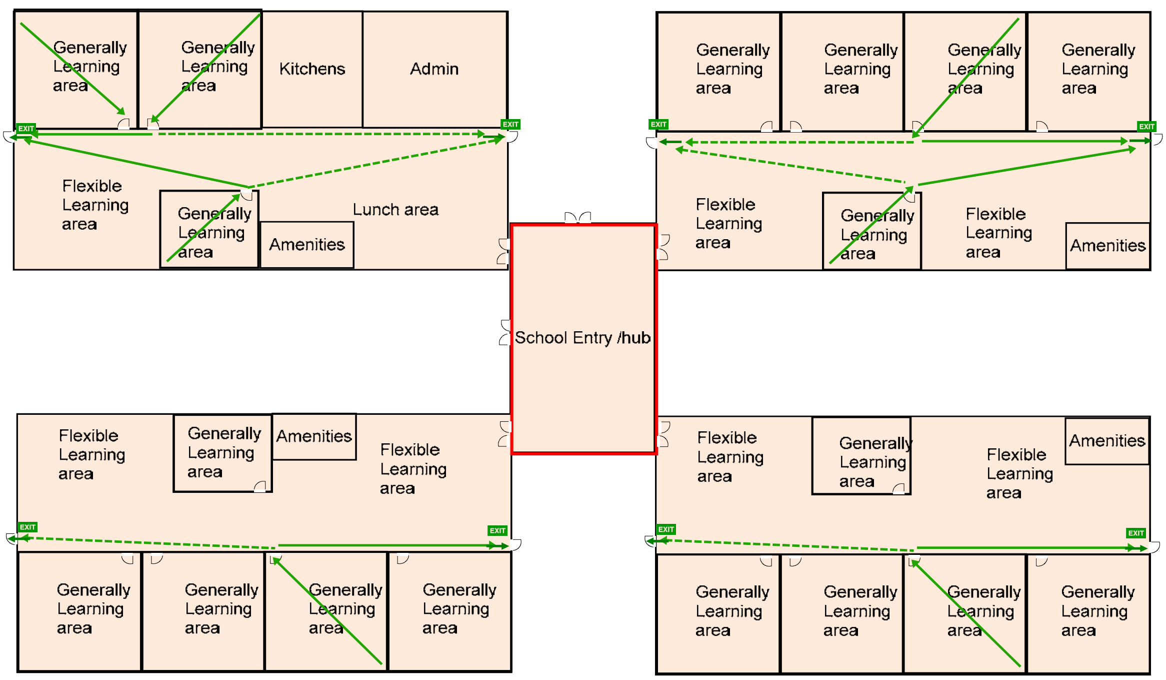
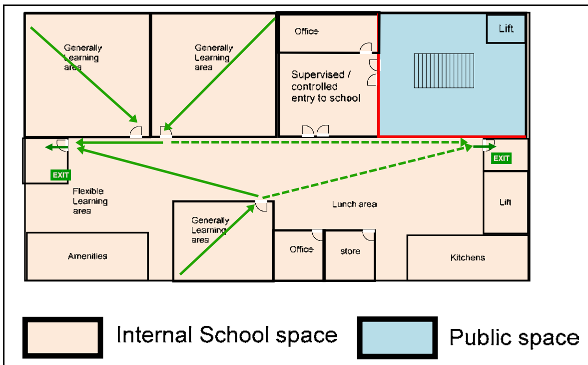
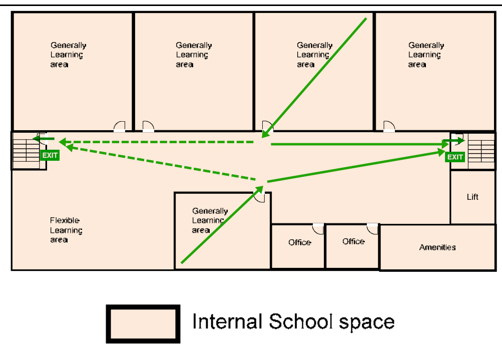


Figure C Layout of Single Storey Reference Primary school





Level 1 Plan including school entry from ground level	Level 2 to 4 plan

Figure D Layout of 5-storey Primary School Building

Each module was rectangular having a floor area of approximately 900m^2 (40m x 22.5m). For the single storey reference building the modules were connected by a central hub, and for the high-rise options each module formed a complete floor. The ground floor for the high-rise options was mixed use, representing current trends for high-rise schools to be co-located with public / civic facilities.

Enhancements to NCC DTS provisions

There were a number of enhancements to the minimum NCC DTS provisions that were incorporated on the design as the QRA process was undertaken which can be classified under the following categories.

Enhancements / assumptions from the start of the project to facilitate the comparative analyses:

- Non-combustible construction was selected for both the single storey case and 5-storey case although not required under the DTS provisions for the single storey building. This selection was made to provide a comparison that was focussed on variations in the height of buildings.
- Fire resistant separations were provided for the single storey case between each of the modules and the centre hub to provide a similar sized fire compartment to the 5-storey case.
- Sizes of openings in external walls and distances from boundaries of the building were selected for demonstration purposes and limits would need to be specified as part of the design.
- For the 5-storey school it was assumed that the ground level was effectively fire and smoke isolated from the school areas and was excluded from the detailed quantitative analysis to facilitate a comparison that focussed on the impact of building height on primary schools. (note: other enhancements required to satisfy general drivers and constraints such as independent evacuation paths for primary school children and security provisions tended to require high levels of separation)
- It was assumed spandrel panels at least 900mm high are provided in the five-storey building not withstanding a dispensation being provided in the NCC for these to be omitted if a building is sprinkler protected. This assumption reflected a likely detail but would need to be stated as a requirement in the fire safety strategy.
- Vehicular access adjacent to the structure will be prevented by design features such as bollards and management procedures put in place to prevent large volumes of combustible materials to be placed against the external façade of the ground floor of the 5-storey building
- There will be an established and operational emergency management organisation in place appropriate to the size of school and documented emergency procedures which adequately address
    - means to promptly instigate an evacuation upon activation of an automatic alarm detection /alarm system if provided
    - means to promptly alert all occupants and instigate an evacuation upon manual detection of a fire.
    - staff training to a high level with any temporary staff also made aware of their responsibilities in the event of a fire and receive the necessary induction and training to facilitate an effective response to a fire emergency which should include;
        - an understanding of how to raise an alarm in the event of a fire and the emergency procedures to be followed during a fire (and other emergencies).
        - knowledge of the fire protection measures in place including locations of exits

Enhancements required to satisfy general drivers and constraints:

- Access for people with disabilities (including consideration of egress in fire emergencies. This was addressed by provision of ramps for the single storey case and provision of refuges within the fire stairs in the fire storey building supplemented by emergency management procedures to address evacuation of people with disabilities.

- Integrating security measures into the design of the building through adapting the building layout rather than relying on access control systems that can be complex to integrate into a design effectively. Examples include;
    - in the event that another occupancy (e.g. secondary school or offices) occupies levels above the primary school, providing independent stairs and exits for the primary school children for the five- storey building to address the risk of students being trampled if access is permitted from other occupancies and to address security requirements to protect the young children.
    - separate lifts for students and accessing school through a 1st floor lobby.
- The provision of safe assembly areas for primary school children during an emergency. Normally provisions for safe evacuation to open space are not adequate for primary school children who are more susceptible to the risk of abduction and have lower awareness of traffic hazards etc.
- A safe path of travel to an external assembly point without exposing children to hazards such as traffic, abduction or the like should be addressed.
- Locate younger students on the lower levels of the school.

Enhancements required based on the outcomes of the Hazard ID process:

- The risk of a fire growing in an unoccupied space and compromising exits prior to evacuation was identified during the Hazard ID process. It was therefore determined that automatic detection and alarm systems should be provided in both the five-storey building and single storey building (reference building 2). A single storey building without an automatic detection and alarm system was also evaluated (Reference Building 1)
- The selection of an automatic sprinkler system as the most appropriate smoke hazard management system for the five-storey primary school building.

Enhancements required to satisfy the proposed NCC Part A8 quantified criteria:

- Design enhancements to a basic automatic sprinkler system and related maintenance and building management systems to increase the effectiveness of the system to 95% to adequately address societal risk

Good practice recommendations for the design team to implement where practicable:

- Provision of two exits from classrooms where practical to address the risk of blocked exits and other emergencies
- Avoid dead ends.
- Procedures for maximising the effectiveness of fire safety systems
- Development and use of an implementation plan.

- A good practice guide or similar advisory document shall be prepared to alert the school operators of potential additional hazards that may need to be addressed when schools are used for other purposes and examples of appropriate mitigation methods. Many States and Territories provide advice / guidelines for principals to follow.

Hazard Identification

To provide a structured approach to the Hazard Identification process and to ensure that the identified hazards were subsequently addressed a risk register was constructed which identified:

- hazards
- proposed control measures
- preliminary qualitative analysis
- proposed quantitative analysis and inputs
- status / actions

The risk register was initially populated based on the FSVM default scenarios with further entries being informed by:

- A review of Fire Statistics, Incident Data and related information
- A Review of DTS provisions in International Codes
- Characterisation of Primary School Occupants
- Additional Matters Identified relating to Building Trends and Practices for high-rise schools and supplementary requirements outside NCC provisions
- A Review of NCC DTS provisions applicable to schools
- Parameters for consideration provided within the NCC 2019 Performance Requirements and proposed for inclusion in Part A8 of the NCC 2018
- Fire safety principles / engineering judgement

The register was maintained throughout the analysis and updated as appropriate.

It is critical to ensuring the analysis adequately considers all major hazards and the relevant scenarios are identified. The hazard ID process therefore needs to be well documented.

Recommendation 4. Guidance materials should be developed describing the application of the Hazard ID process required when determining compliance with the NCC.

Design Modifications Identified during the Hazard ID process

The proposed buildings may require modifications to the proposed fire safety strategy as a direct outcome of the Hazard ID process or the modifications may be determined after confirmation by the detailed QRA.

In the cases undertaken typical examples include:

- the requirement for automatic smoke / alarm systems which was determined directly from the Hazard ID process
- the selection of an automatic sprinkler system as the most appropriate smoke hazard management system for the five -storey primary school building also determined at the Hazard ID process stage.

Selection of Fire Risk Criteria, QRA Methods and Scenario Selection / Development

Selection of QRA methods

The proposed NCC quantified criteria allow QRA methods to be selected based on the specific circumstances relating to the proposed building solution which is appropriate since methods can be expected to vary substantially to reflect the complexity and potential consequences in the same way that design methods used in other engineering disciplines vary to suit the application. The need for this flexibility has been demonstrated by the combination of approaches described below which were adopted for the analysis undertaken in the case studies.

Recommendation 5. Consistent with the current draft NCC Part A8 specific methods of analysis should not be prescribed provided compliance with the quantified metrics can be adequately demonstrated to allow appropriate methods to be selected on a case by case basis.

Determination of Individual and Societal Risks

The fire risk criteria were prescribed in the draft section A8 of the NCC which is considered appropriate since it is a quantified statement of community expectations. However, because of the impact of tenability criteria these also need to be specified as part of the fire risk criteria. (Refer recommendation 2)

For the case studies described in this report the following QRA methods and Scenario Selection / Development approaches were adopted.

A series of fire scenario clusters were defined to reflect the universe of potential fire scenarios which were then consolidated into a series of representative design fires addressing the hazards previously identified. This approach was based on the methods described in ISO 16732-1[1].

A consolidated event tree was then derived by:

- consolidating all the branches with zero consequences that were determined during the PBDB stage based predominantly on an analysis of fire statistics (generally small fires).
- assigning the probabilities for fires occurring in the various types of enclosures derived from fire statistics
- including an automatic sprinkler branch for consideration of sprinkler options.

The representative fire scenarios required further extension to address the status of the door to the room of fire origin, the various cues by which occupants become aware of a fire, and to consider the variability of human behaviour and the evacuation process when evaluating the consequences of the event trees.

This was achieved by:

a) extending the representative fire scenario event trees to address the following means by which occupants are alerted to the occurrence of a fire:
   - automatic (via the smoke detection and alarm system),
   - early manual detection and
   - delayed manual detection.

b) Including the status of the door to the room of fire origin in the extended event trees since this impacts smoke spread and manual detection times.

c) Undertaking ASET / RSET evacuation modelling using the distributions for premovement times and travel speeds assuming the occupants travel as a class group as identified in the technical literature.

The outcomes for the representative fire scenarios with respect to smoke spread were determined using a zone-model (B-Risk) from which the activation of detectors, visual cues and time to untenable conditions for various enclosures were determined.

To derive the Required Safe Egress Time (RSET), or number of people exposed to untenable conditions if RSET > ASET, multi-scenario analyses were undertaken employing the logic shown in Figure E and adopting distributions for travel speeds and response times based on technical literature to reflect the uncertainty associated with human response to fires.

Fire brigade Intervention was also modelled where appropriate using multi-scenario approaches based on the FBIM model [2] and response times based on distributions published in a Report on Government Services [3].

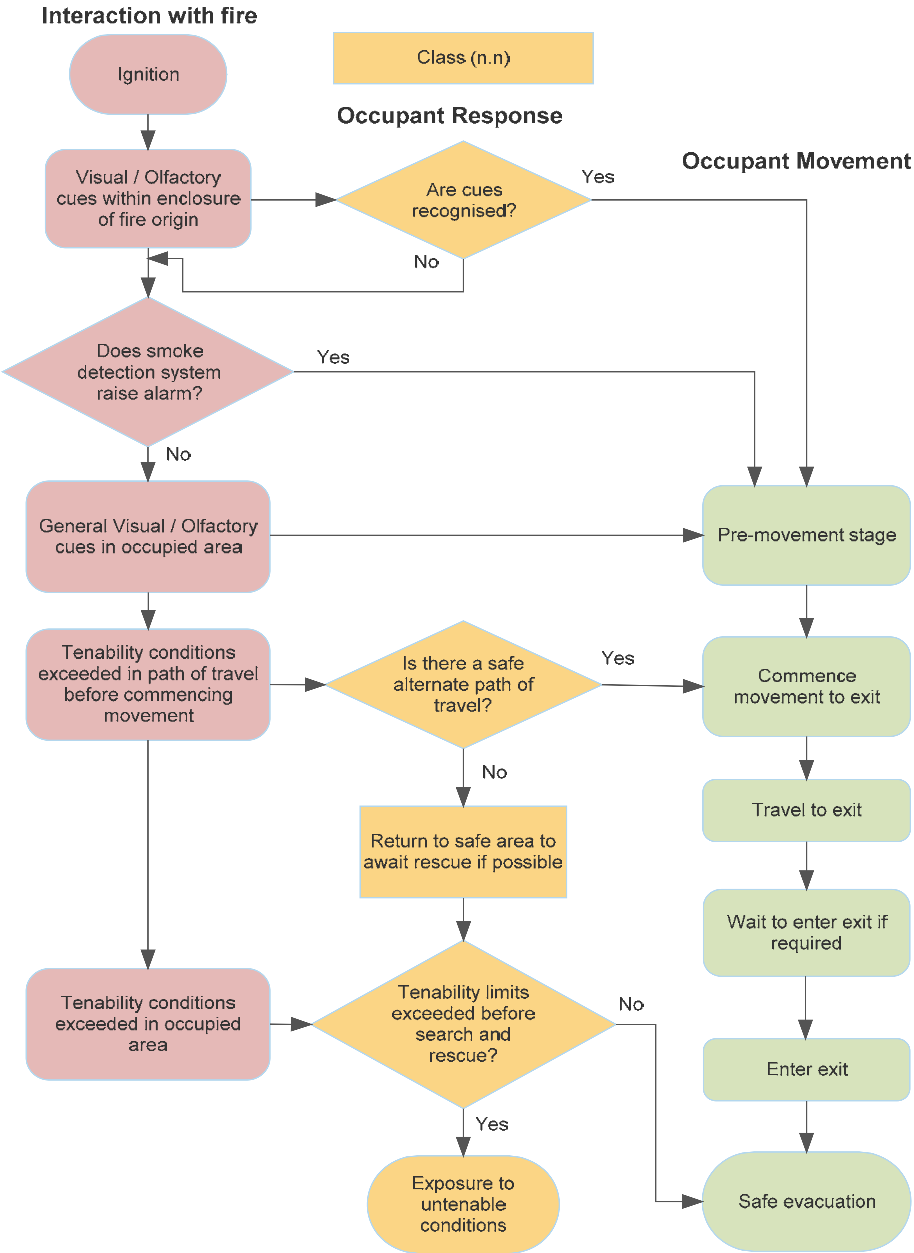


Figure E Flow chart showing occupant response and movement in response to fire

The consequences of fire and smoke spread between floors were estimated using the following QRA methods and scenarios applied to potential fast growth flashover fires:

- Human response and movement and fire brigade intervention was modelled as above.
- Smoke spread to upper levels via stair and lift shafts due to open doors was modelled using B-Risk
- External fire spread estimates were based on estimates derived from fire statistics and Korhonen [4]

- The analysis of internal fire spread to the next level and structural fire resistance was undertaken using the Enclosure / Structural model together with a multi-scenario implementation of the Fire Brigade Intervention model incorporated in the EFT Multi-scenario Quantitative Risk Assessment Framework (England [60]).

Estimates of Risk of Fire Spread for comparison against Fire Spread Metrics

The risk metrics for fire spread between buildings are expressed in terms of the probability of heat flux limits being exceeded. A simple radiant heat flux calculation and frequency estimates based on the probability of flashover occurring in the building were used to derive risk estimates. The estimated risk of failure when exposed to radiant heat was determined using experimental data from technical literature.

The risk metrics for fire spread via the façade are based on the probability that the external façade of a building cannot *withstand* the following scenarios from *reportable fires* not exceeding 0.001:

- flames venting through an opening from an enclosure fire within the building.
- burning items adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas.
- a fire occurring on a balcony (this was not applicable to the specific case).

The analysis undertaken to estimate individual and societal risks due to fire spread from the façade was adapted and extended as appropriate for comparison against the risk of fire spread metric.

The risk metrics for internal fire spread require the probability of fire spread within the building not to exceed prescribed limits. For the 5-storey school building the probability of internal fire spread between storeys needs to be maintained below 0.01 for a reportable fire. The probability of fire spread was based on the probability of a fully developed fire occurring, sprinkler failure and failure of the floor system to prevent fire spread.

In the current draft of NCC Section A8 there is no fire specific metric specified for disproportionate collapse. The risk to occupants as the result of a major collapse was estimated when determining the societal and individual risks for the 5-storey building

Case Study 1: Single-storey School Results

Individual Risk Results Single Storey School

The individual risk (IR) results are shown in Table A for the single storey school.

The applicable tolerable IR criteria from the draft of NCC Section A8 are:

- Lower individual risk limit: 1×10^{-4}
- Lower individual risk limit: 1×10^{-6}

Table A Individual Risk Results

Risk Criteria	Level 3 Tenability Criteria		Level 1 Tenability Criteria		Est. from fire incident data
	Ref. Bld. 1	Ref. Bld. 2	Ref. Bld. 1	Ref. Bld. 2	
Detection / alarm system provided?	No	Yes	No	Yes	Varies
Individual Risk of death / annum	1.10×10^{-6}	2.20×10^{-7}	9.04×10^{-5}	3.29E x 10^{-5}	1×10^{-8}
Normalised IR against lower limit	1.1	0.22	90.4	32.9	0.01
Normalised IR against upper limit	0.011	.0022	0.90	0.33	0.0001

Results are quoted for Level 1 and Level 3 tenability criteria. Level 3 tenability criteria, based predominately of a Fractional Effective Dose (FED) of 0.3 with respect to exposure to heat or CO, were adopted for the case study. Generally, the CO exposure was the critical criteria. A sensitivity analysis was included using tenability criteria based predominantly on visibility of 10m at a height of 2m which was identified as Level 1 tenability criteria.

Reference building 2 included a smoke detection / alarm system that was not included in reference building 1. This comparison was undertaken to check the need for a smoke detection / alarm system that was identified during the Hazard ID process.

The results were normalised against the upper and lower tolerable individual risk limits to facilitate comparison.

Reference building 1 was shown to marginally exceed the lower IR tolerable risk limit but was substantially below the upper limit applying level 3 criteria whereas reference building 2 was significantly below the lower IR limit applying the level 3 criteria demonstrating the major positive impact of providing an automatic detection / alarm system.

As expected, the IR results were very sensitive to the selected tenability criteria, varying between the Level 3 and Level 1 criteria by factors of approximately 80 to 150 for reference buildings 1 and 2 respectively confirming the need to define tenability criteria in conjunction with the prescribed tolerable risk limits (refer recommendation 2)

IR results can also be compared to estimates derived from fire incident data. The IR for Reference Buildings 1 and 2 were approximately 110 times and 20 times greater respectively, than the risk estimated from the fire incident data which relates predominantly to one and two-storey schools.

Possible reasons for these variations are:

- Variations from the case study building and schools in which fires occurred.
- Analysis ignored evacuation through windows and other non-standard evacuation options which could be used in extreme circumstances particularly for single storey buildings.
- Level 3 tenability criteria still contain some conservatism.
- Various other conservative assumptions made regarding input to the analysis.

Societal Risk Results Single Storey School

The societal risk results are shown in and F-N plot in Figure F for the single-storey school compared to the Draft NCC A8 tolerable risk criteria.

It can be seen that F-N plot for reference building 1 marginally exceeds the upper tolerable risk level for N between 30 and 60 people whereas the F-N plot for reference building 2 lies wholly between the upper and lower tolerable risk limits.

Fire incident data based on the period between 1908 and 1958 in the US during which there were a number of multi-fatality school fires which led to substantial changes to building standards are also plotted in Figure F. Whilst the plots are based on crude estimates of the number of schools the plots provide an indication of levels of risk where there is significant aversion to the acceptance of losses. These plots are close to the upper tolerable risk limit.

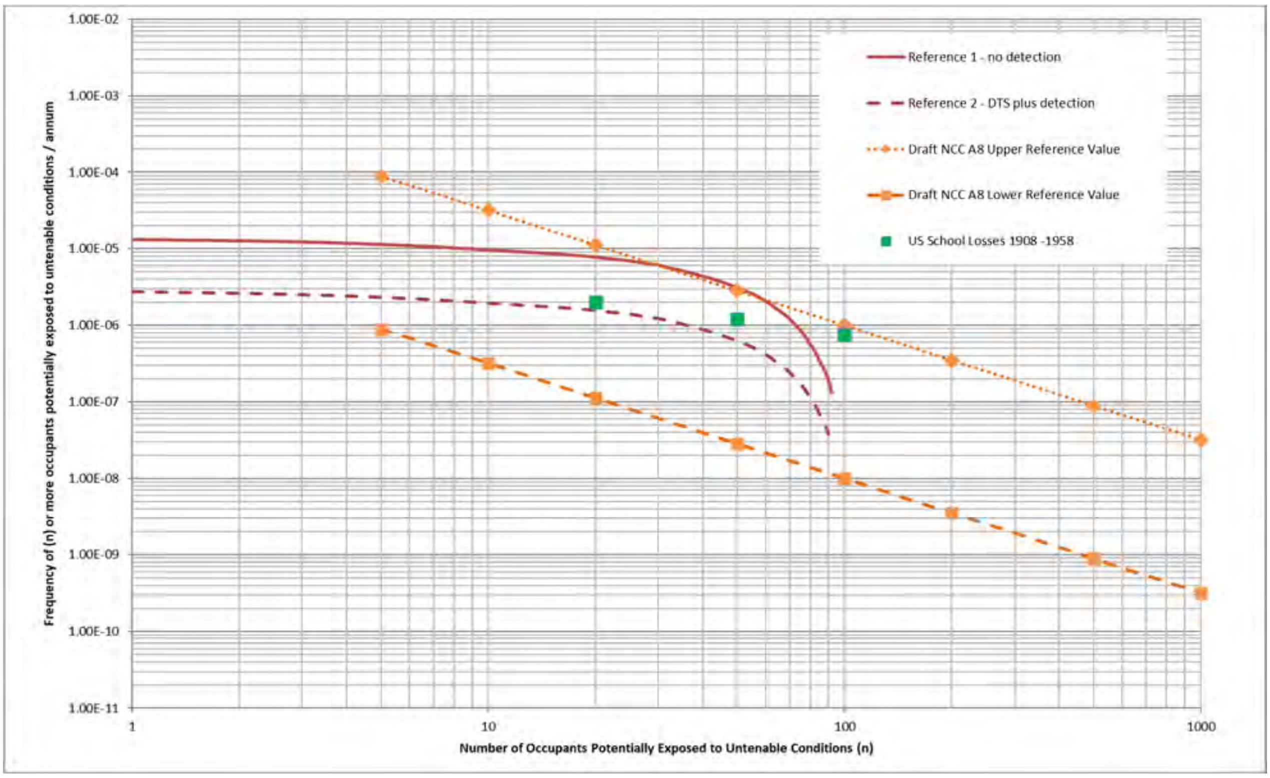


Figure F F-N Plot of Societal Risk for single storey schools

Based on the comparison of the individual risk estimates with fire incident data, fatalities are expected to be overestimated by a factor of approximately 20 for the reference building 2 which would lower the societal risk levels further.

A tentative conclusion based on this case study is that the proposed limits are reasonable but conservative assumptions made to address some uncertainties can be expected to over-estimate losses. The specification of a lower limit and allowing comparison against an appropriate reference building if the lower limit is exceeded is a practical solution in the short to mid-term. It is prudent to retain an upper limit to identify cases where the reference solution presents an unacceptable risk.

Fire Spread Risk Results

a) Fire spread via the façade.

Since this case study is a single storey building the fire spread via the façade criteria are not applicable.

Whilst for a single storey building this is a reasonable assumption it would be helpful to have a clear exclusion within the proposed section A8. Consideration could be given to basing the exclusion on the required type of construction

Recommendation 6 Exclusions should be clearly stated for low-rise buildings with respect to fire spread via the façade criteria. It may be practicable to link thus to the required type of construction if it can be decoupled from the NCC DTS provisions

b) Fire Spread between Buildings

A simple analysis using configuration factors was undertaken which demonstrated that the probability of a reportable fire causing the incident heat flux on the boundary greater than 18kW/m^2, from a fire within the reference building does not exceed 0.001, (i.e. substantially below the 80kW/m^2 permitted) and no further analysis was therefore undertaken.

Since the building was located more than 6m from the boundary, the probability of the façade being able to withstand a maximum heat flux of 10kW/m^2 for 30 minutes must not exceed 0.01. The external façade of the building was of non-combustible construction with double glazed toughened glass windows with pane thickness greater than 6mm. It was therefore expected to satisfy the required criteria based on various experimental results in technical literature. (Klassen [5])

c) Internal Fire Spread

The proposed building does not include numerous SOUs and is only one storey high. Therefore, the probability of fire spread beyond a floor area of 3000m^2 is required not to exceed 0.01 if a reportable fire occurs.

The building comprises four nominal 900m^2 modules and a central hub therefore spread through the entire school building needs to be prevented,

To exceed the 3000m^2 limit the fire needs to spread throughout three modules and the hub. The probability of this occurring was estimated to be substantially below the 0.01 limit ignoring fire brigade intervention based on an event tree analysis.

Case Study 2: Five-storey School Results

Individual Risk Results Five Storey School

The individual risk (IR) was estimated to be approximately 2.21 x 10^{-7} which is significantly below the lower tolerable IR limit of 1 x 10^{-6} and therefore no further analysis would be required to demonstrate compliance with this metric. The estimated individual risk was similar to value obtained for reference building 2.

Societal Risk Results Five Storey School

The societal risk results are shown in and F-N plot in Figure G for the five-storey school compared to the Draft NCC A8 tolerable risk criteria and the two reference buildings (reference building 2 was selected as the most appropriate benchmark based on consideration of fires in unoccupied areas).

It can be observed for N values between 5 and 100 the F-N plot for the proposed five-storey school was between the upper and lower proposed Part 8 criteria and therefore a supplementary comparative approach is required to determine if the proposed 5-storey design meets the Part 8 criteria for societal risk.

Reference building 1 is a basic NCC DTS design without automatic detection / alarm and can be seen to marginally exceed the upper limit for N between 30 and 60 which to some extent confirms the Hazard ID analysis highlighting the importance of providing a detection and alarm system to address fires starting in unoccupied areas and growing undetected to such an extent that exit paths are blocked. The proposed design presents a lower societal risk than the reference 1 building but due to the issue of fires in unoccupied areas reference building 2 was selected for the comparison.

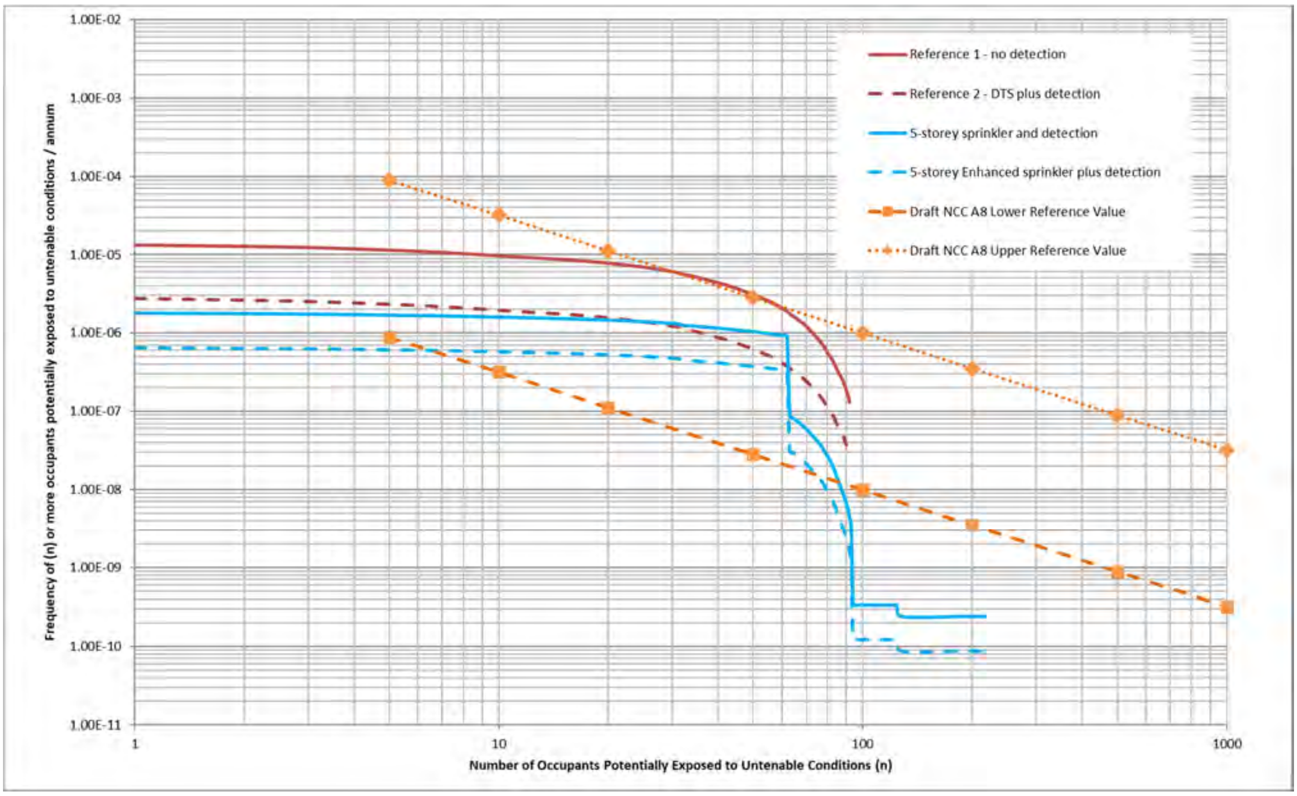


Figure G F-N Plot of Societal Risk for five storey school compared to various benchmarks

For N between approximately 20 and 60 the proposed 5-storey building exceeded the societal risk presented by reference building 2. Below N=20, the proposed 5-storey building presented a lower risk and above N =60 the proposed 5-storey building presented a lower risk than reference 2 and the lower tolerable risk limit from A8.

This is a marginal case and the draft part A8 does not provide any guidance as to how this should be dealt with.

Recommendation 7 Guidance should be provided for situations where the majority of an F-N plot for a proposed building lies below a tolerable risk limit, or an F-N plot for a reference building if a comparative analysis is required to be undertaken, but the plots intersect such that the limits or reference plot are exceeded for a limited range of values of N. This could take the form of a clear but potentially conservative requirement that the whole plot must lie below the limit or benchmark plot from a reference building. Alternatively, a process could be developed to permit minor variations

Notwithstanding the above discussion if a conservative interpretation of A8 is made requiring the total F-N plot for the proposed building to lie entirely below the reference building or lower limit the design would need to be adjusted.

Since the floor of fire origin appears to be dominant, options to improve the performance would include:

- improvements to the reliability of the automatic sprinkler system and / or detection systems

- subdivided the floor to delay smoke spread to the entire floor and stairs, enhance options for occupants to shelter on the floor of fire origin and if necessary, undertake a phased evacuation of the floor.

For demonstration purposes an option to increase the effectiveness of the sprinkler system to 95% was selected and the results are plotted as a dashed blue line in Figure G which lies entirely below the reference 2 building plot and / or lower reference values from A8.

To improve the reliability of the sprinkler system design modifications and procedural measures would need to be established and fully justified using methods such as fault trees.

Fire Spread Risk Results

a) Fire spread via the façade.

The following metrics apply to the five storey building

The probability that the external façade of a building cannot *withstand* the following exposures from *reportable fires* must not exceed 0.001:

A. flames venting through an opening from an enclosure fire within the building.
B. burning items adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas.
C. a fire occurring on a balcony.

Burning items adjacent to the building will be expected to impact on the ground floor non-school parts which are required to be non-combustible. Therefore, the school levels were evaluated for flames venting through an openings which is expected to inherently address small burning items likely to be located adjacent to the structure since the proposed building will be designed to prevent vehicular access in close proximity to the façade.

There are no balconies provided for the fire-storey school building and therefore analysis of balcony fires is not required.

The probability of a reportable fire in an apartment building spreading to the floor above in a concrete building was estimated to be approximately 0.002 without sprinkler protection. Noting the rare occurrence of external spread between floors in high-rise buildings with non-combustible facades it was considered conservative to adopt this value for the subject building since spandrel panels in excess of 900mm are provided as part of the building design.

Allowing for the impact of sprinklers with an assumed effectiveness of 86% the probability of external fire spread can be estimated to be:

0.002 x 0.14 =0.00028 which is substantially less than the nominated limit of 0.001.

Therefore, a more detailed analysis was not considered necessary and it was determined that the metric for fire spread via the façade had been satisfied.

(Note if there are no spandrel panels and if flashover occurs fire spread to the floor above is likely to occur. A low estimate of the proportion of reported flashover fires based on the analysis of fire incident data would be 0.11 ignoring sprinklers. Allowing for the impact of automatic sprinklers with an effectiveness of 86% would reduce the probability of a reportable fire progressing to flashover of 0.0154 which substantially exceeds the prescribed probability limit of 0.001. The DTS concession waives the requirements for spandrel panels if an automatic sprinkler system is provided. This concession is therefore unlikely to be able to be shown to satisfy the proposed criteria unless the external glazing provides a significant level of resistance to exposure to a fire plume)

Recommendation 8 There could be an inconsistency between the nominated probability limit and existing DTS provisions relating to external fire spread in buildings of non-combustible construction. Consideration could be given to varying the probability limit with building height based on considerations of fire brigade intervention.

b) Fire Spread between Buildings

Since the floor layout / opening sizes are the same as the single storey building the same analysis applies which is repeated below for convenience.

A simple analysis using configuration factors was undertaken which demonstrated that the probability of a reportable fire causing the incident heat flux on the boundary greater than 18kW/m^2, from a fire within the reference building will not exceed 0.001, (i.e. substantially below the 80kW/m^2 permitted) and no further analysis was therefore undertaken.

Since the building was located more than 6m from the boundary, the probability of the façade being able to withstand a maximum heat flux of 10kW/m^2 for 30 minutes must not exceed 0.01. The external façade of the building was of non-combustible construction with double glazed toughened glass window with pane thickness greater than 6mm and is therefore expected to satisfy the required criteria based on various experimental results (e.g. Klassen [5])

c) Internal Fire Spread

For the five storey option internal fire spread should be prevented such that when a reportable fire occurs, the probability of fire spread between storeys does not exceed 0.01.

The probability of a reportable fire achieving flashover based on fire incident data is assumed to be approximately 0.11 if the impact of automatic sprinklers is ignored and may occur when the building is occupied or unoccupied.

The probability of the automatic sprinkler system being effective has been assumed to be 0.86 and if the system is effective it will prevent a fire progressing to a fully developed fire.

Therefore, the probability of a fire occurring that could threaten the fire separation between storeys is 0.0154 (0.11 x 0.14)

Assuming a high (conservative) probability of failure of 0.5 for the floor system due to the inclusion of services, construction joints etc the probability of fire spread would be 0.0077 which does not exceed the 0.01 limit and a more detailed analysis considering fire brigade intervention is not required.

It is noted that if the effectiveness of the sprinkler system is increased to 91% the 0.01 probability limit will be satisfied although providing some redundancy by means of providing fire separation is considered appropriate.

Outcome of QRA of a five-storey primary school

Based on the analysis undertaken subject to the provision of an automatic sprinkler system with an effectiveness of at least 95% and implementation of all the complete fire safety strategy it was demonstrated that the quantified requirements proposed in the July draft of A8 of the NCC with modifications nominated in this report were satisfied.

Implementation

The fire safety strategy would then need to be defined in detail in a fire safety strategy and an implementation plan developed to ensure the details are incorporated in the design documentation and subsequently installed and commissioned correctly. The implementation plan should address handover to maximise the probability that fire safety systems will be adequately maintained throughout the building life and an effective Emergency Management Organisation will be in place.

CONTENTS

PART 0 INTRODUCTION AND GENERAL INFORMATION

1. SCOPE, OBJECTIVES AND RISK METRIC OVERVIEW

This report presents case studies illustrating the application of Quantitative Risk Assessment (QRA) approaches to determine if the fire risk metrics defined in the June 2020 draft Part A8 of NCC 2022 as included in Appendix B have been satisfied.

The case studies are based on previous analysis undertaken for the ABCB[6] but have been modified and extended as appropriate to facilitate comparison against the proposed Part A8 risk metrics.

2. FIRE RISK CRITERIA

The risk metrics from the proposed Part A8 including the modifications included in Appendix B are summarised below and will be applied to the case studies:

2.1. RISK OF EXPOSURE TO UNTENABLE CONDITIONS METRICS

Table 1 Individual Risk Tolerance Limits

Building Class Group	NCC Building Classes	Lower Tolerance Limit	Upper Tolerance Limit
Residential / Care Facilities	1,2,4, 9a,9c,3	5×10^{-6}	5×10^{-4}
Other Building Classes	**5,7b,8,6,7a,9b**	**1×10^{-6}**	**1×10^{-4}**

Table 2 Societal Risk Tolerance Limits

Limit	Frequency of N or more people exposed to untenable conditions per annum							
	N=5	N=10	N=20	N=50	N=100	N=200	N=500	N=1000
Lower Tolerance	8.9×10^{-7}	3.2×10^{-7}	1.12×10^{-7}	2.83×10^{-8}	1.0×10^{-8}	3.5×10^{-9}	8.9×10^{-10}	3.2×10^{-10}
Upper Tolerance	8.9×10^{-5}	3.2×10^{-5}	1.12×10^{-5}	2.83×10^{-6}	1.0×10^{-6}	3.5×10^{-7}	8.9×10^{-8}	3.2×10^{-8}

2.2. SPREAD OF FIRE METRICS

(a) A building must avoid the spread of fire between buildings such that:

(i) The probability of a *reportable fire* in a building causing heat fluxes greater than the values listed in Table 3 must not exceed 0.001, at the stated distances from the boundary on an adjacent allotment or at the distances between buildings on the same allotment.

(ii) The probability of a building not being able to *withstand* the heat flux in Table 3 for a period of 30 minutes must not exceed 0.01.

(iii) The probability that the external façade of a building cannot *withstand* the following exposures from *reportable fires* must not exceed 0.001:

A. flames venting through an opening from an enclosure fire within the building;

B. burning items adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas;

C. a fire occurring on a balcony.

(b) A building must avoid the spread of fire within the building such that when a reportable fire occurs, the probability of fire spread does not exceed-

(i) 0.01 to spread outside of an SOU;

(ii) 0.01 to spread between storeys; and

(iii) the values in Table 4.

Table 3 Maximum heat flux

Maximum heat flux (kW/m^2)	Distance from Boundary (m)	Distance between buildings on the same allotment (m)
80	0	0
40	1	2
20	3	6
10	6	12

Table 4 Internal fire spread limits to manage fire spread

Building Classification	Floor Area	Volume	Maximum probability of spread beyond specified floor area and volume
5, 9b	**3000m^2**	**18000m^3**	**0.01**
6,7,8, 9a,9c	2000m^2	12000 m^3	0.01
5-9	18,000m^2	21000m^3	0.001
Class 9c & 9a patient care areas	1000m^2	-	0.01

2.3. DISPROPORTIONATE COLLAPSE METRIC

This is not a metric within the proposed A8 requirements and is currently an NCC Part B requirement. The design of buildings to resist disproportionate collapse can have a significant impact with respect to overall structural adequacy under severe fire conditions and will therefore be indirectly addressed when determining individual and societal risks. A metric could be added if it is desired to explicitly address disproportionate collapse due to severe fire conditions.

3. STAKEHOLDERS

Since generic buildings have been adopted for the analysis rather than a specific building, a modification was necessary to the general performance-based design brief (PBDB) approach.

Typically, the PBDB process will involve the following core stakeholders.

- Fire Safety Engineer
- Building Surveyor Certifier
- Emergency Services (Fire Brigade)

- Client / Owner or Delegate
- Architect / Building Designers

Depending on the complexity of the project the membership of the PBDB team may be expanded to include additional participants such as;

- Fire Safety Practitioners
- Specialist Consultants
- Material Suppliers
- Peer Reviewer
- Tenants Representative
- Building Owners Representative
- Builder
- Insurers

The key stakeholders for the original study undertaken for the ABCB[6] from which the case studies described in this report were derived comprised the State and Territory bodies responsible for building regulation and education, fire authorities, the ABCB and other stakeholders represented by the ABCB together with a Peer Reviewer. For the case studies presented input was again obtained from the primary stakeholder (ABCB) together with a Peer Reviewer.

Supplementary research was undertaken into building trends and practices relating to high-rise schools to account to some extent for the limited stakeholder input during the development of the Performance-based design brief. This approach was considered appropriate considering the generic analysis of buildings being undertaken.

4. Overview of Case Studies

Two case studies will be presented relating to primary schools each housing a maximum of 420 students.

Case study 1 is a typical single storey primary school complying with the NCC 2019 DTS provisions. The majority of existing primary schools in Australia comprise one or two-storey buildings and therefore this was considered to represent a useful study to benchmark or "calibrate" the proposed risk metrics.

Case study 2 is a five storey mixed use building housing a primary school (levels 1-4) with a Class 6 (café) and Class 9b entertainment venue at ground level (effective building height below 25m) which will be treated as a performance solution. The design will use the NCC 2019 DTS provisions as the starting point for the design but with the design options permitted by the DTS provisions selected on the basis of the application of fire safety engineering principles. Additional measures derived to address additional drivers and constraints identified during the equivalent of the Performance-based Design Brief (PBDB) process will also be included.

Case study 2 reflects a developing trend towards the selection of mid-rise and high-rise design options for primary schools in inner suburbs. Since mid-rise and high-rise primary school designs have until recently been rarely adopted in Australia it is considered that Case study 1 will provide the most appropriate reference solution if it is necessary to undertake a comparative analysis to determine if the fire risk metrics defined in the June 2020 draft of Part A8 have been satisfied for case 2.

The case studies are based on previous analysis undertaken for the ABCB[6] but have been modified and extended as appropriate to facilitate comparison against the proposed Part A8 risk metrics.

A typical sized primary school was assumed for both case studies providing accommodation for a maximum of 420 students from Prep to year 6 (i.e. seven-year groups) and two streams per year group with a maximum class size of 30. This is slightly larger than the average primary school size of 360 students as determined in Table 21 of Appendix C but is not an extreme case and is therefore considered a reasonable representative reference case.

The schematic designs for both case studies were developed using a modular approach with the same general format of learning areas to enable the comparative study to focus on matters relating to the height of the building. Within these constraints the ancillary areas were adjusted where necessary to provide workable building layouts as shown in Figure 1 (single storey building) and Figure 2 (5-storey building)

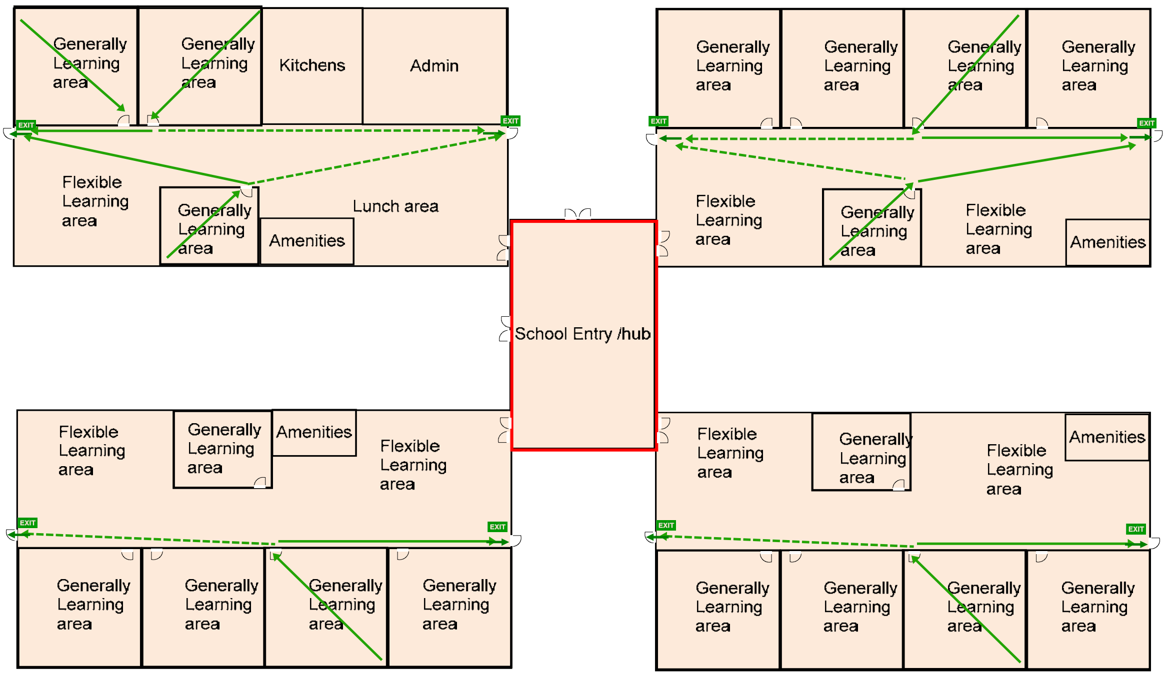


Figure 1 Layout of Single Storey Reference Primary school

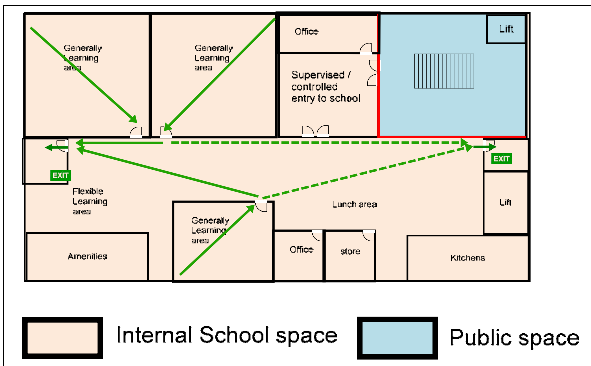
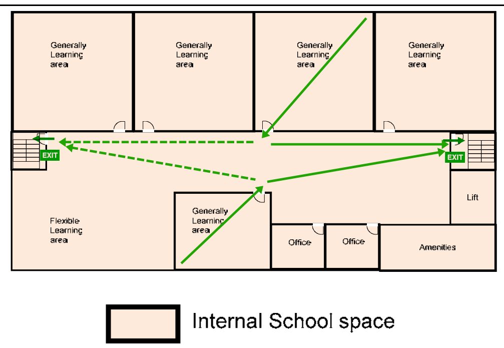
	
Level 1 Plan including school entry from ground level	Level 2 to 4 plan

Figure 2 Layout of 5-storey Primary School Building

Each module was rectangular having a floor area of approximately 900m^2 (40m x 22.5m). For the single storey reference building the modules were connected by a central hub, and for the high-rise options each module formed a complete floor. The ground floor for the high-rise options was mixed use, representing current trends for high-rise schools to be co-located with public / civic facilities.

5. APPROACH AND ORGANISATION OF THE REPORT

An introduction to the case studies and general information is provided in Part 0, Sections 1 to 4.

The single-storey primary school QRA case study is presented in Part 1 of the report and the five-storey primary school QRA case study is presented in Part 2

The Quantitative Risk Assessment processes adopted for this project were selected to address the draft Part A8 Interpretation of fire safety Performance Requirements and were adapted from various guides and sources including the following

- ABCB Tolerable Risk Guidelines [7]
- ABCB Verification Method Handbook [8]
- International Fire Engineering Guidelines [9]
- ISO 16732-1 2015 Fire safety engineering - Fire Risk Assessment Part 1[1]
- BSI PD 7974-7 Application of fire safety engineering principles to the design of buildings Part 7 [10]
- Standards Norway, Fire Safety Engineering Guide for Probabilistic Analysis for Verifying Fire Safety Design in Buildings. 2019 [11]

A flow chart showing the various processes that are required when undertaking a QRA are shown in Figure 3 and the same descriptors will be used for the titles of the various sections within Parts 1 and 2 for clarity.

Since a substantial proportion of data will be common to both case studies much of the common information is provided in Appendices and cross referenced from parts 1 and 2 as appropriate.

It could be considered that implementation is not part of the QRA procedures but it has been included in the flow chart to highlight the importance of ensuring that the selection of materials and products, construction, commissioning and maintenance of the building features that form part of the fire safety strategy are undertaken such that the operational performance and reliability are consistent with the requirements of the fire safety strategy. Similarly, this extends to human factors including, building / facility management, the emergency management organisation and staff training.

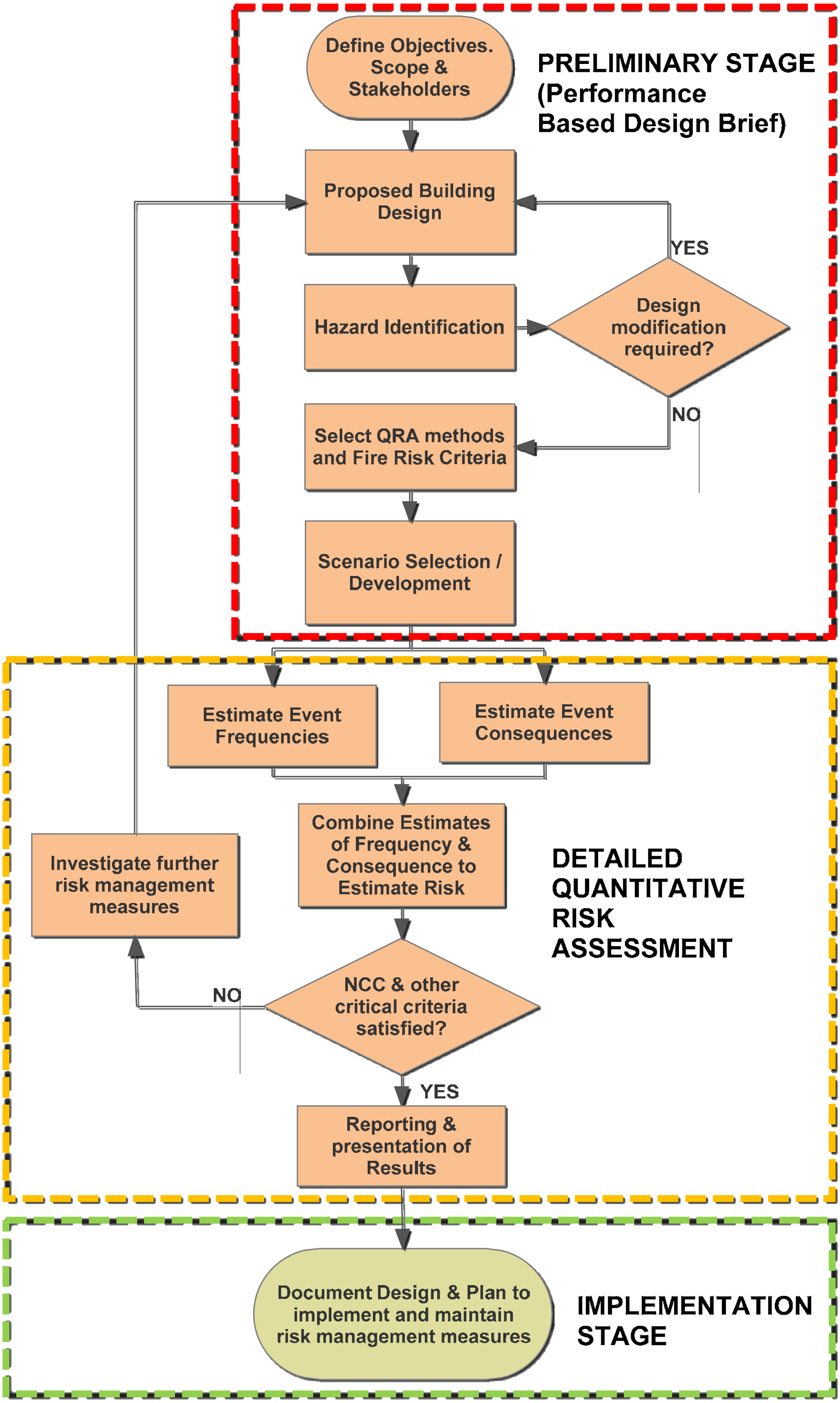


Figure 3 Overview of QRA Process

PART 1 CASE STUDY 1 SINGLE STOREY PRIMARY SCHOOL

6. PRELIMINARY STAGE (PERFORMANCE-BASED DESIGN BRIEF)

6.1. DEFINE OBJECTIVES, SCOPE, AND STAKEHOLDERS

This case study is intended to

- illustrate the application of Quantitative Risk Assessment (QRA) methods to estimate the risk to life and risk of fire spread for a single storey primary school complying with the DTS provisions of NCC 2019
- compare the estimated risks to the fire risk metrics defined in the June 2020 draft Part A8 of NCC 2022 as included in Appendix B and determine if the Part A8 risk metrics have been satisfied
- compare the estimated risks to fire incident data from school buildings in Australia, UK and US.

This case study will also provide a reference case for comparison to the risks associated with Case Study 2 (a five storey primary school)

As this is a case study of a generic building the stakeholders differ from a typical project and comprised ABCB representatives, the author and a peer reviewer. The case study is a rework of a previous study for which input was provided from a broader range of stakeholders including some State and Territory departments responsible for building and / or education.

6.2. PROPOSED BUILDING DESIGN

6.2.1. Overview

The most relevant NCC DTS provisions are summarised in Appendix F. These requirements were further refined and adapted to define the Case 1 reference building which is described in the following sub-sections

6.2.2. Building Use

The proposed single-storey building will be used exclusively as a primary school serving a maximum of 420 students in seven year groups each with two streams and a maximum class size of 30. Refer Appendix D4 for further information. It will therefore be a Class 9b building as defined in the NCC 2019.

6.2.3. General Building Layout

The lay-out of the single storey reference building is shown in Figure 4. It comprises four nominally 900m^2 modules linked by a central hub. Fire walls are provided around the hub such that the school is effectively separated into fire compartments (i.e.< 3000m^2 limit). The modules are located more than 6m apart to minimise the risk of external fire spread between the compartments.

A typical module holds four streams (i.e.104 students and four teachers). One module holds only two streams to provide areas for kitchens, administration and lunch areas

An exit is provided at each end of each module such that:

- no point of the floor is more than 20m from a choice in direction to an exit and
- the distance to the nearest exit does not exceed 40m, and
- the distance between exits is not less than 9m or more than 60m

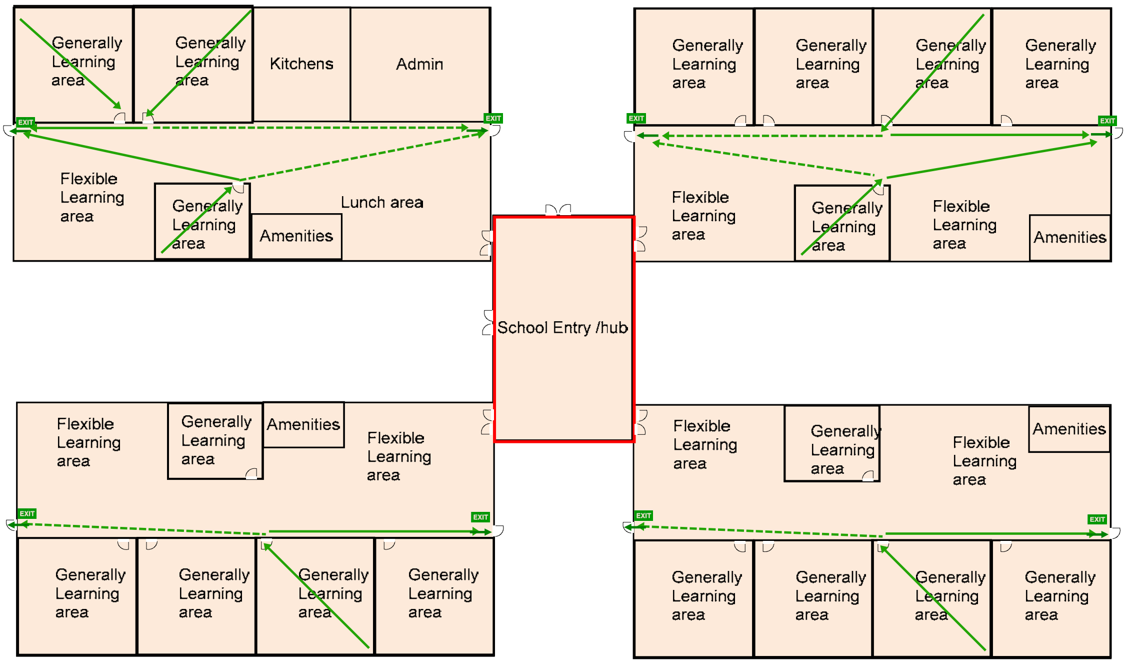


Figure 4 Layout of Single Storey Reference Primary school

The NCC DTS requirements (and further enhancements) that are proposed for inclusion in the building and are relevant to the analysis are summarised in Table 5.

The school is located in its own grounds substantially greater than 6m from an adjacent allotment with an external assembly area available within the grounds.

6.2.4. Fire Safety Measures

6.2.4.1. Basic Measures

Specific fire safety measures derived from the NCC DTS provisions that are to be incorporated in the Case study 1 building are summarised in this section

Table 5 Relevant NCC DTS fire safety provisions for reference single-storey school

NCC Clause	DTS Provision	Reference Building
A6.9(2)	Building Class	Class 9b - School
C1.1	Type of Construction	Type C
C1.9 / D2.2	Non-combustible building elements	Not applicable to Type C construction. **Existing school buildings are a mix of combustible and non-combustible construction. To provide a conservative reference building non-combustible construction was selected**
C1.10 / Spec C1.10 (Table 2)	Floor Linings	CHF 2.2 kW/m^2
C1.10 / Spec C1.10 (Table 3)	Wall and ceiling linings	Public corridors G,2 (W&C) Classroom G3 (W) G,2 (C) Other areas G3 (W) G2 (C)

C2.2	Max-size of fire compartments: Max floor area 3,000m^2 Max Volume 18,000m^2	Max compartment approx. 2000m^2
C2.6	Vertical separation of openings in external walls	Not applicable
Spec C1.1	FRL of Elements of construction – not more than 3m from fire-source feature	Not applicable
Spec C1.1	FRL of non-separating loadbearing elements – not more than 3m from fire-source feature	Not applicable
Clause D1.2(d)(v)	Number of exits required in addition to horizontal exits	Minimum of 1 exit but two required to comply with D1.4 and D1.5
Clause D1.4	Exit Travel distances	Dead-end < 20m Max distance to one exit < 40m
Clause D1.5	Distance between exits	Not less than 9m apart (satisfied) Not more than 60m apart (satisfied)
Clause D1.6	Dimension of Exits Width not less than 1m and 1 m plus 250 mm for each 25 persons (or part) in excess of 100 2 m plus 500 mm for every 75 persons (or part) in excess of 200	Exit doors assumed to be no less than 850mm wide and stair widths 1200mm to simplify use by people in wheelchairs. And 2 exits are provided from each module. Total people / module < 125 therefore minimum requirements is 1.25m. Satisfied if two exits provided
D1.13	Num of persons accommodated Classroom 2m^2 / person Multipurpose hall 1m^2 / person Staff room 10m^2 / person Trade / Prac. area 4m^2 / person	Area based on Learning Places and Spaces Area guidelines for educational spaces[12]. Approx. floor area for a primary school of 7m^2 / student excluding some ancillary areas. For 120 students / module area required would be 840m^2. For multi storey use additional space required for fire stairs, lifts and associated circulation spaces leading to a floor area. Therefore, 900m^2 adopted. As travel distances are slightly increased this is not considered critical and the same size has been adopted for all building options
D3.1 Table D3.1	General Access requirements	To and within all areas normally used by the occupants. For reference building assumed access via ramps and doorway widths of at least 1000mm.
E1.3	Hydrants required if building >500m^2 and within 50km of fire brigade station	Required
E1.4	Fire hose reels	Not required in Classrooms and associated corridors
E1.6	Portable Fire Extinguishes	Required - Table E1.6 defines coverage
E2.2(b)	Automatic shutdown of air handling system not designed to operate as a smoke control system and recycles air from one fire compartment to another and provision of automatic smoke dampers	Not required - independent systems serving each fire compartment. **It is assumed that provision is provided for a staff member to raise a building wide alarm initiating a full evacuation.** **It is noted that TAS E101 has requirements for a detection and alarm system and this approach was adopted for the reference building 2 to reflect good practice and address issues identified during the hazard identification process. No automatic detection system was provided in reference building 1**
E4.2	Emergency lighting	Required (floor area >300m^2)
E4.3	Exit and direction signs	Required

Variations to the NCC DTS requirements relating to schools prescribed in the State and Territory Appendices in Schedule 1 of the NCC are summarised in Table 6.

Table 6 State and Territory Variations from Schedule 1 of the NCC

NCC Clause	Modified DTS Provision	Comments
NSW Table E2.2(b)	(a) Automatic shut-down: A building or part of a building used as an assembly building must be provided with automatic shutdown of any air-handling system (other than non-ducted individual room units with a capacity not more than 1000 L/s and miscellaneous exhaust air systems installed in accordance with Sections 5 and 6 of AS 1668.1) which does not form part of the smoke hazard management system, on the activation of— (i) smoke detectors installed complying with Clause 6 of Specification E2.2a; and (ii) any other installed fire detection and alarm system, including a sprinkler system (other than a FPAA101D or FPAA101H system) complying with Specification E1.5.	Minor variation not considered critical for the proposed comparative analysis
Tas E1.101	Fire detection and alarm system: An automatic fire detection and alarm system must comply with Clauses 4 and 8 of Specification E2.2a.	Applies to schools more than 1-storey high or floor area >500m^2
WA H101.2	In a WA public building - each storey that accommodates more than 50 persons must have more than one exit from that storey.	Applies to educational facilities

Notes: If the school contains shared facilities that are classified as an Entertainment Venue under the NSW venue many State variations apply. This is not relevant to this proposed study.

Tas E1.101 was introduced to address Performance Requirement Tas EP1.7 which is also specified in the Tasmanian Appendix in Schedule 1 of the NCC. Tas EP1.7 states:

An automatic fire detection system must be installed to the degree necessary to alert the fire brigade of fire so that firefighting operations may be undertaken at the earliest possible time appropriate to—

(a) the building functions and use; and
(b) the fire hazard; and
(c) the height of the building; and
(d) the building floor area.

Limitation:

Tas EP1.7 only applies to:

(a) a Class 5 building or Class 6 building having an aggregate floor area of more than 1000 m^2; and
(b) a Class 7 building having a floor area of more than 1000 m^2 in which furniture is stored; and
(c) a Class 8 building which is a special fire hazard building and in which more than 25 persons are employed; and
(d) a Class 9b building which is a school or early childhood centre or a creche which-
    (i) is of more than 1 storey; or
    (ii) has a storey with a floor area more than 500 m^2; and
(e) a Class 9b building.

To comply with these provisions the reference building would require a smoke detection system since the area is greater than 500m^2.

6.2.4.2. Additional Measures identified during PBDB

To address accessibility requirements and facilitate evacuation ramps must be provided at all entrances and exits including fire exits.

6.2.5. Occupancy Characteristics

Occupant characteristics are provided in Appendix D.

6.3. HAZARD IDENTIFICATION

To provide a structured approach to the Hazard Identification process and to ensure that the identified hazards were subsequently addressed a risk register was constructed which identified:

- hazards
- proposed control measures
- preliminary qualitative analysis
- proposed quantitative analysis and inputs
- status / actions

The risk register was initially populated based on the FSVM default scenarios with further entries being informed by:

- A review of Fire Statistics, Incident Data and related information (Appendix C)
- A Review of DTS provisions in International Codes (Appendix C6)
- Characterisation of Primary School Occupants (Appendix D)
- Additional Matters Identified relating to Building Trends and Practices for high-rise schools and supplementary requirements outside NCC provisions (Appendix E)
- A Review of NCC DTS provisions applicable to schools (Appendix F)
- Parameters for consideration provided within the NCC 2019 Performance Requirements and proposed for inclusion in Part A8 of the NCC 2018 (Appendix G)
- Fire safety principles / engineering judgement

The register was maintained throughout the analysis and updated as appropriate and is included in Appendix H.

6.4. DESIGN MODIFICATIONS BASED ON PRELIMINARY HAZARD ID

6.4.1. Required Modifications to the Design

The hazard identification process identified that a rapidly growing fire in an unoccupied room could under some circumstances compromise the paths of travel to exits before all occupants have had the opportunity to evacuate.

Options to address this hazard include,

- provision of independent exits direct to open space from each classroom (GLA)
- provision of an automatic smoke detection and alarm system

For the purposes of this analysis the smoke detection and alarm option was selected for further evaluation since it will provide a more representative reference case for comparison in case 2 and is required for the subject building under a Tasmanian variation to the NCC.

Two cases were evaluated.

- Reference 1 Without a detection and alarm system
- Reference 2 Without a detection and alarm system.

6.5. Selection of QRA Methods and Fire Risk Criteria

6.5.1. Fire Risk Criteria

The fire risk criteria are as specified in Section 2 based on the proposed part A8 of the NCC 2022. The criteria did not include a specification for occupant tenability which can have a significant impact on estimated risk levels.

The Level 3 tenability criteria derived in Appendix B2 were determined to be the most appropriate having regard for the derivation of the upper and lower risk limits and are summarised below:

Level 3 Fractional Effective Dose of 0.3 with respect to thermal exposure or exposure to carbon monoxide or flashover occurring within the fire compartment or disproportionate collapse of the building or a substantial part of the building.

A supplementary design check using a criterion of 10m visibility at a height of 2m will also be undertaken assuming the fire safety measures operate effectively to determine if there is an opportunity for occupants to evacuate during these scenarios. (this could be considered analogous to a serviceability check in addition to a check of the ultimate capacity in structural engineering)

6.5.2. Overview of QRA methods

The primary QRA method was based on event tree analysis using a series of representative scenarios. The events within each representative scenario were assigned probabilities enabling the probability of occurrence for each representative scenario to be determined.

The outcomes (consequences) of the representative scenarios were determined

- with respect to the risk of exposure to untenable conditions using ASET / RSET analyses.
- with respect to the spread of fire metrics using a combination of fire dynamics and heat transfer analysis, experimental data and material properties

The modelling methods adopted were relatively simplistic to limit the modelling resources required but were considered appropriate for the generic analysis being undertaken.

6.5.3. Scenario Selection and Development

To evaluate scenarios the following approach was adopted based on fire scenario clusters and corresponding representative fire scenarios as described in ISO 16732-1 [1]

Fire scenario clusters and the corresponding representative clusters are selected such that the consequence of the representative fire scenarios can be used as a reasonable estimate of the average consequence of scenarios in the fire scenario clusters. The fire risk can then be calculated as the sum over all fire scenario clusters of fire scenario cluster frequency multiplied by representative fire scenario consequence without imposing an undue calculation burden.

The following approaches were used to inform the estimates of probabilities and consequences:

6.5.3.1. Smoke Spread

Smoke spread, times to detector activation and the corresponding alarm, times to untenable conditions and visibility were determined using the zone-model (B-Risk [13]).

6.5.3.2. *Evacuation*

The evacuation analysis was undertaken using simple distributions for premovement times and travel speeds assuming the occupants travel as a group as identified in the technical references. Refer to Appendix D for further information on assumed travel speeds. Human behaviour and decision making in response to fire scenarios are considered as described in 0. Multi-scenario analyses were undertaken to generate distributions of the evacuation times for each floor and to clear the building to facilitate estimates of the number of people exposed to untenable conditions

6.5.3.3. *Fire Brigade Intervention*

Analysis of Fire brigade Intervention was undertaken using a multi-scenario implementation of FBIM [2] where appropriate with response times based on distributions published in a Report on Government Services [3].

7. QUANTITATIVE RISK ASSESSMENT

7.1. ESTIMATION OF EVENT FREQUENCIES AND SCENARIO CONSEQUENCES

7.1.1. General

Frequencies and probability estimates for scenarios have been largely based on fire incident data and technical literature. Since available fire incident data from Australia was limited it has been supplemented by data from other countries (e.g.US and UK). A review of the prescriptive requirements in the US and UK was undertaken so that any significant differences from Australian prescriptive requirements could be taken into account when using international data. In addition, overseas data was compared to the available equivalent Australian data. For further information reference should be made to Appendix C.

General estimates of the effectiveness of fire safety systems were based on fire incident data, recommended values in the data sheets from the FSVM Handbook Annex [14] , technical literature and fire incident data.

7.1.2. Frequency of reported fires

Based on the analysis of the fire incident data undertaken in Appendix C the average frequency of reported fires for primary schools was estimated to be 0.013 / annum and this value was considered a reasonable estimate for the proposed primary school building.

7.1.3. Representative Scenarios – for floor of fire origin

7.1.3.1. *Derivation of Representative fire scenarios*

To derive a series of representative scenarios for quantification of the fire risks the “universe” of possible fire scenarios was broken down into the following general fire scenario clusters and the probabilities of occurrence estimated to enable critical clusters that impact on the risk to life of the occupants to be identified for detailed analysis and low risk scenarios that have a minimal impact on the risk to life to be set aside since further evaluation of consequences will not be required.

a) Fires that occur outside the times the school is occupied – low risk to occupants (approx. 21% of fires derived from Appendix C4.3)
b) Confined fires as defined in the US databases that are unlikely to present a significant risk to occupants that are alert.
c) Fires that were confined to a single item that are unlikely to present a significant risk to occupants that are alert.
d) Fires that occur in isolated parts of the building e.g. plant rooms in separate buildings.

e) Larger fires that may present a significant risk to the building occupants and require further analysis

The clusters identified as a) to d) above represent low risk fire scenarios that can be excluded from further analysis whilst cluster e) represents a cluster of fire scenarios potentially presenting a significant risk.

Further statistical analysis was undertaken and event trees constructed to break the critical fire scenario clusters down into smaller clusters based on location (type of room), fire growth rate, potential for flashover and peak fire size if flashover does not occur as described in Appendix C4.4 to C4.6.

A typical school module was simplified as shown in Figure 5 such that the various enclosures could be consolidated into the following three enclosure types:

- Type 1 Small rooms - stores, kitchen offices, amenities
- Type 2 General Learning Area (classroom)
- Type 3 Libraries / Flexible Learning / General circulation

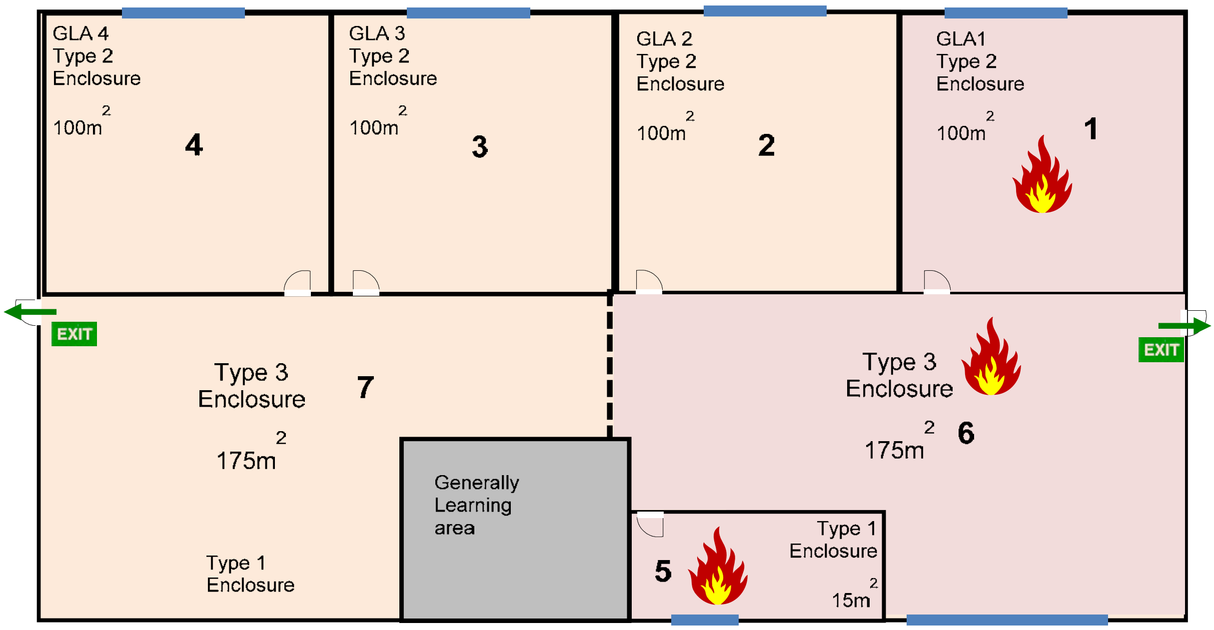


Figure 5 Generic Primary School Level for fire modelling

The plant room is remote from the occupied school in a separate building such that no further analysis was required to assess the risk to occupants of the main school building.

Design fires were located in;

- Enclosure 1 (a Type 2 Classroom)
- Enclosure 5 (a Type 1 ancillary area - stores, kitchen offices, amenities)
- Enclosure 6 (a Type 3 large opening area representative of a library, flexible learning area, general circulation / path of travel to an exit)

The proportion of fires within the cluster of “fast” growth fires was subsequently increased so that it matched the proportion of potential flashover fires occurring during the periods the school was occupied which also takes into account potential increases in growth rates due to relaxations to wall and ceiling lining requirements permitted in sprinkler protected buildings.

Representative scenarios were then assigned to these clusters. The outcomes are shown in Table 7 with representative scenarios occurring in three locations, with three representative design fires in each location to adequately define the range of fires that present a risk to the occupants on the floor of fire origin.

Table 7 Summary of Design Fire Types and Peak HRR during hours of occupation

Encl. Type	Enclosure Description	Fires %	Proportions of fire by Type %				Peak HRR -MW	
			Confined / confined to SBI	Slow	Med.	Fast / Flashover	Slow	Med
1	Small rooms - stores, kitchen offices, amenities	59	75	8.4	9.0	7.6	1.0	1.3
2	General Learning Area (classroom)	24.7	60	24.7	9.0	6.3	2.2	2.6
3	Libraries / Flexible Learning / General circulation	12.3	70	15.9	9.0	5.1	2.7	3.75
4	Plantroom	4	Remote (located on GF) and substantial separation from occupied areas – no further analysis required					

This selection process and assigned probabilities are presented as three event trees in Figure 6.

The branches that were identified as low risk with minimal adverse consequences were then consolidated, probabilities assigned to the proportion of fires occurring in each enclosure yielding the event tree shown in Figure 7. The probability of sprinkler activation was set to zero since no sprinkler protection was provided in the single storey school case.

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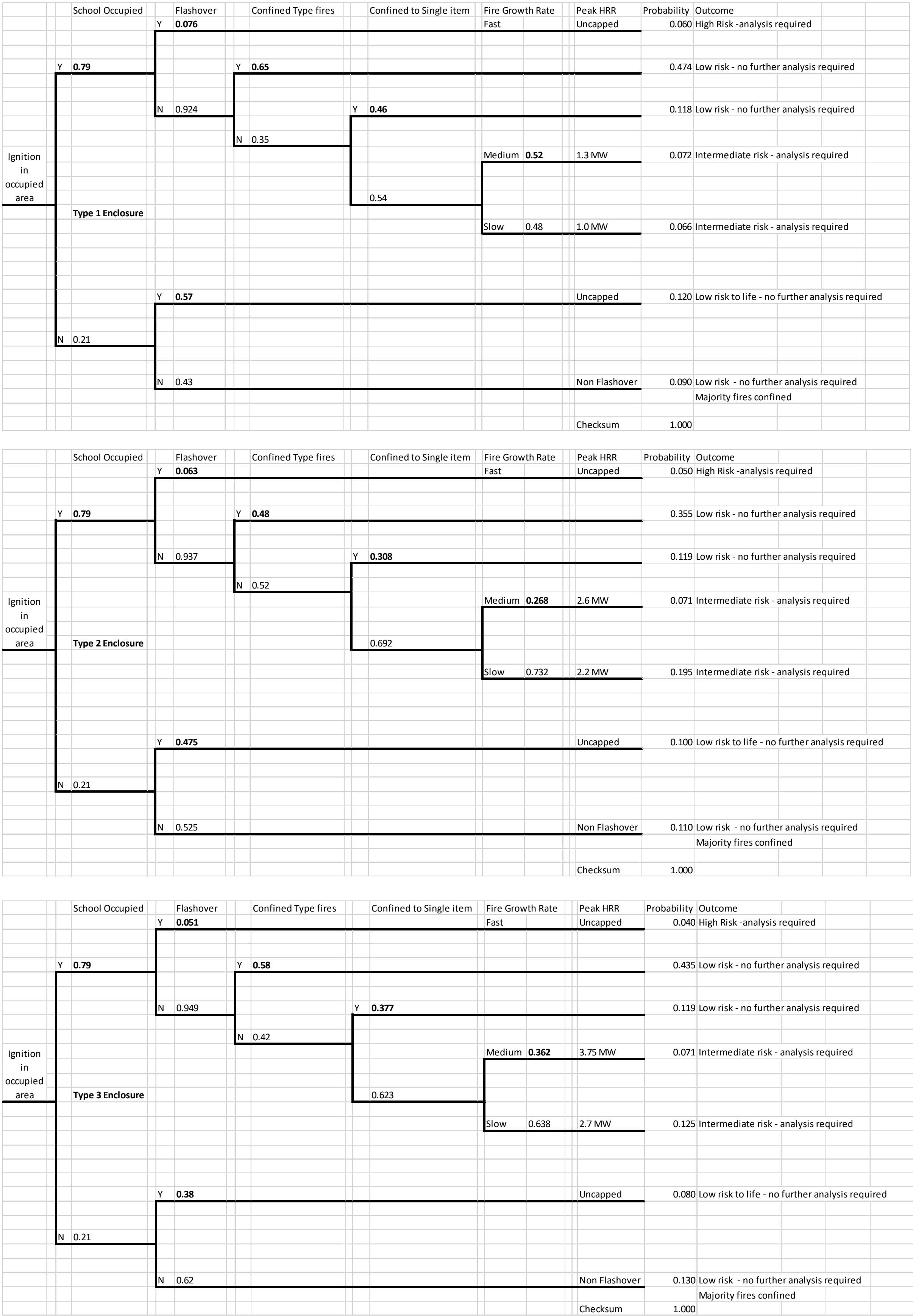

Figure 6 Event trees showing design fire distributions for design enclosures

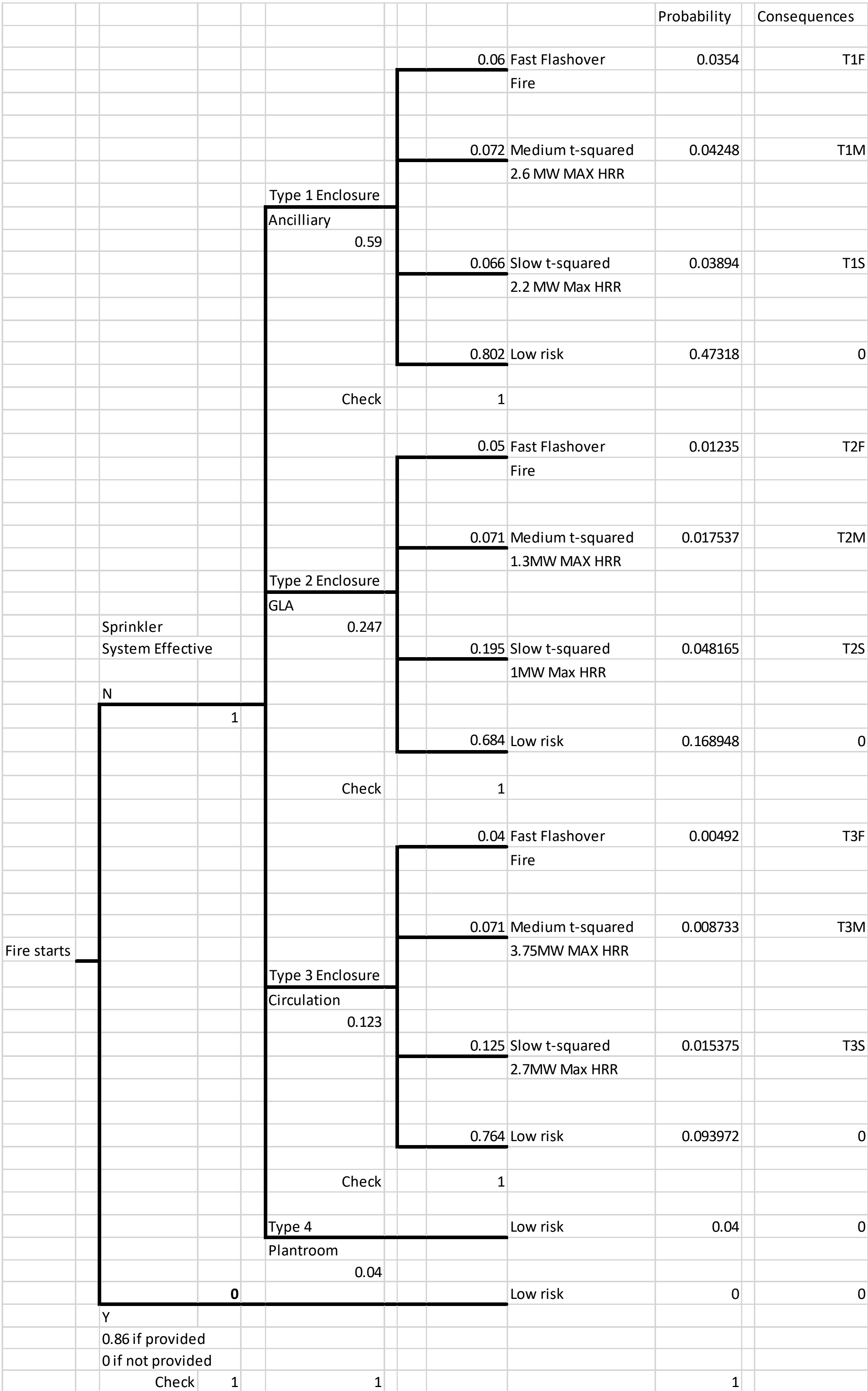

Figure 7 Consolidated Event Tree for Module of Fire Origin

7.1.3.2. *Occupant Response Extension to Fire Scenarios*

The representative fire scenarios require further extension to address the variability of human behaviour and evacuation process. This is achieved by extending the representative fire scenario event trees to address the following means by which occupants are alerted to the occurrence of a fire.

- automatic (via the smoke detection and alarm system),
- early manual detection and
- delayed manual detection.

The status of the door to the room of fire origin is also critical to the time that the occupants will become aware of the fire for the manual detection scenarios and the door status will also impact of the extent of smoke spread and therefore the door status was also included as shown in Figure 8.

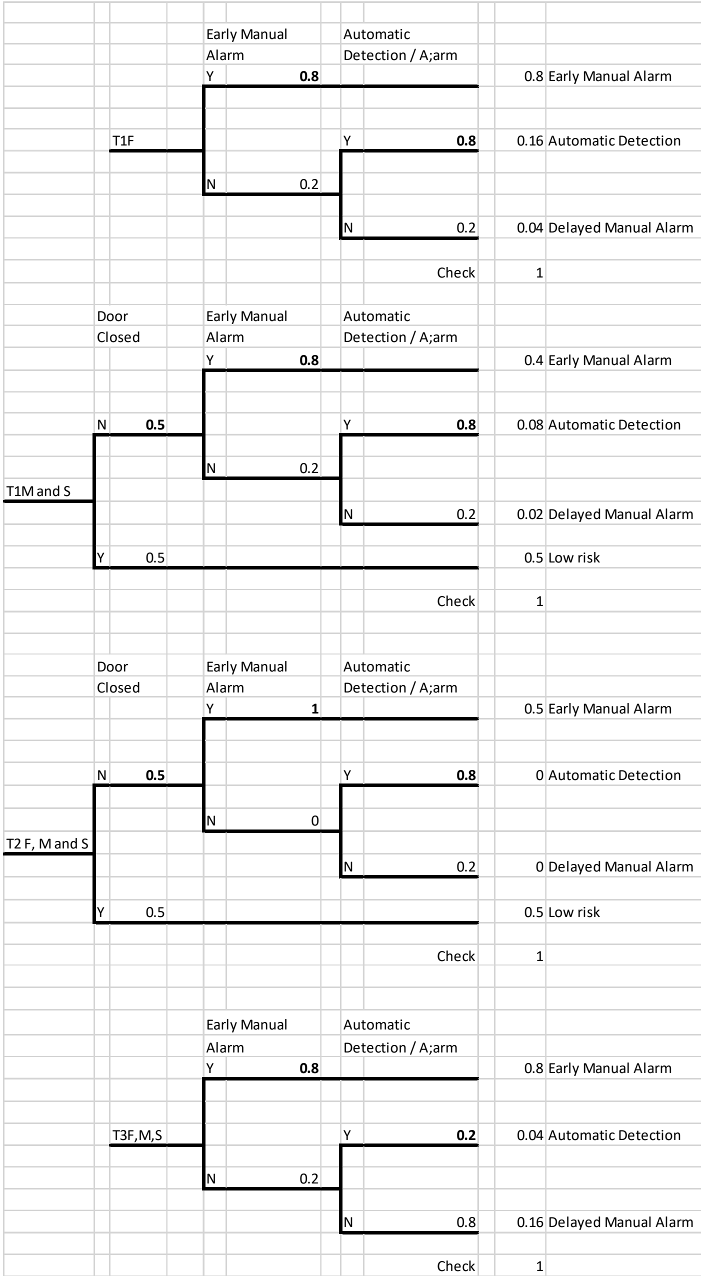

Figure 8 Sub-event trees determining probability of door closure and means of fire detection alarm

7.1.4. Modelling Human Response and Evacuation

The evacuation modelling was undertaken using the distributions for premovement times and travel speeds assuming the occupants travel as a class group as identified in the technical literature. Simple hand / calculations / spread sheet calculations were considered appropriate. Human behaviour and decision making in response to fire scenarios in each of the three types of room identified are considered in 0. The treatment of occupant response to the fire scenarios is described in Appendix K with further details including the derivation of the probabilities of the door status and alarms alerting occupants are provided in Appendix L13.

7.1.5. Fire Detection System

A binary model was applied to the fire detection system. It was assumed the detector either operates at its design sensitivity of fails to operate. Times to detector activation and the corresponding alarm times were determined using a zone-model (B-Risk [13]). Further information is provided in Appendix J3

In some scenarios, where the room of fire origin is occupied, early manual detection preceded the activation of the smoke detector explaining the good safety record of schools without smoke detection systems.

However, for fire scenarios in unoccupied rooms the delayed manual alarm case was applicable, which in some scenarios delayed evacuation to such an extent that unassisted evacuation was not possible due to blocked paths of travel to exits caused by conditions comparable to those associated with those described for the multiple fatality cases reviewed in Appendix C5.2 highlighting the importance of an automatic detection system.

7.1.6. Smoke Spread Modelling

Smoke Spread modelling was undertaken using a zone-model (B-Risk [13]). The application of the model is discussed in Appendix J with additional information relating to scenarios and ASET / RSET analyses provided in Appendix L

7.1.7. Fire Brigade Intervention

Fire brigade Intervention was modelled where appropriate using FBIM [2] and response times based on distributions published in a Report on Government Services [3] as described in Appendix L2.

7.2. RISK ESTIMATES AND COMPARISON TO BENCHMARKS

7.2.1. Derivation of Risk Estimates

The results of the individual components of the analysis are provided in Appendix J through Appendix M and the consolidation of these results to obtain risk estimates is described in Appendix N.

7.2.2. Individual Risk to Occupants

The consolidated individual risk results are shown in Table 8 derived using the Level 3 tenability criteria which were considered to be the most relevant criteria for comparison to the draft Part A8 of NCC 2022. These individual risks were compared to the A8 criteria and to the estimated individual risks derived from fire incident data for school buildings in Australia, UK and US.

Fatalities from school fires have been very rare in recent decades in Australia the UK and US and therefore injury data was used and then adjusted by a factor of 35 to provide an indicative estimate. Further details of this estimate are provided in Section C4.2

Table 8 Comparison of Average Individual Risk Estimates with draft Part A8 of NCC 2022 limits and values estimated from fire incident data

Risk Criteria	Ref. Bld. 1 No detection / alarm	Ref. Bld. 2 With detection / alarm	Est. from fire data	Part A8 lower limit	Part A8 upper limit
Individual Risk of death / annum	1.10×10^{-6}	2.20×10^{-7}	1×10^{-8}	1×10^{-6}	1×10^{-4}
Normalised IR against lower limit	1.1	0.22	0.01	1	100
Normalised IR against upper limit	0.011	2.2×10^{-3}	1×10^{-4}	0.01	1

From examination of the table the modelling results are tending to overestimate the individual risks by a factor of 20 (Ref Bld. 2) to 100 (Ref Bld. 1) when compared to fire statistics which can be explained in part by a tendency to make conservative assumptions to allow for uncertainty.

The hazard analysis and examination of the results based on level 1 criteria indicate that there potentially a significant risk from fires occurring in unoccupied areas and potentially blocking paths of travel to exits prior to evacuation if there is no automatic alarm and detection system This risk may not be reflected in fire incident data for single-storey buildings where ad-hoc exit arrangements via windows / non-fire exits may be used under extreme circumstances which were not incorporated in the modelling.

On this basis reference building 2 which included a detection and alarm system was selected as the primary reference for comparison with Case Study 2 in lieu of the most basic DTS provisions as associated with reference building 1.

7.2.3. Societal Risk to Occupants

The consolidated societal risk results derived from the results in Appendix L for the floor of fire origin and Appendix M for the non-fire floors and were consolidated in Appendix N from which the F-N plot in Figure 9 was derived for the single-storey reference buildings using the Level 3 tenability criteria and compared to the draft Part A8 of NCC 2022 limits and values estimated from fire incident data.

The fire incident data was based on the period between 1908 and 1958 in the US during which there were a number of multi-fatality school fires which led to substantial changes to building standards. Whilst the plots are based on crude estimates of the number of schools the plots provide an indication of levels of risk where there is significant aversion to the acceptance of losses.

Based on the comparison of the individual risk estimates with fire incident data, fatalities are expected to be overestimated by a factor of approximately 20 for the reference building 2 which would lower the societal risk levels further.

A tentative conclusion based on this study is that the proposed limits are reasonable but conservative assumptions made to address some uncertainties can be expected to over-estimate losses. The specification of a lower limit and allowing comparison against an appropriate reference building if the lower limit is exceeded is a practical solution in the short to mid-term, however it is prudent to retain an upper limit to identify cases where the reference solution presents an unacceptable risk. It is noted that the F-N plot of the reference 1 building slightly exceeds the upper

A8 societal risk limit which is consistent with the hazard ID outcome that additional mitigation measures should be provided to address fires occurring in unoccupied areas.

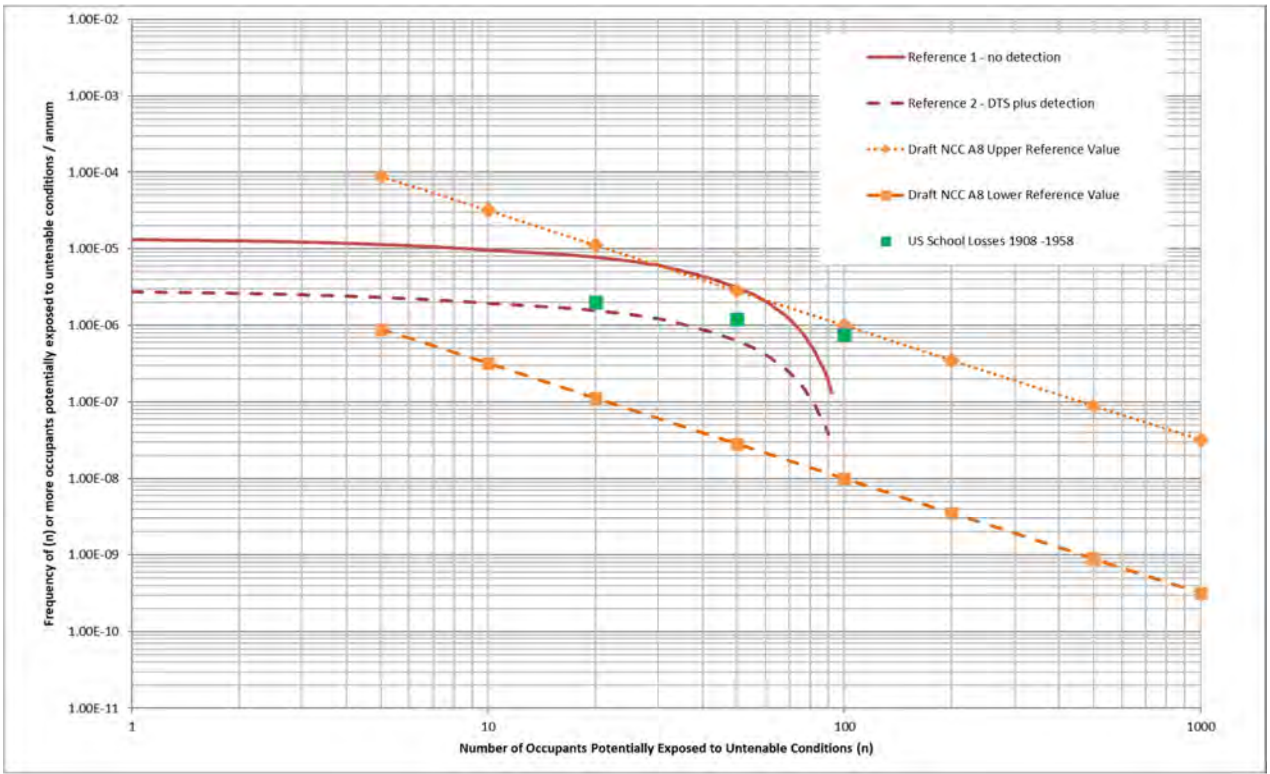

Figure 9 F-N Plot of Societal Risk for single storey schools compared to various Benchmarks

7.2.4. Fire Spread Metrics

7.2.4.1. Fire Spread between Buildings

The following metrics apply

(a) A building must avoid the spread of fire between buildings such that:

(i) The probability of a *reportable fire* in a building causing heat fluxes greater than the values listed Table 9 must not exceed 0.001.

(ii) The probability of a building not being able to *withstand* the heat flux in Table 3 for a period of 30 minutes must not exceed 0.01.

Table 9 Maximum heat flux

Maximum heat flux (kW/m^2)	Distance from Boundary (m)	Distance between buildings on the same allotment (m)
80	0	0
40	1	2
20	3	6
10	6	12

A simple analysis was undertaken in Section N4 which demonstrated that the incident heat flux on the boundary was approximately 18kW/m^2 (a safety factor of 4.44)

Since the building is located more than 6m from the boundary and the façade is required to withstand a maximum heat flux of $10kW/m^2$ for 30 minutes. The external façade of the building is of non-combustible construction with double glazed toughened glass glazing with pane thickness greater than 6mm and is therefore expected to withstand radiant heat fluxes in excess of $10kW/m^2$ based on various experimental results (e.g. Klassen [5])

For further information refer Section N4

7.2.4.2. Fire Spread via the external facade

The following metrics were considered

(iii) The probability that the external façade of a building cannot *withstand* the following exposures from *reportable fires* must not exceed 0.001:

A. flames venting through an opening from an enclosure fire within the building.

B. burning items adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas.

C. a fire occurring on a balcony.

Since this case study is a single storey building the above metrics are considered not to apply and no further analysis was required.

7.2.4.3. Internal Fire Spread

(b) A building must avoid the spread of fire within the building such that when a reportable fire occurs, the probability of fire spread does not exceed-

(i) 0.01 to spread outside of an SOU;

(ii) 0.01 to spread between storeys; and

(iii) the values in Table 10.

Table 10 Internal fire spread limits to manage fire spread

Building Classification	Floor Area	Volume	Maximum probability of spread beyond specified floor area and volume
5, 9b	**$3000m^2$**	**$18000m^3$**	**0.01**
6,7,8, 9a,9c	$2000m^2$	$12000\ m^3$	0.01
5-9	$18,000m^2$	$21000m^3$	0.001
Class 9c & 9a patient care areas	$1000m^2$	-	0.01

The proposed building does not include numerous SOUs and is only one storey high therefore (b)(i) and (ii) do not apply.

The school building is Class 9b and from Table 10 the probability of fire spread beyond $3000m^2$ must not exceed 0.01.

The building comprises four nominally $900m^2$ modules and a central hub therefore spread through the entire school building needs to be prevented, To exceed the 3000m^2 limit the fire needs to spread throughout three modules and the hub. The probability of this occurring was estimated to be substantially below the 0.01 limit ignoring fire brigade intervention based on event tree analysis presented in Section N6.2 and therefore the metric was considered to be satisfied.

For further information refer Section N6

7.3. DISPROPORTIONATE COLLAPSE METRIC

In the current draft there is no fire specific metric specified for disproportionate collapse. Since a single storey school is being considered and tenability conditions are assumed to be exceeded at flashover for this case study it is not considered necessary to undertake further investigations.

8. IMPLEMENTATION

The implementation phase is not applicable to this case study since the primary objective was to estimate the individual and societal fire risks associated with a typical primary school designed generally in accordance with the NCC 2019 DTS provisions and also to estimate the risk of fire spread under various nominated scenarios.

These estimates were compared to estimated risks derived from fire incident data and the proposed NCC Part A8 risk metrics. The single storey primary school will also be used as a reference building for comparison with the proposed design of five-storey primary schools provided in Part 2.

Issues for consideration during implementation will be discussed for the example in Section 11.

PART 2 CASE STUDY 2 FIVE-STOREY PRIMARY SCHOOL

9. PRELIMINARY STAGE (PERFORMANCE-BASED DESIGN BRIEF)

9.1. DEFINE OBJECTIVES, SCOPE, AND STAKEHOLDERS

This case study is intended to

- illustrate the application of Quantitative Risk Assessment (QRA) methods to estimate the risk to life and risk of fire spread for a five storey primary school complying with the DTS provisions of NCC 2019 with enhancements where appropriate.
- compare the estimated risks to the fire risk metrics defined in the June 2020 draft Part A8 of NCC 2022 as included in Appendix B and determine if the Part A8 risk metrics have been satisfied
- if the estimated risk to life lie between the upper and lower risk levels prescribed in Part A8, compare the estimated risks with a reference building evaluated as Case Study 1

As this is a case study of a generic building the stakeholders differ from a typical project and comprised ABCB representatives, the author and a peer reviewer. The case study is a rework of a previous study for which input was provided from a broader range of stakeholders including some State and Territory departments responsible for building and / or education.

9.2. PROPOSED BUILDING DESIGN

9.2.1. Overview

The most relevant NCC DTS provisions are summarised in Table 63 of Appendix F. These requirements were further refined and adapted to define the Case 2 building which is described in the following sub-sections

9.2.2. Building Use

The proposed five-storey building is a mixed use building housing a primary school on levels 1-4 with Class 6 (café) and Class 9b entertainment venue at ground level (effective building height below 25m). Levels 1 to 4 are exclusively used as a primary school serving a maximum of 420 students in seven year groups each with two streams and a maximum class size of 30. Refer Appendix D4 for further background information.

9.2.3. General Building Layout

The layout of the 5-storey primary school building is shown in Figure 10 through Figure 12. The building has a nominally 900m^2 footprint with each level based on similar modules to those used to make up the single storey reference building but with lifts and stairs added. To take account of current building trends the ground floor was shared with a range of community / civic facilities and connects to the remainder of the school via a lobby on level 1 allowing access to the school to be controlled and providing fire and smoke separation.

An external “green space” for sports and play has been provided on the ground floor which also serves as a safe assembly area if an emergency evacuation is required.

The NCC DTS provisions require exits to discharge to a road or open space and defines open space as a space on the allotment, or a roof or similar part of a building adequately protected from fire, open to the sky and connected directly with a public road. Discharge directly to a road may not be appropriate for a primary school and other occupancies housing vulnerable occupants. The provision of a secure assembly point is therefore be considered good practice and has been included in the design.

The fire stairs which are exclusive to the primary school discharge to this external green space whilst remaining in a secure area. Access to the green space for recreational use can be obtained via the stair or lift from the school levels. The provision of stairs for the exclusive use of the primary school occupants was considered good practice and incorporated in the design to address security issues as well as ensuring that the primary school children are not at risk of being crushed by large numbers of adults from other parts of the building during an emergency.

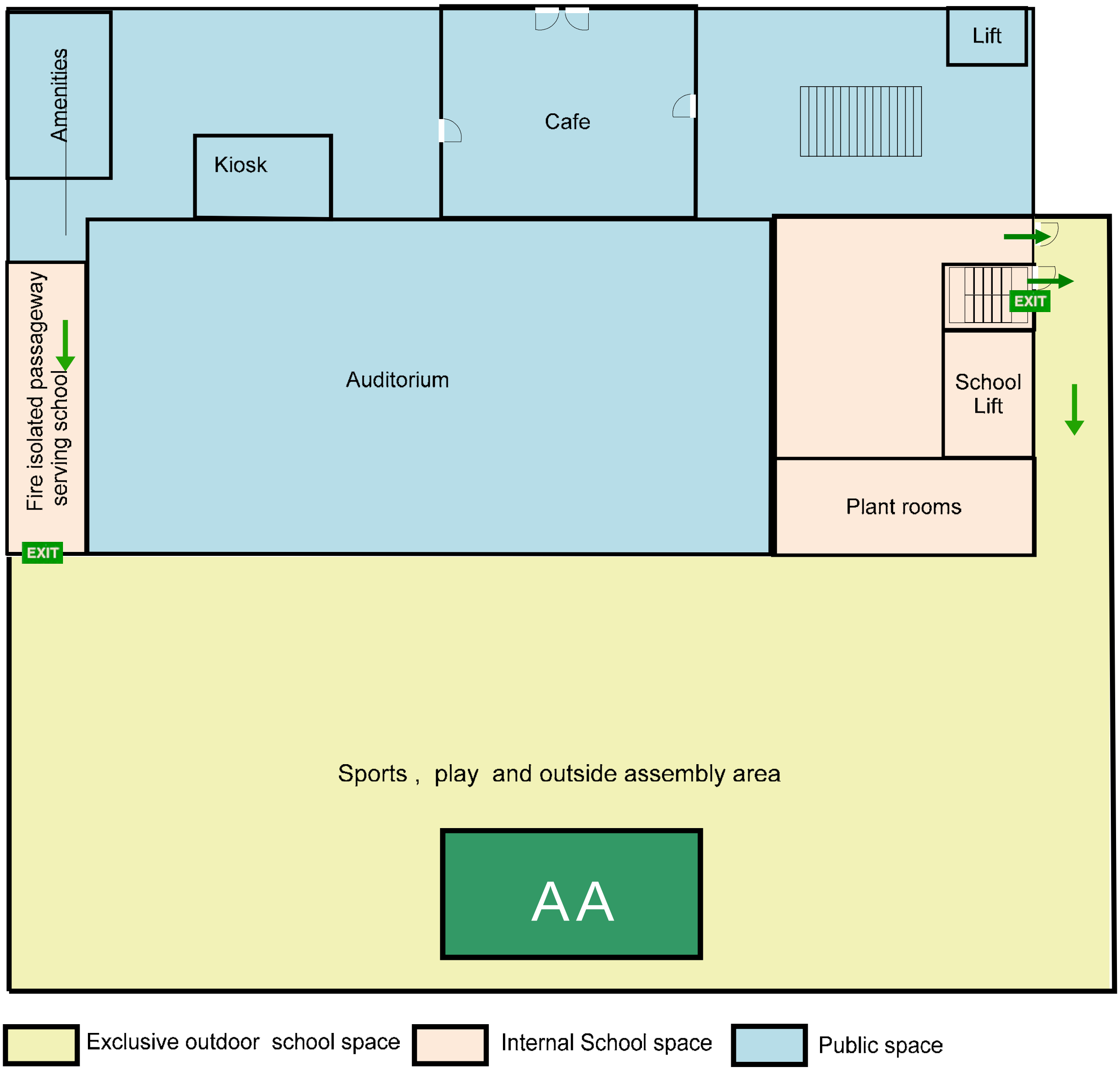

Figure 10 Ground Floor Plan of 5-storey Primary School Building

The first floor is shown in Figure 11 and is linked to the ground floor public areas by a non-required stair and a lift. This area is fire separated from the remainder of the floor. Access to the school being provided via a supervised entry point.

This floor also contains kitchens and the lunch area as well as the preparatory classes following a generally adopted approach of locating the youngest students on the lowest floor

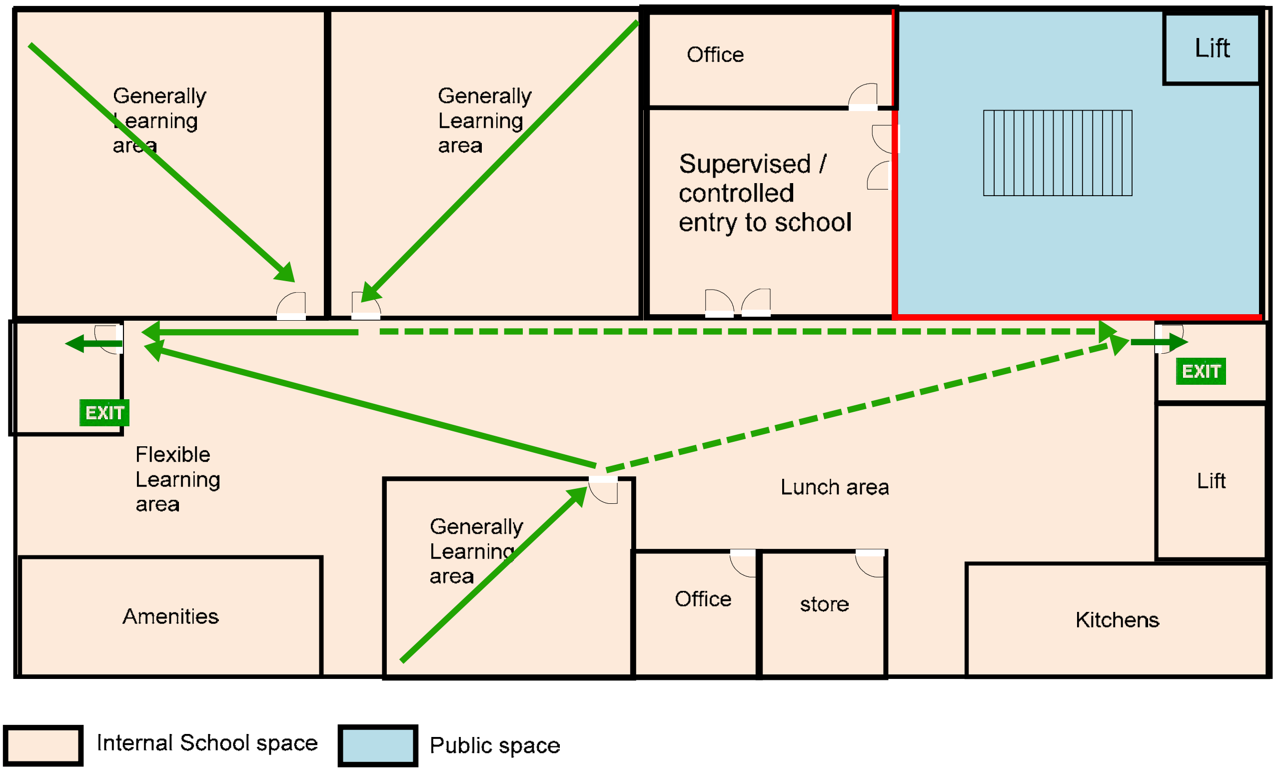

Figure 11 First Floor Plan of 5-storey Primary School Building

Levels 2 to 4 have the same general layout as shown in Figure 12. Each floor forms a fire compartment and holds four streams (i.e.120 students and four teachers) Year 1 and 2 students occupy Level 2 to reduce the number of stairs to be navigated if there is an emergency

An exit is provided at each end of the floor such that:

- no point of the floor is more than 20m from a choice in direction to an exit, and
- the distance to the nearest exit does not exceed 40m, and
- the distance between exits less than 9m or more than 60m.

A large lift is provided, capable of accommodating a full class and teacher for vertical transport under normal use conditions. The use of the lift under fire conditions will not be permitted unless controlled by the fire brigade and therefore the stairs have been constructed with emergency refuges capable of housing students in wheelchairs.

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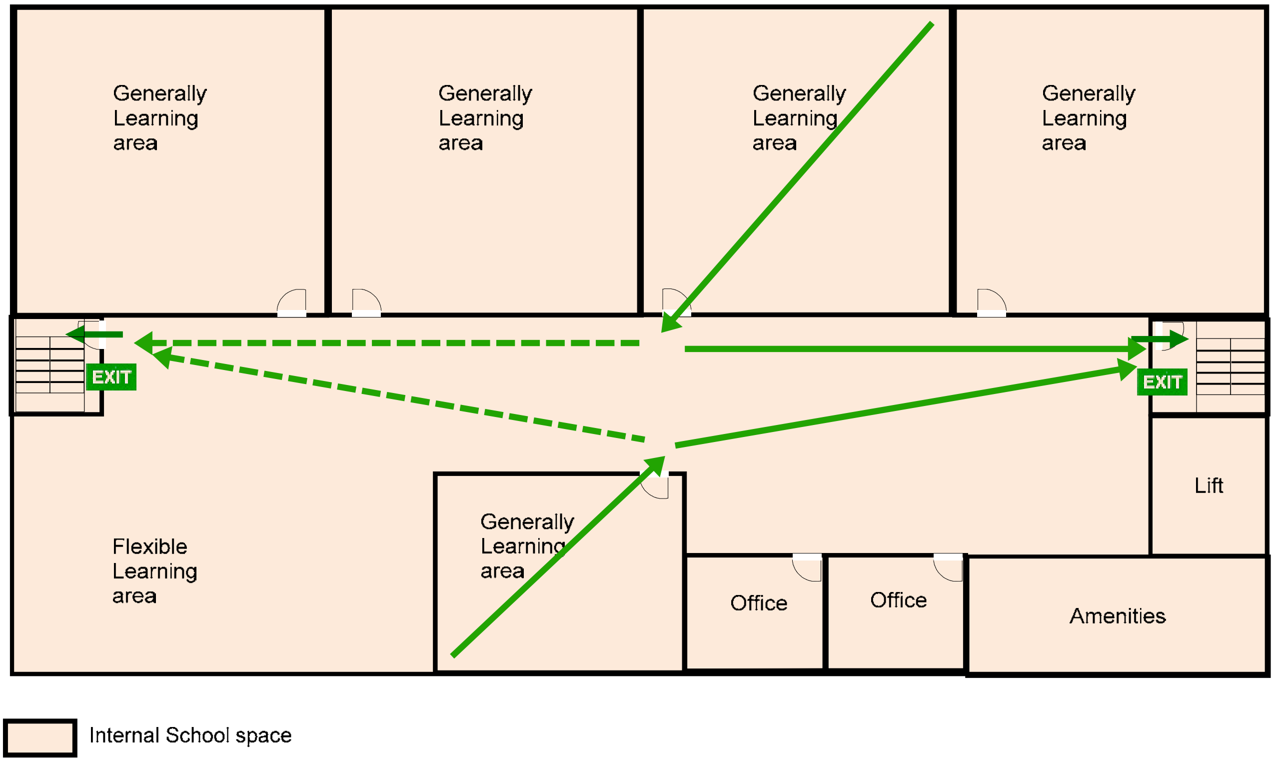


Figure 12 Level 2 to 4 plan of 5-storey Primary School Building

9.2.4. Fire Safety Measures

9.2.4.1. Pre-selection of Smoke Hazard Management Option

NCC Section E2.2 includes four options for smoke hazard management if the building has an effective height of less than 25m but a rise in storeys of more than 3 as indicated in Table 63.

In addition, Clause E 2.3 of the NCC may also be considered to apply which states that:

"E2.3 Provision for special hazards
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."

Whilst this clause does not specifically nominate primary schools, the Guide to the NCC indicates that "Clause E2.3 reinforces the need for careful consideration and sound professional judgement in the application of the smoke hazard management provisions of the BCA. Child Care Centres located above ground are used as an example, where additional smoke hazard management measures may be necessary". It is therefore appropriate to take account of Clause E2.3 for primary schools located above ground level.

A pre-selection process has been undertaken to, select the most appropriate option for detailed analysis with the QRA being used to determine if it is necessary to apply additional measures to amongst other things, address the intent of E2.3.

For most practical configurations the four options apply if buildings are of more than 3 storeys high.

If Class 2 and 3 parts share a fire isolated stair all buildings require pressurisation of the shared fire isolated stairs. Sharing exits with other occupancies introduces significant risks to primary school students and therefore this option has been set aside.

Under Clause E2.2(b) for all options automatic shut-down of air handling plant and an associated partial detection system is expected to be required since it is unlikely separate systems would be provided for each floor.

The four options for comparison are summarised in Table 11 and their effectiveness discussed below.

If the detection system fails there may be a common mode failure of the air pressurisation systems for stairs (Option 2), the automatic building occupant warning system (Option 3) and the zone pressurisation system (Option 4) since none of these systems will be activated automatically if the detection system fails.

Neither the zone pressurisation system, nor the stair air pressurisation systems will significantly reduce the risk to occupants on the floor of fire origin which is the location of highest risk.

Since occupants are awake there is a high probability of early detection of smoke independently of an automatic detection system in occupied spaces.

Table 11 Comparison of smoke hazard management options for Class 9b building less than 25m effective height

NCC Clause	DTS Provision	Estimated System reliability[1]	Estimated System Efficacy
E2.2(b) Required in all cases	Automatic shut-down of air handling system and automatic smoke dampers required if air handling system not designed to operate as a smoke control system and air is recycled.	75% if systems independent	Dependent on smoke detector location -all enclosures not protected
Option 1 Table E2.2a	Automatic fire sprinklers	85-90%	96%
Option 2 Table E2.2a	Automatic air pressurisation for fire isolated exits AS 1668.1 system	50%	Expected to prevent smoke spread to stairs in most cases if operates successfully.
Option 3 Table E2.2a	Smoke detection system complying with Spec E2.2a (AS 1670.1 system activating a building occupant warning system)	85-90%	Occupants required to recognise cue and respond for system to be effective. From FEMA Topical fire report[15] in cases where detectors activated and occupants were present and the response of occupants known, in 96% of events the alarm was recognised and occupants responded.
Option 4 Table E2.2a	Zone pressurisation between floors in accordance with AS 1668.1	30%	Generally, needs to work in conjunction with sprinkler system to attain high degree of efficacy

Note 1 Estimates of reliability based predominantly on Series C Data Sheets prepared to support the Fire Safety Verification Method[16].

Outside normal school hours Options 2-4 would have little impact on fire growth and spread except for potentially alerting the fire brigade if the system is monitored.

If the system is monitored there will be a cost to the community for false alarms either payable by the school or absorbed by the fire brigades.

Option 4 (zone pressurisation system) is a complex system with a very low effectiveness expected, together with high maintenance costs in addition to the capital costs and is therefore not considered further.

Option 2 has a slightly greater reliability than option 4 (although still low). If two stairs are provided with independent systems, the probability of one system operating increases to approximately 0.75. However, since the system is relatively expensive to install and maintain and it is unlikely to have an impact on the floor of fire origin this option has not been adopted. It should also be noted that due to pressurisation of the stair shafts difficulty opening doors increases and younger students may be unable to operate the doors without assistance.

Option 3 is potentially the cheapest option to implement. A skeleton detection system is already required to facilitate shut down of air circulating systems and operate a building wide alarm.

Option 1 (Automatic fire sprinklers) is expected to have the most significant impact both during occupied times on life safety and on property losses for fires occurring outside normal school hours and will significantly improve life safety within the compartment of fire origin and other levels. Since it is independent of the detection and alarm system it also reduces the risk from a common mode failure which is a major contributor to multi-fatality fires.

It is therefore proposed to adopt option 1 to comply with the Table E2.2a DTS provisions for comparison against the reference single storey school. If equivalence is not demonstrated the skeleton smoke detection system required under Clause E2.2b could be upgraded to a full coverage system as potentially the most cost-effective upgrade after considering enhancements to the sprinkler systems.

9.2.4.2. Selected Fire Safety Measures

The NCC DTS requirements relevant to this analysis are summarised in Table 12.

Table 12 Relevant NCC DTS fire safety provisions for five-storey primary school

NCC Clause	DTS Provision	5-Storey - School
A6.9(2)	Building Class	Class 9b - School
C1.1	Type of Construction	Type A
C1.9 / D2.2	Non-combustible building elements	External walls, common walls, fire-resisting walls, shafts· Stairways and ramps
C1.10 / Spec C1.10 (Table 2)	Floor Linings	CHF 2.2 kW/m^2 for fire isolated exits 1.2 kW/m^2 other areas[2]
C1.10 / Spec C1.10 (Table 3)	Wall and ceiling Linings	Fire isolated exits – G1 (W&C) Public corridors, Classroom. Other areas G3 (W&C) [1]
C2.2	Max-size of fire compartments Max floor area 8,000m^2 Max Volume 48,000m^2	Generally, 900m^2 / floor Public area GF and 1st Floor approx. 1020 m^2
C2.6	Vertical separation of openings in external walls Spandrel panel (900mm) Horizontal Projection (1100mm)	Not required - sprinkler protected[1]
Spec C1.1	FRL of Elements of construction – assume floor loads may be >3kPa	Fire resisting; Walls, Shafts and floors 120/120/120[2] (D1.3 requires fire isolated exits)
Spec C1.1	FRL of non-separating loadbearing elements	120/-/-
Clause D1.2(d)(v)	Number of exits required in addition to horizontal exits	Minimum of 2 exits required from each storey

NCC Clause	DTS Provision	5-Storey - School
Clause D1.4	Exit Travel distances	Max dead-end 20m Max distance to one exit 40m
Clause D1.5	Distance between exits	Not less than 9m apart Not more than 60m apart
Clause D1.6	Dimension of Exits	Exit doors assumed to be no less than 850mm wide and stair widths 1200mm to simplify use by people in wheelchairs. And 2 exits are provided from each module. Total people / module < 125 therefore minimum requirements is 1.25m. Satisfied if two exits provided
D1.13	Number of persons accommodated	Area based on Learning Places and Spaces Area guidelines for educational spaces[12]. Approx. floor area for a primary school of $7m^2$ / student excluding some ancillary areas. For 104 students / module area required would be $728m^2$. For multi storey use additional space required for fire stairs, lifts and associated circulation spaces leading to a floor area. Therefore, $900m^2$ adopted. As travel distances are slightly increased this is not considered critical and the same size has been adopted for all building options
D3.1 Table D3.1	General Access requirements	To and within all areas normally used by the occupants. Lift access to all levels. Evacuation refuges nominally 800mm x 1300mm provided within each fire isolated exit at each level providing capacity for two wheelchair users. With additional space to store evacuation chairs.
E1.3	Provision of hydrants required if building $>500m^2$ and within 50km of fire brigade station	Required
E1.4	Fire hose reels. Not required in classrooms and associated corridors	Not required in classrooms and associated corridors
E1.5 / Table E2.2a / E2.3	Automatic fire sprinklers	E2.2a Option 1 selected[3] as most effective options
E1.6	Portable Fire Extinguishes	Required - Table E1.6 defines coverage
E1.8	Fire Control Centre	Not required - floor area assumed < $18,000m^2$
E2.2(b)	Automatic shutdown of air handling system not designed to operate as a smoke control system and provision of automatic smoke dampers	Required, also requires partial detection system and alarm system for activation
E4.2	Emergency lighting	Required
E4.3	Exit and direction signs	Required

Notes;
1 Relaxation since sprinkler systems required
2 Insulation criteria for service shafts reduced to 90 minutes
3 The measures are applicable for schools of more than 3 storeys, or 2 storeys if part of a building that also includes Class 6,7b,8 or 9b parts and also required for fire protected mid-rise buildings

9.2.5. Occupancy Characteristics

Occupant characteristics are reviewed and discussed in Appendix D.

9.3. HAZARD IDENTIFICATION

To provide a structured approach to the Hazard Identification process and to ensure that the identified hazards were subsequently addressed a risk register was constructed which identified:

- hazards

- Proposed control measures
- Preliminary qualitative analysis
- Proposed quantitative Analysis and Inputs
- Status / Actions

The risk register was initially populated based on the FSVM default scenarios with further entries being informed by:

- A review of Fire Statistics, Incident Data and related information (Appendix C)
- A Review of DTS provisions in International Codes (Appendix C6)
- Characterisation of Primary School Occupants (Appendix D)
- Additional Matters Identified relating to Building Trends and Practices for high-rise schools and supplementary requirements outside NCC provisions (Appendix E)
- A Review of NCC DTS provisions applicable to schools (Appendix F)
- Parameters for consideration provided within the NCC 2019 Performance Requirements and proposed for inclusion in Part A8 of the NCC 2018 (Appendix G)
- Fire safety principles / engineering judgement

The register was maintained throughout the analysis and updated together with the proposed building design as appropriate to address identified hazards and /or ensure the NCC and other critical criteria are satisfied. The risk register is included in Appendix H.

9.4. DESIGN MODIFICATIONS BASED ON PRELIMINARY HAZARD ID

9.5. SELECTION OF FIRE RISK CRITERIA AND QRA METHODS

9.5.1. Fire Risk Criteria

The fire risk criteria are as specified in Section 2 based on the proposed part A8 of the NCC 2022. The criteria did not include a specification for occupant tenability which can have a significant impact on estimated risk levels.

The Level 3 tenability criteria derived in Appendix B2 were determined to be the most appropriate having regard for the derivation of the upper and lower risk limits and are summarised below:

- Fractional Effective Dose (FED) of 0.3 with respect to thermal exposure
- Fractional Effective Dose (FED) of 0.3 with respect to exposure to carbon monoxide
- Flashover occurring within the fire compartment
- Occupants remaining in the building at the time of collapse of the building or a substantial part of the building.

A supplementary design check using a criterion of 10m visibility at a height of 2m will also be undertaken assuming the fire safety measures operate effectively to determine if there is an opportunity for occupants to evacuate during these scenarios. This could be considered analogous to a serviceability check in addition to a check of the ultimate capacity in structural engineering.

9.5.2. Overview of QRA methods

The primary QRA method was based on event tree analysis using a series of representative scenarios. The events within each representative scenario were assigned probabilities enabling the probability of occurrence for each representative scenario to be determined.

The outcomes (consequences) of the representative scenarios were determined

- with respect to the risk of exposure to untenable conditions using ASET / RSET analyses,
- with respect to the spread of fire using a combination of fire dynamics and heat transfer analysis, experimental data and material properties
- with respect to collapse using parametric curves for fully developed fires and a lumped thermal mass approach to estimate the scenario time to structural failure and assuming disproportionate collapse occurs if two structural members fail in the same enclosure.

The modelling methods adopted were relatively simplistic to limit the modelling resources required but were considered appropriate for the generic analysis being undertaken.

Note: For projects where a specific feature warrants more detailed consideration a practical approach is to undertake the QRA using relatively simple models and undertake supplementary detailed analysis using more complex techniques for specific features. For example, a detailed structural analysis could be undertaken in lieu of assuming structural failure of two members to realise the benefits of a structure that includes significant redundancies

9.5.3. Treatment of Automatic Sprinkler Systems

A binary model for sprinkler performance was adopted assuming that if the sprinkler operates successfully a fully developed fire will not occur and the occupants would not be expected to be exposed to untenable conditions. It is acknowledged that it is possible for a fatality to occur if a sprinkler system operates successfully but these fatalities are generally limited to people in close contact with the fire or intent on self-harm and any practical fire protection systems are not expected to influence the outcomes.

9.5.4. Scenario Selection and Development

To evaluate scenarios where there is no sprinkler protection, or the sprinkler system is ineffective the following approach was adopted based on fire scenario clusters and corresponding representative fire scenarios as described in ISO 16732-1 [1]

Fire scenario clusters and the corresponding reference clusters are selected such that the consequence of the representative fire scenarios can be used as a reasonable estimate of the average consequence of scenarios in the fire scenario cluster. The fire risk can then be calculated as the sum over all fire scenario clusters of fire scenario cluster frequency multiplied by representative fire scenario consequence without imposing an undue calculation burden.

The following approaches were used to inform the estimates of probabilities and consequences:

9.5.4.1. Smoke Spread

Smoke spread, times to detector activation and the corresponding alarm, times to untenable conditions and visibility were determined using the zone-model (B-Risk [13]).

9.5.4.2. Evacuation

The evacuation analysis was undertaken using simple distributions for premovement times and travel speeds assuming the occupants travel as a group as identified in the technical references. Refer to Appendix D for further information on assumed travel speeds. Human behaviour and decision making in response to fire scenarios are considered as described in 0. Multi-scenario analyses were undertaken to generate distributions of the evacuation times for each floor and to clear the building to facilitate estimates of the number of people exposed to untenable conditions

9.5.4.3. Fire Brigade Intervention

Analysis of Fire brigade Intervention was undertaken using a multi-scenario implementation of FBIM [2] where appropriate with response times based on distributions published in a Report on Government Services [3]

9.5.4.4. Risk to Occupants on floors other than floor of fire origin

Three general fire scenarios were identified that may threaten occupants in other parts of the building:

- Smoke Spread to upper levels via stair and lift shafts
- External Fire Spread to Upper Levels
- Internal fire spread and / or catastrophic collapse of the building

Analysis of smoke spread to the upper levels was modelled taking account of the status of doors leading to shafts.

Theoretical analysis tends to show that in a large proportion of cases external fire spread will occur to the upper levels of a building, but fire statistics tend to indicate the frequency is substantially less if the external façade is non-combustible. An approach drawing on statistical data and a previous analysis undertaken by Korhonen and Hietaniemi [4] was adopted.

The analysis of internal fire spread to the next level and quantification of the risk of catastrophic collapse was undertaken using a simple Enclosure / Structural model together with a multi-scenario implementation of the Fire Brigade Intervention model. This analysis also considered smoke spread to the upper levels of the building to identify scenarios where one or more exits are blocked impacting on the evacuation time and hence number of people remaining in the structure if collapse occurs.

10. QUANTITATIVE RISK ASSESSMENT

10.1. ESTIMATION OF EVENT FREQUENCIES AND SCENARIO CONSEQUENCES

10.1.1. General

Frequencies and probability estimates for scenarios have been largely based on fire incident data and technical literature. Since available fire incident data from Australia was limited it has been supplemented by data from other countries (e.g.US and UK). A review of the prescriptive requirements in the US and UK was undertaken so that any significant differences from Australian prescriptive requirements could be taken into account when using international data. In addition, overseas data was compared to the available equivalent Australian data. For further information reference should be made to Appendix C.

General estimates of the effectiveness of fire safety systems were based on fire incident data, recommended values in the data sheets from the FSVM Handbook Annex [14] , technical literature and fire incident data.

10.1.2. Frequency of reported fires

Based on the analysis of the fire incident data undertaken in Appendix C the average frequency of reported fires for primary schools was estimated to be 0.013 / annum and this value was considered a reasonable estimate for the proposed primary school part of the building.

10.1.3. Effectiveness of Sprinklers

The sprinkler system was assumed to be effective in 86% of scenarios based on the typical value provided in the ABCB Fire Safety Verification Method Data Sheets - Handbook annex [14] unless additional measures are in place to enhance the effectiveness of the sprinkler system.

If the sprinkler system fails to operate successfully it will be conservatively assumed that it will have no impact.

10.1.4. Representative Scenarios – for floor of fire origin

10.1.4.1. Derivation of Representative fire scenarios

To derive a series of representative scenarios for quantification of the risks associated with sprinkler system failure the “universe” of possible fire scenarios was broken down into the following general fire scenario clusters and the probabilities of occurrence estimated to enable critical clusters that impact on the risk to life of the occupants to be identified for detailed analysis and low risk scenarios that have a minimal impact on the risk to life to be set aside since further evaluation of consequences will not be required.

a) Fires that occur outside the times the school is occupied – low risk to occupants (approx. 21% of fires derived from Appendix C4.3)
b) Confined fires as defined in the US databases that are unlikely to present a significant risk to occupants that are alert.
c) Fires that were confined to a single item that are unlikely to present a significant risk to occupants that are alert.
d) Fires that occur in isolated parts of the building e.g. plant rooms.
e) Larger fires that may present a significant risk to the building occupants and require further analysis

The clusters identified as a) to d) above represent low risk fire scenarios that can be excluded from further analysis whilst cluster e) represents a cluster of fire scenarios potentially presenting a significant risk.

Further statistical analysis was undertaken and event trees constructed to break the critical fire scenario clusters down into smaller clusters based on location (type of room), fire growth rate, potential for flashover and peak fire size if flashover does not occur as described in Appendix C4.4 to C4.6 and summarised in Table 13.

A typical school level was simplified as shown in Figure 13 such that the various enclosures could be consolidated into the following three enclosure types:

- Type 1 Small rooms - stores, kitchen offices, amenities
- Type 2 General Learning Area (classroom)
- Type 3 Libraries / Flexible Learning / General circulation

The plant room is located on the Ground floor remote from the occupied school areas with substantial fire separation and distance such that no further analysis was required to assess the risk to school occupants.

Design fires were located in;

- Enclosure 1 (a Type 2 Classroom)
- Enclosure 5 (a Type 1 ancillary area - stores, kitchen offices, amenities)
- Enclosure 6 (a Type 3 large opening area representative of a library, flexible learning area, general circulation / path of travel to an exit)

The proportion of fires within the cluster of “fast” growth fires was subsequently increased so that it matched the proportion of potential flashover fires occurring during the periods the school was occupied which also takes into account potential increases in growth rates due to relaxations to wall and ceiling lining requirements permitted in sprinkler protected buildings.

Representative scenarios were then assigned to these clusters. The outcomes are shown in Table 13 with representative scenarios occurring in three locations, with three representative design fires in each location to adequately define the range of fires that present a risk to the occupants on the floor of fire origin.

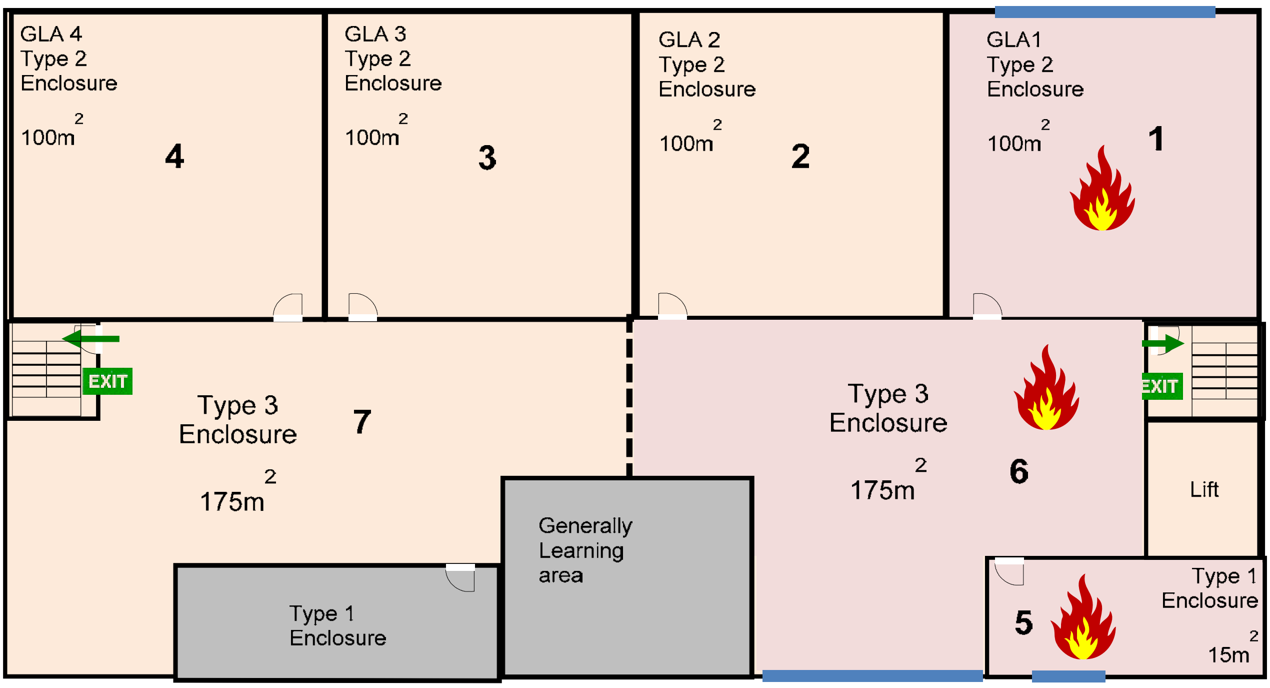


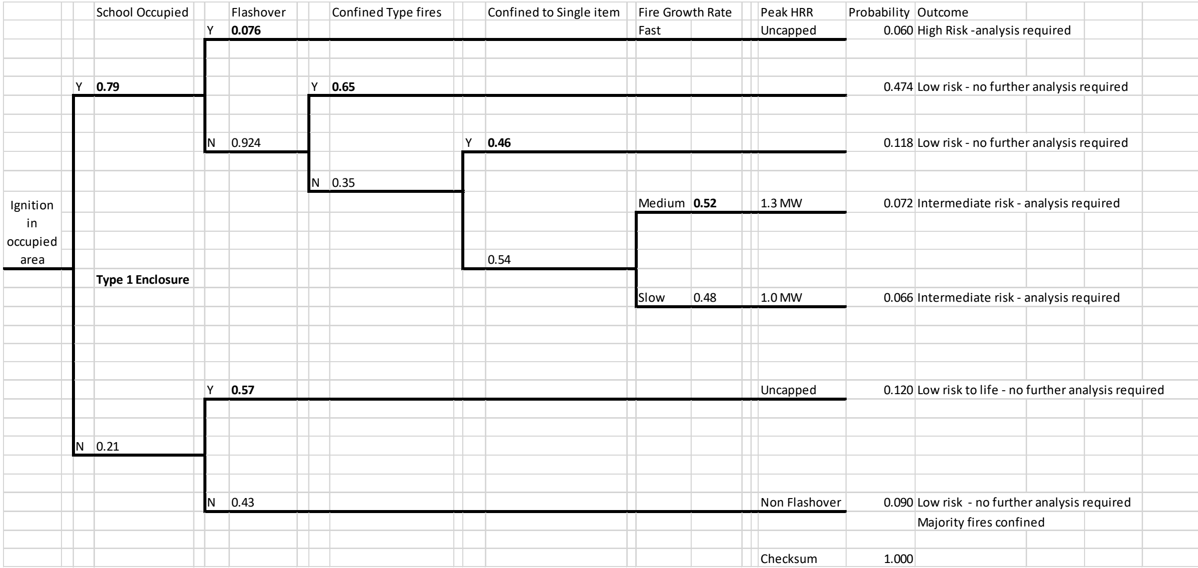
Figure 13 Generic Primary School Level for fire modelling

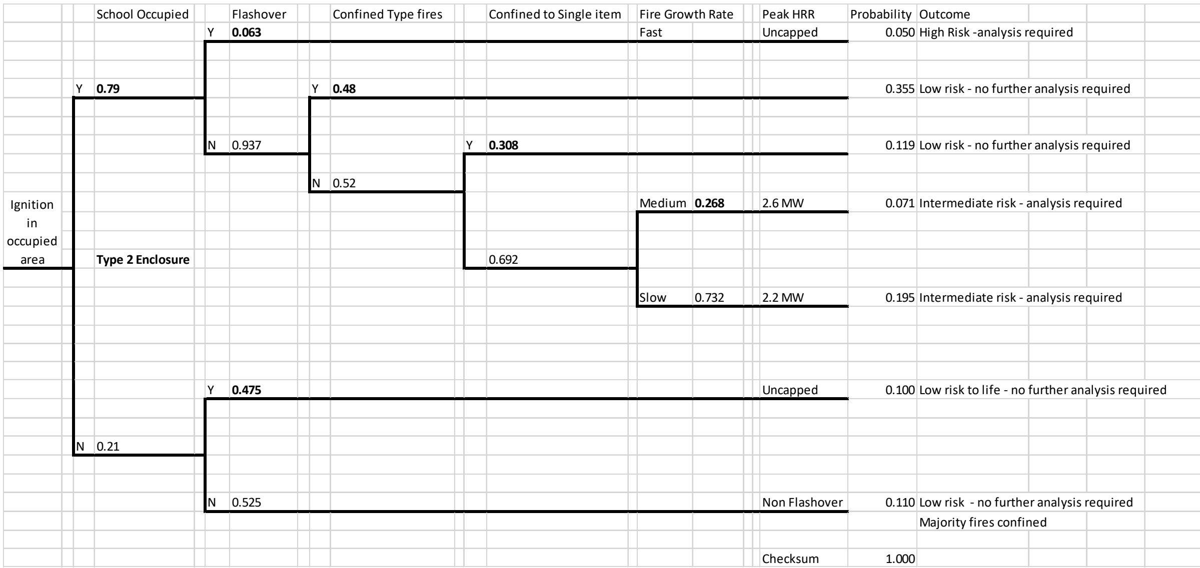
Table 13 Summary of Design Fire Types and Peak HRR during hours of occupation

Encl. Type	Enclosure Description	Fires %	Proportions of fire by Type %				Peak HRR -MW	
			Confined / confined to SBI	Slow	Med.	Fast / Flashover	Slow	Med
1	Small rooms - stores, kitchen offices, amenities	59	75	8.4	9.0	7.6	1.0	1.3
2	General Learning Area (classroom)	24.7	60	24.7	9.0	6.3	2.2	2.6
3	Libraries / Flexible Learning / General circulation	12.3	70	15.9	9.0	5.1	2.7	3.75
4	Plantroom	4	Remote (located on GF) and substantial separation from occupied areas – no further analysis required					

This selection process and assigned probabilities are presented as three event trees in Figure 14.

The branches that were identified as low risk with minimal adverse consequences were then consolidated, probabilities assigned to the proportion of fires occurring in each enclosure and branches added for sprinkler performance yielding the event tree shown in Figure 15.





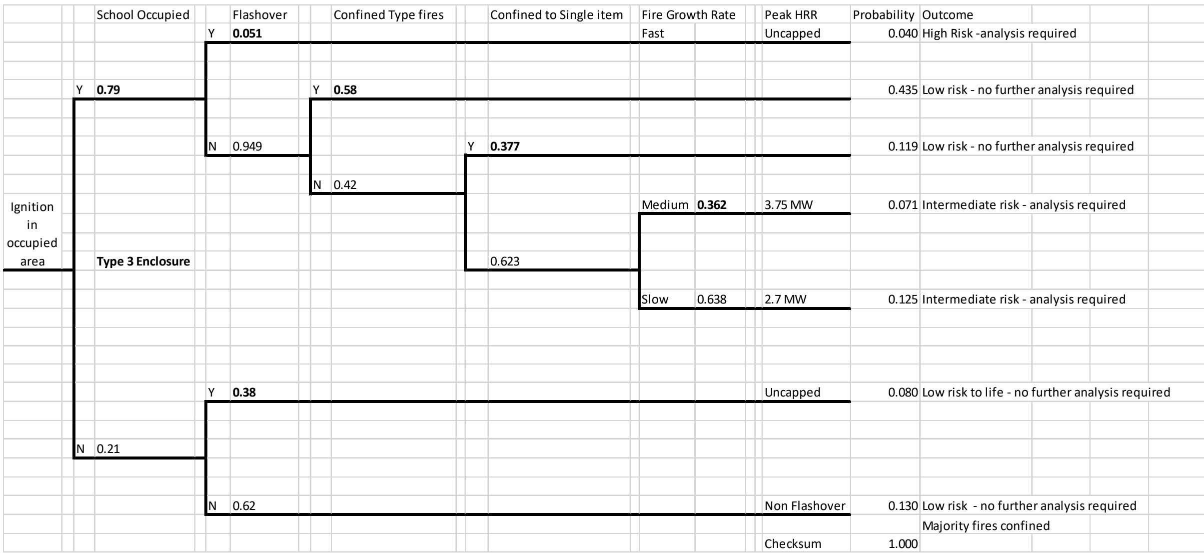


Figure 14 Event trees showing design fire distributions for design enclosures

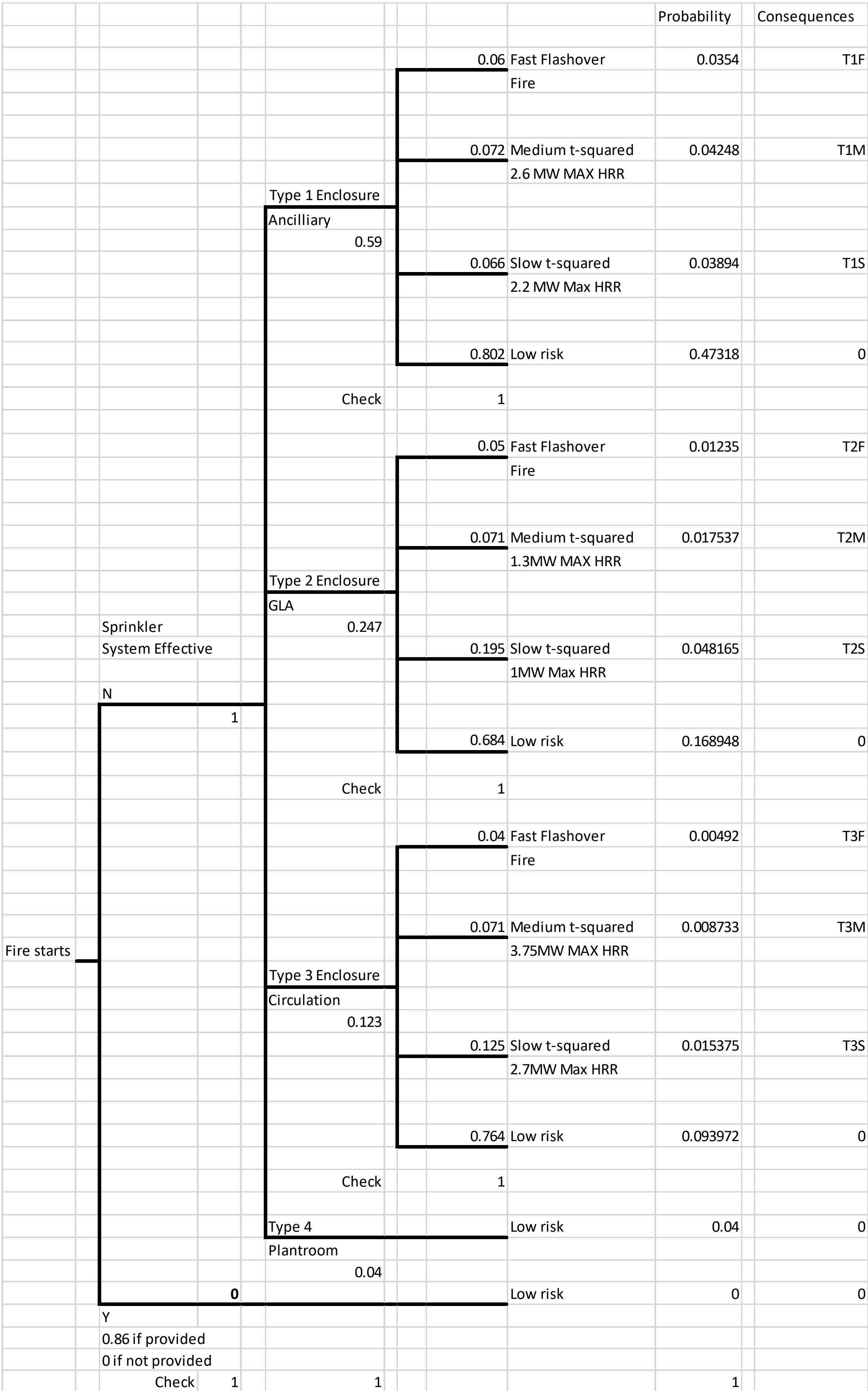


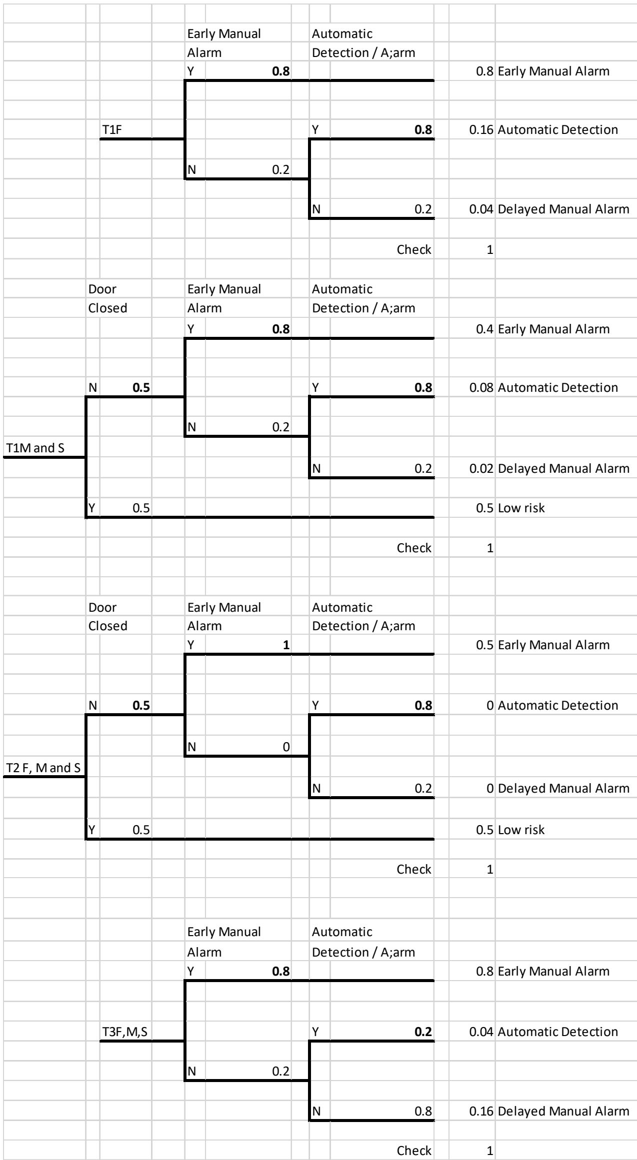
Figure 15 Consolidated Event Tree for Floor of Fire Origin

10.1.4.2. Occupant Response Extension to Fire Scenarios

The representative fire scenarios require further extension to address the variability of human behaviour and evacuation process. This is achieved by extending the representative fire scenario event trees to address the following means by which occupants are alerted to the occurrence of a fire.

- automatic (via the smoke detection and alarm system),
- early manual detection and
- delayed manual detection.

The status of the door to the room of fire origin is also critical to the time that the occupants outside the room of fire origin will become aware of the fire for the manual detection scenarios and the door status will also impact on the extent of smoke spread and therefore the door status was also included as shown in Figure 16.



Note For smaller enclosures (T1F) a flashover condition requires that the door is open and in the general circulation area T3 the areas are not subdivided by doors

Figure 16 Sub-event trees determining probability of door closure and means of fire detection alarm

10.1.5. Modelling Human Response and Evacuation

The evacuation modelling was undertaken using the distributions for premovement times and travel speeds assuming the occupants travel as a class group as identified in the technical references. Simple hand / calculations / spread sheet calculations were considered appropriate. Human behaviour and decision making in response to fire scenarios in each of the three types of room identified are considered in 0. The treatment of occupant response to the fire scenarios is described in Appendix K with further details including the derivation of the probabilities of the door status and alarms alerting occupants are provided in Appendix L13.

10.1.6. Fire Detection System

A binary model was applied to the fire detection system. It was assumed the detector either operates at its design sensitivity of fails to operate. Times to detector activation and the corresponding alarm times were determined using a zone-model (B-Risk [13]). Further information is provided in Appendix J3

In some scenarios, where the room of fire origin is occupied, early manual detection preceded the activation of the smoke detector explaining the good safety record of schools without smoke detection systems.

However, for fire scenarios in unoccupied rooms the delayed manual alarm case was applicable, which in some scenarios delayed evacuation to such an extent that unassisted evacuation was not possible due to blocked paths of travel to exits caused by conditions comparable to those associated with those described for the multiple fatality cases reviewed in Appendix C5.2 highlighting the importance of an automatic detection system.

10.1.7. Smoke Spread Modelling

Smoke Spread modelling was undertaken using a zone-model (B-Risk [13]). The application of the model to the floor of fire origin is discussed in Appendix J with additional information relating to scenarios and ASET / RSET analyses on the floor of origin provided in Appendix L

10.1.8. Fire Brigade Intervention

Fire brigade Intervention was modelled where appropriate using FBIM [2] and response times based on distributions published in a Report on Government Services [3] as described in Appendix L1.

10.1.9. Determination of Risk to Occupants on Floors other than the floor of fire origin

To evaluate the risk to occupants on other floors a fast growing fully developed fire in a Type 1 enclosure was selected to provide a general representation of a fire capable of threatening occupants on other floors. Smaller fires were considered unlikely to threaten occupants on other floors prior to evacuation.

Three general fire scenarios were considered that may threaten occupants in other parts of the building:

- Smoke Spread to upper levels via stair and lift shafts
- External Fire Spread to Upper Levels
- Internal fire spread and catastrophic collapse of the building

Smoke spread to the upper levels was modelled by extending the B-risk model to other floors and considering the status of doors leading to shafts. Further details relating to the occupant evacuation, smoke modelling and quantification of risk from smoke spread to the upper levels are presented in Appendix M.

Theoretical analysis tends to show that in a significant proportion of cases external fire spread will occur to the upper levels of a building, but fire statistics tend to indicate the frequency is substantially less if the external façade is non-combustible as which apply to the five-storey building.

Although a comparative analysis is being undertaken in this study the reference building is a single storey building, therefore there will be no cancelling effect of the impact of assumptions and simplifications relating to fire spread to the floors above. An approach drawing on statistical data and a previous analysis undertaken by Korhonen and Hietaniemi [4] has therefore been adopted.

The Korhonen analysis included a theoretical study which was normalised against statistical data addressing the potential for large over-estimates regarding fire spread over non-combustible materials as identified above. Further details are provided in Appendix M3.

The analysis of internal fire spread to the next level and quantification of the risk of catastrophic collapse was undertaken using the Enclosure / Structural model together with a multi-scenario implementation of the Fire Brigade Intervention model incorporated in the EFT Multi-scenario Quantitative Risk Assessment Framework.

This analysis also drew on the analysis of smoke spread to the upper levels of the building which identified scenarios where one or more exits are blocked impacting on the number of people remaining in the structure if it collapses

A more detailed description of the method and inputs adopted are provided in Appendix M4

10.2. RISK ESTIMATES AND COMPARISON TO ACCEPTANCE CRITERIA

10.2.1. Derivation of Risk Estimates

The results of the individual components of the analysis are provided in Appendix J through Appendix M and the consolidation of these results to obtain risk estimates is described in Appendix N.

10.2.2. Individual Risk to Occupants

The consolidated individual risk results are shown in Table 14 compared to reference building 2 with a breakdown of losses from fires on other floors. The results clearly show, as expected, losses on the floor of fire origin are dominate with a small contribution to the risk from vary low probability high loss fires on other floors.

The net effect is that the individual risk estimates for reference building 2 (see Section 7.2.2) and the proposed 5-storey building are comparable

Table 14 Comparison of Average Individual Risk Estimates for Hi-rise buildings with sprinkler protection and smoke detection systems to reference building 2 applying level 3 tenability criteria

Scenario	reference building 2	5-storey high-rise
Floor of origin	2.20E-07	2.16E-07
Smoke Spread via stair and lift shafts to upper levels	0	2.94E-09
External Fire Spread to upper levels	0	2.14E-09
Fire Induced Collapse of Structure	0	1.69E-10
Total Individual risk from fire scenarios	2.20E-07	2.21E-07
Normalised Against Reference Building	1	1.00

The results are also compared to reference building 1 (compliant with basic NCC requirements which do not require detection and alarm systems in many 1-storey schools) as well as reference case 2 which includes a detection and alarm system and the Part A8 limits in Table 15

Table 15 Comparison of Average Individual Risk Estimates with draft Part A8 of NCC 2022 limits and values estimated from fire incident data

Risk Criteria	Ref. Bld. 1 No detection/ alarm	Ref. Bld. 2 With detection/ alarm	5-storey high-rise with sprinklers, & det./ alarm	Part A8 lower limit	Part A8 upper limit
Individual Risk of death / annum	1.10×10^{-6}	2.20×10^{-7}	$2.21E \times 10^{-7}$	1×10^{-6}	1×10^{-4}
Normalised IR against lower limit	1.1	0.22	0.22	1	100
Normalised IR against upper limit	0.011	0.0022	0.0022	0.01	1

The 5-storey high-rise building with sprinkler and smoke detection / alarm systems was demonstrated to satisfy the lower IR limit and therefore no further analysis would be required to demonstrate compliance with this metric.

10.2.3. Societal Risk to Occupants

The consolidated societal risk results are presented as an F-N plot in Figure 17 for the 5-storey primary school building compared to reference buildings 1 and 2 and the draft Part A8 of NCC 2022 limits using the Level 3 tenability criteria.

It can be observed for N values between 5 and 100 the plots are generally between the upper and lower proposed Part 8 criteria and therefore a supplementary comparative approach is required to determine if the proposed 5-storey design meets the Part 8 criteria for societal risk.

Reference building 1 is a basic NCC DTS design without automatic detection / alarm and can be seen to marginally exceed the upper limit for N between 30 and 60 which to some extent confirms the Hazard ID analysis highlighting the importance of providing a detection and alarm system to address fires starting in unoccupied areas and growing undetected to such an extent that exit paths are blocked. The proposed design presents a lower societal risk than the reference 1 building but due to the issue of fires in unoccupied areas reference building 2 was selected for the comparison.

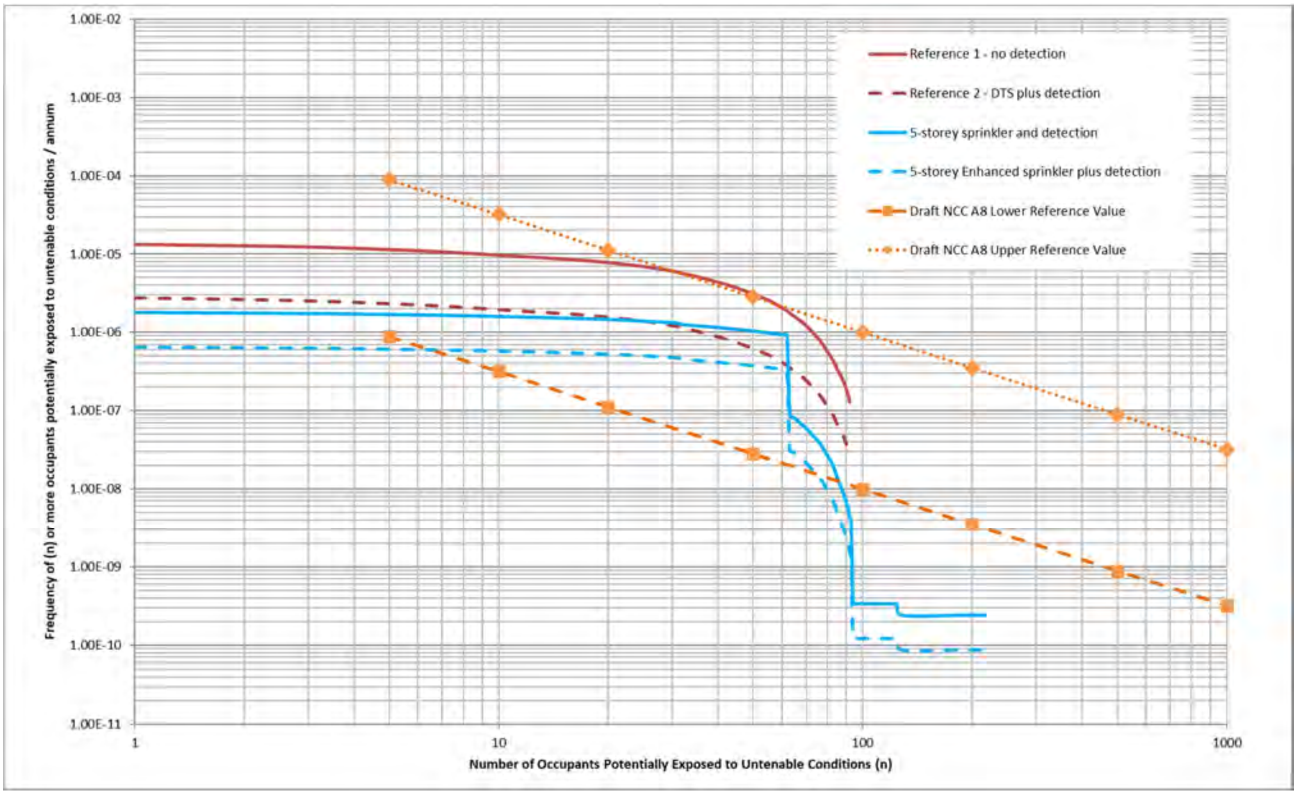


Figure 17 F-N Plot of Societal Risk for five- storey school compared to various benchmarks

For N between approximately 20 and 60 the proposed 5-storey building exceeded the societal risk presented by reference 2. Below N=20, the proposed 5-storey building presented a lower risk and above N =60 the proposed 5-storey building presented a lower risk than reference 2 or was below the lower risk limit from A8.

This is a marginal case and the draft part A8 does not provide any guidance as to how this should be dealt with. It is also noted that when the analysis undertaken for the reference buildings was compared to the available fire incident data it was apparent that the modelling undertaken was over predicting the number of fatalities.

Notwithstanding the above discussion if A8 is interpreted to require the total FN plot for the proposed building to lie entirely below the reference building or lower limit the design would need to be adjusted.

Since the floor of fire origin appears to be dominant, options to improve the performance would include:

- improvements to the reliability of the automatic sprinkler system and / or detection systems
- subdivided the floor to delay smoke spread to the entire floor and stairs, enhance options for occupants to shelter on the floor of fire origin and facilitate a phased evacuation

For demonstration purposes an option to increase the effectiveness of the sprinkler system to 95% was selected and the results are plotted as a dashed blue line in Figure 17 which lies below the reference 2 building plot and / or lower reference values from A8.

To improve the reliability of the sprinkler system design modifications and procedural measures would need to be established and fully justified using methods such as fault trees.

10.2.4. Fire Spread Metrics

10.2.4.1. Fire Spread between Buildings

The following metrics apply

(b) A building must avoid the spread of fire between buildings such that:

(iv) The probability of a *reportable fire* in a building causing heat fluxes greater than the values listed Table 16 must not exceed 0.001.

(v) The probability of a building not being able to *withstand* the heat flux in Table 3 for a period of 30 minutes must not exceed 0.01.

Table 16 Maximum heat flux limits

Maximum heat flux (kW/m^2)	Distance from Boundary (m)	Distance between buildings on the same allotment (m)
80	0	0
40	1	2
20	3	6
10	6	12

A simple analysis was undertaken in Section N4 which demonstrated that the incident heat flux on the boundary was approximately $18kW/m^2$ (a safety factor of 4.44) ignoring the impact of sprinklers. The probability of exposure would be further reduced by the presence of the sprinkler system.

The building is located more than 6m from the boundary and the façade is required to withstand a maximum heat flux of $10kW/m^2$ for 30 minutes. The external façade of the building is of non-combustible construction with double glazed toughened glass glazing with pain thickness greater than 6mm and is therefore expected to withstand radiant heat fluxes in excess of $10kW/m^2$ based on various experimental results (e.g. Klassen [5]). It is therefore considered that this metric has been satisfied.

For further information refer Section N4

10.2.4.2. Fire Spread via the external facade

The following metrics apply

The probability that the external façade of a building cannot *withstand* the following exposures from *reportable fires* must not exceed 0.001:

D. flames venting through an opening from an enclosure fire within the building;

E. burning items adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas;

F. a fire occurring on a balcony.

Burning items adjacent to the building will be expected to impact on the ground floor non-school parts which are required to be non-combustible. Therefore, the school area was evaluated for flames venting through an openings which is expected to inherently address small burning items likely to be located adjacent to the structure since the proposed building configuration does not have vehicular access in close proximity to the façade.

There are no balconies provided for the fire-storey school building and therefore analysis of balcony fires is not required.

From section M3.2 the probability of a reportable fire in an apartment building spreading to the floor above in a concrete building was estimated to be approximately 0.002 without sprinkler protection. Noting the rare occurrence of external spread between floors in high-rise buildings with non-combustible facades it was considered conservative to adopt this value to the subject building since spandrel panels in excess of 900mm are provided as part of the building design.

Allowing for the impact of sprinklers with an assumed effectiveness of 86% the probability of external fire spread can be estimated to be:

0.002 x 0.14 =0.00028 which is substantially less than the nominated limit of 0.001 with a safety factor (approx. 3.6). Therefore, a more detailed analysis was not considered necessary and it was determined that the metric for fire spread via the façade had been satisfied.

10.2.4.3. Internal Fire Spread

(c) A building must avoid the spread of fire within the building such that when a reportable fire occurs, the probability of fire spread does not exceed-

- (i) 0.01 to spread outside of an SOU;
- (ii) 0.01 to spread between storeys; and
- (iii) the values in Table 10.

Table 17 Internal fire spread limits to manage fire spread

Building Classification	Floor Area	Volume	Maximum probability of spread beyond specified floor area and volume
5, 9b	**3000m^2**	**18000m^3**	**0.01**
6,7,8, 9a,9c	2000m^2	12000 m^3	0.01
5-9	18,000m^2	21000m^3	0.001
Class 9c & 9a patient care areas	1000m^2	-	0.01

The 5-storey school building is Class 9b and from Table 17 the probability of internal fire spread between storeys needs to be maintained below 0.01 for a reportable fire.

Each floor is approximately 900m^2 and therefore the 3000m^2 floor area limit is not applicable and there are no separate SOUs on each school level

The probability of a reportable fire achieving flashover based on fire incident data is approximately 0.11 if the impact of automatic sprinklers is ignored and may occur when the building is occupied or unoccupied.

The probability of the automatic sprinkler system being effective has been assumed to be 0.86 and if the system is effective it will prevent a fire progressing to a fully developed fire.

Therefore, the probability of a fire occurring that could threaten the fire separation between storeys is 0.0154 (0.11 x 0.14)

Assuming a high (conservative) probability of failure of 0.5 for the floor system due to the inclusion of services, construction joints etc the probability of fire spread would be 0.0077 which does not exceed the 0.01 limit and a more detailed analysis considering fire brigade intervention is not required.

It is also noted that if the effectiveness of the sprinkler system is increased to 91% the 0.01 probability limit will be satisfied although providing some redundancy is considered appropriate.

For further information refer Section N6

10.3. DISPROPORTIONATE COLLAPSE METRIC

In the current draft A8 there is no fire specific metric specified for disproportionate collapse. The risk to occupants as the result of a major collapse was estimated based on a multi-scenario analysis of fully developed fires undertaken as described in Appendix M.

This information can be used to derive an indicative estimate of the probability of a major collapse, but it should be recognised that the analysis is simplistic and sensitive to assumed inputs

A summary of the inputs required and estimates for designs with sprinkler systems having an effectiveness of 86% or 95% are summarised in Table 18

Table 18 Multi-scenario results summary of results from Appendix B and estimates of a major collapse

Input	Value Base sprinklers	Value enhanced sprinklers
Frequency of reportable fire starts within school / annum	0.013	
Probability of fully developed fire	0.11	
Probability of sprinkler failure	0.14	0.05
Probability of disproportionate collapse if exposed to a fully developed fire	2.5×10^{-4}	
Estimate of frequency of disproportionate collapse	5.01×10^{-8}	1.79×10^{-8}

If necessary, a more detailed analysis of a specific structure should be undertaken.

11. IMPLEMENTATION

11.1. GENERAL

The maximum benefits from the fire engineering process can be obtained through involvement of a fire engineer during the early stages of a design and maintaining their involvement throughout the various design stages, construction and implementation and where practical there should be an ongoing involvement to verify appropriate maintenance and management procedures are in place.

This case study simulated the involvement of a fire safety engineer from the schematic design phase providing opportunities for an effective design to be developed. The following sections identify some critical stages where the input of a fire safety engineer may be beneficial beyond developing an initial design and verifying compliance with the NCC and other requirements. Figure

18 shows schematically the various processes that are required to implement and maintain a fire safety strategy throughout the life of a building

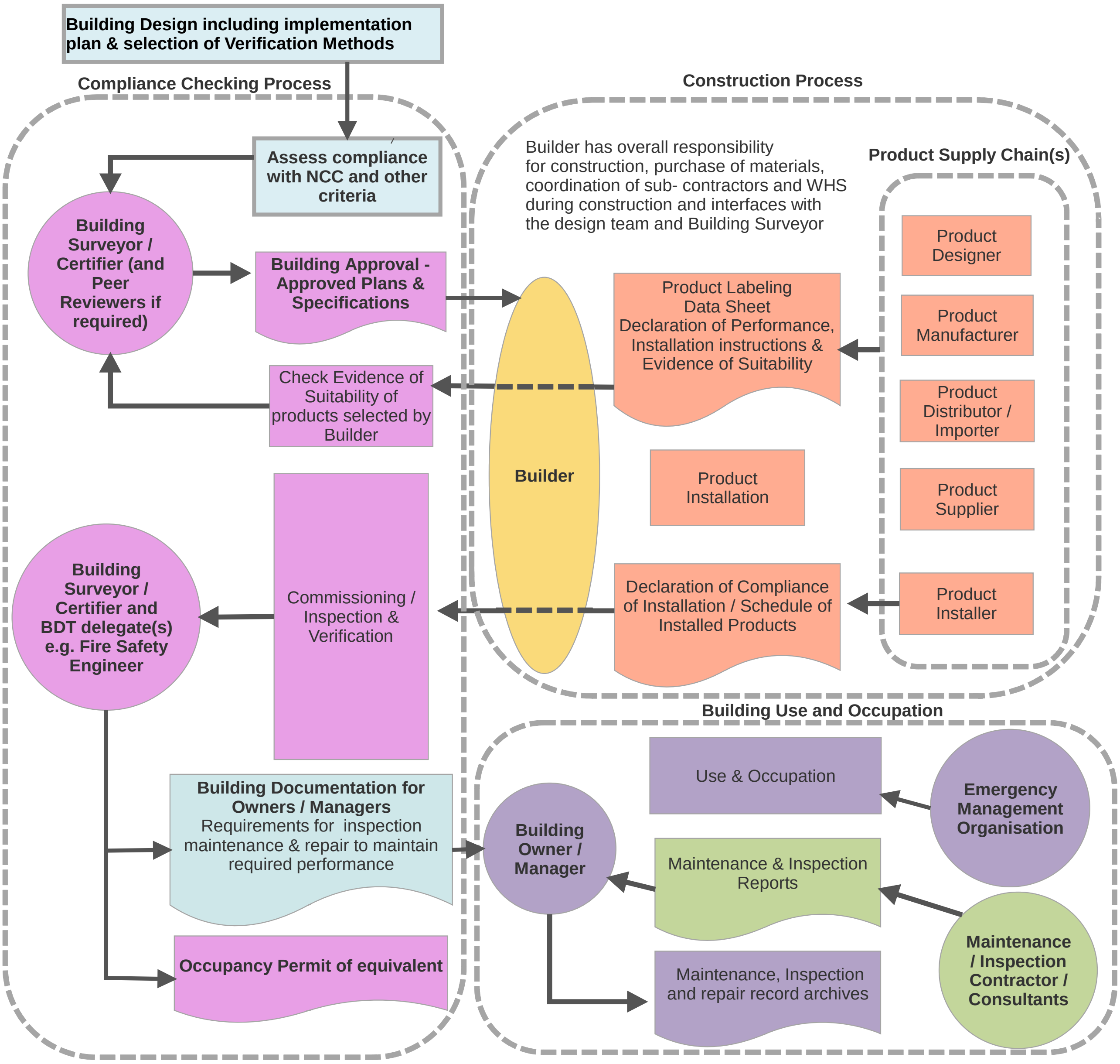


Figure 18 Implementation and Maintenance of a Fire Safety Strategy

11.2. Good Design and Building Management Principles

During the PBDB process, including the hazard identification, a number of good design principles may be identified that may be able to be implemented cost-effectively and enhance the operation of a building if identified during the early stages of a design. In relation to the case study some issues that would fall into this category include:

- Integrating security measures into the design of the building through adapting the building layout rather than relying on access control systems that can be complex to integrate into a design effectively. E.g. separate stairs and lifts for students and accessing school through a 1st floor lobby.

- Encouraging the architect to provide two exits from classrooms where practical to address the risk of blocked exits and other emergencies and minimisation of dead ends
- Provide advice in relation to maximising the effectiveness of fire safety systems
- A safe path of travel to an external assembly point without exposing children to hazards such as traffic, abduction or the like should be addressed.
- If a high-rise school building is shared with community / commercial operations the part of the building that forms the school should be fire and smoke separated and have independent fire exits and lifts (this also relates to security in addition to fire safety)
- Refuges in fire exits should be provided for people that may be unable to evacuate without assistance.
- Where practical, locate younger students on the lower levels of the school.
- A good practice guide or similar advisory document shall be prepared to alert school operators of potential additional hazards that may need to be addressed when schools are used for other purposes and examples of appropriate mitigation methods. Many States and Territories provide advice / guidelines for principals to follow.
- There will be an established and operational emergency management organisation in place appropriate to the size of school and documented emergency procedures which adequately address
    - means to promptly instigate an evacuation upon activation of an automatic alarm detection /alarm system if provided
    - means to promptly alert all occupants and instigate an evacuation upon manual detection of a fire.
    - staff training to a high level with any temporary staff also made aware of their responsibilities in the event of a fire and receive the necessary induction and training to facilitate an effective response to a fire emergency which should include;
        - an understanding of how to raise an alarm in the event of a fire and the emergency procedures to be followed during a fire (and other emergencies).
        - knowledge of the fire protection measures in place including locations of exits

11.3. DETAILED DOCUMENTATION OF THE FIRE SAFETY STRATEGY

The fire safety strategy needs to be clearly defined in a single document that can be updated if necessary. It should go beyond simply listing systems to identify expected performance and required commissioning and maintenance processes. For performance designs this is particularly critical to ensure all required enhancements to systems are implemented. It should also include critical design requirements for the Emergency Management Organisation and fire safety procedures etc.

11.4. DESIGN REVIEW SCHEDULE

Designs often need to be modified during a project and some modifications that are considered to be trivial may have a significant impact on fire safety. It is therefore prudent to define a design review schedule and required documentation to capture these types of variations

11.5. CONSTRUCTION AND COMMISSIONING

As can be seen in Figure 18 the construction and commissioning process is complex and involves many practitioners of different skill levels, Strategies should be put in place to ensure and document the correct implementation of all components of the strategy and verify any interactions between the component parts of the strategy

11.6. BUILDING MANAGEMENT

Building management can be split into two pathways;

Maintaining fire safety equipment

Managing the relevant human resources.

Both these pathways are critical to maintaining the effectiveness of the fire safety strategy.

11.6.1. Fire Safety Equipment

Maintenance procedures should be specified in the design documentation to ensure that fire safety equipment will be adequately maintained, and consideration should be given to specification of audit procedures especially for more complex buildings

11.6.2. Emergency Management Organisation

Human response is often a critical component of a strategy and the establishment / maintenance of an effective Emergency Management Organisation and training regime needs to be addressed in the strategy document and as for the fire safety equipment for more complex buildings consideration should be given to prescribing audit procedures.

APPENDICES

Appendix A. **Definitions**

A1. NCC Terms

These definitions have been reproduced from the NCC but where appropriate supplementary content has been provided in boxed brackets to clarify the definitions further in relation to this report.

Design Fire means the quantitative description of a representation of a fire within the *Design Scenario*.

Design Scenario (Reference *Design Scenario***)** means the specific scenario of which the sequence of events can be quantified, and a fire safety engineering analysis conducted against.

Performance Requirement means a requirement which states the level of performance which a *Performance Solution* or Deemed-to-Satisfy Solution must meet.

Performance Solution means a method of complying with the *Performance Requirements* other than by a Deemed-to-Satisfy Solution.

[the term *Performance Solution* refers to the entire building including and management procedures that are required to ensure the fire safety strategy satisfies all the relevant NCC *Performance Requirements* throughout the life of the building and must address all variations from the Reference DTS compliant Building]

Reference Building, for the purposes of Volume One, means, depending on the application, a *hypothetical building* that is used to calculate the maximum allowable annual energy load, or maximum allowable annual greenhouse gas emissions and determine the thermal comfort level annual energy consumption for the proposed building

[or in the context of the FSVM, a hypothetical building that complies with the fire safety Deemed-to-Satisfy building and is used as a benchmark for the assessment of a *Performance Solution* using the *Fire Safety Verification Method*]

Verification Method means a test, inspection, calculation or other method that determines whether a *Performance Solution* complies with the relevant *Performance Requirements*

A2. Other Defined Terms

Average Individual Risk in the context of this report has been defined using the following equation.

$$IR = \sum_{i}^{n} {}^{(F_i \, . \, C_i)}/_{p_i}$$

where;
IR Average Individual Risk [year^{-1}]
F_i frequency of scenario *i* provided that $C_i \geq 1$ [year^{-1}]
C_i number of occupants exposed to untenable conditions associated with scenario *i* [-]
n total number of scenarios [-]
p_i is the population exposed to scenario *i*

Building Solution means a solution which complies with the NCC *Performance Requirements* and is a—

(a) *Performance Solution*; or

(b) Deemed-to-Satisfy Solution; or

(c) combination of (a) and (b).

Design fire is a quantitative description of assumed fire characteristics within a design fire scenario

Design fire scenario means a specific fire scenario on which a deterministic fire safety engineering analysis will be conducted

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

Fire growth means the stage of fire development during which the heat release rate and the temperature of the fire are generally increasing.

Fire safety engineer (or Fire Engineer) means a *professional engineer* with appropriate experience and competence in the field of fire safety engineering

Fire safety engineering means application of engineering principles, rules and expert judgement based on a scientific appreciation of the fire phenomenon, often using specific *Design Scenarios*, of the effects of fire and of the reaction and behaviour of people in order to:

- save life, protect property and preserve the environment and heritage from destructive fire;
- quantify the hazards and risk of fire and its effects;
- mitigate fire damage by proper design, construction, arrangement and use of buildings, materials, structures, industrial processes and transportation systems;
- evaluate analytically the optimum protective and preventive measures, including design, installation and maintenance of active and passive fire and life safety systems, necessary to limit, within prescribed levels, the consequences of fire.

Fire Safety Level is a general term which can be considered the reciprocal of the fire risk such that if the risk to occupants from fire is reduced the fire safety level is increased.

Fire Safety Strategy means a combination of physical fire safety measures and human measures / factors including maintenance and management in use requirements which have been specified to achieve the nominated fire safety objectives.

Fire scenario means a description of the course of a fire with respect to time identifying key events that characterise the studied fire and differentiate it from other possible fires.

Fire scenario cluster means a subset of fire scenarios, usually defined as part of a complete partitioning of the universe of possible fire scenarios

Fully developed fire means the state of total involvement of the majority of combustible materials in a fire.

Heat release means the thermal energy produced by combustion (kJ).

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

High-rise Building means, in the context of this report, a building of 3 storeys and above. Note; This definition of high-rise incorporates 3-8 storey buildings which are sometimes referred to as mid-rise buildings.

Individual risk is the frequency at which an individual may be expected to sustain a given level of harm from the realisation of a specified hazard.

Performance-based design brief (PBDB) means a process and the associated report that defines the scope of work for the fire safety engineering analysis and the technical basis for analysis as agreed by stakeholders. Note: The term Fire Engineering Brief (FEB) was used in the IFEG 2005 and other related guidance material for the equivalent of a PBDB. The PBDB is a general term relating to all disciplines

Representative fire scenario means a specific fire scenario selected from a fire scenario cluster such that the consequence of the representative fire scenario can be used as a reasonable estimate of the average consequence of scenarios in the fire scenario cluster

Societal risk is the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards. In the context of the ABCB Tolerable risk criteria of VM V1.0 the “given population” is the population of the subject building(s)

A3. General Abbreviations

ABCB	Australian Building Codes Board
ASET	Available Safe Egress Time
BCA	Building Code of Australia (now part of the NCC)
DTS	Deemed to Satisfy
FED	Fractional Effective Dose
FSVM	Fire Safety Verification Method in the NCC
IFEG	International Fire Engineering Guidelines
NCC	National Construction Code
NFPA	National Fire Protection Association
PBDB	Performance Based Design Brief
PBDR	Performance Based Design Report
QRA	Quantitative Risk Assessment
RSET	Required Safe Egress Time
RTI	Response time index

Appendix B. **Proposed Part A8 for NCC 2022**

B1. Draft Part A8 of Governing Requirements dated July 2020

(note: proposed modifications based on a preliminary review

Part A8 Quantification of the fire safety Performance Requirements

Introduction to this Part

This Part includes the quantified metrics that must be used to interpret the fire safety Performance Requirements listed in A8.1 that are not quantified or say *to the degree necessary*. The degree necessary is the degree that achieves the requirements of this part.6

A8.1 Application of Part

(a) **A8.2** of this Part applies to the interpretation of *Performance Requirements* CP1, CP2, CP3, CP4, CP5, CP6, CP7, CP8, CP9, DP4, DP5, DP6, DP7, EP1.1, EP1.2, EP1.3, EP1.4, EP1.6, EP2.1, EP2.2, EP3.2, EP4.1, EP4.2, EP4.3, GP4.1, GP4.2, GP4.3, GP4.4 and

(b) **A8.3** of this Part applies to the interpretation of *Performance Requirements* CP1, CP2, CP3, CP8, CP9, EP1.4.

(c) This Part does not apply where—

(i) a *Performance Solution* is achieved by a demonstrating that the solution is at least *equivalent* to the *Deemed-to-Satisfy Provisions* in accordance with **A2.2(1)(b)**); or

(ii) the *Assessment Method* used to assess a *Performance Solution* is shown to comply with the relevant *Performance Requirements* in accordance with **A2.2(2)(d)**).

A8.2 Fire safety

As a result of a fire occurring within a building, the risk of exposure of occupants to untenable conditions must not exceed the values provided in Table A8.2a and Table A8.2b, with consideration of—

(a) the following hazards, building characteristics and occupant characteristics:

(i) function or use of the building;

(ii) fire load;

(iii) potential fire intensity;

(iv) height of the building;

(v) number of storeys;

(vi) location in alpine areas;

(vii) proximity to other property;

(viii) size of any fire compartment / floor area;

(ix) other elements providing structural support;

(x) number, mobility and other occupant characteristics;

(xi) travel distance;

(xii) exit above and below ground; and

(b) the following prevention / intervention measures hazards:

(i) control of linings, materials and assemblies to maintain tenable conditions for evacuation;

(ii) occupants intervention using firefighting equipment (fire hose reels and fire extinguishers);

(iii) automatic fire suppression;

(iv) emergency services intervention:

A. emergency services access;

B. fire hydrants;

C. fire control centres;

D. automatic notification of (Emergency Services) Fire Brigade;

E. emergency lifts; and

(c) the following means of managing the consequences:

(i) maintain building structural stability;

(ii) avoid spread of fire to exits;

(iii) protection from spread of fire and smoke to allow for orderly evacuation as appropriate or as part of defend in place strategies or provisions of temporary refuges for occupants requiring assistance to evacuate;

(iv) behaviour of concrete external walls in fire;

(v) provide barrier protection from high hazard service equipment;

(vi) provide protection to emergency equipment;

(vii) fire protection of openings and penetrations;

(viii) provision of exits;

(ix) construction of exits;

(x) provision of fire isolated exits;

(xi) provisions for paths of travel to, through and from exits;

(xii) evacuation lifts;

(xiii) automatic warning for sleeping occupants

(xiv) safe evacuation routes; options for consideration include one or more of the following if necessary:

A. smoke detection

B. smoke management systems

C. automatic suppression

(xv) visibility in an emergency – emergency lighting;

(xvi) identification of exits – exit signage; and

(xvii) emergency warning and intercom systems.

Table A8.2a Allowable individual risk of exposure to untenable conditions

Number of people exposed to untenable conditions	**Individual risk per annum (lower tolerable limit)**	**Individual risk per annum (upper tolerable limit)**
≥1 (building classification 2,3,4, 9a or 9c)	5.0×10^{-6}	5.0×10^{-4}
≥1 (building classification 5, 6, 7a, 7b, or 9b)	1.0×10^{-6}	1.0×10^{-4}

Table A8.2b Allowable societal risk of exposure to untenable conditions

Number of people exposed to untenable conditions	**Societal risk per annum (lower tolerable limit)**	**Societal risk per annum upper tolerable limit)**
≥5	$8.9\text{x}10^{-7}$	$8.9\text{x}10^{-5}$
≥10	$3.2\text{x}10^{-7}$	$3.2\text{x}10^{-5}$
≥20	$1.1\ \text{x}10^{-7}$	$1.1\ \text{x}10^{-5}$
≥50	$2.8\ \text{x}10^{-8}$	$2.8\ \text{x}10^{-6}$
≥100	$1.0\ \text{x}10^{-8}$	$1.0\ \text{x}10^{-6}$
≥200	$3.5\ \text{x}10^{-9}$	$3.5\ \text{x}10^{-7}$
≥500	$8.9\text{x}10^{-10}$	$8.9\text{x}10^{-8}$
≥1000	$3.2\text{x}10^{-10}$	$3.2\text{x}10^{-8}$

Note:

Both the Individual and Societal Risk Criteria must be satisfied.

If the lower tolerable limits (individual and societal) ~~is satisfied~~ are not exceeded by the proposed *performance solution* the individual and societal risk criteria can be considered to have been satisfied ~~no further analysis is required~~

If the upper tolerable limits (individual ~~and~~ or societal) ~~is~~ are exceeded by the proposed *performance solution* the individual or societal risk criteria have not been satisfied and modifications to the proposed solution will be required.

If the individual and / or societal risks presented by the proposed *performance solution* lie between the lower and upper allowable risks the proposed *performance solution* can be considered to have been satisfied if the following additional criteria is satisfied if it can be demonstrated that:

The individual and / or societal risk presented by the proposed *performance solution* is less than or equal to that presented by a similar *Deemed-to-Satisfy* compliant reference building that is considered to represent a tolerable risk ~~can be undertaken obtained with the reference building the design is considered acceptable~~

A8.3 SPREAD OF FIRE

(a) A building must avoid the spread of fire between buildings such that:

(i) The probability of a *reportable fire* in a building causing heat fluxes greater than the values listed Table 8.3a must not exceed 0.001 at the stated distance from the boundary on an adjacent allotment or at the distances between buildings on the same allotment.

(ii) The probability of a building not being able to *withstand* the heat flux in Table 8.3a for a period of 30 minutes must not exceed 0.01

(b) The probability that the external façade of a building cannot *withstand* the following exposures from *reportable fires* must not exceed 0.001:

A. flames venting through an opening from an enclosure fire within the building;

B. burning items adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas;

C. a fire occurring on a balcony.

(c) A building must avoid the spread of fire within the building such that when a reportable fire occurs, the probability of fire spread does not exceed-

(i) 0.01 to spread outside of an SOU;

(ii) 0.01 to spread between storeys; and

(iii) the values in Table 8.3b.

Table A8.3a Maximum heat flux

Maximum heat flux(kW/m^2)	Distance from Boundary (m)	Distance between buildings on the same allotment (m)
80	0	0
40	1	2
20	3	6
10	6	12

Table A8.3b Fire spread limits to manage fire spread

Building Classification	Floor Area	Volume	Maximum probability of spread beyond specified floor area and volume
5, 9b	3000m^2	18000m^3	0.01
6,7,8, 9a,9c	2000m^2	12000m^3	0.01
5-9	18,000m^2	21000m^3	0.001
9a patient care areas and Class 9c	1000m^2	-	0.01

New definitions

Individual risk means the frequency at which an individual may be expected to sustain a given level of harm from the realisation of a specified hazard.

Societal risk means frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards.

Reportable fire means a fire that would be reported to the fire brigade ~~and is not already extinguished when the fire brigade arrives.~~

For inclusion in NCC Guide **-** *If a fire is reported to the fire authorities, they are required to respond and therefore the number of reportable fires corresponds to the number of fires attended by the fire authorities. It should be noted that a large proportion of fires occur and are dealt with by occupants and the fire brigades are not called. These small fires that are extinguished by occupants or self-extinguish are not defined as reportable fires.*

Withstand in the context of A8.3(a) means that in response to an imposed fire action the following conditions must not occur;

- ~~Extent and velocity of fire spread is detrimental to the safe egress evacuation of occupants or fire service intervention in an area away from the floor and/or room of origin.~~ Fire spread more than 5m above an opening in the façade through which flames are venting. (The risk to life of occupants and as appropriate impact on emergency service intervention as a result of the extent and velocity of fire spread should be evaluated under A8.2)
- Fire Spread more than 2m beyond the extent of flames from a burning item adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas
- Ignition and propagation as the result of the imposed heat flux from a fire in an adjacent building or potential building on an adjoining allotment (embers are likely to be present and therefore piloted ignition should be considered if combustible materials are present).
- Ignition and fire propagation within cladding materials and building cavities.
- Release of flaming droplets.
- Release of significant quantities of debris (criteria should be developed during the PBDB process having regard for the proximity of other property and the requirements of the emergency services. The risk to life of occupants evacuating the building from falling debris should be evaluated under A8.2).
- Structural failure.

B2. Determination of Untenable conditions for Occupants

The above draft of Part A8 expresses the risk criteria for occupants in terms of the risk to exposure to untenable conditions but does not provide a definition of tenable (or untenable).

The NCC FSVM applies two tenability criteria at a height of 2 m above floor level:

- conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 or where the distance to an exit is 5 m or less, where visibility may fall to 5m. The FSVM handbook [8] indicates that the visibility should be calculated assuming backlit exit signs.

- a fractional Effective Dose FED for thermal effects greater than 0.3. The FSVM handbook refers to ISO 13571:2012 [17] for guidance on determining the FED;

In an absolute analysis the results can be sensitive to assumed tenability criteria and preliminary analysis showed that a substantial difference in outcomes could be expected between the visibility criteria and the FED concept applied to thermal effects and exposure to toxic species.

Considering the visibility criteria, if a smoke layer falls to slightly below 2m and visibility in the hot smoke layer falls below 10m it is unlikely that an occupant will be seriously injured let alone be exposed to life threatening conditions unless exposure is prolonged or the conditions deteriorate considerably.

However, the selection of the risk criteria for occupants in Part A8 was based on fatality rates and therefore the application of visibility criteria would be expected to over-predict fatalities by over an order of magnitude. For example based on fire incident data in Appendix C the ratio of injuries requiring hospitalisation to fatalities is of the order of (35:1).

Tenability criteria were therefore based on the fractional effective dose (FED) concept as defined in ISO13571 [17] for both exposure to heat and toxic species (based on CO concentrations).

ISO 13571 defines tenability in terms of the ability of humans to perform cognitive and motor-skill functions at an acceptable level when exposed to a fire environment.

The fractional effective dose (FED) of 1 as defined in ISO 13571 means that the conditions would be classified as untenable for 50% of the population (i.e. cognitive and motor-skill functions would be significantly compromised.

Assuming a log-normal distribution as suggested in ISO 13571 in the absence of other relevant data, exposure to a FED of 0.3 means that the conditions would be expected to be classified as untenable for approximately 11.4% of the population.

The situation is further complicated by:

- the variability of product species produced by fires
- simplifications required to model smoke spread
- superimposed airflows that influence smoke spread through a building.
- occupant vulnerability (e.g. younger primary school students may be more susceptible)

To address these limitations initially three tenability criteria were investigated as detailed below which were subsequently reduced to Level 1 and Level 3:

Level 1 Visibility criteria applied at 2m above floor level – serious injuries unlikely to occur unless occupants are in intimate contact with fire

Level 2 Smoke layer height above 1.5m and no level 3 criteria are exceeded - serious injuries are unlikely to occur unless occupants are in intimate contact with the fire, but occupants may be exposed to some relatively minor level of harm. (the use of this level was of limited value and was subsequently not included in the final analysis.

Level 3 Fractional Effective Dose of 0.3 with respect to thermal exposure or exposure to carbon monoxide or flashover occurring within the fire compartment or disproportionate collapse of the building or a substantial part of the building.

Flashover has been included since it is a significant factor in determining the fire hazard associated with a fire scenario as noted by Drysdale [18]. There is a relatively high probability that occupants are exposed to life threatening conditions if these criteria are exceeded. Similarly, if disproportionate collapse of a building occurs there will be a high probability that any remaining occupants will not survive.

The level 3 criteria were used to determine if the risk to life criteria within Part A 8 were satisfied noting that at 0.3 FED there is likely to be an appreciable safety factor to allow for uncertainties of approximately an order of magnitude.

The level 1 criteria are more appropriate for design purposes since the design of buildings should minimise the risk of non-fatal injuries as well as fatalities. A check was therefore made during the derivation of the strategy for scenarios with fire mitigation measures operating effectively to determine if there is sufficient opportunity for occupants to evacuate provided the mitigation measures operate effectively.

Appendix C. Fire Statistics, Incident Data and Related Information

C1. Australia

C1.1. Number of Schools and Students

The following data was derived from Australian Bureau of Statistics Report 4221.0 – Schools, Australia 2018 and the related data sets[19] and ABS report 3101.0 [20]

The Australian Population in Sept 2018 was approximately 25,101,900

Table 19 Number of Primary and Secondary Schools in Australia 2018

School Type	NSW	Vic.	Qld	SA	WA	Tas.	NT	ACT	Aust.
Primary	2107	1547	1137	453	678	157	78	83	6240
Secondary	513	339	259	78	136	42	22	25	1414
Combined	310	243	269	160	201	55	82	21	1341
Special schools	171	109	80	25	79	7	6	5	482
Total	**3101**	**2238**	**1745**	**716**	**1094**	**261**	**188**	**134**	**9477**

Table 20 Number of Full Time Equivalent Primary School Students by Grade for 2018

Year (Grade)	**Total Students - FTE**
Pre-Year 1 (Foundation Year)	321,938
Year 1	314,817
Year 2	314,059
Year 3	315,934
Year 4	313,228
Year 5	316,331
Year 6	310,004
Year 7 primary	20,083
Ungraded primary	20,766
Primary School Total	2,247,160

Table 21 Number of Full Time Equivalent School Students for 2018 and Average School Size

School Level	**Total Students - FTE**	**Ave Students / School**
Primary School	2,247,160	360
Secondary School	1,641,394	1160
Total	3,888,554	508

C1.2. Enrolment Sizes of Primary Schools and Student Teacher Ratios

The following data was derived from Australian Bureau of Statistics Report 4221.0 – Schools, Australia 2018 and the related data sets[19].

Table 22 Enrolment Sizes for Primary Schools

PRIMARY ENROLMENT RANGE	NSW %	Vic. %	Qld %	SA %	WA %	Tas. %	NT %	ACT %	Aust. %
1–35	14.3	10.1	17.1	6.6	9.0	3.8	25.6	---	12.3
36–100	12.3	12.2	15.0	15.7	11.2	18.5	10.3	7.2	13.0
101–200	15.0	18.6	10.6	18.5	18.1	23.6	15.4	14.5	15.9
201–400	30.5	31.0	21.5	34.7	34.5	42.7	32.1	36.1	30.1
401–600	16.6	17.4	16.3	17.0	19.3	10.2	15.4	32.5	17.1
601+	11.2	10.7	19.5	7.5	7.8	1.3	1.3	9.6	11.6
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The Student to Teacher staff ratios provided in Table 23 are an indicator of the level of staffing resources used and are not a measure of class size. They also do not take into account teacher aides and other non-teaching staff who may also assist in the delivery of school education and assist with evacuation

Table 23 Student to Teacher Ratios for Primary Schools

State/Territory	Student to Teaching Staff Ratio
NSW	15.4
Vic.	14.3
Qld	14.7
SA	15.1
WA	15.5
Tas.	14.8
NT	13.0
ACT	15.3
Aust.	14.9

C1.3. Fire Losses

Few fire statistics are published in Australia and the limited data available tends to focus on high risk occupancies such as homes and residential properties.

However indicative estimates of the fire risks in primary schools in terms of injuries requiring hospital treatment can be derived from Pointer and Tovell [21] from which the data presented in Table 24 to Table 26 has been derived.

Typically, the age of primary school students varies from 5 to 12 years which lies within the bands of 5 to 9 and 10-14 in the extracted tables. The injuries for these two age bands that occurred in schools, other institutions and public administration areas was 6 for the year 2013-2014 which will therefore tend to provide an overestimate of the injuries in primary schools.

Table 24 Number of hospitalised burn cases, by place of occurrence and age, Australia, 2013–14

Place of occurrence	0–4	5–9	10–14	15–24	25–44	45–64	65+	Total
Home	638	146	85	243	596	400	241	2,349
Residential institution	1	0	2	5	9	3	19	39
School, other institution and public administration area	9	0	6	4	17	31	18	85
Sports and athletics area	0	2	3	6	8	1	2	22
Street and highway	11	6	4	51	65	40	13	190
Trade and service area	16	2	3	86	85	48	5	245
Industrial and construction area	1	0	1	25	69	36	4	136
Farm	2	7	2	21	24	21	12	89
Other specified place of occurrence	48	14	11	63	98	57	12	303
Unspecified place of occurrence	235	78	76	387	665	387	144	1,972
Total	**961**	**255**	**193**	**891**	**1,636**	**1,024**	**470**	**5,430**

Table 25 Type of external cause for hospitalised burn cases, by age, Australia, 2013–14

Age group	Exposure to smoke, fire and flames		Contact with heat and hot substances		Other external causes of burn injury	
	Number	%	Number	%	Number	%
0–4	108	6.8	758	31.2	95	6.7
5–9	60	3.8	148	6.1	474	3.3
10–14	57	3.6	84	3.5	52	3.7
15–24	331	20.9	284	11.7	276	19.5
25–44	586	37.1	535	22.0	515	36.3
45–64	316	20.0	396	16.3	312	22.0
65+	122	7.7	228	9.4	120	8.5
Total	**1,580**	**100**	**2,433**	**100**	**1,417**	**100**

Table 26 Hospitalised burn cases, by cause of burn, Australia, 2013–14

Type of external cause	All Ages		Age 5-9		Age 10-14	
	Number	%	Number	%	Number	%
Exposure to smoke, fire and flames	1,580	29.1	60	23.6	57	29.5
Contact with heat and hot substances	2,433	44.8	148	58.0	84	43.5
Other external causes	1,417	26.1	47	18.4	52	27.0
Total	5,430	100.0	255	100	193	100

For the age group 10-14, 29.5% of burn cases resulted from exposure to smoke, fire and flames and therefore it will be assumed that approximately 1.8 injuries that required hospitalisation; (6 x 0.295), occurred in primary schools due to accidental fires during the 2013-2014 year.

An indicative individual risk of injury per year in a primary school due to an accidental fire will therefore be estimated to be approximately 1.8 / 2,247,160 = 8.0 x 10^{-7}.

The Report of Government Services [3] included data from 2015 relating to fire injuries requiring hospitalisation and fire fatalities. There were 3416 hospital admissions and 97 fatalities due to fire yielding a ratio of approximately 35 injuries to 1 fatality. If this ratio is applied to the individual risk of injury derived above it would yield an individual risk to life for a primary school student / year due to accidental fires of 2.2×10^{-8} which is substantially less than the lower tolerance limit for Individual Risk proposed for Section A8 of NCC of 1×10^{-6} (refer Section 2.1)

Since the data sample size in Australia is relatively small for infrequent events such as injuries and fatalities resulting from fires in schools and relevant published data is limited, the above estimate has been supported by data from other countries such as the US and UK.

C1.4. Australian Fire Statistics (1989 – 1993)

Despite the publication of Australian Statistics being very limited some reasonably comprehensive data was published between 1989 and 1993 which was analysed by Dowling and Ramsay[22]. It included fire statistics for Educational buildings (Schools and further education facilities combined). Whilst this data is approximately 30 years old some indicative estimates can be obtained

During the four-year period there were 1384 reported fires recorded (345 /annum) in educational facilities. The statistics were estimated to provide approximately 85% coverage of actual fires and therefore this reported rate should be increased accordingly. Conversely a proportion of education buildings relate to tertiary education facilities and therefore the number of reported fires occurring in school buildings would be less than the reported number for education facilities. To derive a crude estimate of the frequency of fires it was assumed that approximately 85% of educational facilities are schools. Therefore, adjustments for coverage of the statistics and the proportion of school buildings will tend to balance out and it will therefore be assumed that approximately 345 reportable school fires occur / annum during this period.

ABS report 4221.0 - Schools Australia, 1992 [23] indicates that there were an average of 9981 schools and 3071920 students between 1990 and 1992 providing an indicative frequency of fire of 345 / 9981 = 0.035 fires / annum and an average school size of 308 students.

C2. United States

C2.1. Numbers of Schools and Students

The following data was derived from the Digest of Education Statistics (Tables 101.10, 205.40 and 216.20)[24] for 2009 and 2015 and applies to Elementary and Secondary Schools only

US population 2009: 306,772,000

US population 2015: 325,344,000

Table 27 Number of Elementary and Secondary Schools in the US

School Type	Private 2009	Public 2009	Total 2009	Private 2015	Public 2015	Total 2015
Elementary	21420	67140	88560	21910	66758	88668
Secondary	2780	24651	27431	2950	24040	26990
Combined	9160	5730	14890	9720	6788	16508
Other	10	1296	1306	0	590	590
Total	33370	98817	132187	34580	98176	132756

Table 28 Number of Students Attending Elementary and Secondary Schools in the US

School Type	Private 2009	Public 2009	Total 2009	Private 2015	Public 2015	Total 2015
Elementary	2,937,090	31,547,988	34,485,078	2,892,010	32,225,908	35,117,918
Secondary	785,810	15,930,401	16,716,211	774,650	15,731,561	16,506,211
Combined	1,765,590	1,542,734	3,308,324	2,083,870	2,049,039	4,132,909
Other	0	1,094,055	1,094,055		3,263	3,263
Total	5,488,490	50,115,178	55,603,668	5,750,520	50,009,771	55,760,291

Elementary schools correspond to Australian Primary Schools

From Table 202.30 of the Digest of Education Statistics in 2013 there were 7,450,000 children under the age of 5 in centre-based care and a further 1,721,000 in family childcare in another home.

C2.2. Topical Fire Report School Building Fires (2009-2011)

A topical report on School Building Fires collating data predominantly from the National Fire Incident Reporting System was published by the US Federal Emergency Management Agency (FEMA)[15].

School properties as defined in this study included the following (Australian description in brackets);

- Preschools and day-cares
- Kindergartens
- Elementary schools (primary schools)
- Middle junior and high schools (secondary schools)
- Other non-adult schools

During this period there was an average of 10,300 school property fires a year of which approximately 39% related to school buildings (approx. 4000 / annum). Fires relating to school buildings are most relevant to this study.

The topical report indicates that one reported fire death occurred outside on school property resulting from suicide by fire with the other four reported deaths during the period 2009-2011 occurring in a residential day care facility in 2011.

The proportion of fires by facility type was provided from which the frequency of reported fire starts was estimated in Table 29

Table 29 Frequency of fires by Education facility Type (2009-2011)

Education Facility Type	Approx. number of fires / annum	Number of Schools	Frequency of reported fire starts / annum	Average number of students / schools
Pre-school & Day Care	728			
Elementary School	1120	88560	0.013	389
Middle Jun / Highschool	1744	42321	0.041	473

The topical fire report compared losses for school buildings against other non-residential buildings yielding the results summarised in Table 30.

Table 30 Fire Losses for School Buildings compared to Other non-residential buildings (2009-2011)

Loss Parameter	School Building fires	Other non-residential building fires (excluding schools)
Fatalities / 1000 fires	0.4	1
Injuries / 1000 fires	13.5	9.8
Dollar loss / fire	14,060	27,350

The 0.4 fatalities relate to a childcare facility with no fatalities occurring within elementary school (primary school) buildings which are the subject of this report

An approximate estimate of individual risk to children from fires in school buildings can be obtained by dividing the number of fatalities a year by the number of children attending the schools.

There were 1.33 fatalities / annum that occurred in a residential care facility with approximately 1,721,000 children exposed to the risk yielding an individual risk of fatality / annum for a child attending a family day care centre of 7.72×10^{-7} which is less than the lower general tolerance limit of 1×10^{-6}. It should be noted that the building in which the four fatalities occurred was a domestic house and when the fire occurred there were no adults on the premises which is not representative of a primary school.

Since there were no other fatalities in schools during the 3-year period it is indicative of a very low individual risk which will be very sensitive to individual events.

If the 1.33 fatalities / annum are apportioned over the total school population (approximately 55 million) the individual risk of death / annum to a child whilst at school or pre-school from fire would be approximately 2.4×10^{-8} which is consistent with the estimate for primary schools based on the limited Australian data.

The US fire statistics classify fires as confined and non-confined fires. Confined fires are small fires confined within cooking pots, fireplaces and other non-combustible containments. Approximately 62.9% of school building fires were classified as confined with the remaining 37.1% having potential for fire spread and further growth.

The statistics also identify the extent of spread of fire with

- 74.9% confined to the object of origin
- 17.5% confined to the room of origin and
- 7.6 % spreading beyond the room of fire origin

If it is assumed that for flashover to occur fire spread beyond the room of fire origin has to occur (an approach described by Apte et al[25] for determining the proportion of flashover fires) the proportion of flashover fires can be estimated to be approximately 7.6% of reported fires assuming no automatic suppression.

C2.3. Structure Fires in Educational Properties (NFPA report)

An analysis of fires in education properties was undertaken by Campbell[26] for the period 2011 to 2015. Educational properties in this study included the following (Australian description in brackets);

- Day care centers;

- Nursery schools
- Elementary schools (primary schools)
- Middle, junior, and high schools;(secondary schools)
- College classroom buildings and adult education centers.

During the period US fire departments responded to 4980 fires in educational properties /annum.

Campbell [26] indicates that the fires caused an average of one reported fire death per annum and 70 civilian injuries. Since a multi fatality fire in a day care centre occurred in 2011, it is likely this event accounts for most if not all fatalities between 2011 and 2015 and the same incident was included in the Topical Fire Report School Building Fires (2009-2011) [15].

The proportion of fires by facility type was provided from which the frequency of reported fire starts was estimated in Table 31 for selected education facilities.

Table 31 Frequency of fires by Education facility Type (2011-2015)

Education Facility Type	Approx. num. of fires / annum	Num. of Schools	Frequency of reported fire starts / annum	Average num. of students / school
Day Care	548	-	-	
Pre-school	200	-		
Elementary School	1120	88668	0.013	396
Middle / High school	1670	42321	0.039	487
Other non-adult	440	-		
Adult education / college classroom	647			

Campbell compared losses for school buildings from which the results summarised in Table 32 have been calculated.

Table 32 Fire Losses for School Buildings (2011-2015)

Loss Parameter	Pre-school	Elementary Schools	Middle / High school
Reported Fires	200	1120	1670
Injuries / 1000 fires	0	10	25
Property loss / fire-US$	5,000	18,000	11,000

Since there were no reported fatalities in elementary (primary schools) during the period the individual risk of death during this period can be assumed to be < 1 / 35,117,918 =2.8 x 10^{-8}.

The individual risk of injury per year in an elementary school due to an accidental fire was approximately 10 x 1.12 / 35,117,918 = 3.2 x 10^{-7}.

The individual risk of injury per year in a high school due to an accidental fire has been estimated to be approximately 25 x 1.67 / 16,506,211 = 2.5 x 10^{-6}.

Table 33 presents data on the number of fires and losses by the time of day provided by Campbell which has been split into two time periods with significantly different fire and loss patterns.

Table 33 Fires and Associated Losses by time of Day 2011-2015

Time of day	Fires Num	Fires %	Injuries Num	Injuries %	Property damage - US$M	Property damage -%	Property damage / fire US$k
7:00-7:59 a.m.	140	4.0%	5	9.3%	$1	2.2%	$7
8:00-8:59 a.m.	220	6.4%	2	3.7%	$0	0.0%	$0
9:00-9:59 a.m.	290	8.4%	3	5.6%	$2	4.4%	$7
10:00-10:59 a.m.	330	9.5%	14	25.9%	$1	2.2%	$3
11:00-11:59 a.m.	350	10.1%	9	16.7%	$0	0.0%	$0
12:00-12:59 p.m.	340	9.8%	7	13.0%	$1	2.2%	$3
1:00-1:59 p.m.	300	8.7%	6	11.1%	$3	6.7%	$10
2:00-2:59 p.m.	270	7.8%	2	3.7%	$1	2.2%	$4
3:00-3:59 p.m.	190	5.5%	4	7.4%	$3	6.7%	$16
4:00-4:59 p.m.	160	4.6%	0	0.0%	$2	4.4%	$13
5:00-5:59 p.m.	130	3.8%	1	1.9%	$1	2.2%	$8
7.00am-6pm	**2720**	**78.6%**	**53**	**98.1%**	**$15**	**33.3%**	**$6**
6:00-6:59 p.m.	120	3.5%	0	0.0%	$2	4.4%	$17
7:00-7:59 p.m.	100	2.9%	0	0.0%	$3	6.7%	$30
8:00-8:59 p.m.	80	2.3%	0	0.0%	$1	2.2%	$13
9:00-9:59 p.m.	70	2.0%	0	0.0%	$3	6.7%	$43
10:00-10:59 p.m.	60	1.7%	0	0.0%	$1	2.2%	$17
11:00-11:59 p.m.	50	1.4%	0	0.0%	$2	4.4%	$40
Midnight-12:59 a.m.	40	1.2%	0	0.0%	$0	0.0%	$0
1:00-1:59 a.m.	30	0.9%	0	0.0%	$5	11.1%	$167
2:00-2:59 a.m.	30	0.9%	0	0.0%	$4	8.9%	$133
3:00-3:59 a.m.	30	0.9%	0	0.0%	$3	6.7%	$100
4:00-4:59 a.m.	30	0.9%	1	1.9%	$1	2.2%	$33
5:00-5:59 a.m.	40	1.2%	0	0.0%	$3	6.7%	$75
6:00-6:59 a.m.	60	1.7%	0	0.0%	$2	4.4%	$33
6.00pm – 7am.	**740**	**21.4%**	**1**	**1.9%**	**$30**	**66.7%**	**$41**
Total	3460	100.0%	54	100.0%	$45	100%	$13

From 7am to 6pm whilst the school is expected to be staffed with numerous occupants;

- 78.6% of fires occur
- 98.1% of injuries occur
- 33.3% of property losses occur

This is the critical period for analysis from a life safety perspective.

From 6pm to 7am the school is expected to be effectively closed unless additional functions are held and during this time;

- 21.4% of fires occur
- 1.9% of injuries
- 66.6% of property losses occur

This period is more critical if property loss is considered.

Therefore, when assessing individual and societal risk to the occupants of a school it is reasonable to assume approximately 21% of fires will occur when the school is unoccupied and the risk to occupants does not need evaluating.

The property damage is expected to correlate approximately with the fire size. The average property damage per fire outside the hours a school is likely to be occupied is approximately 7 times the property damage when occupied indicating that most serious (and fully developed fires) occur when the building is unoccupied.

Campbell derived the leading causes of fires in schools together with the associated losses which are presented in Table 34. It should be noted that the % values do not sum to 100% because not all causes are presented, and some causes may be common to the same scenario.

Intentional and playing with heat sources present the most significant risk to life and property. Unfortunately, this data does not separate the elementary school statistics and the proportions may differ to the middle / high schools.

Table 34 Leading Causes of fires in schools 2011-2015

Leading Cause	Fires - Num	Fires - %	Injuries-Num	Injuries - %	Prop Damage - US$Millions	Property Damage -%
Intentional	1,550	45%	25	43%	$18	37%
Cooking equipment	990	29%	6	11%	$1	2%
Playing with heat source	680	20%	11	19%	$14	28%
Heating equipment	330	10%	7	12%	$3	7%
Electrical distribution & lighting equipment	300	9%	5	9%	$6	12%
Smoking materials	110	3%	1	1%	$5	11%

For the development of fire scenarios during the Hazard ID process the area of fire origin and associated losses requires consideration. Table 35 has been prepared from data presented by Campbell and indicates the increased hazard associated with unconfined fires. Unconfined or non-confined fires refers to fires that were not contained to a small area (i.e. not small insignificant fires)

Cooking equipment (38% of fires) and intentionally set fires (36%) were the leading cause of fires in educational properties. Fires that were intentionally set accounted for the highest shares of civilian injuries (37%) and direct property damage (31%). More than two of five fires (44%) in educational properties occurred between 9 a.m. and 2 p.m.

One-quarter (25%) of the fires in educational properties began in a lavatory or locker room, accounting for 17% of civilian injuries and 2% of direct property damage. One-fifth (20%) of fires began in a kitchen or cooking area, with these fires causing 14% of injuries to civilians and 3% of direct property damage, as shown in Figure 3 and Table 10. Fires that began in a laboratory caused 2% of fires, but 21% of civilian injuries (and 3% of direct property damage).

Table 35 Area of Origin and Confined Status by School Fires

Area of Origin	Total Fires	Total Fires %	Total Inj.	Total Inj. %	Non Conf. Fires	Non Conf. Inj.	Conf. Fires	Conf. Inj.
Lavatory, locker room or check room	1080	31	12	21	360	7	720	4
Kitchen or cooking area	470	14	7	13	60	1	410	5
Small assembly area, less than 100m^2	150	4	4	7	80	4	60	0
Unclassified outside area	140	4	0	0	30	0	110	0
Unclassified area of origin	110	3	1	2	50	1	70	0
Trash or rubbish chute	110	3	3	5	10	2	110	1
Heating equipment room	90	3	1	2	30	0	60	1
Hallway, corridor, or mall	90	3	0	0	40	0	50	0
Unclassified function area	80	2	0	0	40	0	40	0
Exterior roof surface	70	2	1	2	60	1	0	0
Office	60	2	1	2	30	1	30	0
Other known area of origin	970	28	26	46	630	25	340	1
Chimney or flue	10	0	0	0	0	0	10	0
Total	3430	100	56	100	1420	42	2010	12

Table 36 Extent of Flame Spread for School Fires

Area of Origin	Total Fires	Total Fires %	Total Inj.	Total Inj. %	Dir. Prop Dam $M	Dir. Prop Dam/fire $1000	Inj. / 1000 fires
Confined fire identified by incident type	2000	58	13	22	0	-	6.5
Confined to object of fire origin	510	15	10	17	2	8	19.6
Confined to room of origin	630	18	29	51	9	50	46.0
Confined to floor of origin	70	2	1	2	3	42	28.6
Confined to building of origin	190	6	2	3	31	163	10.5
Beyond building of origin	30	1	2	4	3	100	66.7
Total	3430	100	56	100	48	14	16.3
Total beyond room of fire origin	290				37	127	

In the most recent NFPA report on the U.S. Experience with Sprinklers, Marty Ahrens estimated that sprinklers were present in 39% of the fires reported in educational properties (2010-2014). The report found that 97% of fires in educational properties with sprinkler systems were confined to the room of origin, compared to 88% of fires in educational properties with no sprinkler system. A crude estimate of the average reduction in direct property losses due to the presence of sprinklers can be made by assuming a reduction in the average loss from the largest 9% of fires from US$127,000 to US$50,000 = US$77,000. Therefore, the reduction in direct losses / reportable fire would be approximately U77,000 x 0.09 i.e. approx. $US7,000 (A$10k).

C3. United Kingdom

C3.1. Numbers of Schools and Students

The data presented in Table 37 relating to the number of schools and pupils was derived from Education and training statistics for the UK: 2018 [27].

The UK population in mid-2017 was approximately : 66,000,000 [28]

Table 37 Number of Schools and Students in the UK in 2018

School Type	Number of Schools	Number of pupils
Nursery	3,037	145,400
Primary	20,863	5,548,600
Middle	13	12,200
Secondary	4,190	3,853,200
Non-maintained mainstream	2,404	595,200
Special schools	1,258	131,600
Pupil referral units	352	16,700
Total	**32,117**	**10,302,900**

The number of primary and secondary school students in England in 2002 was 8,187,227 and the total number of schools in England was 25,615 [29].

Total number of UK schools in 2000/01 was 34,715 from education and training statistics for the UK: 2018 [27].

Since the reporting of UK fire statistics has varied over time there is a mix of data available relating to schools and schools plus further education facilities and reported for either UK, Great Britain or England.

To analyse the fire statistics the geographic distribution of schools and students has been derived for the 2016/17 year in Table 38 and the numbers of students in schools has been compared with the number of full time students in further education in Table 39. The part-time students were excluded because the proportion of time they spend at the education facility will vary and the impact of this exclusion would be to overestimate the individual risk to occupants.

Table 38 Geographic Distribution of Students and Schools in the UK for 2016/2017

Geographic Area	Student - numbers	Students -%	Schools numbers	Schools - %
England	8,669,080	84.5	24,281	75.6
Wales	475,889	4.6	1,617	5.0
Scotland	781,371	7.6	5,045	15.7
Northern Ireland	333,500	3.3	1,170	3.6
Great Britain	9,926,340	96.7	30,943	96.4
Total - United Kingdom	10,259,840	100.0	32,113	100.0

Table 39 Distribution between school students and full-time further education students in the UK for 2016/17

Education Facility	Full-time students	Full time students - %

Schools	10,259,840	84.8
Further education full time	1,834,600	15.2
Total	12,094,440	100.0

Note Excludes 607,700 part-time further education students

C3.2. Building Bulletin 100: Design for fire safety in Schools – Fire Statistics

The following is a summary and analysis of the fire statistics relating to school fires which were included in Building Design Bulletin 100 [30].

Figure 19 shows a plot of the number of school fires between 1993 and 2005.

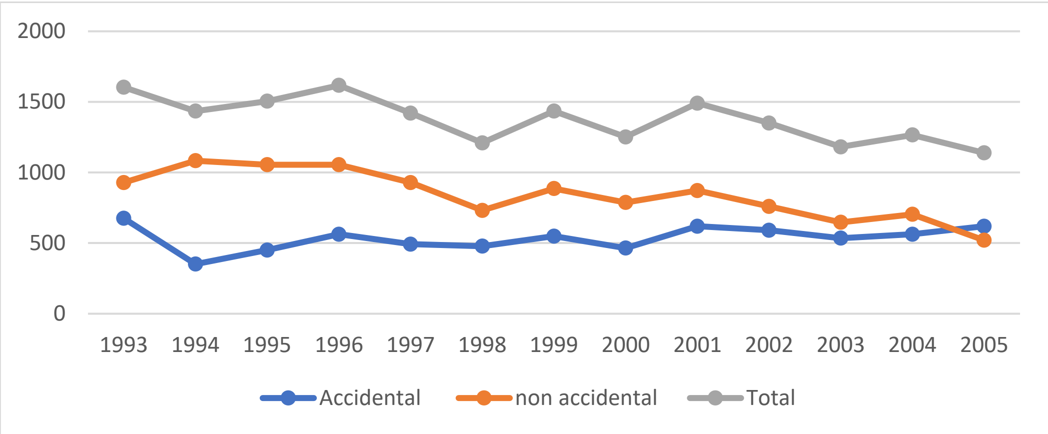


Figure 19 Number of School Fires in the UK between 1993 and 2005

An indication of the frequency of school fires per year can be obtained by assuming the number of fires occurring in 2000/2001 is the average for year 2000 and 2001 values from Figure 19 and assuming the number of schools is 25,615 from Section C3.1 yielding an average frequency of all fires 0.05 fires /annum.

During the period 1994 to 2002 only one person died in 14,700 fires yielding a fatality rate of approximately 0.07 fatalities /1000 fires. The fatality was a 56-year-old which occurred close to the point of origin in a roof space where the person had been working with a blow torch or similar heat source.

Since the fatality was not a student or teacher it is not appropriate to estimate the individual risk of fatality /annum for a student based on this event but the average frequency of a fatality occurring in a school between 1994 and 2002 can be estimated to be approximately; 0.07 /1000 x 0.05 = 3.5 x 10^{-6} fatalities / annum. It should be noted that more recent statistics discussed below show a substantial reduction in the frequency of fires to 0.02 fires / annum / school and no fatalities occurred in school fires for the eight-year period from 2010 to 2018.

During the period between 1994 and 2002 an average of 51 injuries occurred (approx. 30 injuries / 1000 fires). This injury rate was less than all other occupancies except for offices and car parks during this period.

A breakdown of the injuries for 2002 during which there were 46 injuries is summarised Table 40.

Approximately 29 injuries requiring treatment were due to either smoke inhalation or burns and data is not provided as to the severity of the injuries or need for hospital admissions. From these statistics it can be estimated that the average individual risk of injury to students due to smoke inhalation or burns from fires in a UK school for 2002 was 29 / 8,187,227 = 3.54 x 10^{-6}

The annual direct fire losses from school fires in the UK for the period 2000-2004 was £58 million yielding a loss of approximately £45,000 /fire. These losses exclude additional costs such as hiring alternative accommodation etc.

Data on the locations of fires in schools based on fire statistics from 2002 were also included in Building Bulletin 100 [30] from which the data in Table 41 was derived.

Table 40 Break Down of Injuries from UK School Fires in 2009

Injury	Number	Percentage
Smoke inhalation	14	30.4
Burns	5	10.9
Physical injuries	4	8.7
Shock	2	4.3
Other injuries	2	4.3
Precautionary checks	19	41.3
Total	46	99.9[1]

Note 1 Rounding Error

Table 41 Locations of Fires in Schools in UK 2002 from Building Bulletin 100 [30]

Locations of fires	% of reported fires
Classroom	29
Cloakroom /toilets	15
Storeroom	11
Kitchen Canteen	10
Circulation spaces	7
Boiler /Plant room	5
Main hall / place of assembly	5
Office	5
Other	13
Total	100

C3.3. Fire Statistics from Great Britain and England

General Fire Statistics have been published by the UK Government with the most recent collections covering Great Britain from 2010 to 2014[31] and England from 2014 to 2018[31]

For the four-year period 2010/11 to 2013/14 data was provided specifically relating to schools throughout Great Britain from which Table 42 has been prepared

Table 42 Fire Statistics for Schools in Great Britain 2010 to 2014

Statistic	2010/11	2011/12	2012/13	2013/14	Ave
Total fires	686	584	579	554	601
Total Injuries	24	23	30	21	25
Fatalities	0	0	0	0	0
Injuries /1000 fires	35	39	52	38	41

There were no fatalities during this period and the Injuries per 1000 fires averaged 41.

Using the 2016/2017 data from Table 38 it will be assumed that there were 9,926,340 students and 30,943 schools

The average frequency of reported fires in schools in Great Britain for the four-year period 2010 -

2014 was 601 / 30,943 (i.e. approximately 0.02 fires /annum / school). The average individual risk of injury / annum during this period can be estimated to be 25 / 9,926,340 (i.e. approximately 2.52 x 10^{-6})

For the eight-year period from 2010/11 to 2017/18 the school statistics and further education fire statistics were grouped but accidental and deliberate fires were identified as shown in Table 43 for England. There were no fatalities in educational facilities which includes all school types including primary schools and the injuries / 1000 fires averaged 38.

Using the 2016/2017 data from Table 39 and applying a 0.85 reduction factor since the statistics relate only to England it will be assumed that there were 12,094,440 x 0.85 students (approximately 10,280,274 students). The average individual risk of injury /annum due to fire in educational facilities during this period can be conservatively estimated to be approximately 28 / 10,280,274 (i.e. approximately 2.72 x 10^{-6}).

Table 43 Fire Statistics for Education Facilities in England 2010 to 2018

Statistic	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Ave
Accidental	-	600	602	572	508	527	552	540	557
Deliberate	-	221	170	127	136	125	137	142	151
Total	**855**	**821**	**772**	**699**	**644**	**652**	**689**	**682**	**727**
Accidental Inj.	-	18	28	20	22	26	10	14	20
Deliberate Inj.	-	10	4	1	1	6	5	21	7
Total Injuries	**35**	**28**	**32**	**21**	**23**	**32**	**15**	**35**	**28**
Fatalities	0	0	0	0	0	0	0	0	**0**
Inj. /1000 fires	41	34	41	30	36	49	22	51	38

For the period from 2000/2001 to 2013/14 statistics on the extent of injuries were also provided from all fires indicating approximately 46% were due to burns and or being overcome by smoke but the proportion of injured people admitted to hospitals could not be found. This general proportion is comparable to 41.3% of injuries relating to burns and or being overcome by smoke in school fires in 2009.

C4. Derivation of Inputs and Analysis of Statistics

C4.1. Frequency of Reported Fire Starts and Average Number of Students

A practical method to quantify and compare the frequency of significant fire starts is to express the frequency in terms of the frequency of reported fires / school /annum. This has the advantage of the ready availability of statistics on the number of schools, number of students and number of reported fires.

It is expected that the rate of reported fires will increase to some extent based on the number of students in a school and therefore the average size of the schools in terms of student numbers should also be estimated to compare statistics from various sources.

The results from the statistics derived in Sections C1 to C3 are summarised in Table 44

Table 44 Comparison of frequency of reported fires

Source / Country	Years	Frequency of reported fires / school / annum	Average size of school - students
Australia Primary and Secondary	1989-1993	0.035	308
Australian Primary Schools	2018	-	360
US FEMA - Primary	2009-2011	0.013	389
US-FEMA Secondary	2009-2011	0.041	473
NFPA - Primary	2011-2015	0.013	396
NFPA - Secondary	2011-2015	0.039	487
Great Britain Primary & Secondary	2010-2014	0.02	320
UK Primary and Secondary	2000-2001	0.05	320

There has been a downward trend in the number of building fires and associated losses over the last 20 years. For example, the Department for Communities and Local Government [31] estimated that fires in buildings that were not dwellings have declined by more than half compared to that in 2003-04.

The estimates for the frequency of fires in the UK and Australia, dating from 1989-1993 and 2000-2001 are therefore expected to significantly overestimate current rates and estimates will be based on more recent statistics.

The US data (where separate statistics are available for primary and secondary schools are available) shows that the rate of fire starts / school / annum is significantly higher in secondary schools. This can partly be attributed to the larger size of secondary schools, but the rate of fires / student would still be significantly greater.

The frequency of reported fires for Australian Primary schools (R) will be assumed to be of the order of 0.013 fire per school / annum with an average school size of 360 students.

For the proposed school layouts, a typical floor or module holds 120 students and therefore the frequency per floor or module / annum will be assumed to be 0.0043.

C4.2. Individual Risk Estimates from Fire Statistics

Individual risk can be expressed 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 NCC section A8 nominates a lower limit of 1×10^{-6} below which the risk is considered acceptable without additional justification and an upper limit of 1×10^{-4}. Above the upper limit the risk is considered unacceptable. Between the upper and lower limits, a comparative study against a reference building considered to present an acceptable risk is required.

The applicable level of harm is exposure to untenable conditions and since the above limits were derived from consideration of fatalities the level of harm equates to death and frequency is per year.

The statistics analysed indicate that deaths resulting from fires in educational facilities are very rare and tend to occur under unusual circumstances.

For example,

- only one fatality could be identified in the UK data which occurred to a tradesperson carrying out hot works in a ceiling cavity who was near the fire
- The only fatalities reported in the US Topical Fire Report School Building Fires (2009-2011)

related to a day-care centre fire – not a school. (Press reports indicate a fire in a day-care facility occurred in Houston in 2011 killing four children at a time when there was no supervision within the building. e.g. New York Daily News [32])

- The Structure Fires in Educational Properties (2011-2015 NFPA report) indicates on average one fatality / year occurs in all educational facilities including day-care centres and specifically identifies an average fatality rate over the period in day care centres as 1 fatality / year. This is therefore likely to be accounted for by the Houston fire in 2011 with four fatalities.

To provide a context for the lower tolerable risk limit, if there is an individual risk of a fatality of a student / annum in a primary school of 1×10^{-6}, over the long term the average fatalities / annum could be expected to approximate to the values calculated in Table 45. The calculated fatality rates / annum are substantially higher than values derived from the published statistics analysed in the previous sections indicating that the tolerable risk limit is being met with the existing buildings. It should however be noted that since fatalities are rare the statistics are likely to be very sensitive to a specific event such as the Houston family day care fire.

Table 45 Calculated fatalities / annum in Primary schools assuming an individual risk to students of 3.39×10^{-07}

Geographic area	Number of primary school students	Average calculated fatalities / annum assuming individual risk of 1×10^{-6}
Australia	2,247,160	2.3
United Kingdom	5,548,600	5.6
US	35,117,918	35.1

Since the frequency of injuries is higher than fatalities it is useful to compare the individual risk derived from fire statistics by adopting injury as the harm parameter although the results will be sensitive to the definition of injury.

From Table 40, in 2009 in the UK there were 46 injuries due to fires in schools of these approximately 41% were directly related to either smoke inhalation and or burns, a further 41% were precautionary checks with the remainder being attributable to physical injury, shock and other injuries.

The US data does not provide a breakdown of the severity of injuries so it could not be determined if the injuries were precautionary checks, shock or other injuries. Therefore, no adjustments were made to allow for precautionary checks

The Australian estimates were based on hospital admissions for burns and smoke inhalation and therefore may understate minor injuries that did not require admission to hospital however the age group selected would include some secondary school students which may therefore overstate the number of injuries.

Table 46 compares indicative estimates for the individual risk of injury from school fires derived from various data sets.

Table 46 Comparison of Individual Risk of injury from School fires

Geographic area / data set	Individual risk of injury from a school fire /annum $\times 10^{-7}$
Australia 2013; hospitalised burn and smoke inhalation cases -Primary school age	8.0[1]
US 2009-2011 All schools	8.2
US 2011-2015 Primary schools	3.2
US 2011-2015 Secondary schools	25.0
United Kingdom – All schools	25.2 (10.0)[2]

Note 1 Estimated based on hospital admissions for burns and smoke inhalation
Note 2 Value in brackets excludes precautionary checks and relates to burns and smoke inhalation injuries only

Table 47 compares indicative estimates of injuries / 1000 fires from school fires derived from various data sets.

Table 47 Comparison of Injuries / 1000 school fires

Geographic area / data set	Injuries /1000 fires
Australia	-
US 2009-2011 All schools	12.5
US 2011-2015 Primary schools	10
US 2011-2015 Secondary schools	25
United Kingdom – All schools England 2010 to 2018	38 (16)[1]

Note 1 Value in brackets excludes precautionary checks and relates to burns and smoke inhalation injuries only

Considering the variations in practices for the collection of data, the low frequency of injuries and potential differences in construction practices the individual risk estimates and injuries /1000 fires from the three countries are broadly consistent and if no more relevant data is available it is reasonable to make use of the more detailed fire statistics from the US and UK and related publications for Hazard Identification purposes and to derive inputs for the quantitative analysis.

A value for injuries /1000 fires (h_i) of 10 will be assumed for an average Australian primary school (360 students).

An indicative value for the average individual risk can then be obtained from

$IR_i = R.\ h_i / 1000 / n$ **Equation 1**

Where;

IR_i is the individual risk of injury for a student from a school fire / annum

R is the rate of reportable fires / annum

h_i is the number of injuries /1000 fires

n is the number of students.

Assuming R = 0.013, hi = 10, n = 360 yields

$IR_i = 3.61 \times 10^{-7}$

This value of the Individual risk of injury is consistent with the estimate for a primary school in Table 46 and indicates the risk of injury is very low and corresponding risk of fatality would be substantially lower.

If a ratio of 35 to 1 is assumed for injuries to fatalities based on estimates derived from the Report on Government Services in Section C1.3 the estimated Individual Risk of death due to fire in a school can be estimated to be of the order of 1×10^{-8}.

C4.3. Fires Outside Normal School Hours

From Section C2.3 approximately 21% of fires were estimated to occur outside normal school hours (6pm-7.00am) but only 1.9% of injuries occurred during this period despite 66.7% of property losses occurring.

When considering life safety the analysis will focus on the 79% of fires occurring between 7am and 6pm and fire modelling of scenarios outside these hours will only be undertaken when determining compliance with the fire spread metrics from Section 2 .

C4.4. Growth Rates of Fires

Holborn et al [33] undertook an analysis of fire sizes, fire growth rates and times between events using data from fire investigations in the Greater London area between 1996 and 2000 recorded in London Fire Brigade's real fire library. The data included the results from 35 school fires. Whilst this sample size is small and over 20 years old it provides a useful basis for initial estimates which can be further validated against other fire statistics where practicable.

A t-squared fire is defined by the following equation;

$$Q=\alpha t^2 \qquad \textbf{Equation 2}$$

Where Q is the heat release rate (HRR) – kW, t is the time – s and α is the proportionality constant (fire growth parameter) - kW/s^2.

A characteristic growth time (t_g – s), which is the time taken for the *Design Fire* to reach a reference heat release rate Q_g of 1055kW is also used to define t-squared fires in a way that can be more readily related to a fire scenario and can be converted to the proportionality constant using the following equation.

$$\alpha = Q_g / t_g^2 \qquad \textbf{Equation 3}$$

Whilst the proportionality constant can be derived for a specific application it is common to categorise a t-squared fire as Slow, Medium, Fast and Ultra-fast as indicated in Table 48. The very slow growth category and clusters of growth times assigned to each growth category used by Holborn et al [33] for analysis of fire growth rates using data from fire investigations has been presented in Table 48

Table 48 Distribution of t-squared fires for Schools

Growth Category	% of fires derived from Holborn for classroom	Proportionality constant α (kW /s^2)	Growth time T_g (s)	Growth Time Range Cluster (s)
Very slow	40	0.000412	1600	>1600
Slow	47	0.00293	600	400-1600
Medium	9	0.0117	300	200-400
Fast	4	0.0470	150	100-200
Ultra-fast	0	0.188	75	<100

C4.5. Location of Fires and Identification of Low Risk Fires

UK and the US fire statistics include data on the area of fire origin but use differing terminology. The data from Table 35 and Table 41 has been assigned to the area descriptions used for the generic buildings selected for the QRA. Fires that occurred in unspecified areas were redistributed and the data combined to yield Table 49.

Where appropriate judgements had to be made during the redistribution rather than distributing unknown fire locations proportionately to address areas such as storerooms which were only identified in one of the data sets and flexible learning areas / circulation spaces which did not correspond directly to the descriptions adopted in the statistics.

Table 49 also includes the % of confined fires obtained from the US fire statistics. The following description was provided by Ahrens [34] of a confined type of fire:

"NFIRS confined fire incident types are used to describe cooking fires confined to the vessel of origin, confined chimney or flue fires, confined trash fires, confined fuel burner or boiler fires, confined commercial compactor fires, and confined incinerator fires"

Table 49 Area of Fire Origin for design fires

Area of Origin	Fires %	Confined fires %	Confined % of all fires	Non- Confined % of all fires
Amenities	30.7	67	20.6	10.1
Kitchen or cooking area	15.1	87	13.1	2.0
General Learning Areas (Classrooms)	24.7	40	9.9	14.8
Plantroom	4.0	67	2.6	1.3
Flexible learning area / circulation space	12.3	50	6.1	6.1
Office	4.9	50	2.5	2.5
Storeroom	8.4	35	2.9	5.5
Total	100	-	57.7	42.3

For structure fires in schools, injuries /1000 fires have been estimated to be 6.5 for confined fires compared to an average of 31 for non-confined fires based on data from Campbell [26]. For the period 2007-2011 Ahrens [34] estimated there were 7.1 Injuries /1000 fires in pre-school through grade 12 buildings which includes the primary school age group for fires confined to the object of fire origin or defined as a confined fire type. It is reasonable to attribute these injuries to people that are close or in intimate contact with the fire and under these circumstances effective mitigation methods need to focus on fire prevention rather than fire protection measures.

As the metrics for life safety are based on fatalities it is necessary to consider a broader range of non-residential occupancies since no fatalities occurred in the equivalent of primary schools during the period 2007-2011.The fatality rate / 1000 fires for all non-residential properties for fires confined to the object of fire origin or of the confined type was 0.18 /1000 fires compared to average rates for all fire sizes varying from 0.1 for all education properties to 1.4 for industrial and storage occupancies. The fatalities in these circumstances as for the injuries are likely to have resulted by people being close to or in intimate contact with the fire.

Based on the above discussion it is considered reasonable to assume the risk of fatalities from confined fires and fires contained to the object of fire origin is sufficiently low in educational facilities that no further quantification is required. The proportions of confined type fires for fires in specific locations are provided in Table 49 and an additional 15% of fires will be assumed to be confined to the object of fire origin based on extent of fire spread statistics for schools from Campbell[26]. This 15% was distributed to allow for smaller proportions of fires confined to the object of origin where the proportion of designated confined fires is high and larger proportions of fires confined to the object of origin where the proportion of designated confined fires is low having regard for the nature of the contents and use within the area as shown in Table 50.

Table 50 Distribution of Confined fires and fires and fires confined to the object of fire origin

Area of Origin	Fires %	Confined fires %	Confined to object of origin %	Confined and confined to object of origin %
Amenities	30.7	67	15	82
Kitchen or cooking area	15.1	87	3	90
General Learning Areas (Classrooms)	24.7	40	20	60
Plantroom	4.0	67	13	80
Flexible learning area / circulation space	12.3	50	20	70
Office	4.9	50	15	65
Storeroom	8.4	35	15	50
Total	100			

C4.6. Fire Sizes and Proportion of Flashover Fires

General Estimates

Holborn et al. also derived log normal distributions for the fire damaged areas which enabled the percentage of fires above a specified size to be calculated. The size of fire for flashover to occur varies with the size of enclosure amongst other things. The correlation and calculations for schools and all non-residential buildings are presented in Table 51.

For small enclosure sizes a value of 10m^2 of fire damage is considered reasonable for a preliminary estimate of the proportion of fully developed fires. For large enclosures a damage area of 100m^2 may be more appropriate and for intermediate /mixed sizes 20m^2. On this basis for non-sprinkler protected school buildings the estimated probability of flashover would be approximately 11%

Table 51 Extent of fire damage and estimate of proportion of fully developed fires

Occupancy	Num of fires	Log normal distribution. parameters			% of fires with damage greater than			Encl. Size Class	Est. Prob. of FO %
		Mean	SD	E(x)	10m^2	20m^2	100m^2		
Schools	34	0.69	1.89	12	19.7	11.1		M	11
All (excl residential)	441	0.92	1.99	18	24.4	14.8		M	15

An alternative approach is to consider the proportion of fires where spread occurred beyond the room of fire origin. Ahrens[35] estimated that sprinklers were present in 39% of the fires reported in educational properties (2010-2014). The report found that 97% of fires in educational properties with sprinkler systems were confined to the room of origin, compared to 88% of fires in educational properties with no sprinkler system. This infers that the probability of flashover would be approximately 12% without sprinkler protection.

Detailed estimates of Fire Sizes and Proportion of Flashover Fires

The proportion of flashover fires will vary between different rooms or functional areas with a higher proportion occurring in smaller enclosures with higher concentrations of combustible contents and more ignition sources. A more detailed analysis taking account of these factors has been undertaken below;

The Heat release rate for flashover Q_{FO} (kW) was calculated using the following relationship derived by Peacock[36] from early work by McCaffrey but adopted a upper layer temperature at flashover of 600°C

$$Q_{FO} = 740(h_k A_T A_w H^{1/2})^{1/2}. \text{ Equation 4}$$

where
A_T is the internal surface area of the enclosure (m^2)
A_w is the Area of ventilation opening (window or door) (m^2)
H is the height of ventilation opening (m)
h_k is the Effective heat transfer coefficient ($kW/m^2 \cdot K$).

For a growing fire, a semi-infinite approximation can used with $h_k = (k\rho c/t)^{1/2}$

where
k is the thermal conductivity of the lining (kW/mK) – (0.25 W/mK from Thomas [37]
c is the heat capacity lining (kJ/kg/K) - 0.95 kJ/kg/K from Thomas[37]
ρ is the density kg/m^3 ($600 kg/m^3$ assumed standard grade)
t is the characteristic time taken as approximately 200s

which yields a value for h_k of 0.027 ($kW/m^2 \cdot K$). The properties of plasterboard vary considerably over the range of temperatures the linings are exposed to and lining materials other than plasterboard may be also be used. A uniform distribution varying between 0.017 and 0.037 $kW/m^2 \cdot K$ was adopted to take this variability into account.

The generic layouts can be consolidated into three types of enclosures for detailed analysis as shown in Table 52. The distributions for the Type 2 and 3 enclosures were taken from Appendix 3 based on Canadian studies and the Type 1 was based on a review of typical design schedules for Australian primary schools.

Table 52 Consolidation of Enclosures and Inputs for determining distributions of the minimum HRR required for Flashover

Enclosure Type	Description	Minimum Floor area-m^2	Maximum Floor area-m^2	Mean Floor area-m^2	Standard Deviation - m^2	Distribution Type
Type 1	Small rooms including stores, Kitchen / food preparation area, offices, Amenities	10	20	15	-	Uniform
Type 2	General Learning Area (classroom)	21.8	104.2	76.8	22.5	Normal
Type 3	Libraries / Flexible Learning / General circulation	87.8	185.5	128.9	44.1	Normal

Enclosure heights for Type 2 and 3 enclosures assume uniform distributions with a minimum ceiling height of 2.7m taken from minimum design requirements specified by some Education departments and a maximum value of 3m. For the smaller type 1 enclosure, a uniform distribution with a minimum ceiling height of 2.4m and a maximum of 2.7m was adopted. It is acknowledged that there could be some local areas with minimum heights of 2.1m but these would be unlikely to apply for the whole enclosure.

Door heights opening areas were assumed to be 2.05m to reflect height limitation specified to allow doors to be more easily operated. Opening widths were based on 0.85m minimum door widths to allow for wheelchair access. For the analysis of flashover fires, it was assumed that a minimum of one door would be fully open to provide an adequate air supply for fire growth to the point of flashover. Where more than one door was provided uniform distributions were adopted allowing a distribution between one door and all doors being open.

These distributions were input into equation 4 to determine the minimum heat release rate required for flashover using a multi-scenario and the distributions presented in Figure 20 were obtained.

Distributions for the peak HRR from non-flashover fires were obtained using the Log Normal coefficients derived by Holborn for schools which are summarised in Table 51 assuming a heat release rate per m^2 of $250kW/m^2$. The percentage of scenarios where flashover could occur was then estimated based on a multi-scenario analysis by comparing the peak HRR obtained from the Holborn correlation for schools with the HRR required to achieve flashover yielding the following;

Type 1 Small rooms including Stores, Kitchens, Offices, Amenities ……. 27% (18% adopted)

Type 2 General Learning Area (Classrooms)………………………………..14.8% (15% adopted)

Type 3 Libraries / Flexible Learning / General Circulation Areas ……………9.8% (12% adopted)

This estimate is not consistent with the general estimates for schools that do not consider differences in enclosure sizes. The scale of the Type 1 enclosures is similar to room sizes in domestic dwellings and the contents and ignition sources in these areas also have some similarity to dwellings. In view of the limited data the percentage of flashover fires in Type 1 enclosures will therefore be assumed to be approximately 18% based on estimates for dwellings reported by Apte[25].

From Section C2.3 approximately 21% of fires were estimated to occur outside normal school hours (6pm-am) but only 1.9% of injuries occurred during this period despite 66.7% of property losses occurring. It therefore follows that there will be a disproportionate number of large fires at times when the school is unoccupied. Outside occupied hours small fires would either self-extinguish (and not be reported) or grow to larger fires since early intervention would be unlikely. The proportions of fires during occupied and unoccupied periods have therefore been estimated by assuming that 66.7% of fires that progress to flashover occur outside the times the school is occupied.

To avoid unnecessary duplication of the analysis the areas of fire origin were consolidated into three Types of Enclosure which are described in Table 53 along with details of the design fires for analysis. The design fires were derived using the following process for the times when the building is occupied.

a) the confined fires and fires confined to a single object were derived from the statistics. For the Type 1 enclosures the proportion of fires was the total for all the small enclosures and the confined fires percentage was estimated by proportioning the confined fires for each of the types of room.

b) The proportion of the flashover fires was estimated as described above and the table shows the daytime use proportion adjusted for the 79% of fires that occur during the hours the school is occupied

c) A fast growth rate was assumed for all the flashover fires. The proportion of fast fires was slightly higher than the estimates based on Holborn which will provide a level of conservatism.

d) The proportion of fires with a medium growth rate were derived from Holborn and used directly.

e) The very slow and majority of slow growth fires were assumed to apply to the confined fires and fires confined to the object of fire origin which do not require further analysis. The remainder of the slow growth fires were allocated to a slow growth group of fires that was assumed to progress to large flaming (non-flashover) fires.

f) The peak heat release rate for the medium growth non-flashover fires was based on a nominal 5th percentile of the distribution of fire sizes required for flashover. (actual values varied from 3.8 percentile for large enclosures to 7.1% for small enclosures – refer Figure 20)

g) The peak heat release rate for the slow growth fires assumed that the highest 9% of estimated peak HRRs that were not treated as flashover fires applied to the medium growth rate fires. The peak HRR for slow fires, that were not confined or confined to a single item were then assumed to be below the threshold of the 9% range attributed to medium growth fires.

The outcomes are summarised in Table 53 Summary of Design Fire Types and Peak HRR and shown in event tree format in Figure 21.

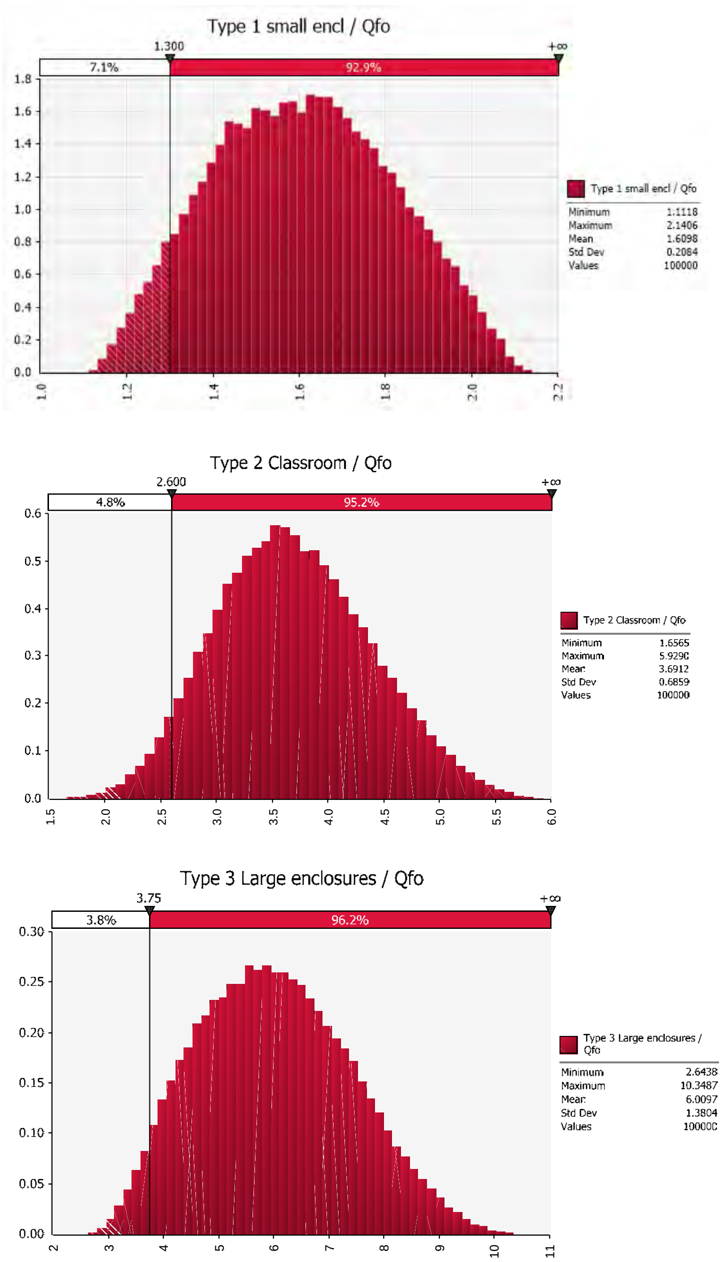


Figure 20 Distributions of minimum heat release rate required for flashover

Table 53 Summary of Design Fire Types and Peak HRR during hours of occupation

Encl. Type	Enclosure Description	Fires %	Proportions of fire by Type %				Peak HRR -MW	
			Confined / confined to SBI	Slow	Med.	Fast / Flashover	Slow	Med
1	Small rooms - stores, kitchen offices, amenities	59	75	8.4	9.0	7.6	1.0	1.3
2	General Learning Area (classroom)	24.7	60	24.7	9.0	6.3	2.2	2.6
3	Libraries / Flexible Learning / General circulation	12.3	70	15.9	9.0	5.1	2.7	3.75
4	Plantroom	4	On separate level					

The burning duration of the capped slow and medium fires was calculated based on the assumption that the duration would be similar to that of a fully developed fire. The total fire load density for primary schools is approximately 426 MJ/m^2 based from Hadjisophocleous [38] and summarised in Appendix I. Assuming a burning rate of 250kW/m^2 yields:

a peak duration for slow and medium non-flashover fires of 426 x 10^3 / 250s = 1704s (≈30 mins)

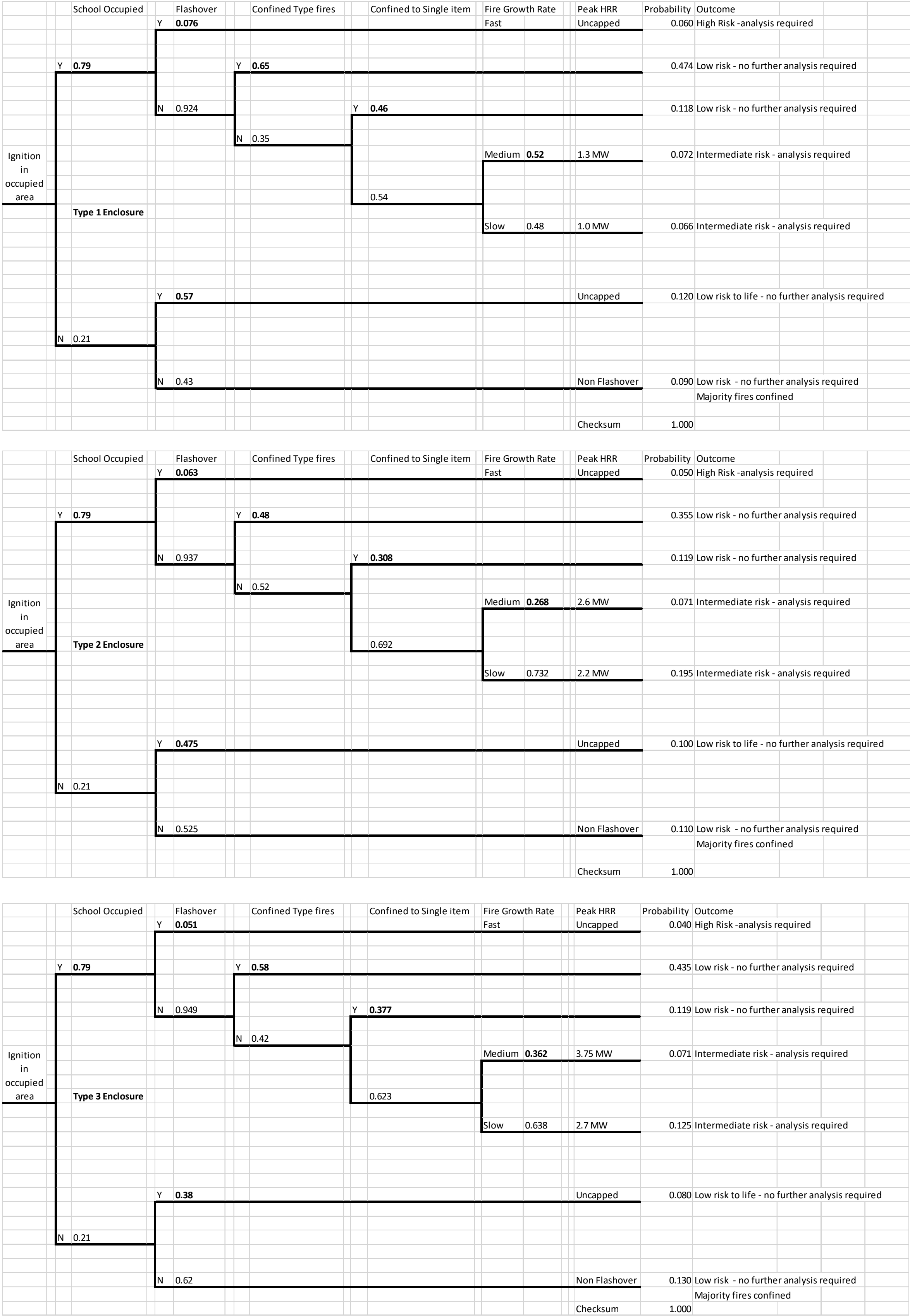


Figure 21 Event trees showing design fire distributions for design enclosures

C4.7. Performance of Sprinklers

When analysing the performance of Automatic Sprinkler Systems, Hall [39] assumed that fires were too small to activate sprinklers if the fire was a contained Type of for non-contained fires the number of fires that were too small to activate the sprinklers was obtained from the fire reports.

For the period 2007 – 2011 there were an average of 2020 fires in educational properties where sprinklers were present and of these there were 440(21.8%) non-contained fires that were too small to operate the sprinklers and 1400(69.3%) cases where the fire was coded as a confined fire leaving 180(8.9%) of fires qualifying as being considered to be large enough to activate a sprinkler head.

The sprinklers operated in 87% of the remaining fires and were effective if they operated in 97% of fires giving an effectiveness of 84%. This is comparable to the estimate of 86% for a typical wet pipe sprinkler system proposed in the ABCB FSVM Handbook Annex data sheets [14] which will be adopted for the analysis.

Since there are very few fire related fatalities in Educational buildings with or without sprinklers reliance has been placed on statistics from all buildings including residential to define the efficacy of sprinklers with reasonable confidence.

Hall identified the following factors that make fatal injuries possible even when sprinklers are present and operate are;

“1. Victims whose actions or lack of action add to their risk by prolonging their exposure to fire conditions, such as victims who:
(a) act irrationally;
(b) go back into the building after safely escaping;
(c) are unable to act to save themselves, such as people who are bedridden or under restraint; or
(d) are engaged in firefighting or rescue;

2. Victims of fires that are beyond the design limits of the system, such as fires that were:
(a) so close that the victim is deemed “intimate with ignition” (a victim condition no longer shown in the data but most closely approximated by “victim in area of fire origin”; they constituted 97% of fatal victims when sprinklers operated vs. 51% of fatal victims when no automatic extinguishing equipment was present;
(b) very fast, such as explosions or flash fires; or
(c) outside the sprinkler-protected area, such as fires originating on exterior areas of the building; and

3. Victims who are or may be unusually vulnerable to fire effects, such as:
(a) older adults, age 65 or older (who constituted 59% of fatal victims when sprinklers operated vs. 30% of fatal victims when no automatic extinguishing equipment was present, in Table 4-2), or
(b) people who are in poor health before fire begins.”

Within a primary school environment with adequate supervision the factors listed in item 1 and item 3 are generally not applicable.

Where people are in close or intimate contact with the fire (item 2), effective mitigation methods need to focus on fire prevention rather than fire protection measures.

It is therefore considered reasonable to assume that if a fire is too small for sprinkler activation or the sprinkler system operates effectively it can be assumed generally that the occupants have been provided with an opportunity to avoid exposure to untenable conditions in buildings such as schools where occupants are expected to be awake. The proportion of such fires approximates to the confined and confined to object of origin values in Table 53.

C5. Comparison of Tolerable Risks with Fire Statistics

C5.1. Estimates of Individual Risk based on Fatalities

Fire statistics (predominately based on existing low-rise buildings) are compared below to the tolerable risks, to determine if the tolerable risk criteria are being met by existing NCC provisions and previous building standards applied to low-rise primary school buildings.

No fire related fatalities within primary school buildings could be identified from the limited Australian data available. As part of a previous study (England 2019 [6]), the State and Territory Administrations were also asked if they were aware of any fatalities or injuries over the last 10-year period, but none were noted. It should be noted that the number of respondents to this question was limited potentially due to privacy issues.

Similar to Australia, fires in primary schools involving fatalities in the UK and US are also very rare with only one fatality identified in the UK relating to a tradesperson carrying out hot works in a ceiling cavity in close proximity to the fire. The only fatalities reported in the US Topical Fire Report School Building Fires (2009-2011) related to a day-care centre fire – not a school. These fatalities are understood to relate to a fire in a day-care facility which occurred in Houston in 2011 killing four children at a time when there was no supervision within the building.

To provide a context for the tolerable risk limits derived in the previous section, if the average annualised individual risk of a fatality of a student in a primary school is 1×10^{-6} an average of 2.3, 5.6 and 35.1 fatalities / annum could be expected in Australia, UK and US respectively. In Appendix C4.2 an estimate of the individual risk of a fatality was made based on the rate of injuries and assuming a correlation with the risk of fatalities yielding an approximate estimate of 1×10^{-8}.

C5.2. Societal Risk Statistics / Multi-fatality Fire Incidents

The NFPA publish details of multi-fatality school fires from kindergarten to year 12 with 10 or more deaths which are summarised in Table 54 together with reports on the events extracted from various publications [40]. It is noteworthy that there were eight events with 10 or more fatalities and two events with more than 100 fatalities in the 50-year period between 1908 to 1958. No fires with 10 or more fatalities have occurred in the 60-year period since 1958. The six fire events are discussed in more detail below:

Table 54 Multi-fatality U.S. school fires with 10 or more deaths

School / Location	Date	Num. of deaths	Type of Event
Lakeview School Collinwood, OH	1908	175	Fire
St. John's Parochial School Peabody, MA	1915	21	Fire
The Cleveland School Kershaw County, South Carolina	1923	77	Fire
Babbs Switch School Hobart, OK	1924	32	Fire
Bath Consolidated School Bath, MI	1927	46	Bombing
Consolidated School, gas explosion New London, TX	1937	294	Gas explosion
Cleveland Hill School Cheektowaga, NY	1954	15	Fire
Our Lady of the Angels School Chicago, IL	1958	93	Fire

Lakeview School Collinwood (175 fatalities)

Lakeview School Collinwood comprised 3 storeys plus a basement with the fire starting in the basement with smoke and flames spreading up the stairway to the upper floors. The building was provided with 2-exits and an external fire escape.

One exit appears to have been compromised by the fire and the second internal exit was blocked with most fatalities occurring at the bottom of this stair. It has been postulated that the door at the base of the stair opened inwards and could not be opened to allow evacuation

St. John's Parochial School Peabody (21 fatalities)

St. John's Parochial School Peabody comprised a 3-storey building plus a basement. There were 672 pupils on the upper three storeys. The fire started in the basement with smoke and fire spread occurring to the ground floor via staircases with combustible linings and no fire separations. The exit stairs discharged within the building and exit paths on that floor were compromised due to fire and smoke spread from the basement. Congestion further delayed egress. There were no automatic detection systems or suppression systems. A series of recommendations were made following an investigation which have subsequently been included in modern building codes and other regulations including provisions such as the following (using current terminology);

- Controls of lining materials
- Fire separation of exit stairways and direct discharge from the building
- Automatic detection and suppression with alarms monitored by fire services and alarms sounding throughout the building
- Fire separation of services / plantrooms
- Requirements for regular drills and emergency procedures

Cleveland School Kershaw County (77 fatalities)

The School comprised a 2-storey framed building nominally 30m x 10m in area. At the time of the fire the building was being used for an event with the upper floor forming an auditorium holding between 200 and 300 occupants at the time of the fire. Oil lamps suspended from the ceiling were used for lighting, and one of these ignited the combustible ceiling with the fire spreading rapidly to the stage area and igniting the stage curtains. There was a single exit from this level with combustible linings and the exit did not maintain a constant width. The exit became congested and subsequently blocked due to the number of people trying to evacuate. Many occupants escaped through the upper storey windows.

Babbs Switch School Hobart (32 fatalities)

The school was a small single storey lightweight timber-structure approx. 7.5m x 11m. At the time of the fire there were estimated to be 200 to 250 occupants attending an event. There was one exit with an inwardly opening door. Oil lamps were used for lighting with additional use of candles. A Christmas tree was ignited, and rapid-fire growth occurred. Windows were covered with steel mesh. The fire exit was effectively blocked, and egress could not be achieved through windows due to steel security mesh

Cleveland Hill School Cheektowaga (15 fatalities)

The fire occurred in an 8-room annex to the main school building. The annex was a single storey lightweight timber-structure approximately 36m x 15m (54m^2) with a central corridor approximately 10m wide. Manual alarm boxes (manual call points) were provided in the corridor to activate a local alarm. At the time of the fire only the music room was occupied by 31 pupils and 3 adults. The fire initiated in an unoccupied room and grew undetected until the fire broke through the closed door flashing down the corridor and entering the music room through an open door. It was impossible to exit via a corridor and teachers broke windows and assisted all but 10 of the occupants to evacuate. Of the 21 pupils evacuated 19 were injured and five later died in hospital. The delayed detection of this fire was identified as the most significant factor in the NFPA Quarterly April 1954 [41] which indicated that the tragedy may have been averted by the provision of an automatic detection or sprinkler system throughout the building activating a local alarm and automatically alerting the fire authorities.

Our Lady of the Angels School Chicago (93 fatalities)

The following details have been extracted from the NFPA quarterly 1959 [42] The fire occurred in the north wing of a 2-storey plus basement school building housing a total of over 1200 occupants with 569 people in the north wing (floor area of approximately 600m^2).

The fire occurred at the bottom of the rear stairway (one of three serving the north wing) and spread rapidly via the stairway after a window in the basement was broken due to heat, increasing the ventilation to the fire. Shortly after discovery it was postulated that flashover occurred on the upper level corridor of the North wing serving six classrooms and entered the shallow roof space. This prevented evacuation of the occupants of five classrooms via internal stairs. The occupants of one classroom in the north wing evacuated earlier, prior to a general building alarm being raised.

Occupants of the first storey evacuated the building relatively easily but the evacuation of the annex and southern wings on the second floor was hampered by smoke passing through a corridor door before it was manually closed.

Some occupants that were trapped in the five classrooms in the upper level of the north wing evacuated externally using ladders or other means but there were 93 fatalities associated with these classes / classrooms.

The following issues have been identified as having contributed to the fire losses;

- Inadequate enclosure of exits
- Inadequate exit capacity (this was not critical to the outcomes since access to the internal stairs was prevented)
- Inadequate choice of egress paths
- Absence of automatic fire sprinkler protection
- Vents in staircases (stair pressurisation is commonly adopted in Australia to achieve similar objectives)
- Absence of automatic detection and alarm system (if sprinkler system not provided)
- Housekeeping
- Delay in raising a fire alarm and notifying fire brigade case an early alarm was raised upon discovery and

A comparison was made to a fire in a 2-storey elementary (primary) school building at Kenilworth that occurred in 1958 with a fire occurring at the bottom of a stairway in which there were no fatalities or injuries. In this case

- the enclosure of the stairs was more effective in restricting smoke spread,
- a building alarm was raised as a first response to discovery of the fire and the fire brigade notified
- an automatic sprinkler system controlled the fire

The above observations have been considered when undertaking the qualitative risk assessment and developing the risk register in Appendix H.

C5.3. Review of Societal Risk Benchmark Options

In Table 55 the approximate return period for a multi-fatality fire occurring at any school within each country has been estimated for reference points of 20, 50 and 100 or more fatalities /annum. Due to the smaller population in Australia the return periods are longer than the US and there is no history of large losses from fires in school buildings.

In the US during the 50 year period 1908-1958 there were 2 school fires with close to or exceeding 100 fatalities, 3 fires with 50 or more fatalities and 5 fires with 20 or more fatalities based on the data summarised in Section C5.2. These losses were not considered acceptable and changes to building standards were subsequently implemented. These correspond to 25,17 and 10 year return periods.

Table 55 Estimated Return period for multi-fatality fires in Schools within Geographic areas based on Upper and Lower tolerable risk criteria

Geographic area	Number of schools	Return period for all schools within each country – years					
		20 or more deaths		50 or more deaths		100 or more deaths	
		Upper L 1.12×10^{-5}	Lower L 1.12×10^{-7}	Upper L 2.83×10^{-6}	Lower L 2.83×10^{-8}	Upper L 1.0×10^{-6}	Lower L 1.0×10^{-8}
Australia	9477	9.4	942	37	3729	106	10552
United Kingdom	32117	2.8	278	11	1100	31	3114
US	132756	0.7	67	3	266	8	753
US fire data 1908-1958	-	10		17		25	

The US population at the midpoint of the 1908 to 1958 was approximately 125 million compared to approximately 325 million in 2015. In 2015 there were approximately 132,756 schools. A crude estimate of the average number of schools between 1908-1958 can be obtained assuming the number of schools is proportional to the population yielding approximately 51060 schools. This yields annual societal risk values per school of 7.8×10^{-7} for N >100, 1.2×10^{-6} for N >50 and 2.0×10^{-6} for N >20,

In the subsequent 62 years a search could not find any records of school fires in the US resulting in large numbers of fatalities. There was one fire in a domestic style childcare centre leading to 4 fatalities If there had been 1 such fire during this period assuming typically an average of 100,000 schools the average frequency / school would have be 1.6×10^{-7}.

C6. Comparison of International Design Codes

C6.1. Overview

Whilst there are many common themes, the detailed implementation and terminology used varies between national codes. A summary of some of the relevant features of each code considered most significant to this study are provided in the following sections.

Section C6.5 includes a comparison with the NCC of the prescriptive fire safety provisions most relevant to this study in Table 58 and

Table 59 for the building configurations considered in the report.

C6.2. United States

There are variations in the Codes adopted between States but generally, either the International Building Code (IBC) or an NFPA code is adopted. In this review the International Building Code 2018 [43] has been referenced.

Primary Schools fall within Educational Group E which applies up to the 12th grade. Therefore, the same provisions apply to both secondary and primary schools as is the case in Australia. There are some differing requirements for day care facilities applying to children older than 2½ but these lie outside the scope of this study.

The fire resistance requirements are based on the type of construction which depends on parameters such as the fire compartment areas, the number of storeys, fire brigade access and occupancy classification. For the building configurations considered in this report;

- the single storey reference building can be of Type V construction the least fire resistant,
- the 5-storey building requires Type IB construction.

Type IA and B construction are broadly similar to the Australia Type A construction and the Type V to Type C construction.

The IBC generally requires educational buildings greater than 1 storey to be sprinkler protected.

Manual call points are required to activate an alarm for a single storey building but partial smoke detection systems are required for multi-storey buildings. In addition, CO detection is required in all classrooms.

Wall and ceiling linings are classified in accordance with ASTM E84 or UL 723 and are grouped in the following classes in accordance with their flame spread and smoke-developed indices.

Class A = Flame spread index 0-25; smoke-developed index 0-450.

Class B = Flame spread index 26-75; smoke developed index 0-450.

Class C = Flame spread index 76-200; smoke developed index 0-450.

Class A provides the most resistance to flame spread and Class C the least. In a similar manner to the NCC concessions are allowed if sprinkler systems are provided.

C6.3. United Kingdom

Approved Documents are issued by the Secretary of State to provide prescriptive solutions for some of the more common building situations in order to satisfy the UK Building Regulations. Approved Document B [44] including Amendments [45] relates to fire safety and Clause 0.27 states “The design of fire safety in schools is covered by Building Bulletin (BB) 100 published by DfES [30]. Part B of the Building Regulations will typically be satisfied where the life safety guidance in that document is followed”. Building Bulletin 100 has therefore been referenced to derive typical prescriptive provisions. The scope of BB100 relates to schools in England and Wales only.

The guidance in BB 100 provides some flexibility and for certain provisions requires an assessment of risk.

The guide indicates that generally reliance can be placed on manual call points rather than an automatic detection system to raise an alarm but for higher risk buildings automatic detection with various extents of coverage may be required.

Subject to less than 60 people being within a room, the maximum dead-end from a room to a choice of direction is typically 18m for a classroom and where there is a choice of direction the total travel distance to an exit should not exceed 45m. Different distances apply to other areas presenting different hazards and corridor dead-ends should be avoided unless compensatory measures are provided (e.g. automatic detection).

Refuges are required for mobility-impaired people which can be located within a fire exit stair or corridor or adjacent lobby.

When calculating the fire exit stair capacity, one stair is discounted unless provided with lobbies and the stair is pressurised. For the building configurations and floor populations considered in this report two fire exit stairs are sufficient.

Fire resistance requirements are generally limited to 60 minutes or 30 minutes except for fire fighter shaft for life safety applications.

Lining material requirements for wall and ceiling linings are summarised in Table 56. The NCC specifies Group 3 wall linings and Group 2 ceiling linings for rooms such as classrooms in non-sprinkler protected schools and Group 2 in corridors (circulation spaces) which is less stringent than the BB100 approach. BB100 includes some relaxations for notice boards and similar attachments but also applies specific restrictions on some attachments and features manufactured from plastics.

Table 56 Lining material requirements from BB100

Location	European Class	Similar Australian Group Number[1]
Small rooms of area not more than 30m²	D-s3, d2	3
Other rooms	C-s3, d2	2
Other circulation spaces	B-s3, d2	1

Note 1; Estimates of similar Australian Group numbers are based on the ISO 9705 testing used for comparative purposes during the initial development of the Single Burning Item test used for the European Classification and should not be used as the basis of determining Group numbers based on European testing for use in Australia.

The maximum area for any compartment is limited to 800m² for un-sprinklered buildings and 2000m² for sprinkler protected buildings except for single storey schools without basements. Therefore, since the compartment areas in the proposed 5-storey building are greater than 800m², sprinkler protection is required.

BB 100 makes extensive use of cavity barriers to protect concealed spaces which are used to a more limited extent in Australia (e.g. fire-protected timber construction and some external wall applications)

External wall surfaces less than 1000mm from a compartment are required to attain Class B-s3,d2 which approximates to the Australian Group 1 performance, and for multistorey buildings if more than 1000mm from the boundary. Class C-s3,d2 was applicable for up to 10m above ground or any part which pupils have direct access to. This approximates to Australian Group 2. A concession was also provided allowing timber cladding at least 9mm thick which would be expected to attain Australian Group 3 performance.

It is however noted that BB 100 predates a number of Amendments to Approved document B [45] relating to external walls.

These amendments require materials which become part of an external wall, or specified attachment, of a relevant building to attain a Classification of A2-s1, d0 or A1 which approximates to the Australian requirements for “non-combustibility” based on AS 1530.1. These additional requirements are only applicable to buildings with a storey (not including roof-top plant areas or any storey consisting extensively of plant rooms) at least 18 metres above ground level and which-

(i) Contain one or more dwellings
(ii) Contain an institution (i.e. a building whether described as a hospital, home, school or other similar establishment) which is used as living accommodation for, or treatment, care or maintenance of persons—
(a) suffering from disabilities due to illness or old age or other physical or mental incapacity, or
(b) under the age of five years,
where such persons sleep on the premises
(iii) Contain a room for residential purposes (excluding any room in a hostel, hotel or boarding house)

Since the school buildings being considered in this project do not involve any of these factors, the original BB 100 document is taken as being applicable.

Fire-fighting shafts are required if the floor area of a storey exceeds 900m^2 and the floor is more than 7.5m above fire and rescue vehicle access level. The multi-storey options considered in this report are on the threshold of the 900m^2 limit.

Approved Document B requires sprinkler protection for all floors over 30m. Building Bulletin (BB) 100 advocates the use of fire suppression or additional compartmentation to address property protection issues as well as life safety. It expects sprinkler systems to be provided in most new schools except for a small proportion where the fire risks are shown to be low. For the examples considered in this study it would be expected that sprinkler systems would be required for the 5-storey option but the requirement would be dependent on a risk assessment for the single storey reference building and has therefore been indicated as optional in Table 58.

C6.4. New Zealand

The New Zealand Building Regulations require compliance with the New Zealand Building Code which includes prescriptive solutions in a number of acceptable solution documents. C/AS4 Acceptable Solution for Buildings with Public Access and Educational Facilities (Risk Group CA)[46] is applicable to schools.

For the reference building and 5-storey building, a manual fire alarm system plus smoke detectors is required. The reference single storey school option does not require connection to the fire service but for multi-storey applications the alarm systems must be connected to the fire service.

However Fire and Safety Design Requirements for Schools (July 2008) incorporating the 2018 Amendments[47] published by the Ministry of Education requires all new schools to be protected by an Automatic Sprinkler System therefore these requirements have been incorporated in the summary tables (Table 58 and

Table 59).

Fire resistance requirements are generally limited to 120 minutes (property rating) or 60 minutes (life rating) but these are reduced to 60 minutes and 30 minutes respectively if a sprinkler system is provided and the insulation criteria is waived in sprinkler protected buildings. Property rating is generally the fire resistance rating to be applied to elements of construction that allows for protection of other property and therefore generally applies to the structural frame and external walls although it may be applied to other critical elements. Life rating is generally the fire resistance rating to be applied to elements of construction that allows movement of people from their location in a building to a safe place.

A minimum of two escape routes are required for the school building configurations being considered and except for specific exclusions no dead ends are permitted. For the configurations considered in this report two doors from each occupied enclosure would be required with a maximum distance of travel to both fire exits, of 100m.

Similar methods are used for the classification of wall and ceiling linings as the NCC. The NZ requirements are compared with the closest Australian requirements in Table 57.

Table 57 Lining material requirements from NZ Acceptable Solution C/AS4

Location	No Sprinklers		Sprinklers	
	NZ Group	Aus. Group	NZ Group	Aus. Group
Exit ways	1	1	2	1
Crowd spaces	2	3(w) 2 (c)	3(w) 2 (c)	3
Other occupied spaces	3	3(w) 2 (c)	3	3

The combustibility of external walls is generally addressed through the use of a cone calorimeter test with the most stringent controls applied to walls less than 1m from the boundary. There are lower stringency requirements for walls greater than 7m high and 1m or more from the boundary and no requirements for buildings more than 1m from the boundary with a building height less than 7m. (i.e. max two storeys).

Requirements for Exit Signage and Emergency Lighting are provided in other documents referenced by the regulations and the NZ Building Code. It is noteworthy that spandrel panels are required to be 1.5m high if there are no horizontal projections compared to 0.9m in Australia. This could have an impact on external fire spread.

C6.5. Summary of Findings from the Review of International Approaches

Typical prescriptive provisions are summarised in Table 58 and

Table 59. These do not represent the entire prescriptive requirements but identify common provisions for comparison from which the following conclusions can be drawn;

- Generally, the prescriptive requirements become more stringent as the building height increases
- Some relaxations to wall and ceiling linings are permitted as a concession if sprinkler protection is provided
- For high-rise buildings the fire resistance levels prescribed by the NCC and US IBC are significantly more stringent than NZ and UK
- Generally, the minimum number of fire exits / stairs are similar for the subject buildings but the NZ provisions relating to dead-ends and travel distances vary significantly from the other codes
- Australia does not have specific requirements for manual call points distributed through schools whereas the other codes do.
- Generally, all codes require some form of automatic detection and alarm if buildings are greater than 1-storey although partial detection systems are common
- Although not specified in all cases by the various Building Codes for 5-storey and single storey schools in NZ and the UK the government departments responsible for education either mandate or strongly recommend automatic sprinklers in all new school buildings whilst the US IBC requires new educational buildings greater than 1-storey to be sprinkler protected.
- The US, UK and NZ included more detailed requirements for access for fire fighters than the NCC.

Table 58 Comparison of Selected International provisions for reference single-storey school

Provision	Aus - NCC	US - IBC	UK AD B	NZ
Type of Construction	Type C	Type V	-	-
Non-combustible building elements	Not applicable to Type C const.	Not applicable to Type V const.	Not applicable	Generally, not applicable but optional method of control for external walls
Wall and ceiling linings	Public corridors G,2 Classroom G3 (W) G,2 (C) Other areas G3 (W) G2 (C)	Exits A Corridors B Rooms C	Small rooms D-s3, d2 Other rooms C-s3, d2 Other circulation spaces B-s3, d2	Exits ways G1 Crowd spaces G3[1] Other occupied spaces G3
FRL of Elements of construction –	Not required	Generally, not required	60/-/- if required	Property rating 60/60/-[1] Life rating 30/30/-[1]
FRL of non-separating loadbearing elements	Not required	Generally, not required	Generally, not required	Property rating 60/-/-[2] Life rating 30/-/-[1]
Number of exits required in addition to horizontal exits	Minimum 2 required for building configuration	Minimum 2 required for building configuration	Minimum 2 required for building configuration	Minimum 2-required from each room
Exit Travel distances	Dead-end < 20m Max distance to one exit < 40m	Dead end < 22.9m and serving not more than 49 people	Dead end typically < 18m and serving not more than 60 people. Max distance to one exit < 45m	No dead-ends 100m max to both exits
Emergency lighting	Required	Required	Required. – Some concessions for areas with natural light	Required
Exit and direction signs	Required	Required	Required	Required
Detection and Alarm	Not required	Manual call points activating an alarm CO Detectors in classrooms	Manual call points activating an alarm	Manual call points and detection system activating an alarm system
Automatic fire sprinklers	Not required	Not required	Optional	Not required by C/AS4 but required by MoE for new schools

Notes; 1 Relaxation since sprinkler systems required

Table 59 Comparison of Selected International provisions five-storey primary school

Provision	Aus - NCC	US - IBC	UK AD B	NZ
Type of Construction	Type A	Type IA		-
Non-combustible building elements	Generally, required[1]	Generally required	Not applicable	Generally, not applicable but optional method of control for external walls
Wall and ceiling Linings	Fire isolated exits – G1 Public corridors, Classroom etc. G3[2]	Exits B[1] Corridors C[1] Rooms C	Small rooms D-s3, d2 Other rooms C-s3, d2 Other circulation spaces B-s3, d2	Exits ways G1 Crowd spaces G3[2] Other occupied spaces G3
General FRL of Elements of construction	Fire resisting; Walls, Shafts, floors and fire	Structural frame 120/120/120	Structural frame 60/60/60 (reduced to 30/30/30 if sprinklered. Fire-	Property rating 60/60/-[2] Life rating 30/30/-[2]

Provision	Aus - NCC	US - IBC	UK AD B	NZ
	isolated exits 120/120/120	Shafts etc. 120/120/120	fighting shaft 120/120/120 from outside 60/60/60 from inside. Other shafts, lobbies etc. 30/30/30	
FRL of non-separating loadbearing elements	120/-/-	180/-/-	60/-/- or 30/-/- if sprinklered.	Property rating 60/-/-[2] Life rating 30/-/-[2]
Number of exits required in addition to horizontal exits	Minimum 2 required for building configuration	Minimum 2 required for building configuration	Minimum 2 required for building configuration	Minimum 2-required from each room
Exit Travel distances	Max dead-end 20m Max distance to one exit 40m	Dead end < 22.9m and serving not more than 49 people	Dead end typically < 18m and serving not more than 60 people. Max distance to one exit < 45m	No dead-ends 100m max to both exits
Automatic fire sprinklers	NCC E2.2a sprinkler option selected	Required	Required – compartments > 800m^2	Not required by C/AS4 but required by MoE for new schools
Detection and Alarm	Partial detection system and alarm system	Partial detection system plus manual call points activating an alarm CO Detectors in classrooms	Partial detection system plus manual call points activating an alarm assumed	Manual call points and detection system activating an alarm system
Emergency lighting	Required	Required	Required. – Some concessions for areas with natural light	Required
Exit and direction signs	Required	Required	Required compartments > 800m^2	Required

Notes;
1 Some concessions apply such as fire protected timber permitted by clause C1.13 if sprinkler protection provided.
2 Relaxation since sprinkler systems required

Appendix D. Characterisation of Primary School Occupants

D1. Primary School Children Overview

In Australia the age of Primary school children typically varies from 5 – 12 years commencing at a preparatory level and progressing to Year 6 or 7.

The Tasmanian SEMC Policy Statement - Emergency Management Framework for Vulnerable People [48] includes a useful summary of risk factors and special consideration for children which is summarised below:

“Children can behave unpredictably in response to stressful situations or may be overwhelmed because of their level of physical, cognitive and emotional development. Typical vulnerabilities include the following:

- Lack the ability to independently access transportation assistance and services.
- May become separated from family and caregivers.
- May not have an appropriate level of understanding of the threat.
- Susceptible to injury and depend on others for livelihood, decision-making and emotional support.

- May suffer greater harm from exposure to smoke or chemical agents because of their size, metabolism, respiratory rates and other factors.
- More likely to develop dehydration, malnutrition and exhaustion quicker than adults and more susceptible to infectious diseases and severe forms of illness.
- Treatments that would be adequate for adults might be inappropriate for children e.g. children need different medication doses and medical equipment sizes to adults. Water pressure used to decontaminate adults may be inappropriate for young children.
- May have additional health care or medication needs but are unable to communicate those needs

A study undertaken into the prevalence and fire safety implications of Early Childhood Centres by Page and Norman[49] summarised the findings of Taciuc and Dederichs [50] based on surveys with 87 responses (62 teachers and 25 fire experts) from USA, Germany, Denmark, Romania, and Canada. It was found that between 30 and 36 months, children are generally capable of understanding and following simple fire evacuation instructions. It is therefore expected that Primary school children will generally be able to evacuate a building under the supervision of a staff member and will not need to be carried.

D2. Pre-movement and Travel Times for Primary School Students.

Hamilton et al[51] investigated pre-evacuation times, movement times on stairways and movement on the horizontal plane. Results presented include 12 full-scale evacuations on four primary schools with students aged between 4 and 12 years, together with comparisons against the results from previous studies. The findings of this paper are of direct relevance to this study and were therefore used as the primary basis for estimating evacuation times taking account of the cognitive ability of children and their physical capabilities.

After the alarm has been raised the time to evacuate comprises a pre-movement time and a travel time. The results from Hamilton et al were included in a pre-evacuation database established by Lovreglio [52] which notes that the pre-evacuation (pre-movement times) of schools, refer to the time to leave the classroom as a single group. The results from Hamilton et al and most other school studies relate to simultaneous evacuation.

Generally, the pre-movement times for primary schools were low compared to most other occupancies. The pre-movement times were measured as the time the group left the classroom and can be represented as a triangular distribution with minimum, mode and maximum values of 5s, 15s and 60s as shown in Figure 22.

Horizontal travel speeds are generally comparable to those for the general population with the mean speed being of the order of 1.2m/s for adult lead groups. Horizontal travel speeds can be also be represented by a triangular distribution with minimum, mode and maximum values of 0.51m/s, 1.25m/s and 2.68m/s as shown in Figure 23 for adult lead groups. The results are more variable for children led groups but with a higher mean speed of 1.6m/s, therefore adult lead group data will be used for the analysis.

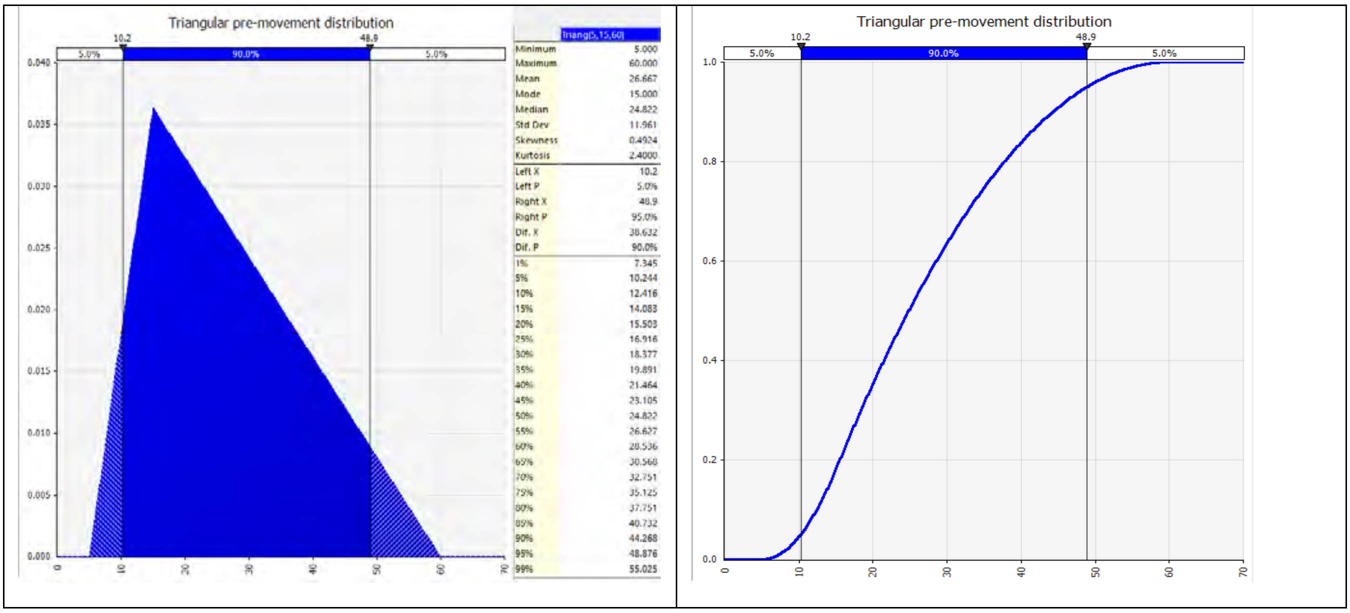


Figure 22 Distribution Representing pre-movement times for Primary School Classes

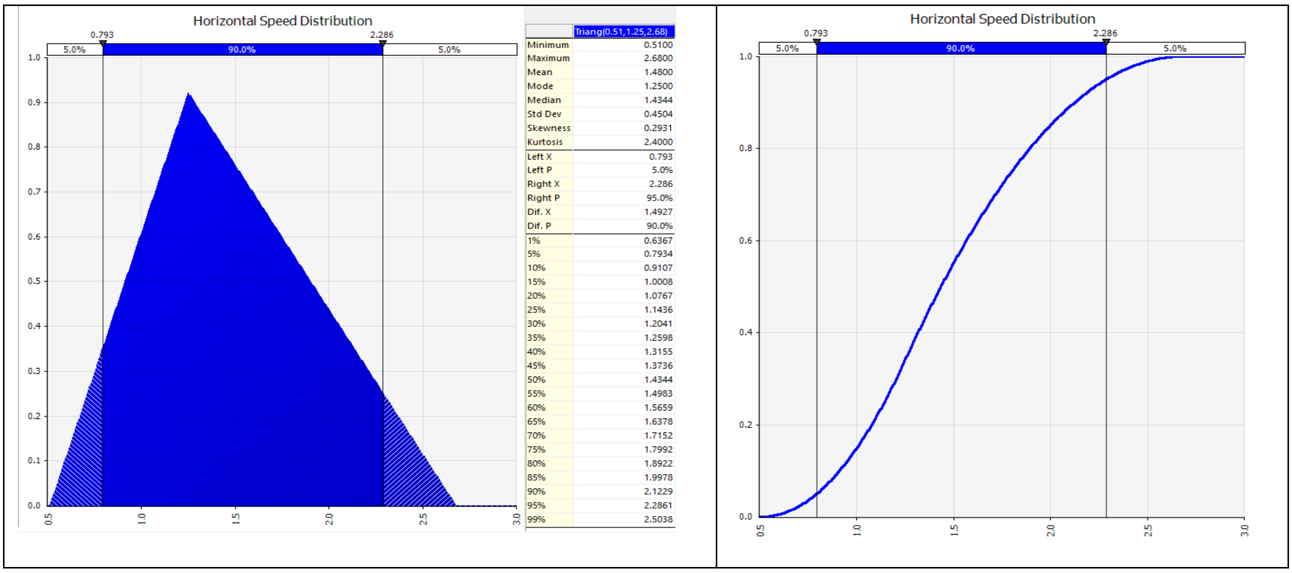


Figure 23 Distribution Representing horizontal travel speeds for Primary School Classes.

Vertical travel down stairways varies significantly with the age of the students. At age 11, it is comparable to the general population; but decreases approximately linearly with decreasing age. A triangular distribution can again be selected for simplicity as shown in Figure 24 for 11-year-olds. This can then be adjusted using an "age factor" for younger students as shown in Table 60.

Table 60 Vertical Travel speeds for Primary school Classes with Age adjustment

Age -y	Age factor	Min	Mode	Max
5	0.46	0.29	0.51	0.72
6	0.55	0.35	0.61	0.86
7	0.64	0.40	0.71	1.00
8	0.73	0.46	0.81	1.15
9	0.82	0.52	0.91	1.29
10	0.91	0.57	1.01	1.43

11	1.00	0.63	1.11	1.57

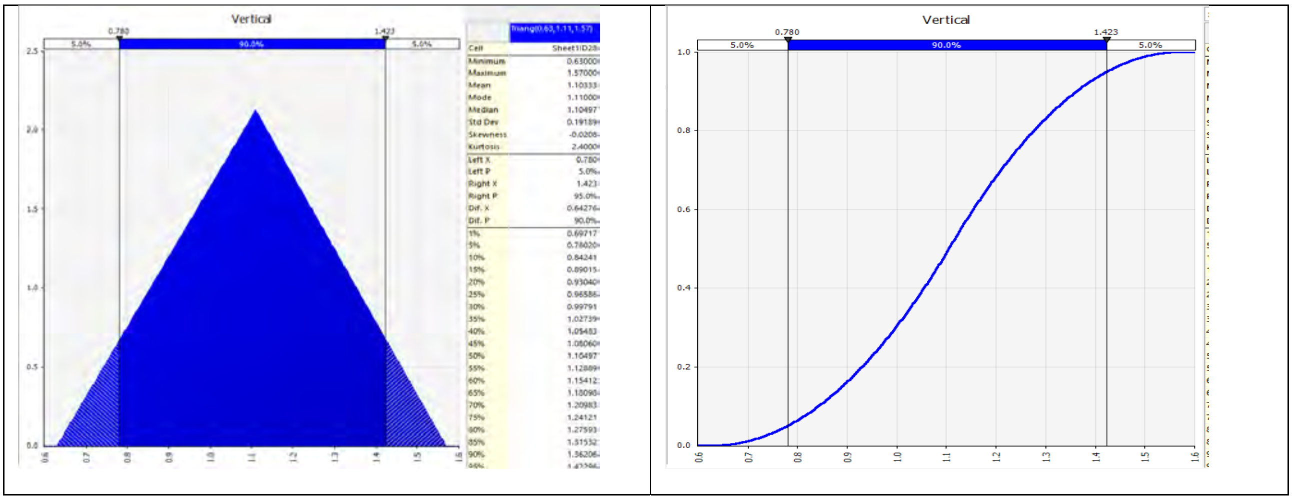


Figure 24 Distribution Representing vertical travel speeds for 11-year old Primary School Class.

D3. Students with Disabilities

There will be a proportion of students with disabilities and provision needs to be made for the safe evacuation of these students.

The Australian Curriculum Assessment and Reporting Authority (acara) reports the proportion of school students with disability and the data from 2017 is presented in Table 61.

Table 61 Distribution of students with disability by level of adjustment and category of disability, as a percentage of total student population, Australia (2017) from acara [53]

Level of adjustment	Cognitive	Physical	Sensory	Social- Emotional	All
Support within QDTP	2.7	1.8	0.2	1.4	6.2
Supplementary	5.0	0.7	0.3	2.1	8.2
Substantial	1.7	0.2	0.1	1.0	3.0
Extensive	1.0	0.1	0.1	0.3	1.5
All	10.4	2.8	0.7	4.9	18.8

If it is assumed that there are approximately 104 students / floor for a multi-storey building and (1%) require wheelchairs it would be appropriate to provide evacuation refuges nominally 800mm x 1300mm within each fire isolated exit providing capacity for two wheelchair users / floor plus additional space to store evacuation chairs. This is not prescribed in the NCC but can be regarded as representing good practice.

D4. Class sizes and student to staff ratios.

Details on class sizes are published for Victorian Government Schools and are summarised in Table 62. The average class size was approximately 22 students for all years with only 0.2% of classes having over 30 students.

The Prep to year 2 group would be expected to be the most vulnerable (youngest) and the mean class size was approximately 21 only 0.1% of classes were larger than 30 pupils and 3.2% larger than 25 students. Feedback from a survey of State and Territory Administrations indicate class levels could be up to a maximum of approximately 30 students therefore this number was selected for analysis of the buildings.

Table 62 Percentage of Primary Class Sizes by Size Grouping, February 2018 for Government Schools in Victoria derived from Department of Education and Training - Victoria [54]

Size Groupings	Prep	Year 6	Prep-Year 2	Years 3-6	All Primary
10 and Under	3.1	1.9	*1.7*	*1.5*	1.4
11–15	7.4	3.2	*3.8*	*2.1*	2.6
16-20	49.7	11.1	*37.0*	*11.5*	23.6
21–25	38.3	54.6	*54.3*	*58.8*	57.0
26-30	1.4	28.7	*3.2*	*25.8*	15.2
Over 30	0.1	0.6	*0.1*	*0.4*	0.2
Number of Classes	3,209	3,175	8,138	9,024	16,833
Average Class Size	19.4	23.4	20.7	23.4	22.2

From Table 23 of Appendix C the average student to teacher ratios for primary schools across Australia is approximately 15. This is based on full time equivalent teachers and students and does not represent the teacher to student ratio for a class. The maximum teacher to student ratio in a class will be assumed to be 30 (i.e. one teacher /class). The class teacher's focus will be the evacuation of the students they are responsible, with other members not assigned to a class at the time of a fire alarm responding in accordance with the emergency procedures.

From Table 21 of Appendix C the average primary school has approximately 360 students. This lies within the most prevalent size group of 201- 400 students in Table 22 and therefore is considered a reasonable initial estimate of a typical school size for the case studies

If the primary school has students from Prep to year 6 (i.e. seven-year groups) and two streams per year group and a class size of 30 the total number of students will be 420. This is 16.7% above the average size of a primary school but was adopted since 15% of primary schools have class sizes between 26 and 30 but only 0.2% with class sizes above 30 in Victoria and therefore is representative of schools with larger class sizes.

Appendix E. **Additional Matters for Consideration**

E1. Building Trends and Practices Relating to High-Rise Schools

The residential populations within Australian City CBDs and inner suburbs has increased substantially over recent decades creating a demand for additional schools within these areas. Sufficient land in these areas to construct new low-rise schools following traditional design approaches is either not available, or if it is available, it may not be financially viable.

It is not desirable to locate schools (particularly primary schools) substantial distances from the catchments they serve and therefore there is a demand to house schools in high-rise buildings.

It has been identified that, the low-rise model for schools requires some adjustments when applied to high-rise schools with regard to function and use.[55, 56]. These adjustments may have some implications for fire safety within schools.

The following observations have been identified predominately from a review of case study analyses of emerging multi-storey school models undertaken by Swinburn[55] supplemented by a literature review by Gray et al [56] and various press articles;

a) **Optimum height.** Building heights up to four stories allow extensive use of stairs.
b) **Floor sizes.** 2000m^2 is an ideal size for stacked schools but can vary from 500m^2 to 6000m^2 depending on the site and population. Small floor plates and consequently additional floors are costly and inefficient.
c) **Specific needs for Primary school and students'**

   Primary schools and their students.

   - spend most of their time in one classroom except for sports and recreational play, reducing the vertical circulation load on the building throughout the day.
   - require more open space for recreational play including both structured and unstructured activities.
   - require more assistance with evacuation, (Stacking via year levels is broadly adopted because it allows younger and smaller students to evacuate safely during an emergency)
   - require specific considerations for drop off / pickup at arrival and dismissal times.
   - arrangement of the floor plates would have more classrooms around a central space for students to spill out on to.
   - primary school students have less day to day integration with the city than secondary students, due to safety concerns for young unsupervised children in city streets
   - having younger students on lower floors reduces their independence for lifts. Older students could be more responsible at using lifts.

d) **Building Configurations**

   Traditional office style configurations, where floorplates are stacked on top of each other with no connections between floors is generally considered the least desirable outcome for a vertical school, particularly for secondary schools from a building use perspective. Grouping 2 or 3 levels into a zone or hub connected by an atrium, or non-fire isolated non-required stairways is a preferred option for secondary schools where students could spend most of the time within a hub. This reduces demand for the use of lifts. These features do however present fire safety challenges

   Based on the above the demand for interconnecting floors is likely to be less for primary schools. Whilst the NCC DTS provisions (D1.12) do allow for some connections between floors application of E2.3 is likely to require further consideration and the adoption of performance approach may be more appropriate

e) **Mixed use and Shared Tenancies**

   There tends to be two workable models for city schools: a civic/co-sharing model, or a fortress model whereby it is gated, children cannot leave, and the public cannot enter.

   Whilst it is possible under the NCC for a school to be part of a multi-tenancy, mixed use building this approach has a number of drawbacks making it an undesirable option. Examples include;

   - potential shared egress paths compromising evacuation of the primary school students

- general security issues and the limited ability for the school to control these matters
- other tenancies may be incompatible with the use as a school and vice-versa
- differing priorities of tenants to building maintenance and safety.

It is therefore most appropriate for high-rise primary school buildings to be either, a stand-alone development or to share a location with community / civic facilities. For a shared location, issues such as maintenance, staffing, emergency control organisations and security still need to be addressed.

The form of a high-rise school lends itself to a configuration where the ground floor (which attracts high rents and is often underutilised due to security concerns) can be considered a public area that can be leased out or used for other community services. Locating sports facilities, libraries entertainment venues, cafes and other rentable spaces on the ground level with a secured school area above is a common configuration that makes the school a focus for the community whilst creating profitable opportunities for underutilised spaces.

If these commercial / co-location operations extend beyond the ground floor, systems can be provided to control access to the secured parts of the school. However, some duplication of emergency exits may be required.

The concept can be extended to neighbouring buildings and facilities such as sports centres, parks, galleries and museums that may assist the education of students. This allows a vertical school to maximise the available space and reduce construction / maintenance costs.

f) **Building Circulation**

Secondary students move between specialised spaces while most of a primary student's education experience can be facilitated in one classroom except for sport and recreational activities. However even the limited vertical circulation (e.g. at arrival and departure from school) for primary students in high-rise buildings presents a number of challenges. Some typical solutions include;

- Avoiding lifts as a primary circulation method where possible.
- Locating younger students on lower levels
- Staggering start and dismissal times to reduce load on lifts
- Sizing lift car sizes to fit a whole primary class so that the teacher can keep students together and supervise them while moving between floors.
- Providing adequate space around lifts for students to be assembled before and after use of the lifts.
- Make better use of fire stairs for inter-floor use when the building is solely occupied by the school. If mixed-use design is considered independent escapes and addition security measures are required. This is commonly achieved by restricting public access to the ground level and providing secure access to the school above
- Providing multiple circulation paths to reduce congestion. This can also help minimise dead ends from a fire safety perspective.

g) **Providing Outdoor Spaces.**

Maximising outdoor learning opportunities and access to daylight is considered essential. All vertical schools investigated by Swinburn [55] desired a large sports field as part of their facility. This is also a specific requirement for some States in Australia. The shared use of public parks and facilities presents an option particularly for secondary schools but there are drawbacks particularly in relation to availability and need for supervision particularly of primary school students.

The provisions for primary students are different to secondary because of the greater need for security, supervision and more unstructured play spaces which may be easier to accommodate in a high-rise school.

There are advantages to the provision of a single or limited number of larger outdoor spaces as detailed below:

- Requires less resources to supervise a single large space than many smaller spaces
- Lunchtimes can be staggered reducing year group interactions
- Easier to provide adequate security and safety measures in a single or few locations
- It is more practical to acoustically separate classrooms from a few external spaces to minimise disruption.

Preferred options for providing recreational facilities on tight high-rise sites include;

- the utilisation of rooftops which sit above structural systems. To facilitate this, plantrooms and building services should be located in basement levels where possible.
- Selecting a site with a large enough footprint to accommodate sufficient open spaces.
- Where practical construct the school buildings to one side of the site maximising the available ground level recreational spaces.

h) **Green Spaces**

Gray et al. [56] found that contact with nature is crucial in terms of the physical, emotional and cognitive development of students and that nature must be "designed into" vertical schools through the creation of green spaces and/or outdoor areas. Ideally these areas should be unstructured.

Similar observations have been made by Knox and Parry-Husbands [57], with respect to exposure to wood in the built environment which is thought to provide a connection to nature and therefore improve physical and mental wellbeing.

i) **Design Life of Schools**

During the design life of a school it may have to adapt to the changing needs of the community. For example, changes to the community demographic may increase or decrease the number of students or the mix of students that are served by the school. Student behaviours may also change during the life of a building.

Planning how the original school is organised and can be expanded with minimal disruption is critical to the model’s success as a school. For example,

- structural systems could be over engineered allowing for the provision of additional floors later.
- core and shell models could be employed for anticipated expansion with fit-out being undertaken when the school is ready to occupy the additional areas.

Another significant advantage to the core and shell model is the school’s flexibility to be converted into offices should the school close.

j) **Accessibility**
All areas of school buildings are required to be accessible to students in accordance with the NCC which necessitates consideration of evacuation for people with disabilities from all areas during a fire emergency.

k) **Innovative materials and prefabrication**

The use of massive timber products, other innovative systems and prefabrication in the construction of high-rise buildings is becoming more prevalent. This reduces the impact of construction in inner cities and accelerates the building process.

l) **External assembly areas after emergency evacuation**

The construction of primary schools within a city environment presents additional challenges that may not be foreseen in building codes and standards. For example, in an emergency the whole school will need to evacuate to a safe assembly point. If a primary school is land locked between major roads for example it may be necessary to cross-major roads to access the assembly point. This should be addressed at the time the site of a school is selected.

> Performance requirements and DTS provisions do not address travel from an exit to a safe assembly point very well. The performance requirements are silent on the matter and the DTS provisions use the term open space extensively which is defined as “a space on the allotment, or a roof or similar part of a building adequately protected from fire, open to the sky and connected directly with a public road.” Consideration could be given to modification of the performance requirements and DTS provisions or provision of additional guidance.

m) **Performance-based Designs**

The adoption of performance solution pathway to allow the use of fire engineering approaches to the design of buildings is common and has been used for multi-storey schools in Australia.

Common applications are expected to be used to implement many of the trends highlighted above including;

- designs that adopt innovative building configurations with fire safety provisions being tailored to provide flexibility in the design of openings between floors, atria and circulation spaces, more suited to vertical spaces and the constraints of specific sites
- designs to permit access control / security systems to be designed for specific building configurations and site constraints
- increased usage of exposed massive timber structural members and other innovative systems suited to primary schools
- incorporation of green spaces within buildings
- use of lifts for evacuation
- optimisation of fire safety measures for specific applications.

E2. Supplementary Non-NCC requirements

A survey of State and Territory Stakeholders represented on the ABCB BCC committee has been undertaken to, amongst other things, identify Australian jurisdictional administrative and operational provisions and guidance materials in addition to the NCC that may impact the effectiveness of NCC fire safety provisions for Primary Schools.

Generally, the States and Territories rely on the NCC but Tasmania indicated that variation and determination relating to bushfire exposure which lies outside the scope of this study and NSW highlighted the need for consideration of evacuation of multi storey buildings used for Kindergarten to Year 2.

Appendix F. Summary of NCC DTS Provisions

Table 63 Summary of NCC DTS Options for Reference and 5 storey Schools

NCC Clause	DTS Provision	Reference Building	5-Storey - School
A6.9(2)	Building Class	Class 9b - School	Class 9b - School
C1.1	Type of Construction	Type C	Type A
C1.9 / D2.2	Non-combustible building elements	Not applicable to Type C construction	External walls, common walls, fire-resisting walls, shafts[1] Stairways and ramps
C1.10 / Spec C1.10 (Table 2)	Floor Linings	CHF 2.2 kW/m^2	CHF 2.2 kW/m^2 or 1.2 kW/m^2 for areas other than fire isolated stairs if sprinkler protected
C1.10 / Spec C1.10 (Table 3)	Wall and ceiling Linings	Public corridors G 1,2 (W&C) Classroom G1,2,3 (W) G1,2 (C) Other areas G1,2,3 (W) G1,2 (C)	Fire isolated exits – G 1 (W&C) Public corridors G 1, 2 (W&C) Classroom G1,2,3 (W) G1,2 (C) Other areas G1,2,3 (W) G1,2 (C)
C2.2	Max-size of fire compartments	Max floor area 3,000m^2 Max Volume 18,000m^2	Max floor area 8,000m^2 Max Volume 48,000m^2
C2.6	Vertical separation of openings in external walls	Not required	Spandrel panel (900mm) Horizontal Proj. (1100mm)
Spec C1.1	FRL of Elements of construction	Ext. wall <1.5m from fire source feature and common walls / fire walls 90/90/90 Ext. wall 1.5m-3.0m from fire source feature 60/60/60	Fire resisting; Walls, Shafts and floors 120/120/120[3] (D1.3 requires fire isolated exits)
Spec C1.1	FRL of non-separating loadbearing elements	Ext. wall <1.5m from fire source feature and common walls / fire walls 90/-/- Ext. wall 1.5m-3.0m from fire source feature 60/-/-	120/-/-
Clause D1.2(d)(v)	Number of exits required in addition to horizontal exits	Minimum of 1 exit required	Minimum of 2 exits required from each storey
Clause D1.4	Exit Travel distances	Max dead-end 20m Max distance to one exit 40m	Max dead-end 20m Max distance to one exit 40m
Clause D1.5	Distance between exits	Not less than 9m apart Not more than 60m apart	Not less than 9m apart Not more than 60m apart
Clause D1.6	Dimension of Exits	Width not less than 850mm and 1 m plus 250 mm for each 25 persons (or part) in excess of 100; 2 m plus 500 mm for every 75 persons (or part) in excess of 200	Width not less than 850mm 1 m plus 250 mm for each 25 persons (or part) in excess of 100; 2 m plus 500 mm for every 60 persons (or part) in excess of 200
Clause D1.11(a)(ii)	Horizontal Exits	Not counted as required exit	Not counted as required exit
D1.13	Num of persons accommodated	Classroom 2m^2 / person Multi-purpose hall 1m^2 / person Staff room 10m^2 / person Trade / prac. area 4m^2 / person	Classroom 2m^2 / person Multi-purpose hall 1m^2 / person Staff room 10m^2 / person Trade / Prac. area 4m^2 / person

NCC Clause	DTS Provision	Reference Building	5-Storey - School
D3.1 Table D3.1	General Access requirements	To and within all areas normally used by the occupants	To and within all areas normally used by the occupants
E1.3	Provision of hydrants	Required if building >500m[2] and within 50km of fire brigade station	Required if building >500m[2] and within 50km of fire brigade station
E1.4	Fire hose reels	Not required in Classrooms and associated corridors	Not required in Classrooms and associated corridors
E1.5 / Table E2.2a	Automatic fire sprinklers	Not required	E2.2a Option 1 rise in storeys more than 3[4] E2.2a Option 1 (fire isolated stair shared with Class 2,3 or 4 part.
E1.6	Portable Fire Extinguishes	Required - Table E1.6 defines coverage	Required - Table E1.6 defines coverage
E1.8	Fire control Centre	Not required - floor area assumed < 18,000m^2	Not required - floor area assumed < 18,000m^2
E2.2(b)	Automatic shut-down of air handling system not designed to operate as a smoke control system and recycles air from one fire compartment to another and provision of automatic smoke dampers	Required, also requires partial detection system	Required, also requires partial detection system
E2.2 Table E2.2a	Automatic air pressurisation for fire isolated exits AS 1668.1 system	Not applicable	E2.2a Option 2 rise in storeys of more than 3[4] E2.2a Option 2 fire isolated stair shared with Class 2,3, or 4 part) incorporates partial detection system to activate system
E2.2 Table E2.2a	Smoke detection system complying with Spec E2.2a (AS 1670.1 system activating a building occupant warning system	Not applicable	E2.2a Option 3 rise in storeys of more than 3[4] E2.2a Option 3 fire isolated stair shared with Class 2,3, or 4 part)
E2.2 Table E2.2a	Zone pressurisation between floors in accordance with AS 1668.1	Not applicable	E2.2a Option 4 rise in storeys of more than 3[4] - also requires partial detection system to activate system
E4.2	Emergency lighting	Required (floor area >300m^2)	Required
E4.3	Exit and direction signs	Required	Required

Notes;
1 Fire protected timber permitted by clause C1.13 if sprinkler protection provided.
2 Relaxation since sprinkler systems required
3 Insulation criteria for service shafts reduced to 90 minutes
4 The measures are applicable for schools or more than 2 storeys if part of a building that also includes Class 6,7b,8 or 9b parts

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Appendix G. Hazard Identification – Supporting Information

G1. NCC Performance Requirements and FSVM Fire Scenarios

BP1.1

(a) A building or structure, during construction and use, with appropriate degrees of reliability, must—
  (i) perform adequately under all reasonably expected design actions; and
  (ii) withstand extreme or frequently repeated design actions; and
  (iii) be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage; and

(iv) avoid causing damage to *other properties*, by resisting the actions to which it may reasonably expect to be subjected.

(b) The actions to be considered to satisfy **(a)** include but are not limited to—
  (i) permanent actions (dead loads); and
  (ii) imposed actions (live loads arising from occupancy and use); and
  (iii) wind action; and
  (iv) earthquake action; and
  (v) snow action; and
  (vi) liquid pressure action; and
  (vii) ground water action; and
  (viii) rainwater action (including ponding action); and
  (ix) earth pressure action; and
  (x) differential movement; and
  (xi) time dependent effects (including creep and shrinkage); and
  (xii) thermal effects; and
  (xiii) ground movement caused by—
    (A) swelling, shrinkage or freezing of the subsoil; and
    (B) landslip or subsidence; and
    (C) *sitework* associated with the building or structure; and
  (xiv) *construction activity actions*; and
  (xv) termite actions.

CP1

A building must have elements which will, to the degree necessary, maintain structural stability during a fire appropriate to—

(a) the function or use of the building; and
(b) the *fire load*; and
(c) the potential *fire intensity*; and
(d) the *fire hazard*; and
(e) the height of the building; and
(f) its proximity to *other property*; and
(g) any active *fire safety systems* installed in the building; and
(h) the size of any *fire compartment*; and
(i) *fire brigade* intervention; and
(j) other elements they support; and
(k) the *evacuation time*.

CP2

(a) A building must have elements which will, to the degree necessary, avoid the spread of fire—
  (i) to *exits*; and
  (ii) to *sole-occupancy units* and *public corridors*; and

Application: CP2(a)(ii) only applies to a Class 2 or 3 building or Class 4 part of a building.

(iii) between buildings; and
(iv) in a building.

(b) Avoidance of the spread of fire referred to in **(a)** must be appropriate to—
(i) the function or use of the building; and
(ii) the *fire load*; and
(iii) the potential *fire intensity*; and
(iv) the *fire hazard*; and
(v) the number of *storeys* in the building; and
(vi) its proximity to *other property*; and
(vii) any active *fire safety systems* installed in the building; and
(viii) the size of any *fire compartment*; and
(ix) *fire brigade* intervention; and
(x) other elements they support; and
(xi) the *evacuation time*.

CP3 A building must be protected from the spread of fire and smoke to allow sufficient time for the orderly evacuation of the building in an emergency.

Application:

CP3 only applies to—

(a) a *patient care area* of a Class 9a *health-care building* ; and

(b) a Class 9c building.

CP4

To maintain tenable conditions during occupant evacuation, a material and an assembly must, to the degree necessary, resist the spread of fire and limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to—
(a) the *evacuation time*; and
(b) the number, mobility and other characteristics of occupants; and
(c) the function or use of the building; and
(d) any active *fire safety systems* installed in the building.

Application:

CP4 applies to linings, materials and assemblies in a Class 2 to 9 building.

CP5

A concrete *external wall* that could collapse as a complete panel (e.g. tilt-up and pre-cast concrete) must be designed so that in the event of fire within the building the likelihood of outward collapse is avoided.

Limitation:

CP5 does not apply to a building having more than two *storeys* above ground level.

CP6

A building must have elements, which will, to the degree necessary, avoid the spread of fire from service equipment having—
(a) a high *fire hazard*; or
(b) a potential for explosion resulting from a high *fire hazard*.

CP7

A building must have elements, which will, to the degree necessary, avoid the spread of fire so that emergency equipment provided in a building will continue to operate for a period of time necessary to ensure that the intended function of the equipment is maintained during a fire.

CP8

Any building element provided to resist the spread of fire must be protected, to the degree necessary, so that an adequate level of performance is maintained—
(a) where openings, construction joints and the like occur; and
(b) where penetrations occur for building services.

CP9

Access must be provided to and around a building, to the degree necessary, for *fire brigade* vehicles and personnel to facilitate *fire brigade* intervention appropriate to—
(a) the function or use of the building; and
(b) the *fire load*; and
(c) the potential *fire intensity*; and
(d) the *fire hazard*; and
(e) any active *fire safety systems* installed in the building; and
(f) the size of any *fire compartment*.

DP1

Access must be provided, to the degree necessary, to enable—
(a) people to—
  (i) approach the building from the road boundary and from any *accessible* carparking spaces associated with the building; and
  (ii) approach the building from any *accessible* associated building; and
  (iii) access work and public spaces, accommodation and facilities for personal hygiene; and
(b) identification of *accessways* at appropriate locations which are easy to find.

Limitation:
DP1 does not apply to a Class 4 part of a building.

DP2

So that people can move safely to and within a building, it must have—
(a) walking surfaces with safe gradients; and
(b) any doors installed to avoid the risk of occupants—
  (i) having their egress impeded; or
  (ii) being trapped in the building; and
(c) any stairways and ramps with—
  (i) slip-resistant walking surfaces on—
    (A) ramps; and
    (B) stairway treads or near the edge of the nosing; and
  (ii) suitable handrails where necessary to assist and provide stability to people using the stairway or ramp; and
  (iii) suitable landings to avoid undue fatigue; and
  (iv) landings where a door opens from or onto the stairway or ramp so that the door does not create an obstruction; and
  (v) in the case of a stairway, suitable safe passage in relation to the nature, volume and frequency of likely usage.

DP4

Exits must be provided from a building to allow occupants to evacuate safely, with their number, location and dimensions being appropriate to—
(a) the travel distance; and
(b) the number, mobility and other characteristics of occupants; and
(c) the function or use of the building; and

(d) the height of the building; and
(e) whether the *exit* is from above or below ground level.

DP5

To protect evacuating occupants from a fire in the building *exit* must be fire-isolated, to the degree necessary, appropriate to—
(a) the number of *storeys* connected by the *exits*; and
(b) the *fire safety system* installed in the building; and
(c) the function or use of the building; and
(d) the number of *storeys* passed through by the *exits*; and
(e) *fire brigade* intervention.

DP6

So that occupants can safely evacuate the building, paths of travel to *exits* must have dimensions appropriate to—
(a) the number, mobility and other characteristics of occupants; and
(b) the function or use of the building.

Limitation:
DP6 does not apply to the internal parts of a *sole-occupancy units* in a Class 2 or 3 building or Class 4 part of a building.

DP7

Where a lift is intended to be used in addition to the *required exits* to assist occupants to evacuate a building safely, the type, number, location and fire-isolation must be appropriate to—
(a) the travel distance to the lift; and
(b) the number, mobility and other characteristics of occupants; and
(c) the function or use of the building; and
(d) the number of *storeys* connected by the lift; and
(e) the *fire safety system* installed in the building; and
(f) the waiting time, travel time and capacity of the lift; and
(g) the reliability and availability of the lift; and
(h) the emergency procedures for the building.

EP1.1

A fire hose reel system must be installed to the degree necessary to allow occupants to safely undertake initial attack on a fire appropriate to—
(a) the size of the *fire compartment*; and
(b) the function or use of the building; and
(c) any other *fire safety systems* installed in the building; and
(d) the *fire hazard*.

EP1.2

Fire extinguishers must be installed to the degree necessary to allow occupants to undertake initial attack on a fire appropriate to—
(a) the function or use of the building; and
(b) any other *fire safety systems* installed in the building; and
(c) the *fire hazard*.

EP1.3

A fire hydrant system must be provided to the degree necessary to facilitate the needs of the *fire brigade* appropriate to—
(a) fire-fighting operations; and
(b) the *floor area* of the building; and
(c) the *fire hazard*.

Application:
EP1.3 only applies to a building where a *Fire brigade* is available to attend.

EP1.4

An *automatic* fire suppression system must be installed to the degree necessary to control the development and spread of fire appropriate to—

(a) the size of the *fire compartment*; and
(b) the function or use of the building; and
(c) the *fire hazard*; and
(d) the height of the building.

EP1.6

Suitable facilities must be provided to the degree necessary in a building to co-ordinate *fire brigade* intervention during an emergency appropriate to—

(a) the function or use of the building; and
(b) the *floor area* of the building; and
(c) the height of the building.

EP2.1

In a building providing sleeping accommodation, occupants must be provided with *automatic*
warning on the detection of smoke so they may evacuate in the event of a fire to a *safe place*.

Application:
EP2.1 only applies to a Class 2, 3, 9a or 9c building or Class 4 part of a building.

EP2.2

(a) In the event of a fire in a building the conditions in any *evacuation route* must be maintained for the period of time occupants take to evacuate the part of the building so that—
  (i) the temperature will not endanger human life; and
  (ii) the level of visibility will enable the *evacuation route* to be determined; and
  (iii) the level of toxicity will not endanger human life.
(b) The period of time occupants take to evacuate referred to in **(a)** must be appropriate to—
  (i) the number, mobility and other characteristics of the occupants; and
  (ii) the function or use of the building; and
  (iii) the travel distance and other characteristics of the building; and
  (iv) the *fire load*; and
  (v) the potential *fire intensity*; and
  (vi) the *fire hazard*; and
  (vii) any active *fire safety systems* installed in the building; and
  (viii) *fire brigade* intervention.

Limitation:

EP2.2 does not apply to an *open-deck carpark* or *open spectator stand*.

EP3.2

One or more passenger lifts fitted as emergency lifts to serve each floor served by the lifts in a building must be installed to facilitate the activities of the *fire brigade* and other emergency services personnel.

Application:
EP3.2 only applies to—
(a) a building with an *effective height* of more than 25 m; and
(b) a Class 9a building in which *patient care area* are located at a level that does not have direct access to a road or *open space.*

EP4.1

To facilitate safe evacuation in an emergency, a building must be provided with a system that—
(a) ensures a level of visibility sufficient to enable *exits*, paths of travel to *exits* and any obstacles along a path of *exit* to be identified; and
(b) Activates instantaneously upon the failure of an artificial lighting system, to the degree necessary, appropriate to—
(c) the function or use of the building; and
(d) the *floor area* of the building; and
(e) the distance of travel to an *exit*.

Limitation:
EP4.1 does not apply to the internal parts of a *sole-occupancy unit* in a Class 2, 3 or 9c building or Class 4 part of a building.

EP4.2

To facilitate evacuation, suitable signs or other means of identification must, to the degree necessary—
(a) be provided to identify the location of *exits*; and
(b) guide occupants to *exits*; and
(c) be clearly visible to occupants; and
(d) operate in the event of a power failure of the main lighting system for sufficient time for occupants to safely evacuate.

Limitation:
EP4.2 does not apply to the internal parts of a *sole-occupancy unit* in a Class 2 or 3 building or Class 4 part of a building.

EP4.3

To warn occupants of an emergency and assist evacuation of a building, a sound system and intercom system for emergency purposes must be provided, to the degree necessary, appropriate to—
(a) the *floor area* of the building; and
(b) the function or use of the building; and
(c) the height of the building.

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Table 64 Performance Requirements, Parameters for Consideration and Fire Scenarios from the Fire Safety Verification Method

Performance Requirement	PC - function or use of the building	PC- fire load	PC- potential fire intensity;	PC- fire hazard;	PC- height of the building / num. of storeys	PC- its proximity to other property	PC- any active fire safety systems	PC- size of any fire compartment / floor area	PC- fire brigade intervention	PC- other elements they support	PC- evacuation time	PC- Number, mobility / occupant charact.	PC- travel distance	PC- Exit above or below ground	PC- Fire Safety System	BE – Blocked Exit	UT – Unoccupied Enclosure fire	CS – Concealed Space	SF – Smouldering Fire	IS – Internal Surfaces	CF – Challenging Fire	RC – Robustness Check	SS – Structural Stability	HS – Horizontal Spread	VS –Vertical Spread	FI – Fire Brigade Intervention	UF – Unexpected Catastrophic failure
CP1	●	●	●	●	●	●	●	●	●	●	●	○	○		○	✓	✓	✓	✗	✗	✓	✓	✓	✗	✗	✓	✓
CP2	●	●	●	●	●	●	●	●	●	●	●	○	○		○	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓
CP3	○	○	○	○			○		○		○					✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗	✗
CP4	●						●				●	●	○		○	✗	✗	✗	✗	✓	✗	✗	✗	✗	✓	✗	✗
CP5		○	○	○	○											✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗
CP6				○												✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
CP7	○	○	○	○			○									✗	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✗
CP8	○	○	○	○	○	○	○	○	○	○	○					✓	✓	✓	✓	✗	✓	✓	✓	✗	✓	✗	✗
CP9	●	●	●	●			●	●	●							✗	✗	✗	✗	✗	✓	✓	✓	✗	✗	✓	✓
DP4	●				●						○	●	●	●		✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
DP5	●				●				●						●	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓	✗
DP6	●										○	●				✓	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
DP7	●				●						○	●	●		●	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
EP1.1	●			●				●							●	✗	✗	✗	✓	✓	✓	✓	✗	✗	✗	✗	✗
EP1.2	●			●											●	✗	✗	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗
EP1.3				●				●	●							✗	✗	✗	✓	✗	✓	✓	✗	✗	✗	✓	✗
EP1.4	●	○		●	●			●	○							✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
EP1.6	●				●			●								✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
EP2.1							○									✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
EP2.2	●	●	●	●	○		●		●		○	●	●	○	○	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗
EP3.2					○				●							✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
EP4.1	●							●					●			✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
EP4.2								○				○	○			✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
EP4.3	●				●			●								✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗

G2. NCC Proposed A8 Criteria for Consideration

As a result of a fire occurring within a building, the risk of exposure of occupants to untenable conditions must not exceed the values provided in Table A8.2a and Table A8.2b, with consideration of—

(d) the following hazards, building characteristics and occupant characteristics:

- (i) function or use of the building;
- (ii) fire load;
- (iii) potential fire intensity;
- (iv) height of the building;
- (v) number of storeys;
- (vi) location in alpine areas;
- (vii) proximity to other property;
- (viii) size of any fire compartment / floor area;
- (ix) other elements providing structural support;
- (x) number, mobility and other occupant characteristics;
- (xi) travel distance;
- (xii) exit above and below ground; and

(e) the following prevention / intervention measures hazards:

- (i) control of linings, materials and assemblies to maintain tenable conditions for evacuation;
- (ii) occupants intervention using firefighting equipment (fire hose reels and fire extinguishers);
- (iii) automatic fire suppression;
- (iv) emergency services intervention:
  - F. emergency services access;
  - G. fire hydrants;
  - H. fire control centres;
  - I. automatic notification of (Emergency Services) Fire Brigade;
  - J. emergency lifts; and

(f) the following means of managing the consequences:

- (i) maintain building structural stability;
- (ii) avoid spread of fire to exits;
- (iii) protection from spread of fire and smoke to allow for orderly evacuation as appropriate or as part of defend in place strategies or provisions of temporary refuges for occupants requiring assistance to evacuate;
- (iv) behaviour of concrete external walls in fire;
- (v) provide barrier protection from high hazard service equipment;
- (vi) provide protection to emergency equipment;

(vii) fire protection of openings and penetrations;

(viii) provision of exits;

(ix) provision of fire isolated exits;

(x) provisions for paths of travel to exits;

(xi) evacuation lifts;

(xii) automatic warning for sleeping occupants

(xiii) safe evacuation routes; options for consideration include one or more of the following if necessary:

D. smoke detection

E. smoke management systems

F. automatic suppression

(xiv) visibility in an emergency – emergency lighting;

(xv) identification of exits – exit signage; and

(xvi) emergency warning and intercom systems.

Appendix H. Risk Register

Table 65 Risk Register

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
1 (BE)	BE Blocked Exit – Fire blocks evacuation path	Two exits provided from each floor, dead ends limited to 20m early detection and or suppression	Fire occurring close to doorway in Classroom Probability of fire occurring and growing to a size that will block an exit while the room is occupied to such an extent that evacuation is not possible is unlikely but not impossible. Only option would be to provide two exits to each classroom. A fire on another floor could potentially block both exit stairs	Fire exits at each end of floor provide choice of direction. If one exit blocked evacuation time will be extended. This was evaluated as part of the QRA and the risk quantified	Risk Analysis considered a fire blocking access to one fire exit and consequences of extended evacuation times. Possibly provide good design guidance suggesting additional exits from classrooms where practicable since may also address other emergencies. QRA also considered both exits being blocked from a fire on another floor. Refer Appendix L
2 (UT)	UT Fire in a normally unoccupied room threatens occupants of other rooms	Multi-storey buildings - sprinkler protection. Choice of direction for evacuation	More significant for reference building but impact largely mitigated by choice of exits If partial or no smoke detection or automatic suppression options provided significant fire growth could occur prior to occupants being alerted	Fire occurs in unoccupied room on path of travel to an exit Probability of fire growing un-noticed and breaking out rapidly to be considered including failure of systems	Evaluated as part of QRA using Type 1 and Type 3 enclosure fires with delayed manual detection assuming failure of detection systems and area unoccupied. Appendix L. The analysis indicated this was a hazard therefore two reference buildings were analysed with and without detection systems. It is considered good practice to include a detection system in a single storey school to address this hazard. Detection systems were required for 5-storey options.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
3 (CS)	Fire starts in Concealed space growing and potentially endanger people in an adjacent area.	Forms of construction will have limited concealed spaces with penetrations to service shafts being sealed. For multi-storey options, fire resistant elements are either required to be non-combustible or of fire protected timber with extensive use of cavity barriers required under DTS provisions to address spread through cavities	These scenarios will be indirectly addressed by the UT scenarios where automatic fire suppression systems have failed.	Addressed as part of UT	Evaluated as part of QRA. See item 2
4 (SF)	A fire is smouldering near a sleeping area		Not applicable schools considered in analysis do not provide sleeping accommodation.	No further analysis required	Not applicable
5 (HS)	A fully developed fire in a building exposes the external walls of a neighbouring building (or potential building) and vice versa	Separation distances and for multi-storey options fire-resistant construction and either non-combustible construction or fire protected timber construction required	DTS provisions are assumed to prevent spread between buildings and will apply to all options.	For case studies distance between buildings is large and issues are not expected but risk analysis will be undertaken to demonstrate the use of metrics	Calculations indicate relevant NCC A8 criteria are satisfied
6 (VS)	A fire source exposes a wall and leads to significant vertical fire spread	Vertical fire spread is not applicable to the single-storey reference building. For multi-storey options external entire external wall will be non-combustible. Automatic fire sprinklers are also provided in addition to spandrels	No further analysis required for the single-storey reference building. External fires are not expected to spread to upper levels since the external cladding is non-combustible. There is a residual risk of fire spread to upper floors from fully developed fires on the floor below. This will be prevented if the automatic sprinkler system operates successfully. If the sprinkler system fails, the probability of spread will depend on ventilation conditions the building configuration and fire brigade intervention	For multistorey building probability of fire spread will be estimated and compared to the metrics	Evaluated as part of QRA. Refer Appendix M. Enhancements to improve reliability of sprinklers could be provided in a good design guide. Detailed analysis indicated the need for enhancements to improve sprinkler effectiveness which are mandated.
7 (IS)	Fire spread involving internal finishes - Interior surfaces are exposed to a growing fire that potentially endangers occupants	This hazard is mainly controlled though the prescription of wall and ceiling lining group numbers and the provision of automatic sprinklers	The basic growth rates and fire sizes derived from fire statistics relate to typical lining materials but because sprinkler systems are prescribed concessions can be applied to the lining materials and Group numbers will vary between the options. This will be evaluated as part of the QRA	The proportion of fires allocated to growth rates and maximum fire sizes will account for a range of Group numbers in the QRA	Evaluated as part of QRA. The selected fires represented the upper range of each design cluster (e.g. medium fires were capped when approaching flashover.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
8 (FI)	Facilitate fire brigade intervention to the degree necessary	This scenario does not relate to a specific hazard but represents a potential hazard control strategy	Fire brigade intervention will have a potential impact of both life safety and property protection	Fire brigade Intervention will be integrated into the QRA. Response times will be based on statistical data from a Report on government services and timing of interventions estimated using the FBIM	Evaluated as part of QRA throughout the analysis.
9 (UF)	Unexpected catastrophic failure - A building must not unexpectedly collapse during a fire event	The main control strategies are the requirements for the structure to achieve FRLs, provision of automatic sprinklers, fire brigade intervention and design to address Performance requirement BP1.1 (iii) which requires a structure to be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage;	For the single storey reference building FRLs are not prescribed, there will be no automatic suppression and the structure will generally not be designed to prevent collapse but the consequences with respect to life safety may not be significantly affected since evacuation will be prompt. The multi-storey buildings have all the listed initial control strategies and it is expected that the FRLs will be enough to prevent collapse under most circumstances. Therefore, for collapse to occur it is likely that there will need to be one or more gross defects, sprinkler system failure and relatively slow fire brigade intervention.	This will be evaluated as part of the QRA considering the probability of gross defects, the fire severity and the probability of sprinkler system failure and other related parameters for consideration. The probability of a fire leading to a major structural collapse was estimated if a disproportionate collapse metric is specified	Evaluated as part of QRA. Impact was quantified in the analysis. Refer Appendix M4
10 (CF)	Challenging fire - Worst credible fire in an occupied space	Overall fire safety strategy with detection and automatic fire sprinkler systems being primary elements of strategy	Priority will be life safety which will be reliant on prompt evacuation which in addition to the physical fire safety provisions will also rely on the Emergency Management Organisation incorporating training and emergency procedures.	This will be addressed as part of the QRA which will consider a distribution of fires which will incorporate challenging fires.	Evaluated as part of QRA
11 (RC)	Robustness check - the requirements of the NCC should be satisfied if failure of a critical part of the fire safety systems occurs	The fire safety strategy will incorporate levels of redundancy	The design incorporates levels of redundancy and the smoke hazard management option was selected to provide a diverse system (with sprinklers) to minimise the impact of common mode failures (refer Section 9.2.4.1 for qualitative analysis)	The QRA will considers the potential failure of all parts of the fire safety system including common mode failures and simultaneous failures of more than one part. This inherently addresses the robustness check with comparison against a reference building.	Evaluated as part of QRA considering reliability of the systems and low probability events involving multiple failures.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
12 (SS)	Structural Stability and other properties. - Building does not present risk to other properties in a fire event. Consider risk of structural failure	The main control strategies are the requirements for the structure to achieve FRLs, provision of automatic sprinklers, fire brigade intervention and design to address Performance requirement BP1.1 (iii) which requires a structure to be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage;	This is essentially a subset of the ID 9 (UF) and reference should be made to the entries above for that hazard	Structural performance incorporated in analysis of risk to occupants and independently assessed with respect to consideration of fire spread metrics.	Evaluated as part of QRA. See above comments
13	Dead-end corridors with multiple room entrances increase risk from Hazards1 and 2	Generally addressed through good design principles – not regulated in NCC.	Impact reduced by sprinklers in multi-storey options. Potential direct egress from single-storey building classrooms.	Not a feature of proposed building configuration since reflects poor detailing	Suggest inclusion in good practice guide or equivalent and Instruction to architect
14	Fires in other occupancies / public areas	Generally addressed through a combination of good design principles – not currently regulated in the NCC such as provision of separate fire stairs / exits and NCC DTS provisions such as fire separation of different occupancies and automatic fire sprinkler systems etc. Emergency Management Organisation and Building Management should be under control of the school	The case studies adopted a strategy of restricting public areas to the lower levels if provided and having a secure school area above often with independent egress. Generally, the management of the building is under control of the school with the public areas providing other civic functions. Ensuring that a cohesive Emergency Management Organisation can be put in place and fire safety equipment effectively managed	The 5-storey building layout and assumed emergency management procedures for the QRA incorporated good practice principles	Good practice principles such as security arrangement and EMO should be provided.
15	Injury to young children and / or delayed evacuation due to mix of occupant capabilities in fire isolated stairs during an evacuation of multi-storey buildings can lead to crowd crush and blocked exits causing.	Generally addressed by having a dedicated building as a multi-storey primary school. If other occupancies are included in the building, they should be located on the ground level, but the school should maintain overall responsibility for management of the building and maintain secure and independent egress for students from the building	Separation of school students from other occupants during evacuation supported by appropriate emergency management procedures is expected to address the hazard	The 5-storey building layout and assumed emergency management procedures were considered in the QRA	Principles such as security arrangement and EMO should be provided.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
16	Exposure of students to hazards after evacuating the school during an emergency	Select a site that is not landlocked by major roads or other hazards with adequate outdoor space at ground level such that is also suitable to be used as a secure assembly area with appropriate paths of travel from building exits to the assembly area.	It is generally assumed when applying the NCC DTS provisions that once a person evacuates a building, they can safely proceed to assembly areas even if it is necessary to crossroads and are not vulnerable to hazards such as abduction. For primary school aged students this is not necessarily the case and safe secure areas are generally necessary although not prescribed by the NCC	For the QRA it will be assumed that there is a safe and secure assembly area with a safe path of travel from the building.	A secure outdoor area at ground level that can also be used as an assembly area with a safe path of travel from the building exits was required
17	Vulnerability of young students - Children can behave unpredictably in response to stressful situations or may be overwhelmed because of their level of physical, cognitive and emotional development. Their response speeds and travel speeds may therefore be impacted	Primary school students (including preparatory grade students) are old enough to be able to walk on the horizontal or downstairs under the supervision of a teacher, Provision of an early alarm and early suppression reduces the risk of exposure to smoke and associated stress. Training of all staff members (even temporary staff) with respect to emergency procedures and regular fire drills increases the probability of a prompt evacuation. The youngest children will be located on the lower levels to facilitate as quick an evacuation as possible for the youngest students	Evacuation drills have shown that primary school aged students can respond promptly to an alarm although travel speeds particularly downstairs can be reduced. The Emergency Management Organisation, evacuation procedures, training and drills can have a significant impact on the evacuation time although these building operational matters lie outside the scope of the NCC. It is also critical that the staff are familiar and trained to use the Building Occupant Warning System if provided in accordance with the emergency procedures	For the purposes of the QRA it will be assumed that adequate staff training is provided, and staff members have the capability of raising a general building evacuation alarm manually. Pre-movement times and travel speeds for primary school children have been derived from literature based on field observations	Evaluated as part of QRA The need for an active EMO, training, drills and capability of staff to raise an alarm could be addressed in the guide. Also include requirement for youngest students to be housed on lowest available level.
18	Increased risk during evacuation of people with limited mobility	Provide evacuation refuges nominally 800mm x 1300mm within each fire isolated exit providing capacity for two wheelchair users / floor. Also provide additional space to store evacuation chairs. Emergency procedures should ensure that wheelchair users are always accompanied and where appropriate evacuation chairs can be used for evacuation of wheelchair users	A place of relative safety for wheelchair users and a supporting staff member has been provided that is readily accessible on each floor during the initial evacuation phase. If conditions deteriorate facilities have also been provided to facilitate evacuation via the stair if necessary	For the QRA it will be assumed that wheelchair users evacuate as part of a class group to an emergency stair and if safe to do so will wait with a supporting staff member. If conditions deteriorate an evacuation using an evacuation chair will be attempted	Instruction for provisions of evacuation refuges to be issued.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
19	Increased risk during evacuation for people with other disabilities	For the purposes of this study it is assumed that necessary support systems such as buddies are in place and that evacuation will occur as part of the class group	Assumed evacuate as part of the class group with assistance from a buddy if necessary	Assumed same pre-movement time and travel speeds as remainder of group with support of buddy	Requirement for consideration of people with disabilities should be included.
20	No means of raising a general building evacuation alarm in the reference building	Make a provision for some form of building announcement and warning system.	It will be assumed that a provision and the necessary training has been made to raise an alarm throughout the school requiring evacuation	No undue delay will be assumed due to the use of a non-specific system with time based on use of a Specification NCC E2.2a Building announcement and Warning System	A general provision requiring a detection and alarm system was assumed as part of the solution for the 5-storey building
21	Large openings between floors encouraged by modern building trends particularly in secondary schools to improve communication and create 2 or 3 floor zones that a student can spend most of the day in. This type of arrangement will facilitate rapid smoke spread	Openings between two floors are permitted under the deemed-to-satisfy provisions without specific provisions but sprinklers and detection / alarm systems are required to reduce the hazard. To accommodate the modern trends, it is likely that performance solutions will be adopted in many multi-storey school buildings.	For the proposed example a fire- resistant lobby separating different occupancies on the first floor has been adopted since a single storey referenced building has been adopted facilitating a reasonably similar configuration for comparison. Fire / smoke separation is provided in the example case with hold-open self-closing fire doors	Proposed building configurations will be considered as part of the QRA	Proposed configuration with fire and smoke separation.
22	Fires when school is unoccupied may not present a significant risk to life of the students but there is a greater probability of a major fire causing extensive damage to a school. The extent of damage and impact of the fire is likely to be significantly greater unless mitigation methods are applied	The most effective control strategy would be an automatic fire sprinkler system. Compartmentation is less effective alternative since venting flames from a ventilation controlled fully developed fire may by-pass the compartmentation and smoke spread through a multi-storey building could be extensive	The consequences of a major fire in a multi-storey school building are likely to be much greater than a traditional single storey building even if there is no loss of life. For example, if classrooms are lost in a single storey school within its own grounds, portable classrooms can be shipped in to maintain the schooling. For a high-rise school in an inner-city area this may not be possible because of space constraints and students may have to relocate to other schools causing a major disruption to their schooling.	Addressed to some extent by application of fire spread metrics which apply when building is occupied and unoccupied	Addressed by evaluation of fire risk metrics / inclusion of fire sprinkler system. This includes consideration of outside hours building is occupied.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
23	Fully developed fire on ground floor public area threatening school levels above by the following scenarios: a) External fire spread via openings in external walls b) Fire spread to the level above due to failure of separating elements including service penetrations c) Global structural collapse of the structure d) smoke spread to upper levels via shafts and smoke spread to fire isolated exits	a) primary - sprinkler protection; secondary - non-combustible façade / floor to floor separation and fire brigade intervention; tertiary control is evacuation b) primary - fire resistant construction and fire brigade intervention; secondary- sprinkler protection; tertiary - evacuation c) primary - fire resistant construction and fire brigade intervention; secondary - sprinkler protection; tertiary - evacuation d) primary - sprinkler protection; secondary - independent fire isolated stairs and lifts serving the school; tertiary - evacuation	a) See ID6(VS) b) If fire resistant construction achieves its design objective fire spread will not occur and smoke spread would be expected to be constrained but only required if sprinkler system fails. If both systems fail reliance would be placed on evacuation but with building wide alarm evacuation is expected to commence prior to fire spread to the floor above providing greater opportunity to evacuate than a fire occurring on a school level and since the evacuation paths are independent, they are unlikely to be compromised c) See ID 9 (UV) d) Since there will be no direct connections this is considered a minimal risk	Design segregates ground floor from upper levels	Detailed analysis not part of case study. Fire and smoke separation required with no shared emergency exits and lifts.
24	Temporary use of school for other activities. There were two multi-fatality fires in school buildings in the US in the early to mid-twentieth century that occurred when schools were used for other public assembly functions. In these fires, there where large numbers of occupants, inadequate egress provisions and ignition sources / combustible materials present	The NCC Classification systems can be applied to address other uses, but the extent of the application of the current NCC provisions to existing buildings where there may be a change of use (even within the broad classification of Class 9b buildings) is an administration issue which is addressed by State and Territory legislation. Where multiple uses are anticipated there is potential for fire safety to be addressed during the design phase, but management systems need to be in place to ensure all necessary controls are implemented	Where multiple uses are anticipated a design can normally be derived to address the different uses. The provision of an auditorium on the ground level that could be shared between community and school activities is a reasonable example that was used as part of the generic analysis undertaken. However, there is a significant risk associated with uses that were not anticipated as part of the design or if management systems are not in place to ensure, maximum permitted occupant numbers are not exceeded, hazards such as pyrotechnics and highly combustible decorations are not introduced, fire safety systems are maintained and an effective emergency management organisation is in place at all times etc.	This hazard generally relates to compliance with the building fire safety strategy and administrative procedures that are in place to maintain compliance. The quantitative analysis has assumed that appropriate management systems are in place on the basis that adequate guidance it provided.	A good practice guide or similar advisory document should be prepared to alert school operators of potential additional hazards that may need to be addressed when schools are used for other purposes and examples of appropriate mitigation methods. Many States and Territories provide advice / guidelines for principals to follow.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
25	Over Congestion in paths of travel to exits and exits leading to crowd crush and blocked exits causing. This has been a major contributor to multi-fatality fires in schools in the early to mid-twentieth century.	a) Limit number of occupants in building. b) Provide adequate capacity for timely evacuation including additional capacity in case an exit or path of travel to exit is blocked. c) Design of exits to avoid constrictions and as far as practical avoid convergence of large flows of people or competing flows in different directions d) Design of doorways and hardware such that doors open in the direction of travel and can be opened readily without a key. e) Reduce the need for evacuation under extreme conditions using automatic detection and alarm systems to provide an early warning and automatic sprinkler systems to limit the size of fires f) Provide adequate capacity for occupants to move away from exits after evacuating.	a) The NCC DTS provisions provide default values for the number of occupants but allows for this to be varied based on specific building configurations. The maximum building population is identified and used to determine size and in some cases number of exits. b) NCC DTS determines provision of exits on population and distance of travel to exits c) NCC DTS provide specific design requirements for exits but converging flows and competing flows can occur. It would be useful to provide information on these issues as a good practice guide. d) Design of door hardware and direction of opening is addressed by NCC DTS provisions and AS 1905.1 (for fire doors) e) The impact of detection and suppression systems will be evaluated as part of the quantitative analysis. It may be more appropriate to provide information on these issues as a good practice guide.	Items a) to e) will be addressed as part of the detailed analysis using typical inputs for the population and building layouts as described in the body of the report. Exits will be assumed to be designed in accordance with the NCC DTS provisions. For item f) the generic designs for analysis include adequate provisions for occupants to move away from exits	All these items were incorporated in the QRA and analysed for various scenarios including blocked exits as appropriate.

ID	Hazard	Initial Control Strategies	Qualitative Analysis	Quantitative Analysis / Inputs	Status / Action
26	Smoke spread simultaneously blocking all paths of travel. Whilst the potential of a fire blocking an exit has been identified under Hazard ID 1 and a fire growing in a normally unoccupied room Hazard ID 2 a common theme in multi-fatality fire reports relates to fires growing in unoccupied areas and spreading rapidly throughout a network of corridors preventing access to all available exits even though they may be at opposite ends of a corridor. Corridor networks may be compromised on the floor of origin or if there are openings between levels on upper floors	For single storey buildings this could be addressed by including direct egress from classrooms and other normally occupied spaces and / or the provision of early detection and alarm or automatic sprinklers. Smoke barriers / doors within corridors could reduce the potential numbers exposed if the hazard cannot be adequately addressed by other means. For multi-storey buildings direct egress from individual classrooms and other occupied spaces may not be possible however if external balconies provide green spaces, for example, this may be able to be achieved by providing appropriate stairs connecting the different levels. Typically, this approach may need to adopt a performance pathway. More commonly reliance would need to be placed on a fire detection and alarm systems and automatic fire sprinklers. Smoke barriers / doors within corridors or smoke lobbies could reduce the potential numbers exposed if the hazard cannot be adequately addressed by other means.	The fire incidents reviewed highlight this as a potential multi-fatality scenario which can be addressed by combinations of. • good house-keeping measures • control of lining materials • provision of early automatic detection and alarm • provision of automatic fire sprinklers • provision of adequate choices of exits • smoke separation of paths of travel to exits • smoke pressurisation or venting systems • an effective Emergency Management Organisation	The quantitative analysis will evaluate this potential scenario including considerations where failure of one or more of the mitigation measures occurs	This hazard will be evaluated as part of the QRA in conjunction with other scenarios including ID 1(BE) ID 2(UT) ID 3 (IS) ID 9 (UF) ID10 (CF) ID 11(RC) Results indicated that it is possible for occupants to be trapped on a level although closing doors to prevent smoke spread can have a large impact on tenability.

Appendix I. Enclosure Dimensions and Fire Loads

In order to calculate the exposure of a structure to fully developed fires it is necessary to define the fire load enclosure dimensions and ventilation conditions amongst other things. There can be significant variations in published data on fire loads due to the age of the data and changing nature of the contents of buildings as well as cultural variations between countries and varying survey methods.

Guidelines such as the IFEG[9] and draft data sheets prepared to support the use of the ABCB Fire Safety Verification Method[58] provide general values for fire loads. Data from these sources relating to the type of occupancies considered in this report are summarised in Table 66.

Table 66 Suggested Fire Load Distributions from FSVM Draft Data Sheets[58]

Building Type	Min- FL MJ/m^2	Mean - FL MJ/m^2	Standard Deviation MJ/m^2
Class 9b Assembly Typical	200	500	150
Class 9b Assembly high	200	780	115
Class 9b School	200	500	150

For the school enclosures results from surveys conducted in Canada in 2009 (Hadjisophocleous and Chen [38]), provide data more representative of modern schools which also includes room and window dimensions. This data is summarised in Table 67 through Table 69 using Australian School Type terms and will be used as input for modelling fully developed fires within the school areas.

Table 67 Fire Loads in School Buildings from Hadjisophocleous and Chen[38]

School Type	Surveyed rooms	Moveable fire load density (MJ/m2)				Total fire load density (MJ/m2)			
		Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Primary	Classrooms	174.4	483.3	303.9	79.5	253.9	541.9	397.5	87.1
Primary	Computer rooms	172.8	233.7	211.4	33.6	233.5	506.5	331.5	151.9
Primary	Libraries	357.1	684.6	545.8	157.8	386.8	944.7	641.1	244.0
Primary	All	172.8	684.6	329.5	129.9	233.5	944.7	426.3	151.5
Secondary	Classrooms	70.3	340.3	137.2	70.0	117.2	413.6	192.6	84.0
Secondary	Computer rooms	136.6	348.2	201.0	71.9	178.9	391.2	241.1	71.3
Secondary	Science rooms	269.9	461.8	336.0	63.8	314.9	487.4	379.5	57.2
Secondary	Art rooms	368.3	595.9	490.7	93.5	401.4	622.5	544.4	101.1
Secondary	Libraries	431.7	653.7	537.8	111.3	471.0	714.5	586.2	122.3
Secondary	All	70.3	653.7	265.1	155.9	117.2	714.5	313.7	157.3

Table 68 Floor Areas of School Rooms from Hadjisophocleous and Chen[38]

School Type	Surveyed rooms	Sample size	Minimum Floor area-m^2	Maximum Floor area-m^2	Mean Floor area-m^2	Standard Dev. - m^2
Primary	Classrooms	20	21.8	104.2	76.8	22.5
Primary	Computer rooms	3	58.9	85.3	73.9	13.6
Primary	Libraries	4	87.8	185.5	128.9	44.1
Primary	All	27	21.8	185.5	84.2	31.2
Secondary	Classrooms	15	60.3	74.0	69.6	4.2
Secondary	Computer rooms	8	53.4	107.0	82.6	18.9
Secondary	Science rooms	10	86.4	122.0	104.7	10.6
Secondary	Art rooms	4	97.6	135.7	116.2	17.4
Secondary	Libraries	3	195.6	400.8	274.6	110.4
Secondary	All	40	53.4	400.8	101.0	59.5

Table 69 Window areas of School Rooms from Hadjisophocleous and Chen[38]

School Type	Surveyed rooms	Samples	Minimum	Maximum	Mean	Standard deviation
Primary	Classrooms	20	7.0	23.4	13.8	5.1
Primary	Computer rooms	3	8.2	25.6	14.2	9.9
Primary	Libraries	4	20.3	94.0	43.7	33.9
Primary	All	27	7.0	94.0	18.3	16.6
Secondary	Classrooms	15	5.7	13.8	9.1	2.6
Secondary	Computer rooms	8	8.6	18.6	13.2	3.1
Secondary	Science rooms	10	3.5	20.0	11.4	5.7
Secondary	Art rooms	4	9.6	24.1	18.0	6.5
Secondary	Libraries	3	15.5	65.1	35.6	26.1
Secondary	All	40	3.5	65.1	13.4	9.9

Standard specifications for new school buildings may exceed minimum NCC requirements particularly with respect to amenity. Typically, classrooms or other general areas greater than 100m^2 are required to be of a minimum height of 2.7m. A uniform distribution of heights for these areas varying from 2.7 to 3m will be assumed for these areas if a distribution is required for analysis or if a fixed value adopted the minimum height of 2.7m will be adopted

For all other areas a uniform distribution in height of 2.4m to 2.7m will be adopted if a distribution is required for analysis or if a fixed value is adopted the minimum height of 2.4 will be adopted. Some ancillary areas such as toilets may have heights in some areas permitted to be reduced to 2.1m however it is not expected to be critical if a height of 2.4m is adopted for these areas.

Classroom and library floor areas are consistent with the Canadian distributions in Table 68 which will therefore be generally adopted where distributions are required.

J1. Overview of Base Smoke Spread Modelling

B-RISK Fire Simulator and Design Fire Tool (Ver 2019.03)[13] was used to undertake the smoke spread modelling. A generic primary school level or module was simplified as shown in Figure 25 such that the various enclosures can be consolidated into the following three enclosure types:

- Type 1 Small rooms - stores, kitchen offices, amenities
- Type 2 General Learning Area (classroom)
- Type 3 Libraries / Flexible Learning / General circulation

A plant room is located on a separate floor of the 5-storey option.

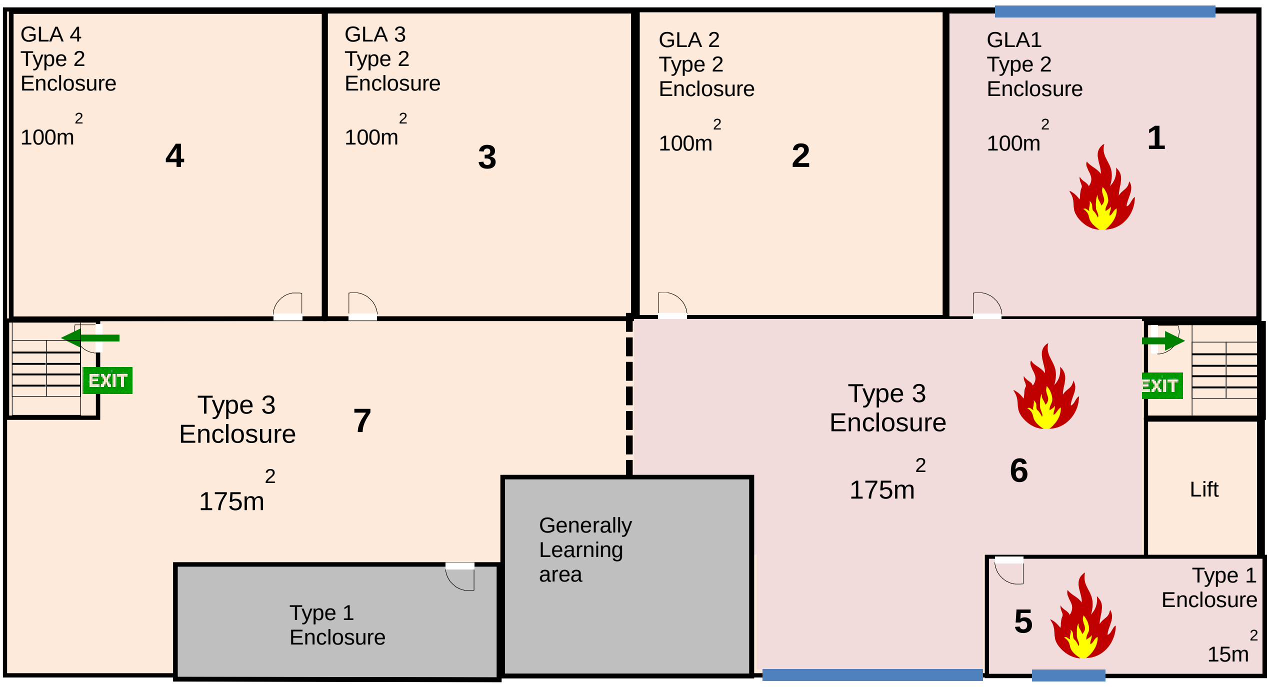

Figure 25 Generic Primary School Level for fire modelling

Design fires were located in;

- Enclosure 5 (a Type 1 ancillary area - stores, kitchen offices, amenities)
- Enclosure 1 (a Type 2 Classroom)
- Enclosure 6 (a Type 3 large opening area representative of a library, flexible learning area, general circulation / path of travel to an exit)

The representation used by the B-Risk Fire Simulator for the floor of origin is shown in Figure 26. Openings nominally 2m high and 25mm wide were provided to one external wall of each enclosure to simulate building leakage, minimise the risk of developing unrealistic building pressures limiting smoke spread and provide adequate air supplies for the severe fire scenarios being simulated prior to breakage of external windows.

In addition, a window was defined in each room in which a fire was located with B-Risk configured to open the window to the room of fire origin when the hot layer temperature exceeds 300°C unless otherwise noted. Doors were typically 2.05m x 850mm when open and 2.05m x 4mm when closed (crudely simulating a door with no seals). The door to one non-fire GLA (classroom) was open and the doors to the remaining two non-fire GLAs were closed to evaluate options for students to shelter in a classroom behind a closed door.

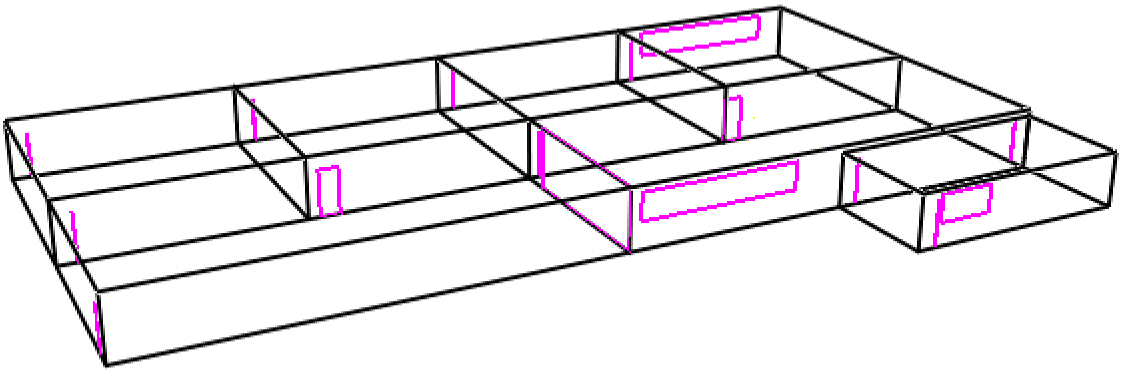

Figure 26 B-Risk Fire Simulator / smoke view representation of typical primary school level

The same configuration has also been adopted for a wing of a single storey school except that the exits will discharge at ground level via ramps and the students will not need to pass through fire stairs to exit the wing.

The following properties were applied to the wall and ceiling linings that were assumed to be clad in plasterboard:

- Density = 810.0 kg/m^3
- Conductivity = 0.160 W/m.K
- Specific Heat = 900 J/kg.K
- Emissivity = 0.88
- Thickness = 13.0 mm

The following properties were applied to the concrete floors;

- Density = 2300.0 kg/m^3
- Conductivity = 1.200 W/m.K
- Specific Heat = 880 J/kg.K
- Emissivity = 0.50
- Thickness = 100.0 mm
-

J2. Design Fire Inputs

The following default properties from B-Risk [13] were adopted for the design fires, as appropriate

- CO Yield pre-flashover(g/g) = 0.040
- CO Yield post-flashover(g/g) = 0.400
- Soot Yield pre-flashover(g/g) = 0.070
- Soot Yield post-flashover(g/g) = 0.140

- Flame Emission Coefficient = 0.80 m^{-1}
- Fuel:

  - Carbon Moles 0.95
  - Hydrogen Moles 2.40
  - Fuel - Oxygen Moles 1.00
  - Fuel - Nitrogen Moles 0.00
- Stoichiometric air/fuel ratio 6.1
- Energy Yield = 20.0 kJ/g
- CO_2 Yield = 1.500 (kg/kg fuel)
- H2O Yield = 0.725 (kg/kg fuel)
- Heat Release Rate Per Unit Area = 250.0 kW/m^2
- Radiant Loss Fraction = 0.35
- Fire Location (for entrainment) is assumed to be in the centre of the room
- Plume behaviour is undisturbed

Table 70 provides a summary of the design fires adopted for each enclosure. The fast fires were assumed to progress to the fully developed phase whereas the slow and medium fires were assumed to plateau and continue burning at a constant rate for a total fire duration of 30 minutes

Table 70 Summary of the Design Fires and Peak HRR

Encl. Type	Enclosure Description	Peak HRR -MW		
		Slow	Med	Fast
1	Small rooms - stores, kitchen offices, amenities	1.0	1.3	Flashover - limited by ventilation
2	General Learning Area (classroom)	2.2	2.6	
3	Libraries / Flexible Learning / General circulation	2.7	3.75	

The post flashover phase of the fast fire was based on the post-flashover wood crib sub-model which is based on the COMPF2 model with the option of flashover occurring when the radiant heat flux at floor level exceeds 20kW/m^2. However, as it is assumed the tenability has been exceeded throughout a fire compartment at the time of flashover if it has not occurred previously and separate modelling has been undertaken to establish if the behaviour of fire-resistant elements the post flashover phase is not critical.

J3. Smoke Detector Activation and Sprinkler Activation

Smoke detector actuation times were predicted by the B-Risk Simulator based on the smoke concentration at the location of the detector taking into account the effect of the smoke concentration within the ceiling jet if present within the enclosure and the calculated optical density within the detector housing as described by Wade [13].

The following inputs were adopted

- Radial Distance from Plume (m) = 7.00 (max permitted by AS 1670.1 for general detection systems)
- Distance below Ceiling (m) = 0.025
- Smoke Optical Density for Alarm (1/m) 0.097
- Detector Characteristic Length Number (m) = 15.00
- Detector response is based on OD inside the detector chamber.

Sprinkler Activation times were predicted using the JET algorithm. Whilst it was assumed, based on fire statistics that if the sprinkler system operates there would be unlikely to be fatalities unless closely involved in the fire for some scenarios the activation times of standard response and fast response sprinklers were compared to times various tenability criteria were exceeded. The following values were used for the comparisons.

	Standard response	Fast response
RTI – $(ms)^{1/2}$	135	50
Activation temp - °C	68	68
Radial distance - m	3.25	3.25
Distance below Ceiling - m	0.025	0.025

An additional time before the alarm sounds was added to the activation time for the alarm state to be registered and alarm sounded, A uniform distribution was adopted with a minimum value of 0s and a maximum of 10s

J4. Application of Tenability Criteria

Level 3 Conditions as defined in Appendix B2 were adopted which comprise.

- Fractional Effective Dose of 0.3 with respect to thermal exposure
- Fractional Effective Dose of 0.3 with respect to exposure to carbon monoxide
- Flashover occurring within the fire compartment
- Disproportionate collapse of an occupied part of the building or a substantial part of the building.

(The FED calculations were undertaken within the B-risk model based on the methods described in ISO 13571 [17].

Supplementary checks applying the level 1 visibility criteria were undertaken as a design check for scenarios where fire mitigation measures operating effectively to check there is sufficient opportunity for occupants to evacuate under these circumstances. Visibility was calculated within the B-risk model for illuminated exit signs based on studies by Jin and Mulholland as described by Wade [13].

To determine if conditions are suitable for fire brigade intervention and search and rescue activities reference was made to the criteria summarised in Table 71 based on criteria from AFAC FBIM v2.2 [2] and SFS Practice Note [59].

Table 71 Tenability Criteria for Fire Brigade Intervention

Criteria	Routine Condition	Hazardous Condition	Extreme Condition	Critical Condition
Max Time -min	25	10	1	<1
Max Air Temp - ºC	100	120	160	>235
Max Radiation – kW/m^2	1	3	4.5	>10
Limiting upper layer temp for radiant heat exposure - ºC (layer interface >2m above floor level)	125	250	300	425
Grouping for this project	Reasonable		Challenging	

Appendix K. **Human Behaviour, Response and Movement**

K1. General

The occupant response to a fire will vary depending upon the location of the fire, fire cues received by occupants, occupant training and emergency procedures and the threat presented by the fire. The main decisions relating to occupant response and movement are shown in Figure 27 which were used for guidance to derive scenarios and evaluate consequences for the QRA.

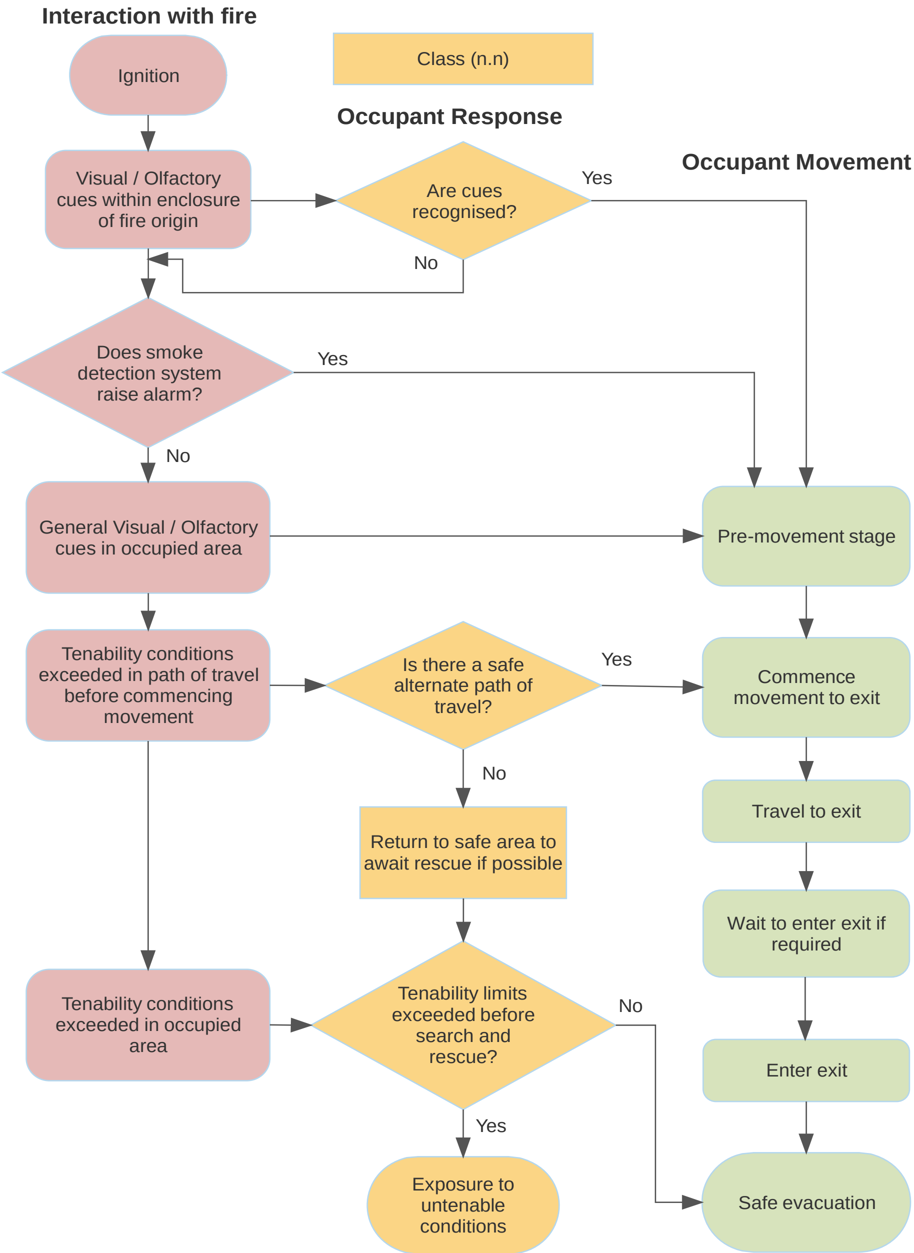

Figure 27 Flow chart showing occupant response and movement in response to fire

The inputs relating to the interaction with the fire were derived from the smoke spread modelling as described in Appendix J.

A probabilistic model was developed to calculate evacuation times using multi-scenario analysis methods based on the distributions derived from literature as described in Appendix M. This was implemented using the @risk add-in to Excel. Walking speeds for travel via stairways were based on the youngest occupants in a group since these were substantially lower than the older students. Horizontal walking speeds and pre-movement times were less variable with age and therefore the distribution was based on the general age range for primary schools.

There was little data in literature regarding the effects of occupant density although the travel speeds quoted by Hamilton [51] related to evacuation of classes as a group and it was observed that students tended to travel down stairs in a single row. Occupant flows through classroom doors and exit doors were calculated on the following basis.

For evacuation of occupants from the General Learning Area of origin an occupant spacing of 1 m was assumed and a single line of occupants was assumed to exit the classroom therefore the flow can be calculated as the speed / 1 (i.e. the same magnitude as the travel speed)

Where queuing to enter the stair occurs a spacing of 0.5m between occupants entering the stair will be assumed and the speed at entry will be based on the walking speed down the stairs or for the single storey reference building the horizontal walking speed. The occupant flow entering the stair will therefore be speed / 0.5m (i.e. 2 x the stair or horizontal travel speed.

For each scenario the flow chart (see Figure 27) will be used to identify the decisions likely to be made by the occupants and the consequences calculated based on the smoke spread analysis and occupant response modelling. The results are presented in Appendix K2 to K4

The responses received to the survey of the administrations in the States and Territories indicated that most States had policies in place requiring schools to establish Emergency Management Organisations and to develop fire emergency plans and run regular fire drills in many cases requiring schools to report on these matters.

When undertaking the analysis and deriving inputs it has been assumed that these practices will be applied in all States and Territories since they are critical to the management of fire (and other) emergencies and that the following measures will be in place in all schools;

- ***There will be an established and operational emergency management organisation in place appropriate to the size of school and documented emergency procedures***
- ***means to promptly instigate an evacuation upon activation of an automatic alarm detection /alarm system if provided***

- ***means to promptly alert all occupants and instigate an evacuation upon manual detection of a fire.***
- ***Staff are trained to a high level with any temporary staff also made aware of their responsibilities in the event of a fire and receive the necessary induction and training to facilitate an effective response to a fire emergency. This should include;***
    - ***an understanding of how to raise an alarm in the event of a fire and the emergency procedures to be followed during a fire (and other emergencies).***
    - ***knowledge of the fire protection measures in place including locations of exits***

It is a requirement of the design that these measures are implemented and maintained through the life of the building.

K2. Response to Fires in Type 2 Enclosures (Classrooms)

For fire scenarios initiating in Type 2 General Learning Areas or Classrooms (enclosures 1 to 4 in the smoke spread analysis) the following assumptions will be made regarding the occupant response;

If a sprinkler system is provided and operates effectively no further analysis is required. The following assumptions apply to scenarios where sprinklers are not provided or do not operate effectively

- It is assumed that each of the four GLAs (class rooms - see Figure 14) are fully occupied at the time of the fire (including the enclosure of fire origin) and a fire cue will be recognised by the occupants between the time of ignition and the smoke layer depth exceeding 5% of the ceiling height. A uniform distribution will be assumed between these points.
- A pre-movement time represented by a uniform distribution between 0 and 30s will be allowed after receipt of the cue before evacuation commences.
- Once evacuation of the GLA commences an early manual alarm will be raised and the remaining occupants will be made aware of the need to evacuate if an automatic alarm has not already sounded.
- Since the GLAs are all occupied it is not necessary to consider a delayed alarm for these scenarios.
- It will be assumed that the fire commences in a GLA close to one of the exits and therefore all occupants of the floor will evacuate from one exit only

K3. Response to Fires in Type 3 Enclosures

For fire scenarios initiating in Type 3 General Circulation areas which may incorporate other functional areas such as libraries and flexible learning areas (enclosures 6 and 7 in the smoke spread analysis) the following assumptions will be made regarding the occupant response;

If a sprinkler system is provided and operates effectively no further analysis is required. The following assumptions apply to scenarios where sprinklers are not provided or do not operate effectively:

- If the enclosure of fire origin is occupied a fire cue will be recognised by the occupants between the time of ignition and the smoke layer depth exceeding 5% of the ceiling height. A uniform distribution will be assumed between these points.
- A delay represented by a uniform distribution between 0 and 30s will be allowed after receipt of the cue before an early manual alarm is raised

- If the enclosure is unoccupied an automatic alarm will be raised if a smoke detection system is provided and operates effectively
- if no automatic alarm is operated and the room is unoccupied a delayed manual alarm will be raised at the time the smoke layer in enclosures 6 or 7 drop below the head of the door (2m) to the adjacent GLAs.
- a delay represented by a uniform distribution between 0 and 30s will be allowed after receipt of the cue before the alarm is raised and as prior to commencement of evacuation.
- It will be assumed that each of the four GLAs are fully occupied at the time of the fire. If Level 1 tenability conditions have not been exceeded the occupants will try to evacuate via the nearest exit or stair. If Level 1 tenability criteria are exceeded, they will remain in the GLA until they are either rescued or the tenability criteria are exceeded.

K4. Response to Fires in Type 1 Enclosures

Type 1 Ancillary areas (enclosure 5 in the smoke spread analysis) were defined as relatively small rooms used as stores, kitchens, offices and amenities with low occupant numbers.

For fire scenarios initiating in these rooms the following assumptions will be made regarding the occupant response;

If a sprinkler system is provided and operates effectively no further analysis is required. The following assumptions apply to scenarios where sprinklers are not provided or do not operate effectively

- if the room is occupied upon ignition the occupants will leave the room and raise an alarm.
- if the room is unoccupied an automatic alarm will be raised if a smoke or heat detector is provided within the space and operates effectively
- if no automatic alarm is operated and the room is unoccupied an early manual alarm may still be raised if the adjacent enclosure is occupied at the time the smoke layer in enclosure 5 drops below the head of the door (2m). A uniform distribution for cue recognition will be assumed with a minimum time of zero addressing occupants within the enclosure and involved in ignition (e.g. cooking / reheating food) to a maximum of the time the smoke layer drops below 2m potentially alerting occupants in the adjoining enclosure)
- if both the room of fire origin and the adjoining enclosure are not occupied a delayed alarm will be raised. The time the smoke layer (in enclosures 6 or 7 in the smoke spread analysis) drops to 2m allowing smoke to enter the GLAs will provide the cue to the occupants
- a delay represented by a uniform distribution between 0 and 30s will be allowed after receipt of the cue before the alarm is raised and evacuation commences.
- It will be assumed that each of the four GLAs are fully occupied at the time of the fire. If Level 1 tenability conditions have not been exceeded the occupants will try to evacuate via the nearest exit or stair. If Level 1 tenability criteria are exceeded, the occupants will remain in the GLA until they are either rescued or the tenability criteria are exceeded.

Appendix L. Analysis of Risk to Occupants on the Floor of Fire origin.

L1. Overview of Analysis

A series of fire scenario clusters were defined to reflect the universe of potential fire scenarios based on approaches described in ISO 16732-1 [1] which were then consolidated into a series of representative design fires. Refer Section C4.6 for further details.

The event tree shown in Figure 28 was then derived by:
- consolidating all the branches with zero consequences,
- assigning the probabilities for fires occurring in the various types of enclosures from Table 53 which were derived from fire statistics in Section C4.6
- including an automatic sprinkler branch

Note: the no sprinkler intervention case applied to the reference buildings is shown with the sprinkler effective “Yes” branch set to 0. This branch would be changed to reflect the sprinkler system effectiveness for the five storey buildings with sprinkler protection.

The representative fire scenarios required further extension to address the various methods by which occupants become aware of a fire, and to consider the variability of human behaviour and evacuation process when evaluating the consequences of the event tree for branches relating to fires occurring in Type 1 to 3 enclosures.

This was achieved by:

a) extending the representative fire scenario event trees to address the following means by which occupants are alerted to the occurrence of a fire (refer Figure 29 for further details).
   - automatic (via the smoke detection and alarm system),
   - early manual detection and
   - delayed manual detection.

b) Including the status of the door to the room of fire origin in the extended event trees as appropriate and

c) Undertaking ASET / RSET evacuation modelling using the distributions for premovement times and travel speeds assuming the occupants travel as a class group as identified in the technical literature.

Fire brigade Intervention was modelled where appropriate using FBIM [2] and response times based on distributions published in a Report on Government Services [3] as described in Section L2.

To derive the event tree outcomes for Type 1 to 3 enclosure fires multi-scenario analyses were undertaken using spread sheet calculations employing the logic shown in Figure 27 and described in further detail 0, together with the outcomes from smoke spread modelling undertaken using a zone-model (B-Risk [13] as described in Appendix J.

The zone model and multi-scenario analysis results supporting the ASET / RSET analyses for the various branches / branch extensions are presented in this section with references to the corresponding analysis sub-sections being provided in Figure 28. The results are consolidated in subsection L13.

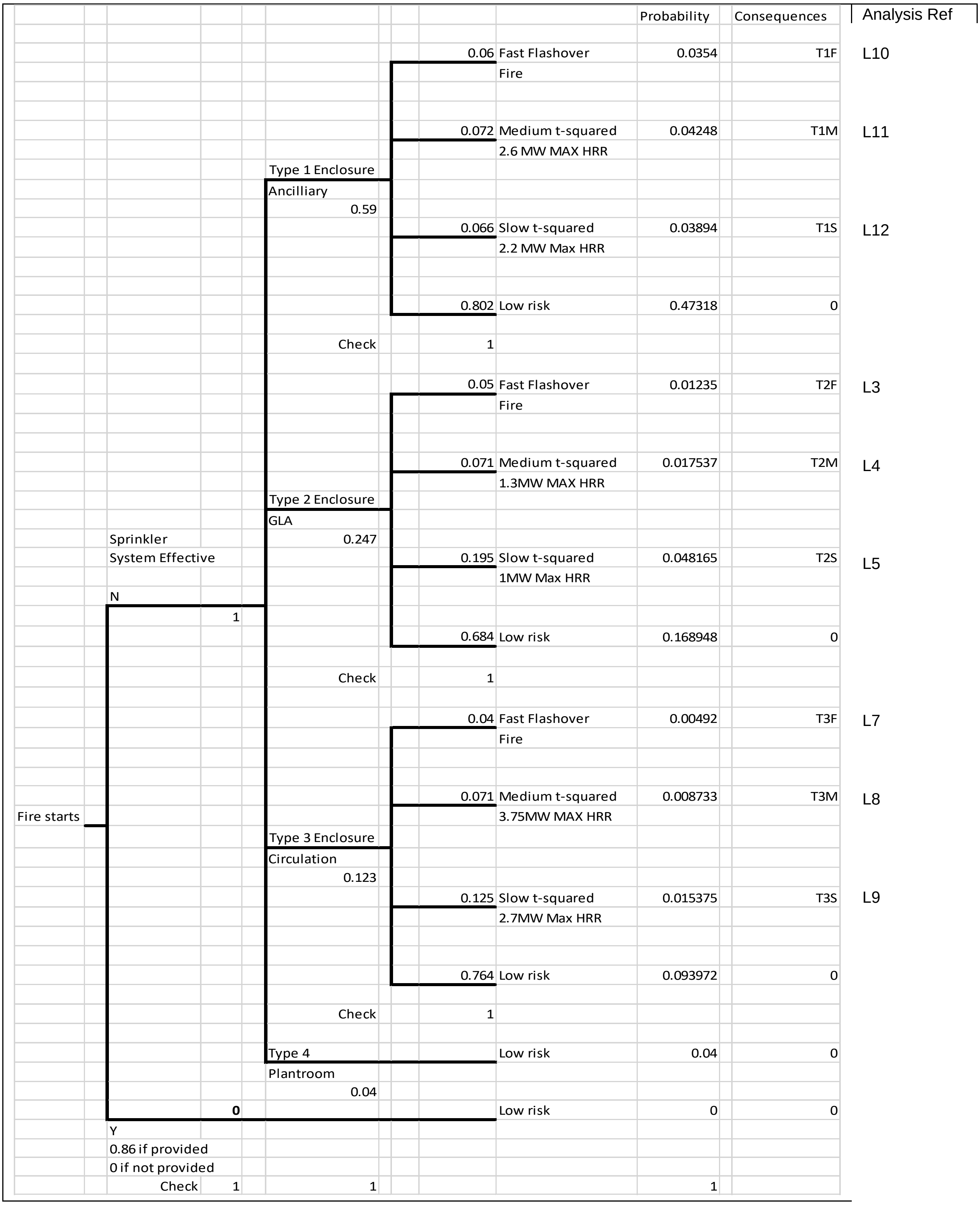

Figure 28 Consolidated Event Tree for Floor of Fire Origin

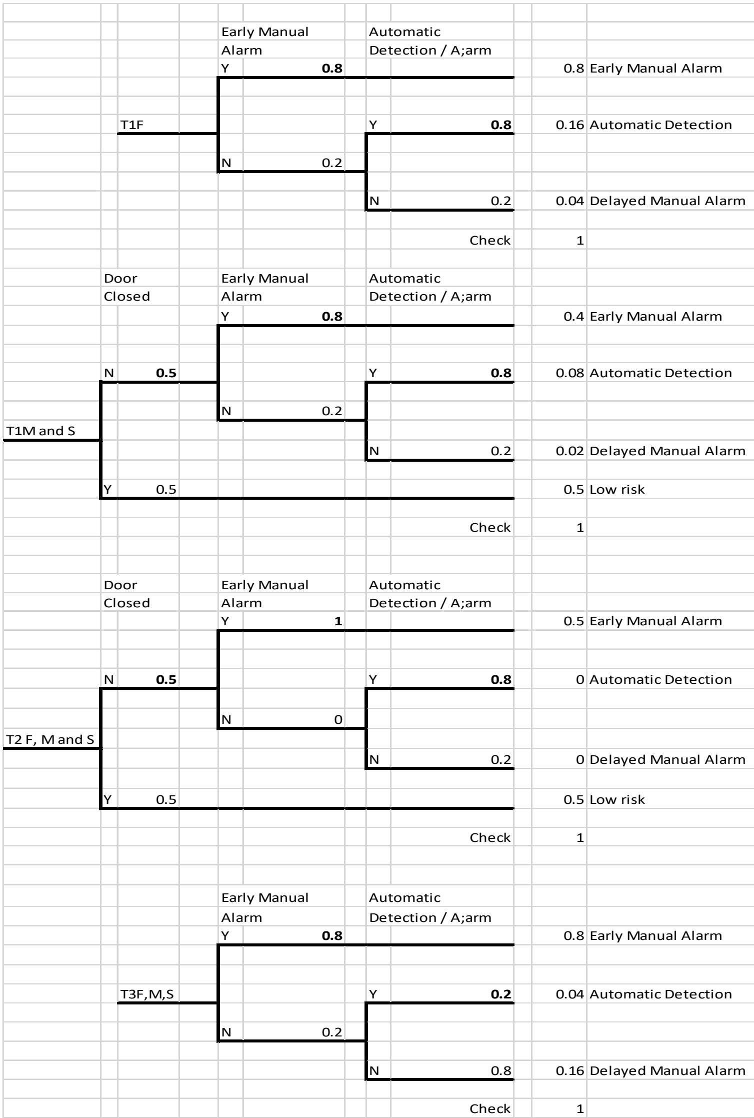

Figure 29 Event trees determining probability of door closure and means of fire alarm

Notes to Figure 29:

1. A binary model was applied to the fire detection system. It was assumed the detector either operates at its design sensitivity of fails to operate. Times to detector activation and the corresponding alarm times were determined using a zone-model (B-Risk [13]). Further information is provided in Appendix J3
2. The probability of an early manual alarm was estimated to be 0.8 for the ancillary and general circulation areas whilst the school is occupied and 1 in an occupied GLA (classroom) because of the large number of occupants that would be alert and wake.
3. The effectiveness of the detection and alarm system was assumed to be 0.8 if the system is provided and zero if not provided. The 0.8 effectiveness is a low estimate when compared to the values in ABCB FSVM Handbook Annex data sheets[14] but was selected to allow for variations in occupant awareness and response to the alarm.
4. The probability of delayed manual detection was calculated on the basis that delayed manual detection would occur if early manual detection does not occur and an automatic detection system is not provided, or the system is not effective. The timing of delayed activation was estimated on the basis of the time that smoke will start entering the GLAs through the head of the door. A uniform distribution was therefore assumed based on the times the smoke layer interface fell to below 2m height in enclosures 6 and 7.
5. The probability of a door being closed to the enclosure of fire origin after evacuation or if the enclosure is unoccupied at the time of the fire was assumed to be 0.5 for the medium and slow growth rate fires occurring within an ancillary or GLAs. The probability of a door being closed was also assumed to be 0.5 for a fast fire in the GLA but taken as 0 for the ancillary areas since ancillary areas could be unoccupied at the time of the fire and the door is required to be open to provided sufficient ventilation to achieve flashover.

L2. Fire Brigade Intervention

L2.1. Fire Brigade Intervention Potential Flashover Fires

Since the proportion of potential flashover fires and fire growth rates for these scenarios were derived from fire statistics it was expected that fire brigade intervention would be unlikely to occur prior to flashover. This was checked by undertaking a fire brigade intervention analysis using a multi-scenario implementation of the AFAC FBIM model [2] as described by England [60] to determine the time to application of water except that the response time distribution adopted to determine the time from receipt of an alarm to arrival of the first fire brigade vehicle at the scene was as shown in Figure 30

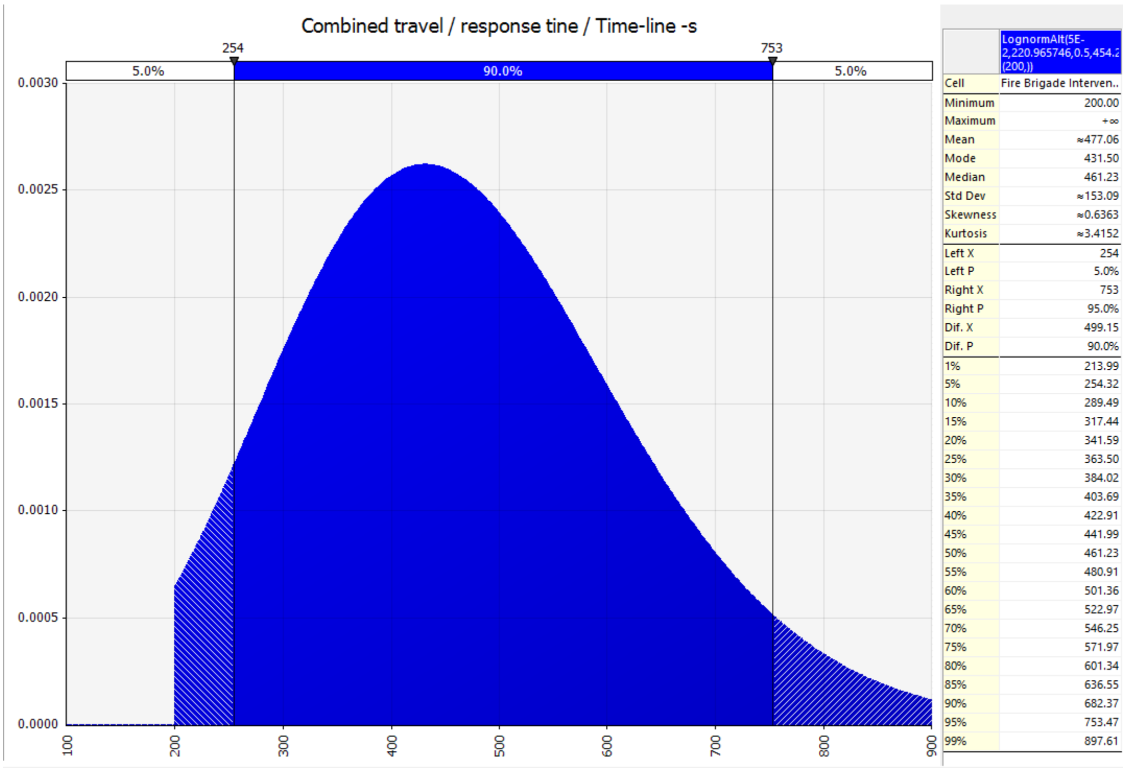

Figure 30 Fire Brigade Response time from receipt of alarm

The 50 and 90 percentile values are compared with the statistics included in the in the Report on Government Services [3] below;

	Assumed Distribution	2016-2017 data range for major cities
50 percentile value	7.7minutes	6.3 to 8.0 minutes
90 percentile value	11.4 minutes	9.2 to 11.7 minutes

It can be seen that the distribution adopted is within the range of values reported but reflects the States and Territories with slower responses providing generally conservative results for most States and Territories. The major city values were adopted since high-rise schools will tend to be in areas with high population densities.

The distribution of the estimated time to apply water to a fire on the first floor obtained is shown in Figure 31 and exceed all the estimated times to flashover therefore for the Fast Flashover fires fire brigade intervention is not expected to have a significant impact in the compartment of fire origin.

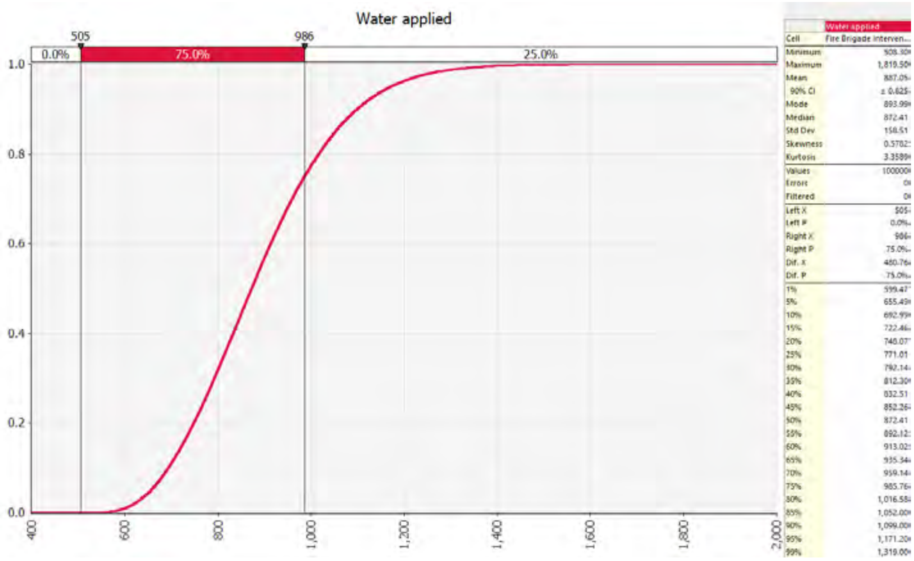

Figure 31 Distribution of the time to application of water to fire on the first floor.

L2.2. Fire Brigade Intervention Non-Flashover Fires

Consideration was given to the impact of Fire Brigade Search and Rescue activities during non-flashover fire scenarios, if occupants had not been exposed to untenable conditions before search and rescue activities commenced. (refer Section M2.2). Figure 32 shows a distribution for the time for commencement of search and rescue for a fire occurring on the first floor which will be used for simple evaluations.

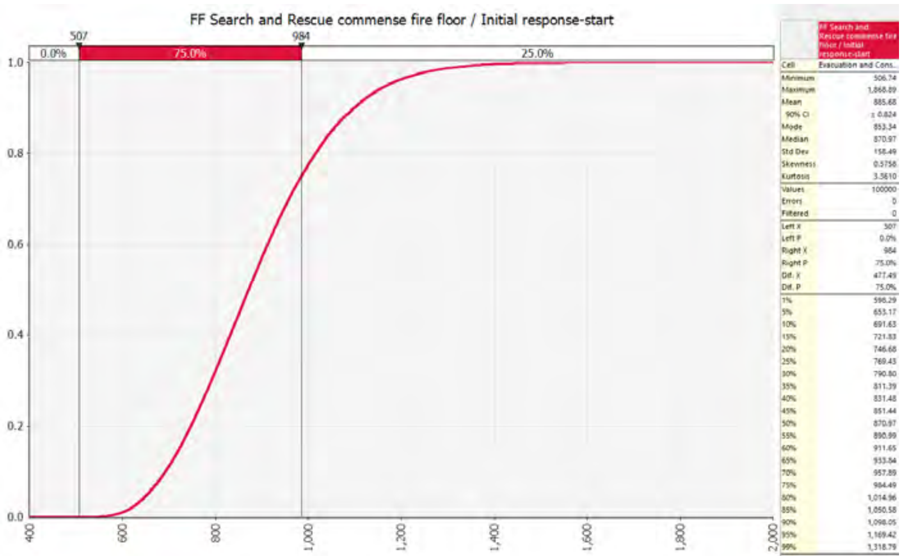

Figure 32 Distribution of time to commencement of search and rescue on the first floor

L3. FAST – Flashover Fires occurring within an occupied General Learning Area (Classroom)

L3.1. Fast Growth Flashover Fire – Room of Fire Origin Performance

The occupant response within the room of fire origin commenced prior to activation of the smoke detector and therefore if the impact of automatic sprinkler protection is ignored the predicted outcomes will be the same for all the building options (i.e. both reference buildings and the 5-storey proposed design). The results vary substantially depending upon the tenability criteria adopted as shown in Table 72 (refer Section J4 for definitions of the tenability criteria for each level). The Level 1 and Level 2 losses are substantially higher than estimates based on statistics which is to be expected having regard for the severe scenario adopted and conservatism within the Level 1 and 2 tenability criteria.

Table 72 Proportions of Occupants Exposed to Untenable Conditions for a fast fire occurring in the room of fire origin

Number of Occupants exposed to conditions exceeding tenability limits	Proportion of fire scenarios		
	Level 1 Tenability	Level 2 Tenability	Level 3 Tenability
0	0.7103	0.9877	1
1	0.0144	0.0028	
2	0.0162	0.0016	
3	0.0141	0.0019	
4	0.0124	0.0012	
5	0.0145	0.0013	
6	0.0127	0.0008	
7	0.0126	0.0007	
8	0.0123	0.0002	
9	0.0124	0.0005	
10	0.0122	0.0006	
11	0.0133	0.0003	
12	0.0121	0.0001	
13	0.0109	0.0001	
14	0.0097	0.0001	
15	0.009		
16	0.0087	0.0001	
17	0.0093		
18	0.0086		
19	0.006		
20	0.0066		
21	0.0059		
22	0.0083		
23	0.0064		
24	0.0054		
25	0.0036		
26	0.005		
27	0.0038		
28	0.0032		
29	0.0027		
30	0.0019		
31	0.0155		
Checksum	1	1	1

The distribution for the time after ignition that the last person leaves the GLA of fire origin is shown in Figure 33 indicating that the required safe evacuation time RSET to avoid any losses would be approximately 125s assuming no automatic suppression.

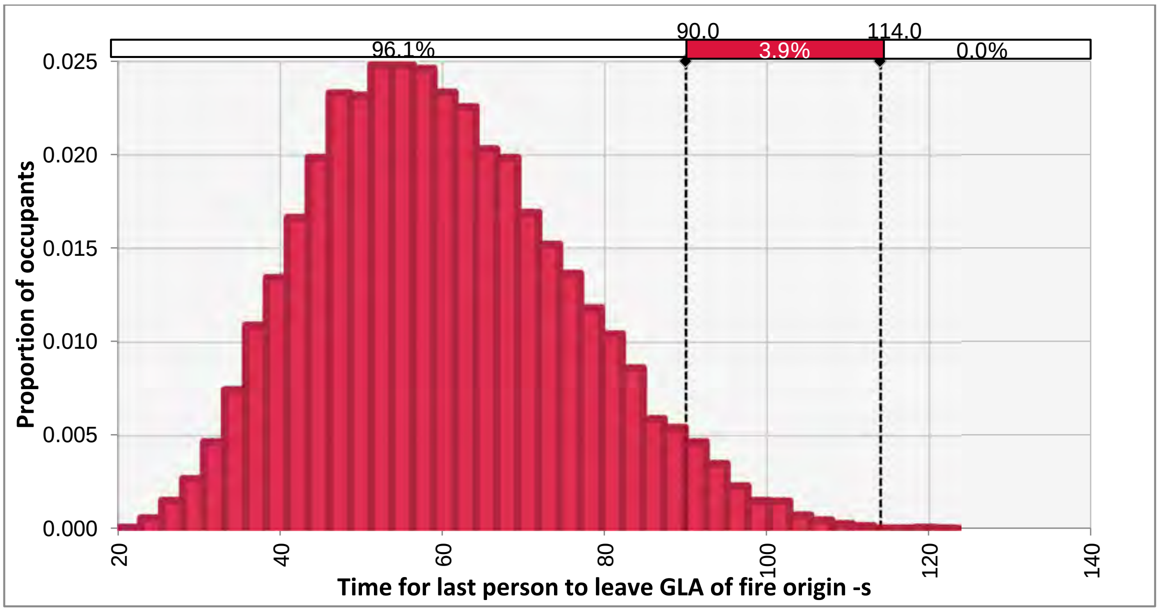

Figure 33 Distribution of the time the last person leaves the GLA of fire origin

To provide a context calculated sprinkler activation times are compared to the times the different levels of tenability criteria were exceeded below:

Sprinkler Activation after 119s - RTI 50 typical design value for fast response head

Sprinkler Activation after 149s - RTI 135 typical design value for modern standard response head

Level 1 Tenability	68s
Level 2 Tenability	98s
Level 3 Tenability	153s

Prior to activation of a sprinkler (nominally 120s to 150s) there will be no difference in the outcomes between the reference and the high-rise options if the same egress options from the class-room are provided and therefore for the purposes of the comparative analysis beyond the room of fire origin it will be assumed that all occupants evacuate the GLA of origin safely for fires occurring in GLAs.

This is considered a reasonable assumption because fire statistics indicate it is very unlikely that persons will not be able to successfully evacuate the GLA of fire origin and if the fire does not block the path of travel to the door and the occupants are not in intimate contact with the fire adequate time for evacuation is expected to be available irrespective of the impact of automatic sprinkler system.

The risk from a fire blocking a path of travel to a single doorway serving a classroom can be significantly reduced by providing two doors to each classroom and / or a fast response automatic sprinkler system. The provision of two doors may also be of benefit during other emergencies. Alternate exits from a classroom, including direct exits from the building, are more likely to be provided in single storey schools and may contribute to the very low losses observed in fire statistics.

L3.2. Fast Growth Flashover Fires – General Smoke Modelling Results – Door open

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for Fast Growing Potential Flashover Fires are summarised in Table 73. The table summarises the results from the B-Risk analyses and includes sprinkler activation times but also the times at which the various parameters are achieved. The stated times are in seconds.

Table 73 Smoke Spread and Tenability Limits - fast fire with the GLA of fire origin door open

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation		Comb Path
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7	
5% smoke layer height - Cue 1	20		182		230	100	120	
20KW HRR - Cue 2	20							
Smoke Detector Activation	55					79	95	
Sprinkler Activation -RTI 50	119							
Sprinkler Activation -RTI 135	149							
Window breakage - Cue 3	212							
Flashover	395							
Upper layer temps °C @390s	513	21	25	21	21	76	51	
Visibility 10m @2m	68	>2400	320	>2400	>2400	150	153	
Smoke layer 2m	68	>2400	240	>2400	>2400	150	153	
Smoke layer 1.75m	82	>2400	277	>2400	>2400	175	165	
Smoke layer 1.5m	98	>2400	300	>2400	>2400	195	179	
FED thermal - 0.3	153					516	683	682
FED CO - 0.3	366		783			520	571	571
Level 1 Tenability	68					150	153	
Level 2 Tenability	98					195	179	
Level 3 Tenability	153	395	395	395	395	395	395	395

Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L3.3. ASET RSET Analysis Fast Fires – Door left open after evacuation of GLA

Scenario Cluster GLA FAST a - High-Rise Smoke Detection System Activates

For this scenario cluster the sprinkler system has been assumed to fail, if provided. Scenarios are analysed with the detection and alarm system operating in accordance with its design intent, if provided. In addition, the visual and olfactory cues from the fire are likely to be strong and unambiguous within the room of fire origin and since the t-squared fire ignores any incipient growth period the time for manual detection has therefore been assumed to be a uniform distribution with a minimum value of t=0s and a maximum of the time the smoke layer depth exceeds 5% of the ceiling height in the room of fire origin. Since the room is occupied by a large number of occupants it will be assumed that manual detection occurs in all cases within the room of fire origin. A prompt evacuation will be implemented by the class teacher and due to the rapid growth of the fire, the exit furthest from the fire will be used by all occupants on the floor.

Other occupants in other enclosures on the floor of origin will be alerted by the automatic detection and alarm system.

A typical evacuation time distribution for all occupants to evacuate via a single stair from the floor of fire origin (i.e. to evacuate into the fire-isolated stair) was obtained from the multi-scenario simulation of a high-rise building and has been included in Figure 34 to provide a general indication of the time for evacuation after an alarm has been recognised. Typical times obtained were a mean evacuation time of approximately 210s and a maximum of 342s. This was not used directly as part of the fuller simulation exercise to determine losses as per Table 74 where it was necessary to determine the number of occupants evacuating prior to the onset of untenable conditions.

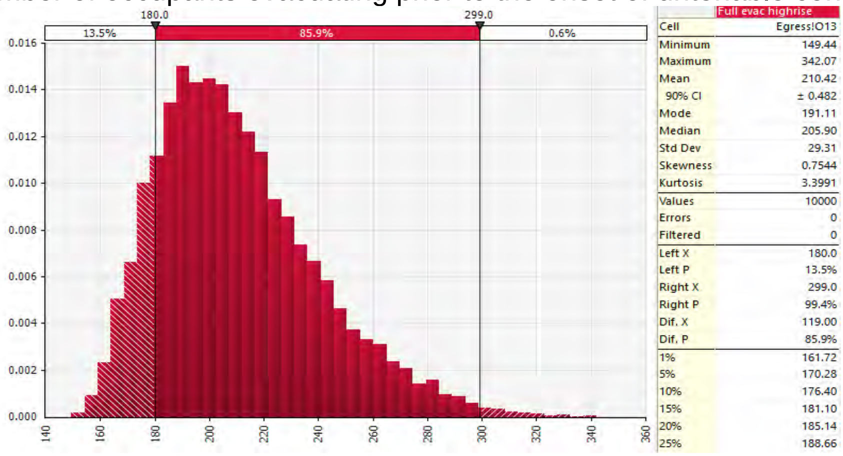

Figure 34 Distribution of time to fully evacuate the floor – high rise, automatic detection

Scenario Cluster GLA FAST b High-Rise Smoke Detection System Failure – Manual Alarm

This scenario cluster is similar to scenario cluster "GLA FAST a" within the GLA of fire origin but once the teacher has ensured the children have commenced evacuating the classroom (occupants are out of immediate danger) and are heading to the fire exit a manual alarm will be raised. This process will depend upon the facilities provided, other staff available at the time and efficiency of the staff members response. A uniform distribution has been adopted with the time to manually raising a general alarm spanning a 60s period from completion of the pre-movement stage. This is intended to represent a school with an effective emergency management organisation and emergency procedures in place with regular training and drills being undertaken.

A typical evacuation time distribution from the multi-scenario simulation of a high-rise building without the smoke detection system operating is shown in Figure 35. It can be observed that the evacuation time is comparable to a building with a detection system in place. This is to be expected if a fire occurs within an occupied room, but a greater variance will be expected for unoccupied rooms which has been considered under the Type 1 and Type 3 enclosure categories.

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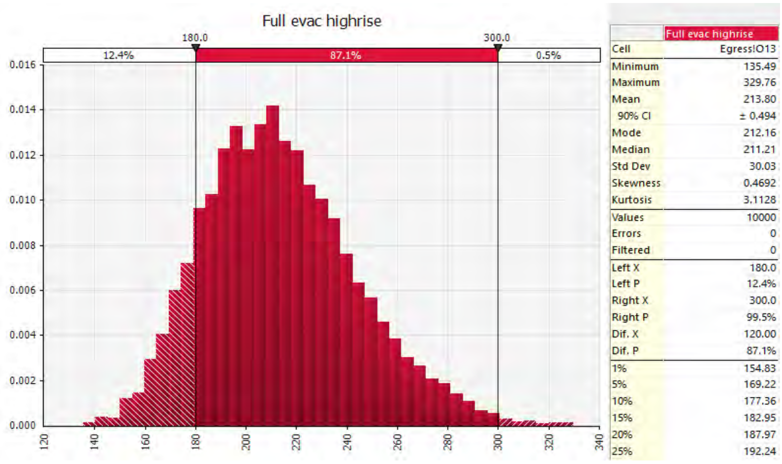

Figure 35 Distribution of time to fully evacuate the floor – high rise, no automatic detection

The outcomes in terms of occupants exposed to the various levels of tenability are summarised in Table 74.

Scenario Cluster GLA FAST c Reference Building with automatic smoke detection / alarm

A typical evacuation time distribution from the multi-scenario simulation of the reference building with a smoke detection system is shown in Figure 36 with a mean evacuation time of approximately 175s and a maximum of 345s.

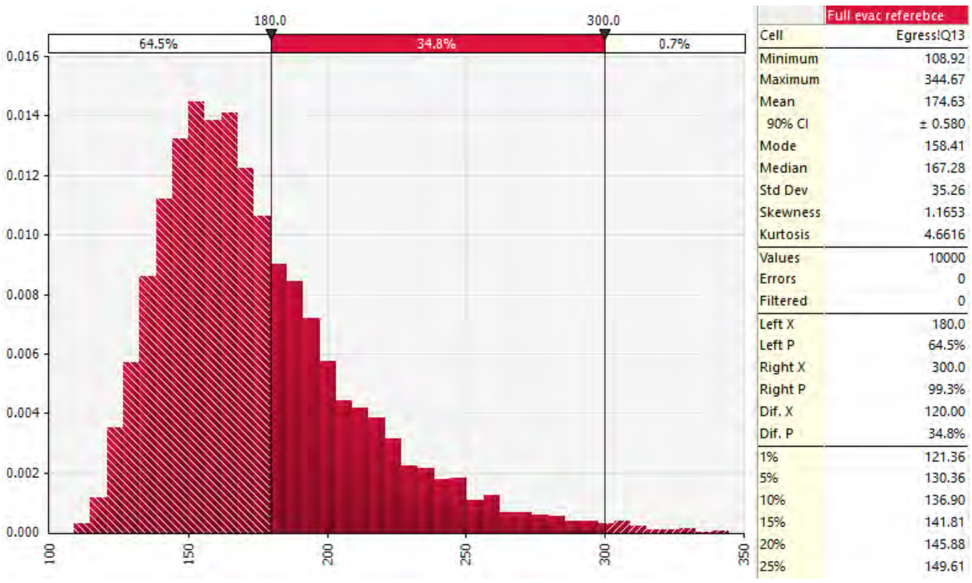

Figure 36 Distribution of time to fully evacuate the floor – reference, automatic detection

The tail of the distribution is very similar to that for the high-rise building, but the mean is 35s less. This distribution reflects the generally faster flow rate for a horizontal evacuation, but the tail reflects scenarios where the flow is substantially less than optimum which may occur in some circumstances and is therefore considered reasonable.

The outcomes in terms of occupants exposed to the various levels of tenability are summarised in Table 74.

Scenario Cluster GLA FAST d Reference Building with no automatic smoke detection / alarm

This scenario cluster is similar to scenarios “GLA FAST c” within the GLA of fire origin but once the teacher has ensured the children have commenced evacuating the classroom and are heading to the fire exit a manual alarm will be raised. This process will depend upon the facilities provided, other staff available at the time and efficiency of the staff members response. A uniform distribution has been adopted with the time to manually raising a general alarm spanning a 60s period from completion of the pre-movement stage. This is intended to represent a school with an effective emergency management organisation and emergency procedures in place with regular training and drills being undertaken.

A typical evacuation time distribution from the multi-scenario simulation without the smoke detection system operating is shown in Figure 37 which shows a similar performance with respect to time to a building with a detection system in place. As noted previously this is to be expected if a fire occurs within an occupied room, but a greater variance will be expected for unoccupied rooms which has been considered under the Type 1 and Type 3 enclosure category.

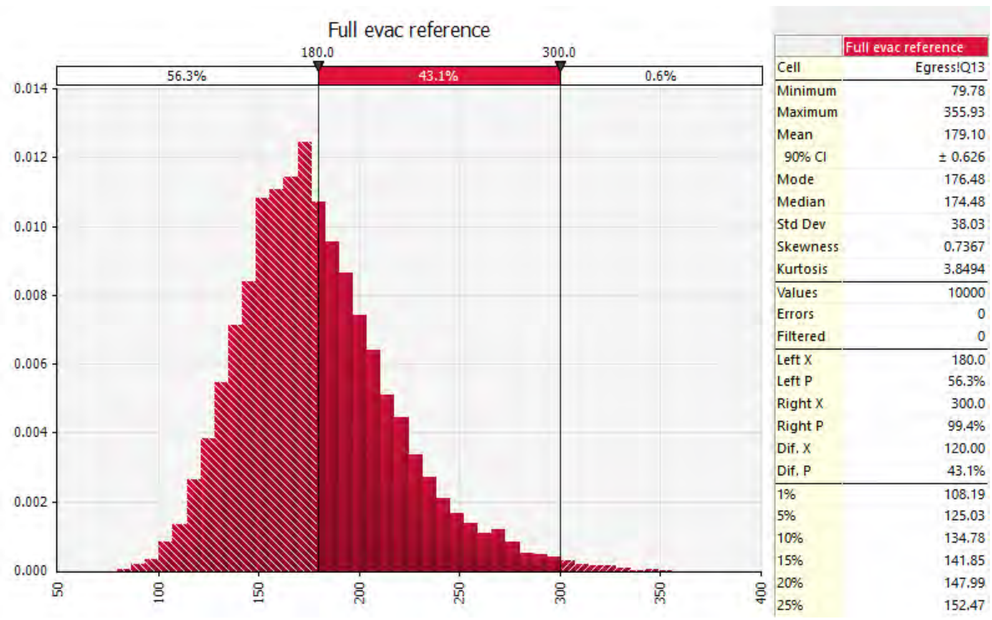

Figure 37 Distribution of time to fully evacuate the floor – reference, no automatic detection

The outcomes in terms of occupants exposed to the various levels of tenability are summarised in Table 74.

Consolidation of Results and Preliminary Analysis

The results for the four scenario clusters described above have been consolidated in Table 74 using the Level 1 and Level 2 tenability criteria. The Level 3 tenability criteria were not exceeded prior to evacuation for any of the scenario groups. These results and the results in all the following consolidation tables in this Appendix take into account the variability of human behaviour and movement. Where occupants on the floor of origin are not exposed to untenable conditions but are unable to evacuate due to blocked exits or paths of travel to exits the impact of fire brigade intervention has been considered in the discussion to the relevant scenario cluster.

Table 74 Probability of exposure to untenable conditions Fast Growth Flashover Fires – Door left open after evacuation of GLA

No of Occupants exposed	High-rise - Detection		Ref. Bld. - Detection		High-rise – No Detection		Ref. Bld. – No Detection	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
0	0.0177	0.1857	0.463	0.7437	0.0066	0.1173	0.362	0.6546
1	0.0022	0.0118	0.0122	0.0065	0.001	0.0071	0.009	0.0074
2	0.0031	0.0125	0.0102	0.005	0.0015	0.0076	0.0091	0.0071
3	0.0022	0.0114	0.0106	0.0074	0.0019	0.0084	0.0076	0.0084
4	0.0025	0.013	0.0089	0.006	0.001	0.0094	0.0083	0.0073
5	0.0024	0.0134	0.0094	0.0054	0.0016	0.009	0.0069	0.0078
6	0.0026	0.0117	0.0105	0.0046	0.0021	0.0109	0.0067	0.0063
7	0.0039	0.0122	0.0099	0.0061	0.0018	0.0095	0.0077	0.0074
8	0.0031	0.0126	0.0106	0.0061	0.0021	0.0136	0.008	0.0082
9	0.0046	0.0139	0.0094	0.0058	0.0025	0.0121	0.0103	0.0082
10	0.0044	0.0149	0.0083	0.0046	0.0019	0.0118	0.007	0.0075
11	0.0062	0.013	0.0104	0.005	0.0026	0.0121	0.0071	0.0077
12	0.0052	0.0159	0.0093	0.0067	0.0026	0.0157	0.0077	0.0074
13	0.0053	0.0151	0.0098	0.005	0.004	0.0143	0.0081	0.0066
14	0.0069	0.0137	0.0074	0.0076	0.0041	0.0149	0.0079	0.0076
15	0.0072	0.0133	0.0095	0.0061	0.0048	0.0135	0.0092	0.0066
16	0.0076	0.0155	0.0087	0.0033	0.0044	0.0153	0.0086	0.0057
17	0.0072	0.0144	0.0096	0.0042	0.0047	0.0137	0.0086	0.008
18	0.0091	0.0157	0.0088	0.0048	0.0063	0.0143	0.0083	0.0045
19	0.0097	0.0151	0.0105	0.0026	0.0052	0.0158	0.0087	0.0078
20	0.0092	0.0141	0.0101	0.0037	0.0055	0.0154	0.009	0.0059
21	0.0092	0.0175	0.0095	0.0039	0.0066	0.0143	0.0105	0.0058
22	0.0103	0.0177	0.0077	0.0036	0.0077	0.0167	0.0101	0.0054
23	0.0116	0.0163	0.0079	0.0049	0.0075	0.016	0.0072	0.0071
24	0.0096	0.0161	0.0093	0.0031	0.0079	0.0159	0.0099	0.0057
25	0.0119	0.0156	0.0077	0.0038	0.0083	0.0171	0.0084	0.0058
26	0.0123	0.0181	0.0094	0.003	0.0077	0.0164	0.0083	0.0057
27	0.0135	0.0144	0.0091	0.0045	0.0086	0.0179	0.0091	0.0058
28	0.0154	0.0172	0.0083	0.0042	0.0084	0.0171	0.0103	0.0061
29	0.0136	0.0174	0.0072	0.0038	0.0104	0.0151	0.0108	0.008
30	0.016	0.0178	0.0079	0.0052	0.0121	0.0174	0.0089	0.0063
31	0.0165	0.0151	0.0068	0.0038	0.0127	0.0186	0.008	0.0048
32	0.0138	0.0137	0.0068	0.0032	0.0127	0.0192	0.0098	0.0048
33	0.0148	0.0163	0.0076	0.0035	0.0127	0.0175	0.0078	0.0049
34	0.0142	0.015	0.0073	0.0035	0.0129	0.0184	0.0094	0.0047
35	0.0135	0.017	0.0079	0.0038	0.0138	0.0162	0.0077	0.0043
36	0.0201	0.0153	0.0066	0.0039	0.0153	0.0188	0.0084	0.0035
37	0.0176	0.014	0.0074	0.003	0.0174	0.0189	0.0089	0.0034
38	0.0181	0.0157	0.0082	0.0038	0.0153	0.0166	0.0087	0.0053
39	0.0168	0.0134	0.0081	0.0033	0.0148	0.0174	0.0099	0.0051
40	0.0162	0.0127	0.0067	0.0029	0.015	0.0157	0.0088	0.0042
41	0.0167	0.0147	0.0062	0.0021	0.0151	0.0192	0.0092	0.0057
42	0.0153	0.0136	0.0058	0.0039	0.0161	0.0155	0.0088	0.0042
43	0.0187	0.0124	0.006	0.0028	0.0194	0.0149	0.0089	0.0038
44	0.0185	0.013	0.0058	0.0031	0.0187	0.0144	0.0109	0.0031
45	0.0208	0.012	0.0045	0.0027	0.0174	0.0157	0.0093	0.0047
46	0.0166	0.0095	0.0052	0.0037	0.0176	0.0141	0.0079	0.0045
47	0.0183	0.0125	0.0058	0.0021	0.0204	0.0144	0.0084	0.0029
48	0.0184	0.0085	0.0038	0.0024	0.0177	0.0137	0.0075	0.0029
49	0.0221	0.0111	0.0045	0.0033	0.0179	0.0134	0.0074	0.0039
50	0.0163	0.0098	0.0047	0.002	0.019	0.0127	0.0086	0.0034
51	0.0191	0.0089	0.0049	0.0015	0.0187	0.0126	0.0076	0.0031
52	0.017	0.009	0.0035	0.0024	0.0213	0.0113	0.0092	0.0034
53	0.0191	0.0087	0.0053	0.0024	0.0204	0.0118	0.0085	0.0023
54	0.0175	0.0065	0.0044	0.0024	0.0201	0.011	0.0072	0.0028
55	0.0191	0.0066	0.0067	0.0017	0.0204	0.0106	0.0077	0.003
56	0.0173	0.0073	0.005	0.0018	0.0198	0.008	0.0071	0.0021
57	0.0196	0.0056	0.0049	0.0015	0.0213	0.0084	0.0071	0.0032
58	0.0192	0.0047	0.0036	0.0023	0.0216	0.0075	0.0063	0.0018
59	0.0161	0.0055	0.0043	0.0014	0.0205	0.0078	0.006	0.0028
60	0.017	0.0056	0.0041	0.0022	0.0211	0.0063	0.0062	0.0021
61	0.0173	0.0042	0.0046	0.0015	0.0193	0.0056	0.0068	0.0023
62	0.0126	0.0035	0.0036	0.0021	0.0211	0.0061	0.0067	0.0029
63	0.0138	0.0039	0.004	0.0015	0.0192	0.0049	0.0061	0.0014
64	0.0157	0.0031	0.0026	0.002	0.016	0.0055	0.0056	0.0019
65	0.0133	0.0034	0.0031	0.0018	0.016	0.0049	0.0049	0.002

No of Occupants exposed	High-rise - Detection		Ref. Bld. - Detection		High-rise – No Detection		Ref. Bld. – No Detection	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
66	0.0123	0.0026	0.0034	0.0017	0.0178	0.0037	0.0059	0.0008
67	0.013	0.0025	0.0036	0.0007	0.0153	0.003	0.0043	0.0016
68	0.0117	0.0027	0.0033	0.0014	0.0159	0.0039	0.006	0.0021
69	0.0111	0.0026	0.0035	0.0015	0.0137	0.0026	0.0066	0.0009
70	0.0107	0.0018	0.0037	0.0008	0.0144	0.0024	0.0035	0.0017
71	0.0077	0.0015	0.0028	0.0011	0.0146	0.0012	0.004	0.0013
72	0.0105	0.0013	0.0036	0.0011	0.0127	0.0026	0.0041	0.001
73	0.0085	0.0011	0.0026	0.002	0.012	0.0015	0.0042	0.0017
74	0.0077	0.0013	0.0024	0.0006	0.0117	0.0007	0.0042	0.0008
75	0.0071	0.0006	0.0023	0.0004	0.0094	0.0012	0.0038	0.0006
76	0.0063	0.0004	0.0026	0.0011	0.0084	0.0011	0.0039	0.0005
77	0.0057	0.0004	0.0025	0.0007	0.0101	0.0008	0.0039	0.0008
78	0.0052	0.0005	0.0025	0.0007	0.0084	0.0003	0.0041	0.0005
79	0.0046	0.0003	0.003	0.0006	0.0081	0.0006	0.0036	0.0002
80	0.0044	0.0005	0.0013	0.0003	0.005	0.0002	0.0043	0.0007
81	0.004	0.0003	0.0021	0.0006	0.0053	0.0003	0.0029	0.0006
82	0.0037	0.0002	0.002	0.0005	0.0077		0.0024	0.0007
83	0.0038	0.0001	0.0019	0.0004	0.0063	0.0005	0.003	0.0007
84	0.0018	0.0001	0.0013	0.0003	0.0046		0.0027	0.0001
85	0.0024	0.0002	0.0018	0.0002	0.0043		0.003	0.0002
86	0.0031	0.0001	0.0017	0.0001	0.0034		0.003	
87	0.0016	0.0001	0.0014	0.0002	0.0019	0.0001	0.0032	0.0001
88	0.0028		0.0014	0.0008	0.0035		0.0019	
89	0.002		0.0017	0.0001	0.0025	0.0001	0.0023	0.0005
90	0.0007		0.001	0.0001	0.0018		0.0014	0.0002
91	0.001		0.0011	0	0.0014		0.0009	0.0002
92	0.0002		0.0013	0	0.0011		0.0012	0.0002
93	0.0006		0.0008	0.0001	0.0012		0.0008	0.0001
94	0.0009		0.0007	0.0001	0.0009		0.0008	0.0001
95	0.0006		0.0009	0.0001	0.0017		0.0011	0.0001
96	0.0002		0.0003	0.0001	0.0004		0.0011	
97	0.0003		0.0008		0.0005		0.0008	
98	0.0002		0.0004		0.0003		0.0004	0.0001
99	0.0003		0.0005		0.0005		0.0006	
100	0.0004		0.0003	0.0001	0.0001		0.0004	
101	0		0.0004		0.0002		0.0004	
102	0.0002		0.0003		0.0002			
103			0.0004		0.0001		0.0002	
104			0.0005				0.0002	
105			0		0.0001		0.0004	
106			0				0.0004	
107			0		0.0001		0.0006	
108			0.0003		0.0001		0.0003	
109			0				0.0003	
110			0.0001					
111			0					
112					0.0001		0.0001	
113							0.0002	
114			0.0001					
115								
116								
117								
118								
119								
120								
121					0.0001			
122								
123								
124								
Checksum	1	1	1	1	1	1	1	1
Av. Occupants exposed / fire	45	24	18	8	51	29	25	10

The average number of occupants exposed to the Level 1 and Level 2 tenability limits per fire were calculated and are also included in the table to enable a simple comparison to be made between the reference building and a high-rise building for a fast t-squared growth phase flashover fire, ignoring the impact of sprinkler protection.

The results for the exceedance of Level 1 and Level 2 tenability limits were normalised against the Reference Building with no detection. The results are shown in Table 75 for the 5 storey building with no sprinkler protection but with and without a smoke detection system and the reference building with and without detection (Reference Building 2 and 1 respectively) but it should be noted that these results relate to a severe fire scenario with conservative tenability criteria. These results were considered when reviewing the initial decision during the Hazard ID processes to consider a reference building and building solution that included detection system and required automatic sprinkler protection in the proposed 5-storey building.

Table 75 Results from Fast Growth Flashover Fire scenario groups – Door left open after evacuation of GLA normalised against the reference building without detection

No of Occupants exposed	High-rise - Detection		Ref. Bld. - Detection		High-rise – No Detection		Ref. Bld. – No Detection	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Normalised Av. Occupants	1.8	2.4	0.7	0.8	2.0	2.9	1	1

L3.4. Fast Growth Flashover Fires – Door closed after evacuation of GLA

This scenario cluster was modelled by closing the door to the room of fire origin after approximately 95s.

Preliminary runs were undertaken that showed that the fire became ventilation controlled with the door closed preventing hot layer temperatures attaining 300°C, the temperature adopted for the failure of the door to the room of fire origin. The failure temperature of the external window was therefore reduced to 175°C so that ventilation would be increased after approximately 150s enabling the fast fire growth to continue through flashover to the fully developed phase.

Failure of the door was simulated when the hot layer temperature attained 300°C after approximately 255s allowing rapid spread of smoke to the adjoining enclosure 6 and then to enclosure 7.

The smoke spread modelling results are summarised in Table 76 and the probability of occupant exposure is shown in Table 77.

Table 76 Smoke Spread and Tenability Limits - fast fire, GLA of fire origin door closed

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation	
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7
Flashover	395						
Upper layer temps @390s	509					87	51
Visibility 10m @2m	68					373	340
Smoke layer 2m	64					373	340
Smoke layer 1.75m	82					410	370
Smoke layer 1.5m	97					440	400
FED thermal - 0.3	152					503	>600
FED CO - 0.3	377					501	542
Level 1 Tenability	68					373	340
Level 2 Tenability	97					440	400
Level 3 Tenability	152	395	395	395	395	395	395

Table 77 Probability of exposure to untenable conditions Fast Growth Flashover Fires – Door closed after evacuation of GLA

No of Occupants exposed	High-rise - Detection		Ref. Bld. - Detection		High-rise – No Detection		Ref. Bld. – No Detection	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
0	0.9999	1	0.9995	1	0.9999	1	0.9996	1
1			0.0002				0.0001	
2								
3	0.0001		0.0001		0.0001			
4								
5							0.0001	
6								
7								
8								
9								
10							0.0001	
11			0.0002					
12								
13								
14								
15								
16							0.0001	
Av. Occupants exposed / fire	0.0003	0	0.0027	0	0.0003	0	0.0032	0

The results indicated that no occupants outside the room of fire origin would be exposed to untenable conditions if the Level 2 or 3 tenability are adopted and the probability of exposure is very low compared to the door open scenarios if the Level 1 tenability criterion is adopted (3 to 5 orders of magnitude less). It is therefore considered reasonable to assume that no occupants are exposed to untenable conditions if the door to the GLA of fire origin is closed after the occupants have evacuated the room. This result can also be conservatively applied to the slow and medium growth fire scenarios clusters and therefore the slow and medium fires will only be evaluated further assuming the door to the GLA of fire origin is left open after evacuation of the room.

L4. Medium Growth – Non-flashover Fire occurring within an occupied General Learning Area (Classroom)

L4.1. Medium Growth – Non-flashover Fire – Room of Fire Origin Performance

The analysis undertaken for a fast fire can conservatively be applied to a medium growth fire without impacting on the risk assessment results if it is assumed all occupants evacuate the room of fire origin satisfactorily. No further analysis within the room of fire origin is therefore required except for determining the time to raise an alarm in the event of a detection system failure or no detection system being provided.

L4.2. Medium Growth – Non-flashover – General Smoke Modelling Results – Door open

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for a Medium Growth Rate non-flashover fire with a steady state peak heat release rate of 2.6MW are summarised in Table 78.

Table 78 Smoke Spread and Tenability Limits - medium fire with the GLA of fire origin door open

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation		Comb Path
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7	
5% smoke layer height - Cue 1	23		260		320	115	165	
20KW HRR - Cue 2	40							
Smoke Detector Activation	84					119	131	
Sprinkler Activation -RTI 50	200							
Sprinkler Activation -RTI 135								
Window breakage - Cue 3	387							
Steady State 2.6MW	470							
Upper layer temps @600s	300	21	25	21	21	50	40	
Visibility 10m @2m	85	>600	420	>600	>600	119	235	
Smoke layer 2m	85	>600	315	>600	>600	119	117	
Smoke layer 1.75m	110	>600	331	>600	>600	250	235	
Smoke layer 1.5m	140	>600	348	>600	>600	283	258	
FED thermal - 0.3	248					>600	>600	>600
FED CO - 0.3	505					>600	>600	>600
Level 1 Tenability	85		420			119	235	
Level 2 Tenability	140		348			283	258	
Level 3 Tenability	248	>600	>600	>600	>600	>600	>600	>600

Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L4.3. ASET RSET Analysis Medium Fires – Door left open after evacuation of GLA

Scenario Cluster GLA MED a - High-Rise Smoke Detection System Activates

For this scenario cluster the sprinkler system has been assumed to fail if provided. The alarm may be activated automatically if a fire detection system is provided and operates in accordance with its design intent or an alarm is raised manually. The visual and olfactory cues from the fire are likely to be strong and unambiguous within the room of fire origin and since the t-squared fire ignores any incipient growth period the time for manual detection has therefore been assumed to be a uniform distribution with a minimum value of t=0s and a maximum of the time for the smoke layer depth to exceed 5% of the ceiling height in the room of fire origin. Since the room is occupied by a large number of occupants it will be assumed that manual detection occurs in all cases within the room of fire origin. A prompt evacuation will be implemented by the class teacher and due to the rapid growth of the fire, the exit furthest from the fire will be used by all occupants on the floor.

Other occupants will be alerted by the automatic detection and alarm system.

A typical evacuation time distribution from the multi-scenario simulation of a high-rise building with a smoke detection system is shown in Figure 38 with a mean evacuation time of approximately 226s and a maximum of 350s.

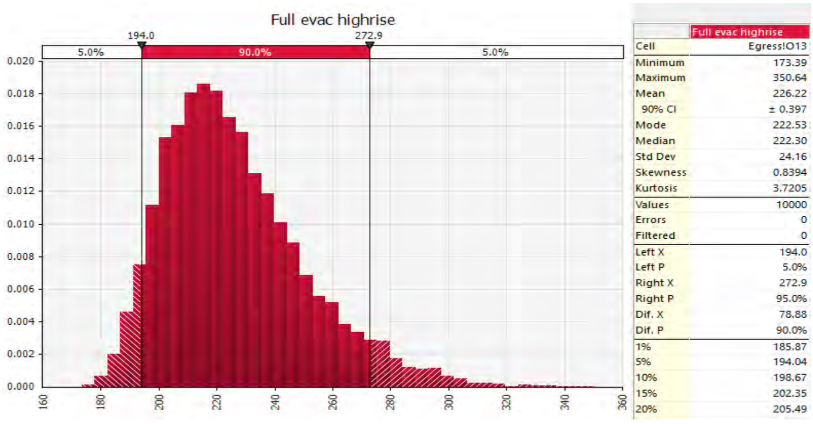

Figure 38 Distribution of time to fully evacuate the floor – high rise, automatic detection medium fire

The outcomes in terms of occupants exposed to the various levels of tenability are summarised in Table 79.

Scenario Cluster GLA MED b High-Rise Smoke Detection System Failure – Manual Alarm

This scenario cluster is similar to scenario cluster “GLA MED a” within the GLA of fire origin but once the teacher has ensured the children are evacuating the classroom (are out of immediate danger) and are heading to the fire exit a manual alarm will be raised. This process will depend upon the facilities provided, other staff available at the time and efficiency of the staff members response. A uniform distribution has been adopted with the time to manually raising a general alarm spanning a 60s period from completion of the pre-movement stage. This is intended to represent a school with an effective emergency management organisation and emergency procedures in place with regular training and drills being undertaken.

A typical evacuation time distribution from the multi-scenario simulation of a high-rise building without the smoke detection system operating is shown in Figure 39 which is slightly less than the time for a building with a detection system in place. This is to be expected if a fire occurs within an occupied room, but a greater variance will be expected for unoccupied rooms which has been considered under the Type 1 and Type 3 enclosure categories.

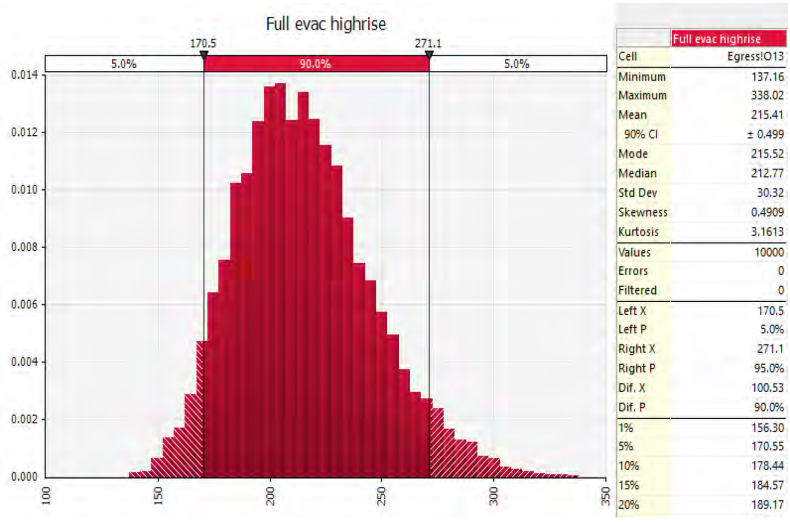

Figure 39 Distribution of time to fully evacuate the floor – high rise, no automatic detection, medium fire.

Since the number of occupants exposed to untenable conditions will be less for the no detection option due to the quicker initial response of occupants within the room of fire origin the no detection outcomes will be used for all scenarios

The outcomes in terms of occupants exposed to the various levels of tenability are summarised in Table 79.

Scenario Cluster GLA MED c Reference Building with automatic smoke detection / alarm, medium fire.

A typical evacuation time distribution from the multi-scenario simulation of the reference building with a smoke detection system is shown in Figure 40 with a mean evacuation time of approximately 194s and a maximum of 360s.

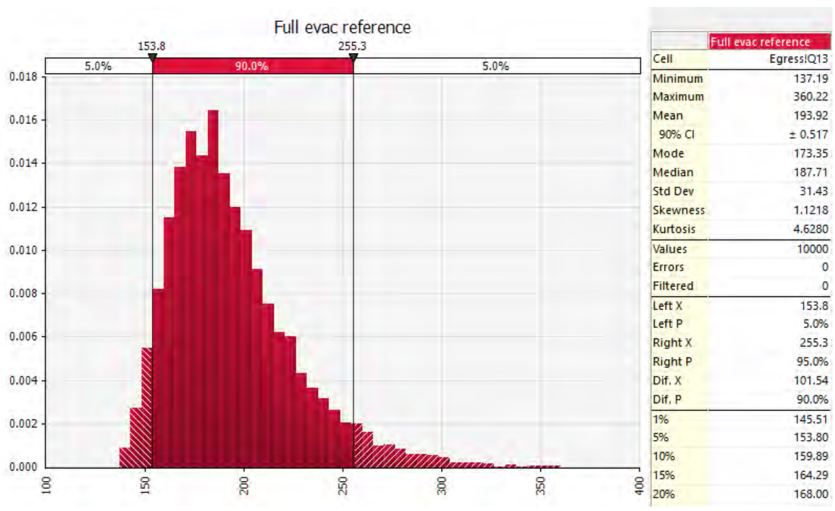

Figure 40 Distribution of time to fully evacuate the floor – reference, automatic detection medium fire

The tail of the distribution is very similar to that for the high-rise building, but the mean is 32s less. This distribution reflects the generally faster flow rate for a horizontal evacuation, but the tail reflects scenarios where the flow is substantially less than optimum which may occur in some circumstances and is therefore considered appropriate.

The outcomes in terms of occupants exposed to the various levels of tenability are summarised in Table 79.

Scenario Cluster GLA MED d Reference Building with no automatic smoke detection / alarm

This scenario cluster is similar to scenarios “GLA MED c” within the GLA of fire origin but once the teacher has ensured the children have started evacuating the classroom and are heading to the fire exit a manual alarm will be raised. This process will depend upon the facilities provided, other staff available at the time and efficiency of the staff members response. A uniform distribution has been adopted with the time to manually raising a general alarm spanning a 60s period from completion of the pre-movement stage. This is intended to represent a school with an effective emergency management organisation and emergency procedures in place with regular training and drills being undertaken.

A typical evacuation time distribution from the multi-scenario simulation of a high-rise building without the smoke detection system operating is shown in Figure 21 which is slightly less than the time for a building with a detection system in place.

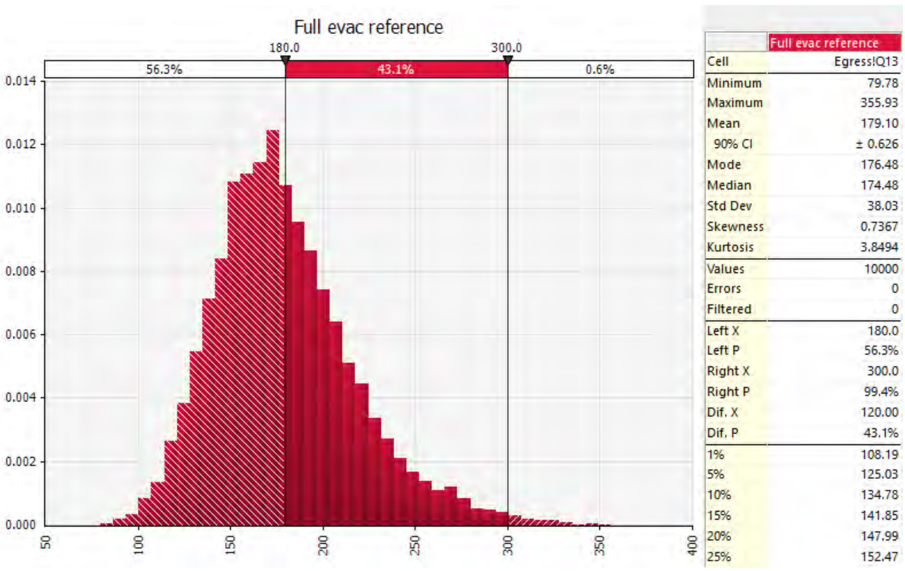

Figure 41 Distribution of time to fully evacuate the floor – reference, no automatic detection

Since the number of occupants exposed to untenable conditions will be less for the no detection option due to the quicker the no detection outcomes will be used for all scenarios

The outcomes in terms of occupants exposed to the various levels of tenability are summarised in Table 79.

Consolidation of Results and Preliminary Analysis

The results for the four scenario groups described above have been consolidated in Table 79 using the Level 1 and Level 2 tenability criteria. The Level 3 tenability criteria were not exceeded in any of the scenario groups.

Table 79 Probability of exposure to untenable conditions Medium Growth Fires – Door left open after evacuation of GLA

No of Occupants exposed	High-rise - Detection		Ref. Bld. - Detection		High-rise – No Detection		Ref. Bld. – No Detection	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
0	0.692	0.8918	0.9336	0.9692	0.7602	0.9096	0.9385	0.9707
1	0.0169	0.0081	0.0038	0.0018	0.0109	0.005	0.0017	0.0015
2	0.0147	0.0078	0.0025	0.0015	0.0107	0.0054	0.0031	0.0008
3	0.0166	0.0068	0.0015	0.0008	0.0093	0.0053	0.0029	0.0008
4	0.0123	0.0059	0.0027	0.0013	0.0106	0.0055	0.002	0.0012
5	0.0145	0.005	0.0021	0.0013	0.0104	0.0049	0.002	0.0009
6	0.0121	0.0056	0.0024	0.001	0.0123	0.0029	0.0017	0.0015
7	0.0147	0.0061	0.002	0.0007	0.0099	0.0044	0.0015	0.0008
8	0.0128	0.005	0.0016	0.0004	0.0083	0.0052	0.0013	0.0009
9	0.0131	0.0061	0.0022	0.0012	0.0083	0.0034	0.0016	0.0012
10	0.0125	0.0048	0.0023	0.0008	0.0095	0.004	0.0012	0.0011
11	0.0111	0.0037	0.0013	0.0009	0.0093	0.0048	0.0021	0.0009
12	0.0111	0.0053	0.0024	0.0005	0.008	0.004	0.0026	0.0011
13	0.0117	0.0052	0.002	0.0009	0.0075	0.0037	0.0012	0.001
14	0.0086	0.0033	0.0016	0.0013	0.0084	0.0029	0.0015	0.0011
15	0.0082	0.0033	0.0016	0.001	0.0067	0.0031	0.0018	0.0005
16	0.0105	0.0028	0.0019	0.0009	0.0075	0.0032	0.0021	0.0004
17	0.0095	0.0019	0.0015	0.0009	0.0069	0.0022	0.0019	0.0008
18	0.0078	0.0027	0.0017	0.0005	0.0065	0.0021	0.0009	0.0009
19	0.0072	0.0027	0.0012	0.0006	0.0059	0.0019	0.0009	0.0006
20	0.0064	0.002	0.0016	0.0004	0.0055	0.0027	0.0006	0.0014
21	0.0065	0.0017	0.0014	0.0013	0.0051	0.0014	0.0024	0.0005
22	0.0067	0.0025	0.0012	0.0011	0.005	0.0017	0.0013	0.0002
23	0.0065	0.0011	0.0014	0.0008	0.0047	0.0016	0.0011	0.0007
24	0.0052	0.0011	0.0007	0.0007	0.0044	0.0012	0.0015	0.0004
25	0.0048	0.0018	0.0012	0.0004	0.0051	0.0007	0.0008	0.0009
26	0.0058	0.0015	0.0009	0.0007	0.0043	0.0008	0.0011	0.0008
27	0.0054	0.0004	0.0008	0.0008	0.004	0.0016	0.0014	0.0008
28	0.0044	0.0003	0.0008	0.0006	0.0041	0.0005	0.001	0.0007
29	0.0039	0.0009	0.0007	0.0006	0.0026	0.001	0.0007	0.0003
30	0.0029	0.0005	0.0015	0.0004	0.0047	0.0006	0.0011	0.0004
31	0.0022	0.0002	0.001	0.0005	0.0026	0.0005	0.0007	0.0002
32	0.0026	0.0004	0.0008	0.0003	0.0023	0.0001	0.0008	0.0005
33	0.0029	0.0003	0.001	0.0007	0.0022	0.0006	0.0011	0.0003
34	0.0029	0.0001	0.0002	0.0003	0.0027	0.0004	0.0009	0.0005
35	0.0022	0.0002	0.0013	0.0002	0.0014	0.0002	0.0006	0.0004
36	0.0011	0.0001	0.0008	0.0002	0.0016	0.0002	0.0006	0.0003
37	0.0019	0.0004	0.0011	0.0005	0.0013	0.0001	0.0012	0.0002
38	0.0017	0.0001	0.001	0.0004	0.001	0.0001	0.0004	0.0001
39	0.0011	0.0001	0.001	0.0001	0.0016	0.0002	0.0004	0.0004
40	0.0006	0	0.0005	0.0003	0.0011	0	0.0008	0.0002
41	0.0009	0	0.0006	0.0001	0.001	0	0.0014	0.0001
42	0.0006	0	0.0005	0	0.0006	0.0002	0.0003	0.0002
43	0.0007	0.0002	0.0004	0.0002	0.0011	0	0.0005	0.0002
44	0.0002	0.0001	0.0009	0.0001	0.0005	0	0.0004	0
45	0.0002	0	0.0007	0.0002	0.0004	0	0.0005	0.0001
46	0.0002	0	0.0005	0.0001	0.0005	0.0001	0.0007	0.0001
47	0.0001	0	0.0005	0	0.0002		0.0002	0
48	0.0003	0	0.0002	0.0001	0.0004		0.0005	0.0002
49	0.0004	0	0.0002	0	0.0002		0.0004	0.0001
50	0.0001	0.0001	0.0005	0.0001	0.0002		0.0001	0
51	0.0003	0	0.0005	0	0.0001		0.0004	0
52	0		0.0002	0	0		0.0001	0.0001
53	0		0.0001	0.0002	0.0001		0.0004	
54	0		0.0002	0.0001	0.0002		0.0001	
55	0.0001		0.0001		0		0.0002	
56	0.0001		0.0001		0		0.0002	
57	0.0001		0.0001		0		0	
58	0		0.0003		0		0.0001	
59	0		0.0001		0		0.0001	
60	0		0		0.0001		0.0002	
61	0		0.0001				0	
62	0.0001		0.0001				0.0001	
63			0				0	
64			0				0	
65			0.0002				0.0001	

No of Occupants exposed	High-rise - Detection		Ref. Bld. - Detection		High-rise – No Detection		Ref. Bld. – No Detection	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
66			0					
67			0.0001					
68								
Av. Occupants exposed / fire	4.29	1.17	1.30	0.53	3.60	1.06	1.23	0.50

The average number of occupants exposed to the Level 1 and Level 2 tenability limits per fire were calculated and are also included in the table to enable a simple comparison to be made between the reference building and a high-rise building for a medium t-squared growth phase non-flashover fire plateauing at a heat release rate of 2.6MW, ignoring the impact of sprinkler protection.

The results for the exceedance of Level 1 and Level 2 tenability limits for the manual detection scenarios were normalised against the Reference Building and are presented in Table 80.

Table 80 Results from Medium Growth Flashover Fire scenario groups – Door left open after evacuation of GLA normalised against the reference building without detection

No of Occupants exposed	High-rise – No Detection		Ref. Bld. – No Detection	
	Level 1	Level 2	Level 1	Level 2
Normalised Av. Occupants	2.9	2.1	1	1

L5. Slow Growth – Non-flashover Fire occurring within an occupied General Learning Area (Classroom)

L5.1. Slow Growth – Non-flashover Fire – Room of Fire Origin Performance

The analysis undertaken for a fast fire can conservatively be applied to a slow growth fire without impacting on the risk assessment results if it is assumed all occupants evacuate the room of fire origin satisfactorily. No further analysis within the room of fire origin is therefore required except for determining the time to raise an alarm in the event of a detection system failure or no detection system being provided.

L5.2. Slow Growth – Non-flashover – General Smoke Modelling Results – Door open

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for a Medium Growth Rate non-flashover fire with a steady state peak heat release rate input of 2.2MW however ventilation control occurred after 703s at a peak of 703s.The HRR is shown plotted against time in Figure 42. Since the ventilation control occurred after the critical period for evacuation no adjustments to the ventilation conditions were made. The smoke spread modelling results are summarised in Table 81.

Table 81 Smoke Spread and Tenability Limits - slow fire with the GLA of fire origin door open

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation		Comb Path
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7	
5% smoke layer height - Cue 1	30		260		320	115	165	
20KW HRR - Cue 2	80							
Smoke Detector Activation	130				683	191	207	

Sprinkler Activation -RTI 50	346							
Sprinkler Activation -RTI 135								
Window breakage - Cue 3	>900							
Peak 1.44 MW @ 703 s then ventilation controlled	703							
Upper layer temps @900s °C	276	21	28	21	22	67	53	
Visibility 10m @2m	133	>900	617	>900	>900	315	360	
Smoke layer 2m	108	>900	443	>900	>900	315	303	
Smoke layer 1.75m	145	>900	467	>900	>900	370	336	
Smoke layer 1.5m	196	>900	490	>900	>900	417	367	
FED thermal - 0.3	406					>900	>900	>900
FED CO - 0.3	682					>900	>900	>900
Level 1 Tenability	133		617			315	360	
Level 2 Tenability	196					417	367	
Level 3 Tenability	406					>900	>900	>900

Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

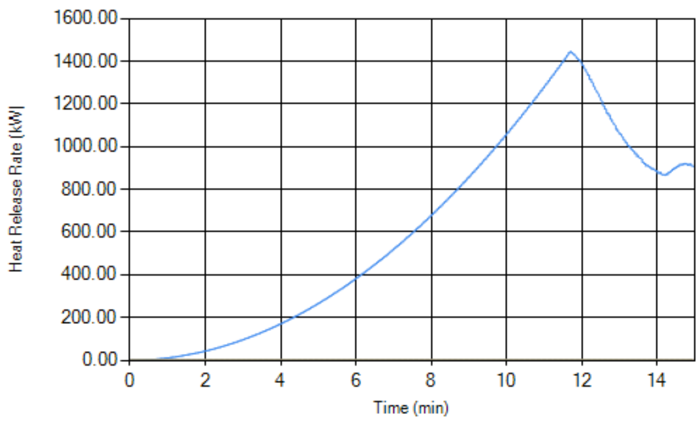

Figure 42 HRR for Slow Fire in GLA showing effect of ventilation control

L5.3. ASET RSET Analysis Slow Fires – Door left open after evacuation of GLA

Scenario Cluster GLAa Slow - High-Rise Smoke Detection System Alarm

For an occupied GLA with a fire having a slow growth rate manual detection is expected to occur prior to activation of the smoke detection system and therefore the evacuation time will tend to be independent of the time to automatic detection and the evacuation times derived for the manual alarm scenarios will also apply to the automatic detection scenarios.

Scenario Cluster GLAb Slow High-Rise – Manual Alarm

This scenario cluster assumes that once the teacher has ensured the children are evacuating the classroom (are out of immediate danger) and are heading to the fire exit a manual alarm will be raised. This process will depend upon the facilities provided, other staff available at the time and efficiency of the staff members response. A uniform distribution has been adopted with the time to manually raising a general alarm spanning a 60s period from completion of the pre-movement stage. This is intended to represent a school with an effective emergency management organisation and emergency procedures in place with regular training and drills being undertaken.

A typical evacuation time distribution from the multi-scenario simulation of a high-rise level without the smoke detection system operating is shown in Figure 43.

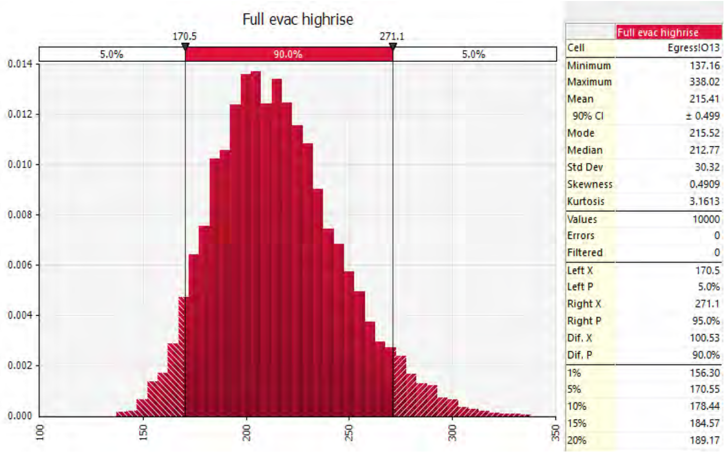

Figure 43 Distribution of time to fully evacuate the floor – high rise, manual alarm

The mean evacuation time using one exit for all occupants is approximately 215s and the maximum is 338s which is less than the time to the first onset of untenable conditions (adopting level 1 criteria) and therefore there will be no occupants exposed to untenable conditions. Whilst the safety margin is small it should be noted that with the slow growth fire it is likely both exits would be used in a fire emergency increasing the safety margin

Scenario Cluster GLAc Slow Reference Building with automatic smoke detection / alarm

For an occupied GLA with a fire having a slow growth rate manual detection is expected to occur prior to activation of the smoke detection system and therefore the evacuation time will tend to be independent of the time to automatic detection and the evacuation times derived for the manual alarm scenarios will also apply to the automatic detection scenarios.

Scenario Cluster GLAd Slow Reference Building – Manual Alarm

This scenario cluster assumes that once the teacher has ensured the children are evacuating the classroom (are out of immediate danger) and are heading to the fire exit a manual alarm will be raised. This process will depend upon the facilities provided, other staff available at the time and efficiency of the staff members response. A uniform distribution has been adopted with the time to manually raising a general alarm spanning a 60s period from completion of the pre-movement stage. This is intended to represent a school with an effective emergency management organisation and emergency procedures in place with regular training and drills being undertaken. A typical evacuation time distribution from the multi-scenario simulation without the smoke detection system operating is shown in Figure 44.

The mean evacuation time using one exit for all occupants is approximately 183s and the maximum is 355s which is less than the time to the first onset of untenable conditions (adopting level 1 criteria) and therefore there will be no occupants exposed to untenable conditions. Whilst the safety margin is small it should be noted that with the slow growth fire it is likely both exits would be used in a fire emergency increasing the safety margin

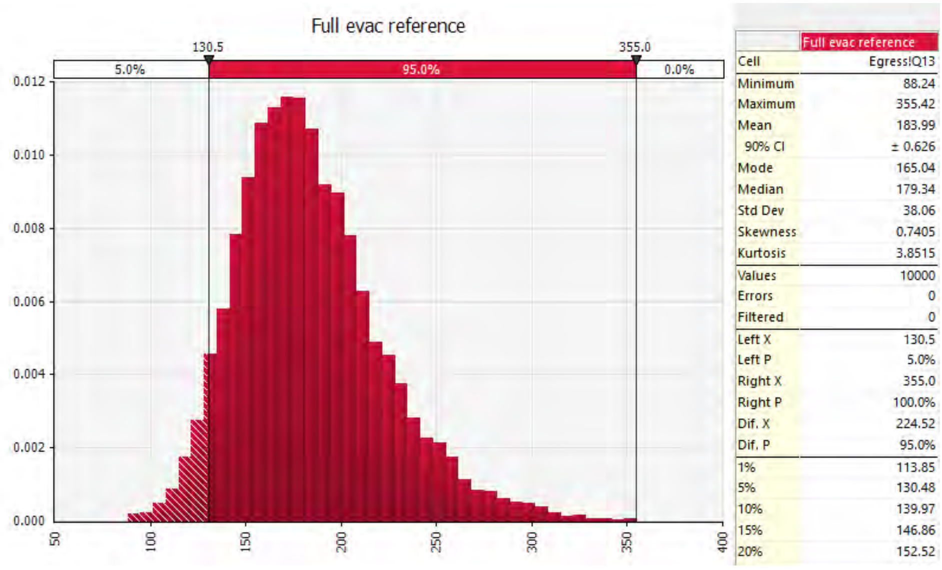

Figure 44 Distribution of time to fully evacuate the floor – reference, manual alarm

Consolidation of Results and Preliminary Analysis

For the slow growth rate fire scenarios, no occupants were exposed to untenable conditions under Level 1 to Level 3 tenability conditions.

L6. Timing of Manual Alarm for Fire in Enclosure Type 3 main circulation space and Occupant Response

The Type 3 enclosure adopted in the generic building layout includes various other functional areas in addition to serving as a general circulation space. The proportion of fires and type of fires in the Type 3 enclosures reflects this configuration.

During the normal hours of operation of the school it is therefore likely that the Type 3 enclosure would be in use and occupied and that some classroom doors to the space would be open. It will therefore be assumed that for most scenarios the fire will be manual detected relatively quickly and a uniform distribution varying between the commencement of the t-squared growth phase and the smoke layer depth exceeding 5% of the room height will be adopted. This group of scenarios has been identified as early manual detection scenarios

However, there may be some scenarios where the area of fire origin is unoccupied and the occupants within the General Learning Areas may not initially receive fire cues. In these scenarios it will be assumed that a fire cue is received when the hot layer interface is 2m or less above ground level. At this stage the smoke is expected to start entering the GLA through the head of the room door even if the door leaf is closed. This group of scenarios has been identified as delayed manual detection scenarios.

The proportions of early and delayed manual detection scenarios will depend on a building configuration and usage. For the purposes of this analysis it was assumed that early detection would occur in 80% of scenarios and delayed manual detection occur in 20% of scenarios.

L7. Fast Growth – Flashover Fire occurring within General Circulation Area (Enclosure Type 3)

L7.1. Fast Growth Flashover Fires – General Smoke Modelling Results

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for Fast Growing Potential Flashover Fires are summarised in Table 82.

Table 82 Smoke Spread and Tenability Limits - fast fire in General Circulation Area.

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation		Comb Path[2]
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7	
5% smoke layer height - Cue 1	165		145		210	30	50	
100kW HRR - Cue 2						46		
Smoke Detector Activation	146				162	54	58	
Sprinkler Activation -RTI 50						134		
Sprinkler Activation -RTI 135						165		
Window breakage - Cue 3						277[1]		
Flashover						505		
Upper layer temps @500s	128	22	87	22	22	502	304	
Visibility 10m @2m	205	840	185	>900	585	138	110	
Smoke layer 2m	205	480	185	320	260	138	110	
Smoke layer 1.75m	218	610	197	450	385	165	132	
Smoke layer 1.5m	230	820	209	650	530	189	154	
FED thermal - 0.3	473	>900	590	>900	>900	196	266	266
FED CO - 0.3	577	>900	609	>900	>900	430	471	471
Level 1 Tenability	205	840	185	>900	585	138	110	
Level 2 Tenability	230	820	209	650 (900)	530	189	154	
Level 3 Tenability	473	505	505	505	505	196	266	266

1 Failure temp for window of 250°C adopted to prevent ventilation control before window breakage
Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L7.2. ASET RSET Analysis Fast Fires –General Circulation Area (Enclosure Type 3)

For these scenarios it will be assumed that all students are within the GLAs and will be alerted by the automatic detection and alarm system or a manual alarm. It has also been assumed that access is available to both stairs and the occupants will use the nearest stair or exit provided they can evacuate their GLA prior to Level 1 tenability criteria (visibility less than 10m at 2m height) being exceeded on the path of travel to the stair or exit entrance. If the occupants remained in the GLA and closed the door the onset of untenable conditions would be delayed significantly.

Scenario Cluster Circ Type 3 FAST Smoke Detection System Activates an Alarm

Results are presented in Table 83 for a high-rise (case a) and a reference single storey building (case b) for an alarm raised by an automatic detection / alarm system. Since flashover occurred in this scenario prior to fire brigade arrival all people still present on the floor of fire origin were assumed to be exposed to untenable conditions and therefore search and rescue activities were not considered.

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Table 83 Probability of exposure to untenable conditions Fast Growth Flashover Fires in general circulation area (Enclosure Type 3) with automatic detection initiating evacuation

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
0	0	0.4652	0.9782	0.078	0.8747	0.993
1	0	0.0288	0.0047	0.007	0.0079	0.0011
2	0	0.0278	0.0033	0.0078	0.0078	0.0014
3	0	0.0277	0.003	0.0073	0.0069	0.0008
4	0	0.0268	0.0031	0.0083	0.0081	0.0006
5	0	0.0295	0.0011	0.0114	0.0068	0.0007
6	0.0002	0.0288	0.0012	0.0098	0.0072	0.0006
7	0	0.0269	0.0016	0.0096	0.0067	0.0005
8	0	0.026	0.0009	0.0099	0.005	0.0002
9	0	0.0262	0.0004	0.0118	0.0048	0.0003
10	0	0.0228	0.0007	0.0114	0.0051	0.0001
11	0.0003	0.0219	0.0003	0.0119	0.0052	0.0003
12	0.0003	0.0242	0.0005	0.0122	0.0046	0.0003
13	0.0004	0.0235	0.0002	0.0104	0.0046	0.0001
14	0.0004	0.0198	0.0004	0.0146	0.0054	
15	0.0007	0.0188	0.0001	0.0121	0.0043	
16	0.0008	0.017	0.0003	0.015	0.004	
17	0.0009	0.017		0.015	0.0051	
18	0.001	0.0143		0.0143	0.0038	
19	0.0014	0.0118		0.0162	0.0023	
20	0.0016	0.0129		0.0145	0.0022	
21	0.0029	0.0108		0.0167	0.0029	
22	0.0032	0.0102		0.0179	0.002	
23	0.0044	0.0091		0.0169	0.0022	
24	0.0041	0.0082		0.02	0.0015	
25	0.0051	0.0051		0.0166	0.0014	
26	0.0061	0.0057		0.0194	0.0011	
27	0.0062	0.0065		0.0202	0.0014	
28	0.007	0.004		0.0196	0.0008	
29	0.0078	0.004		0.0202	0.0005	
30	0.0086	0.0032		0.0213	0.0012	
31	0.0077	0.0018		0.0218	0.0002	
32	0.0096	0.002		0.0241	0.0009	
33	0.0119	0.0027		0.0195	0.0006	
34	0.0103	0.0022		0.0204	0.0002	
35	0.0115	0.0013		0.0175	0.0004	
36	0.0131	0.0005		0.0193		
37	0.0127	0.0012		0.0205	0.0002	
38	0.0145	0.0009		0.0191		
39	0.0164	0.0005		0.0179		
40	0.0149	0.0004		0.0194		
41	0.0141	0		0.0193		
42	0.0153	0.0003		0.0169		
43	0.016	0.0002		0.0174		
44	0.0185	0.0003		0.0172		
45	0.0187	0.0006		0.0173		
46	0.0183	0.0002		0.0163		
47	0.0242	0.0001		0.0154		
48	0.0225	0.0001		0.0137		
49	0.0208	0.0001		0.0138		
50	0.0208			0.0124		
51	0.0206			0.0096		
52	0.0206			0.0098		
53	0.0213			0.0112		
54	0.021	0.0001		0.0103		
55	0.0205			0.008		
56	0.0221			0.0084		
57	0.0226			0.0071		
58	0.0239			0.0057		
59	0.0241			0.0067		
60	0.0209			0.0065		
61	0.0239			0.0049		
62	0.0221			0.0113		
63	0.0209			0.0022		
64	0.0229			0.0041		
65	0.0205			0.0032		

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
66	0.0206			0.0024		
67	0.0191			0.0027		
68	0.0205			0.0032		
69	0.0182			0.002		
70	0.019			0.0019		
71	0.0189			0.0017		
72	0.0165			0.002		
73	0.0153			0.002		
74	0.015			0.0023		
75	0.0144			0.0017		
76	0.0137			0.0012		
77	0.013			0.0012		
78	0.0112			0.0014		
79	0.0101			0.0008		
80	0.0099			0.0003		
81	0.007			0.0012		
82	0.0082			0.0008		
83	0.0066			0.0009		
84	0.0059			0.0007		
85	0.005			0.0003		
86	0.0053			0.0008		
87	0.0044			0.0005		
88	0.0033			0.0004		
89	0.0021			0.0002		
90	0.0024			0.0001		
91	0.0021			0.0004		
92	0.0016			0.0002		
93	0.0016			0.0002		
94	0.0008			0.0002		
95	0.0012			0		
96	0.0008			0.0001		
97	0.0006			0.0002		
98	0.0005			0.0001		
99	0.0006			0		
100	0.0003			0.0001		
101	0.0001			0		
102	0.0002			0.0001		
103				0		
104	0.0006			0		
105				0		
106	0.0002			0		
107				0		
108				0		
109	0.0001			0.0001		
110				0.0001		
Av. Occupants exposed / fire	56.02	6.34	0.0982	30.60	1.40	0.0328
Av occupants exposed normalised to reference bld.	1.83	4.53	2.99	1	1	1

The results indicate that for all three levels of tenability criteria there was a significant increase in risk compared to the reference building if the impact of automatic sprinkler systems in the high-rise building is not considered.

Scenario Cluster Circ Type 3 FAST Early Manual Alarm

Results are presented in Table 84 for a high-rise (case c) and a reference single storey building (case d) for early manual detection from an occupant in the general circulation area. Since flashover occurred in this scenario prior to fire brigade arrival all people still present on the floor of fire origin at the time of flashover were assumed to be exposed to untenable conditions and therefore search and rescue activities were not considered

Table 84 Probability of exposure to untenable conditions Fast Growth Flashover Fires in general circulation area (Enclosure Type 3) with early manual alarm initiating evacuation

Occupants	High-Rise with Early Manual Alarm			Reference with Early Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0	0.1868	0.8935	0.9988	0.6398	0.9773	0.9996
1	0.0154	0.011	0.0002	0.0123	0.0024	0.0003
2	0.016	0.0092	0.0002	0.0125	0.0023	0.0001
3	0.017	0.0099	0.0001	0.0161	0.0019	0
4	0.0181	0.0088	0.0003	0.0144	0.0019	0
5	0.0192	0.0085	0	0.0121	0.0018	0
6	0.0182	0.007	0.0001	0.0115	0.0009	0
7	0.0202	0.0068	0.0001	0.011	0.0009	0
8	0.0174	0.0057	0.0001	0.0127	0.0015	0
9	0.0218	0.0058	0	0.0131	0.0014	0
10	0.0217	0.0039	0	0.0111	0.0016	0
11	0.0215	0.0042	0	0.0117	0.0008	0
12	0.0252	0.0038	0	0.0119	0.001	0
13	0.0231	0.0044	0.0001	0.0121	0.0009	0
14	0.0215	0.0033	0	0.0096	0.0007	0
15	0.0203	0.0025	0	0.0091	0.0002	0
16	0.0201	0.0021	0	0.0107	0.0006	0
17	0.0211	0.0016	0	0.0098	0.0003	0
18	0.0234	0.0013	0	0.0087	0.0001	0
19	0.019	0.0007	0	0.0104	0.0002	0
20	0.0204	0.0011	0	0.011	0.0003	0
21	0.0202	0.0014	0	0.008	0.0001	0
22	0.0182	0.0006	0	0.0063	0.0002	0
23	0.0181	0.0005	0	0.0064	0.0002	0
24	0.0177	0.0006	0	0.0079	0.0003	0
25	0.0175	0.0002	0	0.0088	0	0
26	0.0161	0.0006	0	0.0078	0	0
27	0.0148	0.0001	0	0.0075	0	0
28	0.016	0.0001	0	0.0058	0	0
29	0.0149	0.0003	0	0.0057	0	0
30	0.0155	0.0002	0	0.0055	0	0
31	0.0157	0	0	0.0054	0	0
32	0.0133	0.0001	0	0.0062	0	0
33	0.0139	0	0	0.0053	0.0001	0
34	0.0117	0	0	0.004	0	0
35	0.0108	0	0	0.0041	0	0
36	0.0104	0	0	0.0038	0.0001	0
37	0.0108	0	0	0.0036	0	0
38	0.0086	0	0	0.0028	0	0
39	0.0109	0	0	0.0027	0	0
40	0.0091	0	0	0.0021	0	0
41	0.0082	0.0001	0	0.0022	0	0
42	0.0068	0	0	0.0016	0	0
43	0.0077	0	0	0.0016	0	0
44	0.0071	0.0001	0	0.0016	0	0
45	0.0072	0	0	0.0017	0	0
46	0.007	0	0	0.001	0	0
47	0.0048	0	0	0.0012	0	0
48	0.0053	0	0	0.0004	0	0
49	0.0049	0	0	0.0011	0	0
50	0.0053	0	0	0.0008	0	0
51	0.0056	0	0	0.0005	0	0
52	0.0042	0	0	0.0006	0	0
53	0.0047	0	0	0.0002	0	0
54	0.0033	0	0	0.0002	0	0
55	0.0039	0	0	0.0001	0	0
56	0.004	0	0	0.0003	0	0
57	0.0034	0	0	0.0006	0	0
58	0.0037	0	0	0.0002	0	0
59	0.0031	0	0	0.0004	0	0
60	0.0029	0	0	0.0004	0	0
61	0.0024	0	0	0.0003	0	0
62	0.0023	0	0	0.0002	0	0
63	0.0025	0	0	0	0	0
64	0.0019	0	0	0.0002	0	0
65	0.0012	0	0	0.0003	0	0

Occupants	High-Rise with Early Manual Alarm			Reference with Early Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
66	0.0025	0	0		0	0
67	0.0018	0	0		0	0
68	0.0013	0	0		0	0
69	0.0017	0	0	0.0001	0	0
70	0.0006	0	0	0.0002	0	0
71	0.0006	0	0	0.0002	0	0
72	0.0012	0	0	0.0001	0	0
73	0.0014	0	0	0.0001	0	0
74	0.0008	0	0	0.0001	0	0
75	0.0001	0	0	0.0001	0	0
76	0.0005	0	0		0	0
77	0.0002	0	0		0	0
78	0.0005	0	0		0	0
79	0.0006	0	0		0	0
80	0.0004	0	0		0	0
81	0	0	0		0	0
82	0.0002	0	0		0	0
83	0.0001	0	0		0	0
84	0.0001	0	0		0	0
85	0.0001	0	0	0.0001	0	0
86	0	0	0	0	0	0
87	0	0	0	0	0	0
88	0.0001	0	0	0	0	0
89	0	0	0	0	0	0
90	0	0	0	0	0	0
91	0	0	0	0	0	0
92	0	0	0	0	0	0
93	0	0	0	0	0	0
94	0	0	0	0	0	0
95	0.0002	0	0	0	0	0
Av. Occupants exposed / fire	19.44	0.836	0.0055	6.36	0.178	0.0005
Av occupants exposed normalised to reference bld.	3.1	4.7	11	1	1	1

A key observation is that in populated rooms it is likely that fire cues will be received prior to the activation of a smoke or heat detection system and that the number of occupants exposed to untenable conditions is therefore less. The three levels of tenability vary from Level 1 where the conditions would potentially reduce the capability to evacuate without injury to Level 3 where there is potential for serious injury or fatality. In these scenarios the largest difference from the reference building occurred if the Level 3 criteria are applied and for both the reference and high-rise buildings there were several orders of magnitude difference between losses with the Level 1 and Level 3 tenability criteria.

Scenario Cluster Circ Type 3 FAST Delayed Manual Alarm

Results are presented in Table 85 for a high-rise (case e) and a reference single storey building (case f) for delayed manual detection from an occupant not in the immediate area of the fire. In these scenarios the fire is only detected when smoke enters a General Learning area adjoining the circulation space. Since flashover occurred in this scenario prior to fire brigade arrival all people still present on the floor of fire origin at the time of flashover were assumed to be exposed to untenable conditions and therefore search and rescue activities were not considered.

For these scenarios, as could be expected there were very high losses through all levels of tenability, and these reflect the identified causes and fire scenarios leading to multi-fatality fires in schools described in Section C5.2 such as delayed alarms and fires spreading to escape routes. It should be noted that these scenarios do not take into account the presence of smoke detection systems and automatic sprinklers proposed for the high-rise buildings nor the potential use of alternate egress paths that may be available in single storey buildings such as external doors in GLAs providing direct access to open space.

EFT
Consulting

Table 85 Probability of exposure to untenable conditions Fast Growth Flashover Fires in general circulation area (Enclosure Type 3) with delayed manual alarm initiating evacuation

Occupants	High-Rise with Delayed Manual Alarm			Reference with Delayed Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0	0.0002	0.0002	0.0073	0.0002	0.0006	0.172
1	0		0.0018	0	0.0002	0.0096
2	0		0.002	0	0.0004	0.0088
3	0.0001	0.0001	0.0029	0.0001	0.0002	0.0112
4	0.0001	0.0001	0.0025	0.0001	0.0005	0.0098
5	0.0001	0.0001	0.0031	0.0001	0.0006	0.0108
6	0.0003	0.0004	0.003	0.0003	0.0007	0.0121
7	0.0002	0.0002	0.0049	0.0002	0.0007	0.0109
8	0.0001	0.0001	0.0035	0.0001	0.0008	0.012
9	0.0001	0.0002	0.0059	0.0001	0.0007	0.0109
10	0.0001	0.0001	0.0046	0.0001	0.0009	0.011
11	0.0002	0.0003	0.0063	0.0002	0.0009	0.0131
12	0.0003	0.0003	0.0049	0.0003	0.0011	0.0108
13	0	0.0001	0.0079	0	0.0002	0.0128
14	0.0005	0.0004	0.007	0.0005	0.0015	0.0113
15	0	0.0003	0.0088	0	0.0007	0.0114
16	0.0003	0.0005	0.009	0.0003	0.0017	0.0125
17	0.0004	0.0004	0.0102	0.0004	0.0015	0.0137
18	0.0003	0.0005	0.0095	0.0003	0.0016	0.0124
19	0.0002	0.0004	0.0115	0.0002	0.0016	0.0141
20	0.0005	0.0008	0.0135	0.0005	0.0032	0.0153
21	0.0004	0.0012	0.0127	0.0004	0.0016	0.0152
22	0.0006	0.0011	0.0132	0.0006	0.0028	0.0109
23	0.0003	0.0012	0.0168	0.0003	0.0034	0.0133
24	0.0003	0.0009	0.0152	0.0003	0.0029	0.0113
25	0.0005	0.0015	0.016	0.0005	0.0026	0.0153
26	0.0008	0.0019	0.0163	0.0008	0.0037	0.0139
27	0.0004	0.001	0.0165	0.0004	0.0041	0.0132
28	0.0004	0.0013	0.0175	0.0004	0.0051	0.0129
29	0.0006	0.0011	0.0175	0.0006	0.0037	0.0129
30	0.0005	0.0022	0.0198	0.0005	0.0039	0.0113
31	0.0025	0.0019	0.0183	0.0025	0.0117	0.0236
32	0.0011	0.0018	0.0193	0.0011	0.0063	0.0121
33	0.0013	0.0029	0.0193	0.0013	0.0067	0.011
34	0.0015	0.0019	0.0214	0.0015	0.0068	0.0129
35	0.0005	0.0019	0.02	0.0005	0.0074	0.0144
36	0.0017	0.0031	0.0178	0.0017	0.0071	0.0127
37	0.0017	0.0026	0.0216	0.0017	0.0084	0.0112
38	0.0016	0.0023	0.0194	0.0016	0.0078	0.0134
39	0.0015	0.0032	0.0188	0.0015	0.0096	0.0103
40	0.001	0.0043	0.0197	0.001	0.0084	0.0103
41	0.0023	0.0037	0.0187	0.0023	0.0112	0.0111
42	0.0017	0.0045	0.019	0.0017	0.0128	0.0112
43	0.0023	0.0042	0.0172	0.0023	0.0107	0.0097
44	0.0015	0.0045	0.0169	0.0015	0.0113	0.0091
45	0.0016	0.004	0.0151	0.0016	0.0125	0.0113
46	0.0014	0.0049	0.0155	0.0014	0.0122	0.01
47	0.0025	0.007	0.0145	0.0025	0.0144	0.0089
48	0.003	0.0062	0.0142	0.003	0.0146	0.0084
49	0.003	0.0068	0.014	0.003	0.0147	0.009
50	0.0017	0.0075	0.0147	0.0017	0.0145	0.0092
51	0.0024	0.0073	0.0128	0.0024	0.0146	0.0087
52	0.0019	0.0081	0.0136	0.0019	0.0134	0.0077
53	0.0028	0.0084	0.0114	0.0028	0.0165	0.0082
54	0.0029	0.0094	0.0087	0.0029	0.0174	0.0067
55	0.0029	0.0088	0.0107	0.0029	0.015	0.0085
56	0.0035	0.012	0.0109	0.0035	0.0155	0.0082
57	0.0021	0.0093	0.0097	0.0021	0.0173	0.0093
58	0.0031	0.0113	0.0107	0.0031	0.0177	0.0079
59	0.0027	0.0109	0.0088	0.0027	0.0171	0.0074
60	0.0036	0.0116	0.0116	0.0036	0.0158	0.0072
61	0.0034	0.0122	0.0097	0.0034	0.0203	0.0067
62	0.0234	0.0143	0.015	0.0234	0.0444	0.0096
63	0.005	0.0098	0.0085	0.005	0.0164	0.0073
64	0.0037	0.0115	0.0088	0.0037	0.0149	0.0058
65	0.0059	0.0138	0.0089	0.0059	0.0164	0.0063

Occupants	High-Rise with Delayed Manual Alarm			Reference with Delayed Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
66	0.0064	0.0131	0.0096	0.0064	0.0142	0.0062
67	0.0055	0.0142	0.0096	0.0055	0.0157	0.0051
68	0.0053	0.0159	0.0097	0.0053	0.0162	0.0061
69	0.0043	0.0167	0.0093	0.0043	0.0163	0.006
70	0.0057	0.0176	0.0087	0.0057	0.0143	0.0061
71	0.0047	0.0193	0.0093	0.0047	0.0142	0.0056
72	0.0049	0.0153	0.0097	0.0049	0.0148	0.0057
73	0.0068	0.018	0.0076	0.0068	0.0157	0.0054
74	0.0071	0.0196	0.0072	0.0071	0.0147	0.0044
75	0.0053	0.017	0.0086	0.0054	0.0158	0.0046
76	0.0064	0.0195	0.0076	0.0064	0.0153	0.0053
77	0.0057	0.0171	0.0085	0.0057	0.0151	0.0042
78	0.0064	0.0206	0.0078	0.0064	0.0132	0.0055
79	0.0075	0.0187	0.0072	0.0075	0.0151	0.0042
80	0.0072	0.02	0.007	0.0072	0.0121	0.003
81	0.0061	0.0205	0.0054	0.0061	0.0106	0.0039
82	0.0062	0.0199	0.008	0.0062	0.0129	0.0029
83	0.0065	0.0205	0.0072	0.0066	0.0121	0.004
84	0.0064	0.0227	0.0065	0.0064	0.0121	0.0034
85	0.0079	0.0174	0.0054	0.0079	0.0129	0.0025
86	0.0072	0.0198	0.0046	0.0072	0.0125	0.0021
87	0.005	0.0167	0.0041	0.005	0.0112	0.0022
88	0.0073	0.0195	0.0033	0.0075	0.0103	0.0024
89	0.008	0.0197	0.0035	0.008	0.0116	0.0025
90	0.0083	0.0206	0.0026	0.0082	0.0114	0.0023
91	0.008	0.0185	0.0039	0.008	0.0105	0.0022
92	0.0077	0.0192	0.0026	0.0078	0.0094	0.0019
93	0.0605	0.0181	0.0087	0.0607	0.0108	0.0083
94	0.01	0.0161	0	0.01	0.008	0
95	0.0091	0.0162	0	0.0097	0.0069	0
96	0.0085	0.0162	0	0.0085	0.0074	0
97	0.0109	0.0133	0	0.0109	0.008	0
98	0.0137	0.0192	0	0.0136	0.005	0
99	0.0106	0.0143	0	0.0104	0.0073	0
100	0.0114	0.0146	0	0.0113	0.0056	0
101	0.0126	0.0116	0	0.0125	0.0053	0
102	0.0123	0.0129	0	0.0124	0.0059	0
103	0.0127	0.0105	0	0.0127	0.004	0
104	0.013	0.0118	0	0.0135	0.0045	0
105	0.013	0.0095	0	0.0129	0.0029	0
106	0.0142	0.0076	0	0.0141	0.002	0
107	0.0151	0.0082	0	0.0151	0.0036	0
108	0.0133	0.0065	0	0.0133	0.0023	0
109	0.0167	0.0068	0	0.0169	0.0025	0
110	0.0117	0.0057	0	0.0125	0.0016	0
111	0.0141	0.0042	0	0.0147	0.0013	0
112	0.0135	0.0042	0	0.0139	0.0015	0
113	0.0124	0.0035	0	0.0131	0.0013	0
114	0.0115	0.0028	0	0.0123	0.001	0
115	0.0146	0.0022	0	0.0154	0.001	0
116	0.0148	0.0025	0	0.0152	0.0007	0
117	0.0131	0.002	0	0.0128	0.0009	0
118	0.0156	0.0009	0	0.0156	0.0007	0
119	0.0147	0.0011	0	0.0133	0.0001	0
120	0.0139	0.0011	0	0.0132	0.0009	0
121	0.0132	0.001	0	0.013	0.0006	0
122	0.0166	0.0006	0	0.0157		0
123	0.017	0.0001	0	0.0154	0.0001	0
124	0.2584	0.0003	0	0.2577	0.0002	0
Av. Occupants exposed / fire	100.5	77.6	44.2	100.4	64.4	30.8
Av occupants exposed normalised to reference bld.	1.0	1.2	1.44	1.0	1.0	1.0

L8. Medium Growth – Non - Flashover Fire occurring within General Circulation Area (Enclosure Type 3)

L8.1. Medium Growth Non-Flashover Fire – General Smoke Modelling Results

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for a medium growth rate fire are summarised in Table 86.

Table 86 Smoke Spread and Tenability Limits – Medium fire in General Circulation Area

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation		Comb Path[2]
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7	
5% smoke layer height - Cue 1	241		194		308	36	66	
100kW HRR - Cue 2						92		
Smoke Detector Activation	214				268	83	92	
Sprinkler Activation -RTI 50						227		
Sprinkler Activation -RTI 135						268		
Window breakage - Cue 3						440[1]		
Peak HRR 3750 kW						570		
Upper layer temps @1400s	100	21	84	21	21	287	203	
Visibility 10m @2m	298	>1400	255	>1400	1110	205	145	
Smoke layer 2m	298	710	255	419	386	205	145	
Smoke layer 1.75m	318	>1400	275	535	433	249	181	
Smoke layer 1.5m	336	>1400	292	865	>1400	288	216	
FED thermal - 0.3	820	>1400	1031	>1400	>1400	326	428	326
FED CO - 0.3	965	>1400	1075	>1400	>1400	672	718	672
Level 1 Tenability	298	>1400	255	>1400	1110	205	145	
Level 2 Tenability	336	>1400	292	865	>1400	288	216	
Level 3 Tenability	820	>1400	1031	>1400	>1400	326	428	326

1 Failure temp for window of 200°C adopted to prevent ventilation control before window breakage
Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L8.2. ASET RSET Analysis Medium Fires –General Circulation Area (Enclosure Type 3)

For these scenarios it will be assumed that all students are within the GLAs and will be alerted by the automatic detection and alarm system or a manual alarm. It has also been assumed that access is available to both stairs and the occupants will use the nearest stair or exit provided they can evacuate their GLA prior to Level 1 tenability criteria (visibility less than 10m at 2m height) being exceeded on the path of travel to the stair or exit entrance. If the occupants remained in the GLA and closed the door the onset of untenable conditions would be delayed significantly.

Scenario Cluster Circ Type 3 Medium Growth Fire peaking at 3.75MW - Smoke Detection System Activates an Alarm

Results are presented in Table 87 for a high-rise (case a) and a reference single storey building (case b) for an alarm raised by an automatic detection / alarm system.

Table 87 Probability of exposure to untenable conditions Medium Growth Fires in General Circulation Area (Enclosure Type 3) with automatic detection initiating evacuation

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
0	0.0001	0.9493	1	0.2203	0.9869	1
1	0	0.0079		0.0115	0.0014	
2	0.0002	0.0067		0.0115	0.0013	
3	0.0001	0.0047		0.0125	0.0018	
4	0.0002	0.0048		0.0129	0.0013	
5	0.0002	0.0035		0.0143	0.0006	
6	0.0001	0.0037		0.0142	0.0013	
7	0.0006	0.0041		0.0145	0.0009	
8	0.001	0.0033		0.0171	0.001	
9	0.0007	0.0021		0.0155	0.0006	
10	0.0016	0.0026		0.0169	0.0006	
11	0.002	0.0018		0.0156	0.0004	
12	0.0035	0.001		0.0173	0.0005	
13	0.003	0.0011		0.0157	0.0005	
14	0.0024	0.001		0.019	0.0002	
15	0.0047	0.0011		0.0188	0.0002	
16	0.0053	0.0004		0.0179	0.0002	
17	0.0076	0.0003		0.0216	0.0001	
18	0.009	0		0.017	0	
19	0.0095	0.0003		0.0182	0.0001	
20	0.014	0		0.0193	0	
21	0.0174	0.0003		0.02	0.0001	
22	0.018			0.021		
23	0.0204			0.0211		
24	0.0225			0.0193		
25	0.0243			0.0201		
26	0.0289			0.0187		
27	0.0302			0.0171		
28	0.0288			0.0169		
29	0.0327			0.0177		
30	0.0348			0.0188		
31	0.038			0.0189		
32	0.0395			0.018		
33	0.0392			0.0218		
34	0.0421			0.0153		
35	0.0376			0.0134		
36	0.0365			0.0153		
37	0.0367			0.0154		
38	0.0381			0.0134		
39	0.0322			0.0121		
40	0.0301			0.0124		
41	0.0293			0.0108		
42	0.0278			0.0096		
43	0.0272			0.0101		
44	0.0246			0.0093		
45	0.0216			0.0067		
46	0.0205			0.0076		
47	0.0168			0.0086		
48	0.0175			0.0078		
49	0.0137			0.0068		
50	0.015			0.0055		
51	0.0117			0.0044		
52	0.0113			0.0038		
53	0.0088			0.0038		
54	0.0075			0.0037		
55	0.0072			0.0025		
56	0.0051			0.0017		
57	0.0062			0.0015		
58	0.0057			0.0018		
59	0.0051			0.0013		
60	0.0043			0.0009		
61	0.0037			0.0008		
62	0.0036			0.0023		
63	0.0024			0.0001		
64	0.0018					
65	0.0013					

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
66	0.0013			0.0002		
67	0.0013					
68	0.0006			0.0001		
69	0.0006					
70	0.0009					
71	0.0004					
72	0					
73	0.0005					
74	0.0002					
75	0.0001					
76	0.0002					
77	0					
78	0.0001					
79	0.0001					
80	0					
81	0					
82	0					
83	0					
84	0.0001					
85	0					
86	0					
87	0					
88	0.0001					
Av. Occupants exposed / fire	35.7	0.294	0	19.3	0.083	0
Av occupants exposed normalised to reference bld.	1.85	3.54	-	1	1	-

There were no losses if the Level 3 tenability criteria were applied for either the high rise or the reference building but for the Level 1 and 2 criteria the losses for the high-rise building were higher than the reference building if the impact of sprinkler protection is not taken into account.

Scenarios Cluster Type 3 Medium Growth Fire peaking at 3.75MW – Early Manual Alarm

Results are presented in Table 88 for a high-rise (case c) and a reference single storey building (case d) for an early manual alarm initiating evacuation.

Table 88 Probability of exposure to untenable conditions Medium Growth Fires in General Circulation Area (Enclosure Type 3) with early manual alarm initiating evacuation

Occupants	High-Rise with Early Manual Alarm			Reference with Early Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0	0.7524	1	1	0.9417	1	1
1	0.0176			0.0044		
2	0.0173			0.0037		
3	0.0173			0.004		
4	0.0132			0.0038		
5	0.0145			0.0044		
6	0.015			0.0026		
7	0.0132			0.0028		
8	0.0136			0.0025		
9	0.0124			0.0024		
10	0.0118			0.002		
11	0.0098			0.0026		
12	0.011			0.0018		
13	0.0076			0.0019		
14	0.0094			0.0024		
15	0.0073			0.0017		
16	0.0094			0.0017		
17	0.0062			0.0024		
18	0.0055			0.0014		
19	0.0055			0.0012		
20	0.005			0.0013		

Occupants	High-Rise with Early Manual Alarm			Reference with Early Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
21	0.0044			0.002		
22	0.0031			0.0007		
23	0.0026			0.001		
24	0.0021			0.0009		
25	0.0027			0.0004		
26	0.002			0.0004		
27	0.0019			0.0001		
28	0.0014			0.0005		
29	0.0009			0.0002		
30	0.0011			0.0004		
31	0.0005			0.0001		
32	0.0012			0.0002		
33	0.0001			0.0001		
34	0.0004			0.0001		
35	0.0003					
36	0.0001			0.0001		
37	0.0002					
38						
39				0.0001		
Av. Occupants exposed / fire	2.52	0	0	0.614	0	0
Av occupants exposed normalised to reference bld.	4.10	-	-	1	-	-

There were no losses if the Level 2 or Level 3 tenability criteria were applied for either the high rise or the reference building but for the Level 1 criteria the losses for the high-rise building were higher than the reference building if the impact of sprinkler protection is not taken into account.

Scenario Cluster Circ Type 3 Medium Growth Fire peaking at 3.75MW – Delayed Manual Alarm

Results are presented in Table 89 for a high-rise (case e) and a reference single storey building (case f) for a delayed manual alarm.

Due to the delayed alarm a large number of occupants remained in the GLAs because the Level 1 tenability were exceeded before they could leave the GLA. If the Level 3 criteria are applied the number of occupants exposed is reduced significantly but those remaining in the GLAs would be reliant on fire brigade intervention to assist their evacuation. A separate set of results assuming no fire brigade intervention has been included for information.

From Figure 32, the 50-percentile value for time search and rescue begins for a fire on the first floor is 870s and the 95-percentile value is 1200s. These times will increase further for fires on the upper levels of a high-rise building. The medium fire scenario attains its peak heat release rate after 570s (i.e. before search and rescue begins). In a high-rise building access may only be available from the fire stairs requiring fire brigade personnel to move through enclosures 6 and 7 to the GLAs to rescue remaining occupants where they could be exposed to air temperatures substantially above 200°C. These temperatures present a challenging environment for fire fighters (refer Table 71) where exposure may only be tolerated for up to 1 minute. The probability of this scenario occurring would be significantly reduced by the provision of automatic sprinklers.

For a single storey structure with external access fire fighters may be able to access the GLAs directly through the windows increasing the probability of successful search and rescue activities and reducing the risk to fire brigade personnel.

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Consulting

Table 89 Probability of exposure to untenable conditions Medium Growth Fires in General Circulation Area (Enclosure Type 3) with delayed manual alarm initiating evacuation

Occupants	High-Rise with Delayed Manual Alarm				Reference with Delayed Manual Alarm			
	level 1	Level 2	Level 3 FBI	Level 3 NFBI	level 1	Level 2	Level 3 FBI	Level 3 NFBI
0	0	0.0003	0.9357	0.6115	0	0.0376	0.9904	0.6243
1	0	0.0001	0.0065	0.0122	0	0.0031	0.0026	0.0114
2	0	0.0002	0.0066	0.0116	0	0.0038	0.0013	0.0105
3	0	0.0003	0.005	0.0123	0	0.0034	0.0017	0.0115
4	0	0	0.0041	0.0123	0	0.0034	0.0011	0.0112
5	0	0.0005	0.0055	0.0103	0	0.0039	0.0006	0.0102
6	0	0.0002	0.0041	0.0105	0	0.0031	0.0009	0.0105
7	0	0.0003	0.0042	0.0119	0	0.0036	0.001	0.0112
8	0	0.0004	0.0048	0.0109	0	0.0037	0.0001	0.0102
9	0	0.0003	0.004	0.0114	0	0.0063	0.0001	0.0103
10	0	0.0008	0.003	0.0121	0	0.0054	0.0001	0.0115
11	0	0.001	0.0025	0.0112	0	0.005		0.0108
12	0	0.001	0.0023	0.0102	0	0.0054		0.0095
13	0	0.0013	0.0018	0.0109	0	0.0054	0.0001	0.0104
14	0	0.0009	0.0015	0.0083	0	0.0037		0.0083
15	0	0.0015	0.0016	0.0092	0	0.0063		0.0093
16	0	0.0013	0.0012	0.0093	0	0.0066		0.01
17	0	0.0021	0.001	0.0079	0	0.0075		0.0085
18	0	0.0015	0.0008	0.0092	0	0.0055		0.0093
19	0	0.0021	0.0008	0.006	0	0.0056		0.0066
20	0	0.0032	0.0006	0.0086	0	0.0066		0.0083
21	0	0.0033	0.0006	0.0073	0	0.0074		0.0074
22	0	0.0043	0.0007	0.0054	0	0.0078		0.0048
23	0	0.0038	0.0001	0.0071	0	0.007		0.007
24	0	0.005	0.0004	0.0059	0	0.0083		0.0061
25	0	0.0045	0.0002	0.0053	0	0.0094		0.0056
26	0	0.0051	0	0.0063	0	0.0099		0.0051
27	0	0.0066	0.0001	0.0054	0	0.0096		0.0058
28	0	0.0056	0.0002	0.0062	0	0.0108		0.0066
29	0	0.0087	0.0001	0.0046	0	0.0122		0.0054
30	0	0.0076		0.0045	0	0.01		0.0045
31	0	0.0117		0.0269	0	0.0291		0.0328
32	0	0.0105		0.0032	0	0.0123		0.0025
33	0.0001	0.01		0.0041	0.0001	0.0115		0.0036
34	0	0.0131		0.0025	0	0.0145		0.0025
35	0	0.0126		0.004	0	0.0156		0.0034
36	0	0.0149		0.0032	0	0.0157		0.0026
37	0	0.0156		0.0027	0	0.0147		0.0021
38	0	0.0147		0.0041	0	0.0156		0.0032
39	0	0.0163		0.0036	0	0.0182		0.0034
40	0	0.0182		0.003	0	0.0163		0.0028
41	0	0.0166		0.0021	0	0.0182		0.0012
42	0	0.0182		0.003	0	0.0198		0.0025
43	0.0001	0.0192		0.0028	0.0001	0.0157		0.0028
44	0.0002	0.0208		0.0029	0.0002	0.0199		0.0023
45	0	0.0205		0.0024		0.0193		0.0027
46	0.0001	0.0202		0.0026	0.0002	0.019		0.0027
47	0.0003	0.0228		0.0022	0.0003	0.0188		0.0017
48	0.0001	0.0217		0.0026	0.0001	0.0171		0.0023
49	0.0001	0.0212		0.0024	0.0001	0.0211		0.0025
50	0.0003	0.0235		0.003	0.0003	0.0207		0.0022
51	0.0001	0.0202		0.0021	0.0001	0.0189		0.0018
52	0.0001	0.0235		0.0021	0.0001	0.0198		0.0021
53	0.0003	0.0221		0.0023	0.0004	0.0164		0.0023

Occupants	High-Rise with Delayed Manual Alarm				Reference with Delayed Manual Alarm			
	level 1	Level 2	Level 3 FBI	Level 3 NFBI	level 1	Level 2	Level 3 FBI	Level 3 NFBI
54	0.0004	0.023		0.0018	0.0005	0.0185		0.002
55	0.0001	0.0237		0.0016	0.0001	0.0192		0.0012
56	0.0001	0.0211		0.0021	0.0001	0.0156		0.0019
57	0.0005	0.0218		0.0025	0.0006	0.0176		0.0017
58	0.0003	0.0221		0.0019	0.0003	0.0177		0.0022
59	0.0001	0.0208		0.0015	0.0001	0.0144		0.001
60	0.0002	0.0198		0.0017	0.0003	0.0169		0.0015
61	0.0005	0.0179		0.0015	0.0007	0.014		0.0015
62	0.0126	0.084		0.0089	0.0196	0.1631		0.0123
63	0.0015	0.0125		0.0011	0.0018	0.0035		0.0007
64	0.0014	0.0139		0.0012	0.002	0.0043		0.0003
65	0.0011	0.0133		0.0006	0.0021	0.0039		0.0002
66	0.0021	0.0139		0.0007	0.0027	0.0038		0.0002
67	0.0017	0.0165		0.0009	0.0022	0.0023		0.0005
68	0.002	0.0141		0.0004	0.0027	0.0038		
69	0.001	0.0125		0.0006	0.0022	0.0043		0.0001
70	0.002	0.0121		0.0008	0.0028	0.0036		0.0005
71	0.0023	0.0138		0.001	0.0027	0.0025		0.0003
72	0.0021	0.0108		0.0005	0.0038	0.0032		
73	0.0018	0.0109		0.0002	0.0029	0.0038		0.0002
74	0.0023	0.0107		0.0003	0.0038	0.0024		0.0003
75	0.0025	0.0086		0.0001	0.0041	0.0025		0.0002
76	0.0023	0.0099		0.0003	0.0033	0.0019		0.0002
77	0.0018	0.0092		0.0006	0.004	0.0026		0.0001
78	0.0028	0.0065		0.0003	0.005	0.0017		0.0001
79	0.0028	0.0058		0.0001	0.0048	0.0017		
80	0.0024	0.0076		0.0003	0.0044	0.0021		0.0002
81	0.003	0.0082		0.0003	0.005	0.0016		0.0001
82	0.0026	0.0062		0	0.0042	0.0013		
83	0.0013	0.0065		0.0001	0.0033	0.0013		0.0001
84	0.0029	0.0045		0.0001	0.0044	0.0019		
85	0.0035	0.0058		0	0.0056	0.0006		
86	0.004	0.0048		0.0001	0.0061	0.0014		
87	0.003	0.0036		0	0.0054	0.0009		
88	0.0033	0.0028		0	0.0054	0.0009		0.0001
89	0.0045	0.0033		0	0.0071	0.0006		
90	0.0038	0.0027		0.0001	0.0061	0.0009		0.0001

Occupants	High-Rise with Delayed Manual Alarm				Reference with Delayed Manual Alarm			
	level 1	Level 2	Level 3 FBI	Level 3 NFBI	level 1	Level 2	Level 3 FBI	Level 3 NFBI
91	0.0051	0.0016		0.0001	0.0078	0.0004		0.0001
92	0.0045	0.0019		0.0001	0.0064	0.0005		
93	0.0353	0.0023		0	0.037	0.0003		
94	0.0067	0.001		0	0.0089	0.0002		
95	0.0085	0.0016		0	0.0101	0.0004		
96	0.0094	0.0008			0.0114	0		
97	0.0097	0.0008			0.0109	0.0001		
98	0.0088	0.0006			0.0109	0		
99	0.0098	0.0007			0.0124	0		
100	0.0114	0.0004			0.0124	0.0003		
101	0.0113	0.0003			0.0131			
102	0.0103	0.0004			0.0131			
103	0.0136	0.0002			0.014			
104	0.016	0.0001			0.0147			
105	0.0115	0.0001			0.0138			
106	0.0172	0			0.0172			
107	0.0162	0			0.018			
108	0.0209	0			0.0188			
109	0.0189	0			0.0175			
110	0.0195	0.0001			0.015			
111	0.0227				0.0176			
112	0.0217				0.0189			
113	0.0214				0.0193			
114	0.025				0.0215			
115	0.0252				0.0176			
116	0.0256				0.0184			
117	0.025				0.0185			
118	0.0244				0.0184			
119	0.0228				0.0192			
120	0.0232				0.0192			
121	0.0247				0.0189			
122	0.0232				0.0182			
123	0.0239				0.0174			
124	0.3422				0.3393			
Av. Occupants exposed / fire	111.8	54.0	0.4944	9.075	109.3	43.6	0.0341	8.6147
Av occupants exposed normalised to reference bld.	1.02	1.24	14.4	1.05	1	1	1	1

L9. Slow Growth Fire occurring within General Circulation Area (Enclosure Type 3)

L9.1. Slow Growth Fire – General Smoke Modelling Results

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for a slow growth rate fire are summarised in Table 90.

Table 90 Smoke Spread and Tenability Limits – Slow fire in General Circulation Area

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation		Comb Path[2]
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7	
5% smoke layer height - Cue 1	341		253		443	45	95	
100kW HRR - Cue 2						185		
Smoke Detector Activation	305				485	128	146	
Sprinkler Activation -RTI 50						396		
Sprinkler Activation -RTI 135								
Window breakage - Cue 3						670[1]		
Peak HRR 2700 kW						960		
Upper layer temps @1400s	74	21	67	21	21	232	157	
Visibility 10m @2m	430	>1400	407	>1400	>1400	294	203	
Smoke layer 2m	430	960	343	596	571	294	188	
Smoke layer 1.75m	458	>1400	370	663	645	369	238	
Smoke layer 1.5m	486	>1400	396	896	>1400	442	294	
FED thermal - 0.3	1354	>1400	>1400	>1400	>1400	540	690	540
FED CO - 0.3	1378	>1400	>1400	>1400	>1400	1004	1053	1004
Level 1 Tenability	430	>1400	407	>1400	>1400	294	203	
Level 2 Tenability	486	>1400	407	>1400	>1400	442	294	
Level 3 Tenability	1354	>1400	>1400	>1400	>1400	540	690	540

Notes: Failure temp for window of 150°C adopted to prevent ventilation control before window breakage. Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L9.2. ASET RSET Analysis Slow Fires –General Circulation Area (Enclosure Type 3)

Similar to the medium fires it will be assumed that all students are within the GLAs and will be alerted by the automatic detection and alarm system or a manual alarm. It has also been assumed that access is available to both stairs and the occupants will use the nearest stair or exit provided they can evacuate their GLA prior to Level 1 tenability criteria (visibility less than 10m at 2m height) being exceeded on the path of travel to the stair or exit entrance. If the occupants remained in the GLA and closed the door the onset of untenable conditions would be delayed significantly.

Scenario Cluster Circ Type 3 Slow Growth Fire peaking at 2.7MW - Smoke Detection System Activates an Alarm

Results are presented in Table 91 for a high-rise (case a) and a reference single storey building (case b) for an alarm raised by an automatic detection / alarm system.

Table 91 Probability of exposure to untenable conditions Slow Growth Fires in General Circulation Area (Enclosure Type 3) with automatic detection initiating evacuation

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
0	0.0185	0.9996	1	0.5132	1	1
1	0.0052	0.0002	0	0.0157	0	0
2	0.0048	0	0	0.0147	0	0
3	0.0056	0.0001	0	0.0148	0	0
4	0.0071	0	0	0.0158	0	0
5	0.0072	0.0001	0	0.0162	0	0
6	0.0116	0	0	0.0152	0	0
7	0.0123	0	0	0.0155	0	0
8	0.0166	0	0	0.0155	0	0
9	0.0176	0	0	0.0163	0	0
10	0.017	0	0	0.017	0	0
11	0.0178	0	0	0.0163	0	0
12	0.0224	0	0	0.0146	0	0
13	0.0224	0	0	0.0158	0	0
14	0.0237	0	0	0.013	0	0
15	0.0251	0	0	0.0138	0	0
16	0.0256	0	0	0.0146	0	0
17	0.0306	0	0	0.0145	0	0
18	0.0317	0	0	0.0128	0	0
19	0.0302	0	0	0.0122	0	0
20	0.0341	0	0	0.0148	0	0
21	0.0382	0	0	0.013	0	0
22	0.0371	0	0	0.0112	0	0
23	0.0333	0	0	0.0137	0	0
24	0.0368	0	0	0.0123	0	0
25	0.0351	0	0	0.0105	0	0
26	0.0346	0	0	0.011	0	0
27	0.0348	0	0	0.011	0	0
28	0.0346	0	0	0.0091	0	0
29	0.0333	0	0	0.0095	0	0
30	0.0362	0	0	0.0093	0	0
31	0.0309	0	0	0.0075	0	0
32	0.0301	0	0	0.0076	0	0
33	0.026	0	0	0.0094	0	0
34	0.0258	0	0	0.0074	0	0
35	0.0201	0	0	0.0055	0	0
36	0.0177	0	0	0.005	0	0
37	0.0173	0	0	0.0038	0	0
38	0.0155	0	0	0.0061	0	0
39	0.0131	0	0	0.0034	0	0
40	0.0126	0	0	0.0039	0	0
41	0.0098	0	0	0.0034	0	0
42	0.0081	0	0	0.0032	0	0
43	0.0059	0	0	0.0025	0	0
44	0.006	0	0	0.0018	0	0
45	0.0034	0	0	0.0019	0	0
46	0.004	0	0	0.0008	0	0
47	0.0027	0	0	0.0019	0	0
48	0.0027	0	0	0.0007	0	0
49	0.0023	0	0	0.0003	0	0
50	0.0014	0	0	0.0005	0	0
51	0.0014	0	0	0.0002	0	0
52	0.0006	0	0	0.0001	0	0
53	0.0002	0	0	0	0	0
54	0.0008	0	0	0	0	0
55	0.0001	0	0	0	0	0
56	0.0001	0	0	0	0	0
57	0.0002	0	0	0.0002	0	0
58	0	0	0	0	0	0
59	0.0001	0	0	0	0	0
Av. Occupants exposed / fire	23.4	0.001	0	8.7	0	0
Av occupants exposed normalised to reference bld.	2.7	-	-	1	-	-

There were no losses if the Level 3 tenability criteria were applied for either the high rise or the reference building. For the level 2 criteria there were no losses for the reference building and very low losses for the High-rise case, For the Level 1 criteria the losses for the high-rise building were higher than the reference building if the impact of sprinkler protection is not taken into account.

Scenario Cluster Circ Type 3 Slow Growth Fire peaking at 2.7MW – Early Manual Alarm

Results are presented in Table 92 for a high-rise (case c) and a reference single storey building (case d) for an early manual alarm initiating evacuation.

Table 92 Probability of exposure to untenable conditions Slow Growth Fires in General Circulation Area (Enclosure Type 3) with early manual alarm initiating evacuation

Occupants	High-Rise with early manual alarm			Reference with early manual alarm		
	level 1	Level 2	Level 3	Level 1	Level 2	Level 3
0	0.9975	1	1	0.9991	1	1
1	0.0011	0	0	0.0001	0	0
2	0.0003	0	0	0.0001	0	0
3	0.0002	0	0	0.0004	0	0
4	0.0001	0	0	0	0	0
5	0.0002	0	0	0.0001	0	0
6	0.0002	0	0	0	0	0
7	0.0001	0	0	0	0	0
8	0.0001	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0.0001	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0.0002	0	0	0.0001	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
Av. Occupants exposed / fire	0.009	0	0	0.0043	0	0
Av occupants exposed normalised to reference bld.	2.1	-	-	1	0	0

There were no losses if the Level 2 or Level 3 tenability criteria were applied for either the high rise or the reference building but for the Level 1 criteria the losses for the high-rise building were higher than the reference building if the impact of sprinkler protection is not taken into account but the losses were substantially less than the medium fire scenario.

Scenario Cluster Circ Type 3 Slow Growth Fire peaking at 2.7MW – Delayed Manual Alarm

Results are presented in Table 93 for a high-rise (case e) and a reference single storey building (case f) for a delayed manual alarm. The values quoted assume that search and rescue activities are successful for the people remaining in the GLAs.

Due to the delayed alarm a large number of occupants remained in the GLAs because the Level 1 tenability were exceeded before they could leave the GLA. If the Level 3 criteria are applied the number of occupants exposed is reduced significantly but those remaining in the GLAs would be reliant on fire brigade intervention to assist their evacuation.

For the slow growth rate fire, the peak heat release rate is attained after 960 s after which it is maintained at a steady state of 2.7MW. Temperatures in the upper smoke layer after 1400s for enclosures 6 and 7 were 232°C and 157°C respectively. Search and rescue activities will be required for the delayed manual alarm case for a slow fire and the environment would be challenging (but less so than with the corresponding medium fire case).

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Table 93 Probability of exposure to untenable conditions Slow Growth Fires in General Circulation Area (Enclosure Type 3) with delayed manual alarm initiating evacuation

Occupants	High-Rise with delayed manual alarm			Reference with delayed manual alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0	0.0002	0.9313	1	0.0294	0.996	1
1	0.0001	0.0042	0	0.0035	0.0005	0
2	0.0003	0.0053	0	0.0028	0.0005	0
3	0.0004	0.0056	0	0.0041	0.0008	0
4	0.0001	0.0038	0	0.0039	0.0007	0
5	0.0006	0.0048	0	0.0044	0.0004	0
6	0.0001	0.0044	0	0.0038	0.0005	0
7	0.0005	0.0032	0	0.0037	0.0002	0
8	0.0005	0.0032	0	0.0046	0.0003	0
9	0.0008	0.0041	0	0.0049	0.0001	0
10	0.0008	0.0042	0	0.0055	0	0
11	0.0006	0.0021	0	0.0045	0	0
12	0.0008	0.0023	0	0.0056	0	0
13	0.0006	0.002	0	0.0044	0	0
14	0.0009	0.0022	0	0.0038	0	0
15	0.0011	0.0024	0	0.0041	0	0
16	0.0021	0.002	0	0.0048	0	0
17	0.0022	0.0028	0	0.005	0	0
18	0.0018	0.0018	0	0.0074	0	0
19	0.0017	0.0009	0	0.0051	0	0
20	0.0025	0.0015	0	0.0074	0	0
21	0.0029	0.0007	0	0.0055	0	0
22	0.0031	0.001	0	0.0081	0	0
23	0.0043	0.0008	0	0.0075	0	0
24	0.0042	0.001	0	0.006	0	0
25	0.0039	0.0005	0	0.0072	0	0
26	0.0051	0.0005	0	0.0057	0	0
27	0.0069	0.0002	0	0.0066	0	0
28	0.0068	0.0003	0	0.0092	0	0
29	0.0049	0.0003	0	0.0072	0	0
30	0.0058	0.0002	0	0.0067	0	0
31	0.0097	0.0002	0	0.0285	0	0
32	0.0078	0	0	0.009	0	0
33	0.0091	0	0	0.011	0	0
34	0.0099	0.0001	0	0.0102	0	0
35	0.0096	0.0001	0	0.0102	0	0
36	0.0123	0	0	0.0094	0	0
37	0.0119	0	0	0.0111	0	0
38	0.0138	0	0	0.0117	0	0
39	0.0123	0	0	0.0114	0	0
40	0.0125	0	0	0.0097	0	0
41	0.0132	0	0	0.0099	0	0
42	0.0124	0	0	0.0107	0	0
43	0.0123	0	0	0.0114	0	0
44	0.0126	0	0	0.012	0	0
45	0.0167	0	0	0.0103	0	0
46	0.0165	0	0	0.0105	0	0
47	0.0142	0	0	0.0108	0	0
48	0.017	0	0	0.0113	0	0
49	0.0165	0	0	0.0112	0	0
50	0.0164	0	0	0.01	0	0
51	0.0168	0	0	0.01	0	0
52	0.0164	0	0	0.0103	0	0
53	0.0141	0	0	0.0112	0	0
54	0.0188	0	0	0.0118	0	0
55	0.014	0	0	0.0106	0	0
56	0.0174	0	0	0.0107	0	0
57	0.0161	0	0	0.0094	0	0
58	0.0136	0	0	0.0105	0	0
59	0.017	0	0	0.01	0	0
60	0.0159	0	0	0.0096	0	0
61	0.0141	0	0	0.0106	0	0
62	0.4175	0	0	0.4367	0	0
63	0.0047	0	0	0.0012	0	0
64	0.0055	0	0	0.0018	0	0
65	0.0045	0	0	0.0015	0	0

Occupants	High-Rise with delayed manual alarm			Reference with delayed manual alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
66	0.0047	0	0	0.0018	0	0
67	0.0039	0	0	0.0019	0	0
68	0.0044	0	0	0.0018	0	0
69	0.0044	0	0	0.0013	0	0
70	0.0038	0	0	0.0011	0	0
71	0.0033	0	0	0.0011	0	0
72	0.0033	0	0	0.0014	0	0
73	0.003	0	0	0.0005	0	0
74	0.0035	0	0	0.0006	0	0
75	0.003	0	0	0.0007	0	0
76	0.002	0	0	0.0013	0	0
77	0.0041	0	0	0.0009	0	0
78	0.0028	0	0	0.0008	0	0
79	0.0026	0	0	0.0007	0	0
80	0.0022	0	0	0.0009	0	0
81	0.0017	0	0	0.0007	0	0
82	0.0016	0	0	0.0005	0	0
83	0.0017	0	0	0.0002	0	0
84	0.0013	0	0	0.0007	0	0
85	0.0015	0	0	0.0005	0	0
86	0.001	0	0	0.0003	0	0
87	0.0019	0	0	0.0002	0	0
88	0.0013	0	0	0.0001	0	0
89	0.0011	0	0	0.0001	0	0
90	0.0007	0	0	0	0	0
91	0.0004	0	0	0	0	0
92	0.0005	0	0	0.0001	0	0
93	0.0007	0	0	0.0003	0	0
94	0.0007	0	0	0.0002	0	0
95	0.0006	0	0	0	0	0
96	0.001	0	0	0.0003	0	0
97	0.0003	0	0	0.0002	0	0
98	0.0001	0	0	0	0	0
99	0.0005	0	0	0	0	0
100	0.0001	0	0	0.0001	0	0
101	0.0001	0	0	0.0001	0	0
102	0.0001	0	0	0	0	0
103	0.0003	0	0	0	0	0
104	0.0001	0	0	0	0	0
Av. Occupants exposed / fire	54.1	0.673	0	47.4	0.0164	0
Av occupants exposed normalised to reference bld.	1.1	41	-	1	1	-

L10. Fast Growth Fire occurring within Ancillary Area (Encl. Type 1)

L10.1. Fast Growth Fire – General Smoke Modelling Results

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for a Fast-Growing Potential Flashover Fire are summarised in Table 94

Table 94 Smoke Spread and Tenability Limits - fast fire in ancillary area

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation	
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7
5% smoke layer height - Cue 1	163		159		13	69s	91
100kW HRR - Cue 2					46		
Smoke Detector Activation	138				53	59	81
Sprinkler Activation -RTI 50					106		
Heat detector -RTI 30					86		
Window breakage - Cue 3					171		
Flashover					296		
Upper layer temps @1400s	62	21	51	21	808	135	105
Visibility 10m @2m	248	>1400	273	>1400	33	126	129
Smoke layer 2m	243	772	220	>1400	33	126	123
Smoke layer 1.75m	272	>1400	245	>1400	48	153	140
Smoke layer 1.5m	295	>1400	268	>1400	64	202	156
FED thermal - 0.3	>1400	>1400	>1400	>1400	124	422	622
FED CO - 0.3	599	>1400	682	>1400	283	414	463
Level 1 Tenability	248	>1400	273	>1400	33	126	129
Level 2 Tenability	295	>1400	268	>1400	64	202	156
Level 3 Tenability	296	296	296	296	283	296	296

Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L10.2. ASET RSET Analysis Fast Fires –Ancillary Area (Enclosure Type 1)

For these scenarios it will be assumed that all students are within the GLAs and will be alerted by the automatic detection and alarm system or a manual alarm. It has also been assumed that access is available to both stairs and the occupants will use the nearest stair or exit provided they can evacuate their GLA prior to Level 1 tenability criteria (visibility less than 10m at 2m height) being exceeded on the path of travel to the stair or exit entrance. If the occupants remained in the GLA and closed the door the onset of untenable conditions would be delayed significantly until flashover.

Scenario Cluster Ancillary Type 1 FAST Smoke Detection System Activates an Alarm

Results are presented in Table 95 for a high-rise (case a) and a reference single storey building (case b) for an alarm raised by an automatic detection / alarm system. Since flashover occurred in this scenario prior to fire brigade arrival all people still present on the floor of fire origin were assumed to be exposed to untenable conditions and therefore search and rescue activities were not considered.

The results indicate that for Level 1 and Level 2 tenability criteria there was a significant increase in risk compared to the reference building if the impact of automatic sprinkler systems in the high-rise building is not considered. Evacuation occurred before the level 3 tenability criteria were exceeded.

Table 95 Probability of exposure to untenable conditions Fast Growth Flashover Fires in ancillary area (Enclosure Type 1) with automatic detection initiating evacuation

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
0	0.0016	0.5462	1	0.2526	0.896	1
1	0.001	0.0262		0.0166	0.0067	
2	0.0008	0.0273		0.0171	0.0072	
3	0.0014	0.0279		0.018	0.007	
4	0.0019	0.0276		0.0165	0.0063	
5	0.0016	0.0239		0.016	0.0053	
6	0.0021	0.0248		0.0187	0.0053	
7	0.0024	0.0219		0.0168	0.0061	
8	0.0018	0.024		0.0177	0.0059	
9	0.0021	0.0229		0.0188	0.0051	
10	0.0024	0.022		0.0164	0.0041	
11	0.0027	0.0193		0.0198	0.005	
12	0.0038	0.0189		0.0176	0.0043	
13	0.0044	0.0198		0.017	0.0034	
14	0.0049	0.0173		0.0174	0.0038	
15	0.005	0.0174		0.017	0.0028	
16	0.006	0.0155		0.0162	0.003	
17	0.0056	0.0123		0.0167	0.0034	
18	0.0066	0.0108		0.0182	0.0027	
19	0.0069	0.0104		0.0196	0.0018	
20	0.0099	0.0103		0.018	0.0023	
21	0.0086	0.0077		0.0171	0.0018	
22	0.0062	0.006		0.0168	0.0011	
23	0.0103	0.0082		0.0181	0.0018	
24	0.0082	0.0044		0.017	0.0012	
25	0.0116	0.0044		0.0179	0.0011	
26	0.0096	0.0037		0.0159	0.0009	
27	0.0112	0.0048		0.0146	0.0009	
28	0.0116	0.0018		0.0176	0.0007	
29	0.0125	0.0028		0.0165	0.0007	
30	0.0142	0.0026		0.0138	0.0006	
31	0.0127	0.0014		0.0129	0.0006	
32	0.0131	0.0014		0.014	0.0005	
33	0.0149	0.0014		0.0134		
34	0.0163	0.0007		0.0129	0.0002	
35	0.0175	0.0003		0.0129	0.0002	
36	0.0165	0.0003		0.011	0.0001	
37	0.0182	0.0005		0.0103		
38	0.0163	0.0004		0.0106	0.0001	
39	0.0182	0.0001		0.01		
40	0.0197	0.0001		0.0092		
41	0.0183	0.0001		0.0086		
42	0.0198	0.0002		0.0075		
43	0.022			0.0078		
44	0.0195			0.0063		
45	0.0215			0.0077		
46	0.0225			0.007		
47	0.0199			0.0058		
48	0.0228			0.0054		
49	0.0194			0.0036		
50	0.0213			0.0046		
51	0.0209			0.0041		
52	0.0211			0.0035		
53	0.0203			0.003		
54	0.0215			0.0034		
55	0.0185			0.0031		
56	0.0211			0.0036		
57	0.0201			0.0026		
58	0.0183			0.0024		
59	0.0206			0.002		
60	0.0194			0.0029		
61	0.0177			0.0026		
62	0.0164			0.0013		
63	0.0178			0.001		
64	0.017			0.0021		

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
65	0.0155			0.0017		
66	0.0133			0.0007		
67	0.0125			0.0009		
68	0.0136			0.0012		
69	0.011			0.0005		
70	0.0111			0.0013		
71	0.012			0.0004		
72	0.0088			0.0008		
73	0.0095			0.0006		
74	0.0094			0.0004		
75	0.0084			0.0006		
76	0.007			0.0005		
77	0.0069			0.0004		
78	0.0056			0.0004		
79	0.0059			0.0002		
80	0.0047			0.0002		
81	0.003			0.0001		
82	0.0023			0.0002		
83	0.0031			0.0001		
84	0.0033			0.0008		
85	0.0029			0.0001		
86	0.0017			0.0002		
87	0.0014			0.0001		
88	0.0017			0.0002		
89	0.0006					
90	0.0013			0.0001		
91	0.0006					
92	0.0006					
93	0.0005			0.0001		
94	0.0005					
95	0.0001					
96	0.0002					
97	0.0002					
98	0.0002					
99	0.0001			0.0001		
100	0.0001					
101	0.0002					
102						
103	0.0001					
104						
105						
106						
107	0.0001					
Av. Occupants exposed / fire	47.7	4.94	0	18.0	1.10	0
Av occupants exposed normalised to reference bld.	2.65	4.49	-	1	1	-

Scenario Cluster Ancillary Type 1 FAST Early Manual Alarm

Results are presented in Table 96 for a high-rise (case c) and a reference single storey building (case d) for early manual detection from an occupant in the enclosure of fire origin or the general circulation area. Since flashover occurred in this scenario prior to fire brigade arrival all people still present on the floor of fire origin at the time of flashover were assumed to be exposed to untenable conditions and therefore search and rescue activities were not considered

The results follow a similar trend to the automatic detection scenarios, indicating that for Level 1 and Level 2 tenability criteria there was a significant increase in risk compared to the reference building if the impact of automatic sprinkler systems in the high-rise building is not considered. Evacuation occurred before the level 3 tenability criteria were exceeded. The losses were less than the automatic detection system reflecting the earlier alarm if people are in the vicinity of the fire location.

Table 96 Probability of exposure to untenable conditions Fast Growth Flashover Fires in ancillary area (Enclosure Type 1) with early manual alarm initiating evacuation

Occupants	High-Rise with Early Manual Alarm			Reference with Early Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0	0.3809	0.8946	1	0.7401	0.9783	1
1	0.0195	0.009		0.0118	0.002	
2	0.0189	0.0095		0.0123	0.0015	
3	0.0175	0.0094		0.0132	0.0018	
4	0.0182	0.0084		0.013	0.0016	
5	0.019	0.0079		0.0128	0.0012	
6	0.0179	0.0082		0.0084	0.0013	
7	0.0169	0.0068		0.0114	0.0009	
8	0.0179	0.0056		0.01	0.001	
9	0.0164	0.0055		0.0108	0.0014	
10	0.0166	0.0045		0.0117	0.0009	
11	0.0145	0.0045		0.0095	0.001	
12	0.0153	0.0029		0.0088	0.0011	
13	0.0162	0.0039		0.0076	0.0009	
14	0.0139	0.0036		0.0082	0.0005	
15	0.0136	0.0024		0.0071	0.001	
16	0.0144	0.0021		0.0054	0.0008	
17	0.0121	0.0025		0.0092	0.0004	
18	0.0125	0.0022		0.0066	0.0009	
19	0.0138	0.0007		0.0068	0.0002	
20	0.0124	0.0013		0.008	0.0001	
21	0.0104	0.001		0.0052	0.0003	
22	0.0118	0.0011		0.0053	0.0001	
23	0.0102	0.0003		0.0047	0.0001	
24	0.0101	0.0005		0.0037		
25	0.0104	0.0003		0.0045	0.0001	
26	0.012	0.0003		0.0048		
27	0.0111	0.0002		0.0025	0.0003	
28	0.0121	0.0001		0.004		
29	0.0085	0.0001		0.0031	0.0002	
30	0.0098	0.0002		0.0023		
31	0.0097			0.0022		
32	0.0098			0.0024	0.0001	
33	0.0082			0.0023		
34	0.009	0.0001		0.0022		
35	0.0084	0.0003		0.0021		
36	0.0067			0.0017		
Av. Occupants exposed / fire	14.5	0.852	0	3.88	0.196	0
Av occupants exposed normalised to reference bld.	3.7	4.3	-	1	1	-

Scenario Cluster Ancillary Type 1 Fast Delayed Manual Alarm

Results are presented in Table 97 for a high-rise (case e) and a reference single storey building (case f) for delayed manual detection from an occupant not in the immediate area of the fire. In these scenarios the fire is only detected when smoke enters a General Learning area adjoining the circulation space. Since flashover occurred in this scenario prior to fire brigade arrival all people still present on the floor of fire origin at the time of flashover were assumed to be exposed to untenable conditions and therefore search and rescue activities were not considered.

This scenario is similar to a fast flashover fire in the circulation space; in both cases the circulation space which forms a path of travel to the exit was substantially filled with smoke before the occupants in the classroom were aware of the fire. With level 1 tenability conditions close to all occupants were unable to evacuate the floor successfully. For Level 3 tenability conditions the losses were substantially reduced but occupants that successfully evacuated the floor would have had to move through smoke or queue at the exit in smoke which are not desirable outcomes.

It should be noted that these scenarios do not take into account the presence of smoke detection systems and automatic sprinklers proposed for the high-rise buildings nor the potential use of alternate egress paths that may be available in single storey buildings such as external doors in GLAs providing direct access to open space.

Table 97 Probability of exposure to untenable conditions Fast Growth Flashover Fires in ancillary area (Enclosure Type 1) with delayed manual alarm initiating evacuation

Occupants	High-Rise with Delayed Manual Alarm			Reference with Delayed Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0			0.9698			0.9737
1			0.0047			0.0036
2			0.0038			0.003
3			0.0037			0.0032
4			0.0034			0.0031
5			0.0029			0.0024
6			0.002			0.0019
7			0.003			0.0026
8			0.0014			0.0015
9			0.0017			0.0018
10			0.0014			0.0012
11			0.0007		0.0001	0.0007
12			0.0005			0.0004
13			0.0002			0.0002
14			0.0003			0.0002
15			0.0002		0.0001	0.0002
16			0.0003			0.0003
17						
18						
19						
20						
21					0.0001	
22					0.0003	
23					0.0003	
24					0.0006	
25						
26					0.0001	
27					0.0006	
28					0.0005	
29					0.0008	
30					0.0001	
31					0.0002	
32					0.0006	
33					0.0006	
34					0.0004	
35					0.0016	
36					0.0007	
37					0.0012	
38					0.0012	
39		0.0001			0.0019	
40		0.0001			0.0019	
41		0.0001			0.0024	
42		0.0001			0.002	
43		0.0001			0.003	
44		0.0004			0.0033	
45		0.0004			0.0041	
46		0.0004			0.0032	
47		0.0006			0.004	
48		0.0006			0.0053	
49		0.0009			0.005	
50		0.001			0.0043	
51		0.0011			0.0063	
52		0.0009			0.0066	
53		0.0013			0.0077	
54		0.0018			0.0087	
55		0.0013			0.0082	
56		0.0013			0.009	
57		0.0019			0.0102	
58		0.0014			0.01	
59		0.0022			0.01	
60		0.0031			0.0109	
61		0.0026			0.0122	

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Occupants	High-Rise with Delayed Manual Alarm			Reference with Delayed Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
62		0.008			0.2209	
63		0.0054			0.0145	
64		0.0051			0.0125	
65		0.0056			0.0138	
66		0.0054			0.0156	
67		0.0078			0.0132	
68		0.008			0.0141	
69		0.0079			0.0128	
70		0.0098			0.0139	
71		0.0111			0.0143	
72		0.0103			0.0141	
73		0.0115			0.0135	
74		0.0109			0.0138	
75		0.0122			0.0179	
76		0.0173			0.0157	
77		0.0157			0.0139	
78		0.0162			0.0164	
79		0.0151			0.016	
80		0.0184			0.0138	
81		0.0197			0.0153	
82		0.0173			0.0151	
83		0.0195			0.0164	
84		0.0233			0.0172	
85		0.0256			0.015	
86		0.0233			0.017	
87		0.0255			0.0134	
88		0.0259			0.0148	
89		0.029			0.0136	
90		0.028			0.0137	
91		0.0273			0.0147	
92		0.0306			0.0148	
93		0.0295			0.0109	
94		0.0337			0.0133	
95		0.0301			0.0141	
96		0.0283			0.0129	
97		0.0308			0.0101	
98		0.0261			0.0125	
99		0.0267			0.0111	
100		0.0292			0.0111	
101		0.027			0.0093	
102		0.0243			0.009	
103		0.0229			0.0088	
104		0.0212			0.0065	
105		0.0158			0.0069	
106		0.0183			0.0076	
107		0.0159			0.0051	
108	0.0003	0.0162		0.0003	0.0063	
109	0.0002	0.013		0.0002	0.0038	
110	0.0002	0.0107		0.0002	0.0032	
111	0.0002	0.0098		0.0002	0.0031	
112	0.0004	0.0081		0.0004	0.0036	
113	0.0007	0.0064		0.0007	0.0027	
114	0.0012	0.0083		0.0012	0.0019	
115	0.0017	0.005		0.0017	0.0014	
116	0.0014	0.0052		0.0014	0.0016	
117	0.0026	0.003		0.0026	0.0024	
118	0.0018	0.0028		0.0018	0.0011	
119	0.0024	0.0019		0.0024	0.001	
120	0.0031	0.0021		0.0031	0.0015	
121	0.0034	0.0019		0.0034	0.0012	
122	0.003	0.0015		0.003	0.0007	
123	0.0036	0.001		0.0036	0.0005	
124	0.9738	0.0029		0.9738	0.0028	
Av. Occupants exposed / fire	123.9	90.6	0.153	123.9	74.9	0.139
Av occupants exposed normalised to reference bld.	1	1.2	1.1	1	1	1

L11. Medium Growth Fire occurring within Ancillary Area (Encl. Type 1)

L11.1. Medium Growth Fire – General Smoke Modelling Results

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for a medium growth rate fire are summarised in Table 98.

Table 98 Smoke Spread and Tenability Limits - medium fire in ancillary area

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation	
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7
5% smoke layer height - Cue 1	235		225		17	92	126
100kW HRR - Cue 2					92		
Smoke Detector Activation	210				79	95	104
Sprinkler Activation -RTI 50					176		
Heat detector -RTI 30					138		
Window breakage - Cue 3					316		
Peak HRR 1300 kW					335		
Upper layer temps @1400s	34	21	30	21	310	67	54
Visibility 10m @2m	298	>1400	376	>1400	60	185	190
Smoke layer 2m	298	>1400	280	>1400	40	185	174
Smoke layer 1.75m	318	>1400	299	>1400	62	217	199
Smoke layer 1.5m	349	>1400	317	>1400	90	260	223
FED thermal - 0.3	>1400	>1400	>1400	>1400	203	1024	>1400
FED CO - 0.3	>1400	>1400	>1400	>1400	476	1262	1376
Level 1 Tenability	298	>1400	376	>1400	60	185	190
Level 2 Tenability	349	>1400	376	>1400	90	260	223
Level 3 Tenability	>1400	>1400	>1400	>1400	203	1024	1376

Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L11.2. ASET RSET Analysis Medium Fires –Ancillary Area (Enclosure Type 1)

For these scenarios it will be assumed that all students are within the GLAs and will be alerted by the automatic detection and alarm system or a manual alarm. It has also been assumed that access is available to both stairs and the occupants will use the nearest stair or exit provided they can evacuate their GLA prior to Level 1 tenability criteria (visibility less than 10m at 2m height) being exceeded on the path of travel to the stair or exit entrance. If the occupants remained in the GLA and closed the door the onset of untenable conditions would be delayed significantly.

Scenario Cluster Ancillary Type 1 Medium Smoke Detection System Activates an Alarm

Results are presented in Table 99 for a high-rise (case a) and a reference single storey building (case b) for an alarm raised by an automatic detection / alarm system. The high losses if Level 1 and Level 2 tenability criteria are applied, result from the substantial smoke filling of the paths of travel to exits prior to the alarm being raised but compared to the fast potential flashover fire scenarios the Level 3 tenability conditions are maintained considerably longer and the conditions facing fire brigade personnel in the main circulation areas if search and rescue activities are necessary can be considered routine (temperatures below 100°C).

Table 99 Probability of exposure to untenable conditions Medium Growth Fires in ancillary area (Enclosure Type 1) with automatic detection initiating evacuation

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
0	0.5444	0.9846	1	0.8656	0.9957	1
1	0.0245	0.0022		0.0094	0.0006	
2	0.0269	0.0033		0.0086	0.0009	
3	0.0235	0.0019		0.0086	0.0007	
4	0.0242	0.0015		0.009	0.0006	
5	0.0232	0.0017		0.0074	0.0001	
6	0.0223	0.0011		0.0065	0.0003	
7	0.0216	0.0011		0.0075	0.0002	
8	0.0192	0.001		0.0061	0.0003	
9	0.0183	0.0005		0.0063	0.0001	
10	0.0159	0.0002		0.0064		
11	0.0148	0.0003		0.0068	0.0001	
12	0.0128	0.0002		0.0055	0.0001	
13	0.015			0.0059	0.0001	
14	0.0131	0.0002		0.0044		
15	0.0108	0.0001		0.0042	0.0001	
16	0.0129			0.0044	0.0001	
17	0.0104			0.0025		
18	0.0104	0.0001		0.004		
19	0.0101			0.0036		
20	0.0092			0.003		
21	0.0089			0.0024		
22	0.0078			0.0028		
23	0.0076			0.0016		
24	0.0072			0.0012		
25	0.0077			0.0015		
26	0.0073			0.0008		
27	0.0063			0.0005		
28	0.0059			0.0009		
29	0.0043			0.0003		
30	0.0046			0.0004		
31	0.0042			0.0006		
32	0.0039			0.0004		
33	0.0039			0.0001		
34	0.0035			0.0002		
35	0.003			0.0001		
36	0.0029			0.0001		
37	0.0036			0.0002		
38	0.0021					
39	0.0035					
40	0.0024					
41	0.003					
42	0.0017					
43	0.0021			0.0002		
44	0.0015					
45	0.0008					
46	0.001					
47	0.0014					
48	0.0008					
49	0.0007					
50	0.0004					
51	0.0006					
52	0.0005					
53	0.0002					
54	0.0001					
55	0.0004					
56	0.0004					
57	0.0001					
58	0.0001					
64	0.0001					
Av. Occupants exposed / fire	6.50	0.0696	0	1.40	0.0206	0
Av occupants exposed normalised to reference bld.	4.6	3.4	-	1	1	-

Scenario Cluster Ancillary Type 1 Medium Early Manual Alarm

Results are presented in Table 100 for a high-rise (case c) and a reference single storey building (case d) for an early manual alarm initiating evacuation. If a fire occurred in an occupied area fire cues are provided prior to activation of a detector and the quicker response is reflected in the reduced losses shown in Table 100

Table 100 Probability of exposure to untenable conditions Medium Growth Fires in ancillary area (Enclosure Type 1) with early manual alarm initiating evacuation

Occupants	High-Rise with Early Manual Alarm			Reference with Early Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0	0.9844	0.9999	1	0.9953	1	1
1	0.0034	0.0001		0.0011		
2	0.0012			0.0008		
3	0.0011			0.0007		
4	0.0015			0.0005		
5	0.0016			0.0003		
6	0.001			0.0003		
7	0.0008			0.0002		
8	0.0011			0.0001		
9	0.0006			0.0002		
10	0.0009			0.0002		
11	0.0005			0.0001		
12	0.0001					
13	0.0004			0.0001		
14	0.0004					
15	0.0001			0.0001		
16	0.0002					
17	0.0001					
18	0.0002					
19	0.0001					
20						
21	0.0001					
22						
23						
24						
25						
26						
27						
28	0.0001					
29						
30						
31	0.0001					
Av. Occupants exposed / fire	0.0953	0.0001	0	0.02	0	0
Av occupants exposed normalised to reference bld.	4.8	-	-	1	-	-

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Scenarios Cluster Ancillary Type 1 Medium Delayed Manual Alarm

Results are presented in Table 101 for a high-rise (case e) and a reference single storey building (case f) for a delayed manual alarm initiating evacuation simulating a fire occurring in an unoccupied area.

Table 101 Probability of exposure to untenable conditions Medium Growth Fires in ancillary area (Enclosure Type 1) with delayed manual alarm initiating evacuation

Occupants	High-Rise with Delayed Manual Alarm			Reference with Delayed Manual Alarm		
	level 1	Level 2	Level 3	level 1	Level 2	Level 3
0			1		0.0016	1
1					0.0004	
2					0.0005	
3					0.0003	
4					0.0006	
5					0.0009	
6					0.0002	
7					0.0005	
8					0.0003	
9					0.0006	
10					0.001	
11					0.0009	
12					0.0015	
13					0.002	
14					0.001	
15					0.0017	
16					0.0015	
17					0.0016	
18					0.001	
19					0.0019	
20					0.0029	
21					0.0026	
22					0.0026	
23					0.0029	
24					0.0027	
25		0.0001			0.0031	
26		0.0002			0.0034	
27		0.0002			0.0032	
28		0.0001			0.0036	
29		0.0003			0.0038	
30		0.0003			0.005	
31		0.0002			0.0058	
32		0.0005			0.0045	
33		0.0007			0.0068	
34		0.001			0.007	
35		0.0012			0.008	
36		0.0005			0.0075	
37		0.0024			0.0082	
38		0.0014			0.0088	
39		0.002			0.008	
40		0.002			0.0089	
41		0.0017			0.0093	
42		0.0029			0.0112	
43		0.0025			0.0106	
44		0.0027			0.0098	
45		0.0029			0.0114	
46		0.003			0.0115	
47		0.0044			0.0129	
48		0.0032			0.0126	
49		0.0034			0.0105	
50		0.0036			0.0124	
51		0.0041			0.0123	
52		0.0051			0.0148	
53		0.0047			0.0124	
54		0.0054			0.0149	
55		0.0078			0.0145	
56		0.0074			0.0152	

57		0.0071			0.015	
58		0.0086			0.0141	
59		0.0081			0.0141	
60		0.0103			0.0155	
61		0.0079			0.0144	
62		0.0112			0.1227	
63		0.0089			0.0118	
64		0.0108			0.0116	
65		0.0102			0.0122	
66		0.0107			0.0122	
67		0.0124			0.0135	
68		0.0115			0.0148	
69		0.0136			0.011	
70		0.0154			0.012	
71		0.0137			0.0136	
72		0.0146			0.0114	
73		0.0148			0.0117	
74		0.0134			0.0156	
75		0.0139			0.0154	
76		0.0186			0.0121	
77		0.0173			0.0125	
78		0.0166			0.0104	
79		0.018			0.0132	
80		0.0192			0.0119	
81		0.0225			0.0112	
82		0.0228			0.0097	
83		0.0213			0.0107	
84		0.0187			0.0132	
85		0.0239			0.0108	
86	0.0001	0.0267		0.0001	0.0134	
87		0.0235			0.0116	
88		0.023			0.0093	
89		0.0225			0.0105	
90		0.0242			0.0087	
91		0.022			0.0085	
92		0.0228			0.0101	
93		0.0258			0.0115	
94		0.0236			0.0097	
95		0.0236			0.0078	
96		0.023			0.0097	
97		0.0216			0.007	
98		0.019			0.008	
99		0.0217			0.0074	
100		0.0193			0.0063	
101		0.0195			0.0054	
102		0.0167			0.0048	
103		0.0144			0.0045	
104		0.0167			0.0049	
105	0.0001	0.0123		0.0001	0.0052	
106	0.0001	0.0124		0.0001	0.0047	
107	0.0002	0.0127		0.0002	0.0031	
108	0.0001	0.0091		0.0001	0.0032	
109	0.0003	0.0085		0.0003	0.0019	
110	0.0007	0.0076		0.0007	0.0023	
111	0.0003	0.0057		0.0003	0.0028	
112	0.0013	0.0043		0.0013	0.0019	
113	0.0011	0.0035		0.0011	0.0016	
114	0.0015	0.0035		0.0015	0.0013	
115	0.0015	0.0033		0.0015	0.0011	
116	0.0021	0.0021		0.0021	0.0014	
117	0.003	0.0023		0.003	0.0016	
118	0.0023	0.0019		0.0023	0.0008	
119	0.0024	0.0014		0.0025	0.0007	
120	0.0027	0.002		0.0029	0.0005	
121	0.0036	0.0007		0.0037	0.0005	
122	0.0029	0.0005		0.0029	0.0003	
123	0.0049	0.0008		0.0045	0.0007	
124	0.9688	0.0019		0.9688	0.0014	
Av. Occupants exposed / fire	123.8	83.6	0	123.8	65.2	0
Av occupants exposed normalised to reference bld.	1	1.3	-	1	1	-

L12. Slow Growth Fire occurring within Ancillary Area (Encl. Type 1)

L12.1. Slow Growth Fire – General Smoke Modelling Results

The smoke spread modelling results obtained from the B-RISK Fire Simulator and Design Fire Tool for a slow growth rate fire are summarised in Table 102

Table 102 Smoke Spread and Tenability Limits - slow fire in ancillary area

Parameter - units are secs(s) unless otherwise noted	GLA				Ancillary	Circulation	
	Encl 1	Encl 2	Encl 3	Encl 4	Encl 5	Encl 6	Encl 7
5% smoke layer height - Cue 1	332		314		20	119	185
100kW HRR - Cue 2					185		
Smoke Detector Activation	320				121	156	173
Sprinkler Activation -RTI 50					303		
Heat detector -RTI 30					225		
Window breakage - Cue 3					598		
Peak HRR 1000 kW					584		
Upper layer temps @1400s	31	21	27	21	266	57	47
Visibility 10m @2m	461	>1400	544	>1400	106	265	300
Smoke layer 2m	422	>1400	392	598	51	265	247
Smoke layer 1.75m	449	>1400	417	663	78	328	280
Smoke layer 1.5m	475	>1400	442	896	116	382	315
FED thermal - 0.3	>1400	>1400	>1400	>1400	330	>1400	>1400
FED CO - 0.3	>1400	>1400	>1400	>1400	612	>1400	>1400
Level 1 Tenability	461	>1400	544	>1400	106	265	300
Level 2 Tenability	475	>1400	442	896	116	382	315
Level 3 Tenability	>1400	>1400	>1400	>1400	330	>1400	>1400

Note: Doors to GLA Enclosures 2 and 4 are closed to provide a comparison with GLA 3 where the door is open.

L12.2. ASET RSET Analysis Slow Fires –Ancillary Area (Enclosure Type 1)

For these scenarios it will be assumed that all students are within the GLAs and will be alerted by the automatic detection and alarm system or a manual alarm. It has also been assumed that access is available to both stairs and the occupants will use the nearest stair or exit provided they can evacuate their GLA prior to Level 1 tenability criteria (visibility less than 10m at 2m height) being exceeded on the path of travel to the stair or exit entrance. If the occupants remained in the GLA and closed the door the onset of untenable conditions would be delayed significantly,

Scenario Cluster Ancillary Type 1 Slow Smoke Detection System Activates an Alarm

Results are presented in Table 103 for a high-rise (case a) and a reference single storey building (case b) for an alarm raised by an automatic detection / alarm system.

The losses, if Level 1 tenability criteria are applied, are substantially less than the medium growth fire case and there are no losses if the level 2 criteria are applied which is expected because of the slower growth rate which delays the onset of untenable conditions to a substantially greater degree than the delay in activation of the smoke detector.

Table 103 Probability of exposure to untenable conditions Slow Growth Fires in ancillary area (Enclosure Type 1) with automatic detection initiating evacuation

Occupants	High-Rise with Automatic Detection			Reference with Automatic Detection		
	Level 1	Level 2	Level 3	level 1	level 2	level 3
0	0.9831	1	1	0.9963	1	1
1	0.0036			0.0008		
2	0.0038			0.0003		
3	0.0023			0.0004		
4	0.0013			0.0008		
5	0.0018			0.0004		
6	0.0006			0.0003		
7	0.001			0.0002		
8	0.0003			0.0001		
9	0.0007			0.0003		
10	0.0007					
11	0.0002			0.0001		
12	0.0002					
13	0.0001					
14	0.0001					
15						
16	0.0002					
Av. Occupants exposed / fire	0.0691	0	0	0.0156	0	0
Av occupants exposed normalised to reference bld.	4.4	-	-	1	-	-

Scenario Cluster Ancillary Type 1 Slow Early Manual Alarm

There were no losses under all levels of tenability criteria since early detection occurs if people are in close proximity to the fire and therefore the increase in detection time for the slower growth rate is substantially less than the increase in the time to untenable conditions.

Scenario Cluster Ancillary Type 1 Slow Delayed Manual Alarm

Results are presented in Table 104 for a high-rise (case e) and a reference single storey building (case f) for a delayed manual alarm initiating evacuation simulating a fire occurring in an unoccupied area. The losses remain very high if the Level 1 criteria are applied because the fire is not detected until there has been substantial smoke spread to the path of travel to the exits. However, since the growth rate is slow, and the peak fire size is relatively low the Level three criteria were not exceeded, and the numbers exposed to Level 2 untenable conditions was also reduced relative to the medium growth fire scenario.

Table 104 Probability of exposure to untenable conditions Slow Growth Fires in ancillary area (Enclosure Type 1) with delayed manual alarm initiating evacuation

Occupants	High-Rise with Delayed Manual Alarm			Reference with Delayed Manual Alarm		
	level 1	Level 2	Level 3	Level 1	Level 2	Level 3
0			1		0.0713	1
1					0.005	
2					0.005	
3		0.0001			0.0067	
4		0.0002			0.0062	
5					0.0052	
6					0.0072	
7		0.0001			0.0078	
8		0.0003			0.0082	
9		0.0003			0.0066	
10		0.0003			0.0079	
11		0.0007			0.0079	
12		0.0004			0.0076	
13		0.0011			0.0093	
14		0.001			0.0094	
15		0.0017			0.0096	
16		0.0016			0.009	
17		0.0028			0.0108	
18		0.0024			0.012	
19		0.0029			0.0104	
20		0.0033			0.0103	
21		0.0032			0.0129	
22		0.0052			0.0134	
23		0.0052			0.0126	
24		0.007			0.0151	
25		0.0063			0.0124	
26		0.0086			0.0118	
27		0.0102			0.0163	
28		0.0102			0.015	
29		0.0123			0.0159	
30		0.0135			0.0142	
31		0.0125			0.0157	
32		0.0151			0.0172	
33		0.0171			0.0171	
34		0.0182			0.0194	
35		0.0191			0.017	
36		0.0199			0.0166	
37		0.0228			0.0177	
38		0.0246			0.0178	
39		0.0266			0.0213	
40		0.0274			0.0221	
41		0.0268			0.0188	
42		0.0265			0.0193	
43		0.0243			0.0199	
44		0.0291			0.0199	
45		0.0275			0.0184	
46		0.0267			0.0172	
47		0.0295			0.0194	
48		0.0277			0.0175	
49		0.0296			0.0158	
50		0.0268			0.0173	
51		0.0241			0.0145	
52		0.0253			0.0164	
53		0.0276			0.0146	
54		0.0208			0.0145	
55		0.024		0.0001	0.0147	
56		0.0196			0.0135	
57		0.0222		0.0001	0.013	
58		0.0187		0.0001	0.0144	
59		0.0176			0.0112	
60		0.0161			0.0116	
61		0.0186			0.0118	
62		0.0693		0.0055	0.0952	
63		0.0087		0.0008	0.0008	
64		0.0082		0.0006	0.0014	
65		0.0087		0.0007	0.0008	

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Consulting

Occupants	High-Rise with Delayed Manual Alarm			Reference with Delayed Manual Alarm		
	level 1	Level 2	Level 3	Level 1	Level 2	Level 3
66		0.0082		0.0014	0.001	
67		0.0099		0.0014	0.0011	
68		0.0081		0.0016	0.0008	
69		0.0069		0.0008	0.0005	
70		0.0076		0.0018	0.0006	
71		0.0057		0.001	0.001	
72		0.0053		0.001	0.0008	
73		0.004		0.0011	0.0009	
74		0.0045		0.0022	0.0004	
75		0.0039		0.0022	0.0007	
76		0.0038		0.0021	0.001	
77		0.0027		0.0025	0.0003	
78		0.0027		0.0017	0.0005	
79		0.0031		0.0023	0.0008	
80	0.0001	0.0027		0.0032	0.0003	
81		0.0028		0.0023	0.0003	
82		0.0013		0.0029	0.0003	
83		0.0009		0.0045	0.0003	
84	0.0002	0.0015		0.005	0.0002	
85	0.0001	0.0019		0.0044		
86	0.0003	0.0007		0.0038	0.0003	
87	0.0003	0.001		0.0037	0.0003	
88	0.0004	0.0007		0.0054	0.0002	
89	0.0004	0.0006		0.0059		
90	0.0007	0.0004		0.0061	0.0002	
91	0.001			0.0073		
92	0.0017	0.0001		0.0085	0.0002	
93	0.0014	0.0007		0.0088	0.0002	
94	0.0029	0.0001		0.0087		
95	0.0029			0.0091		
96	0.0033			0.0075		
97	0.0035			0.0083		
98	0.0043			0.01		
99	0.0045			0.0114		
100	0.0075			0.0113		
101	0.0083			0.0124		
102	0.0096			0.0131		
103	0.0093			0.012		
104	0.0113			0.0111		
105	0.0133			0.0162		
106	0.013			0.015		
107	0.0173			0.0158		
108	0.0172			0.0149		
109	0.0211			0.0167		
110	0.0203			0.0145		
111	0.0236			0.0183		
112	0.022			0.0164		
113	0.0254			0.019		
114	0.031			0.019		
115	0.0303			0.0192		
116	0.0297			0.0224		
117	0.0303			0.0234		
118	0.0301			0.0225		
119	0.0365			0.0203		
120	0.0334			0.0227		
121	0.0352			0.0207		
122	0.0343			0.0218		
123	0.0326			0.0205		
124	0.4294			0.423		
Av. Occupants exposed / fire	117.9	48.0	0	113.6	35.8	0
Av occupants exposed normalised to reference bld.						

L13. Consolidation of QRA Results for Occupants on the Floor of Origin

The event tree shown in Figure 45 was derived from the event tree shown in Figure 21 in Section C4.6 by;

- consolidating all the branches with zero consequences,
- assigning the probabilities for fires occurring in the various types of enclosures from Table 53 which were derived from fire statistics and
- including an automatic sprinkler branch

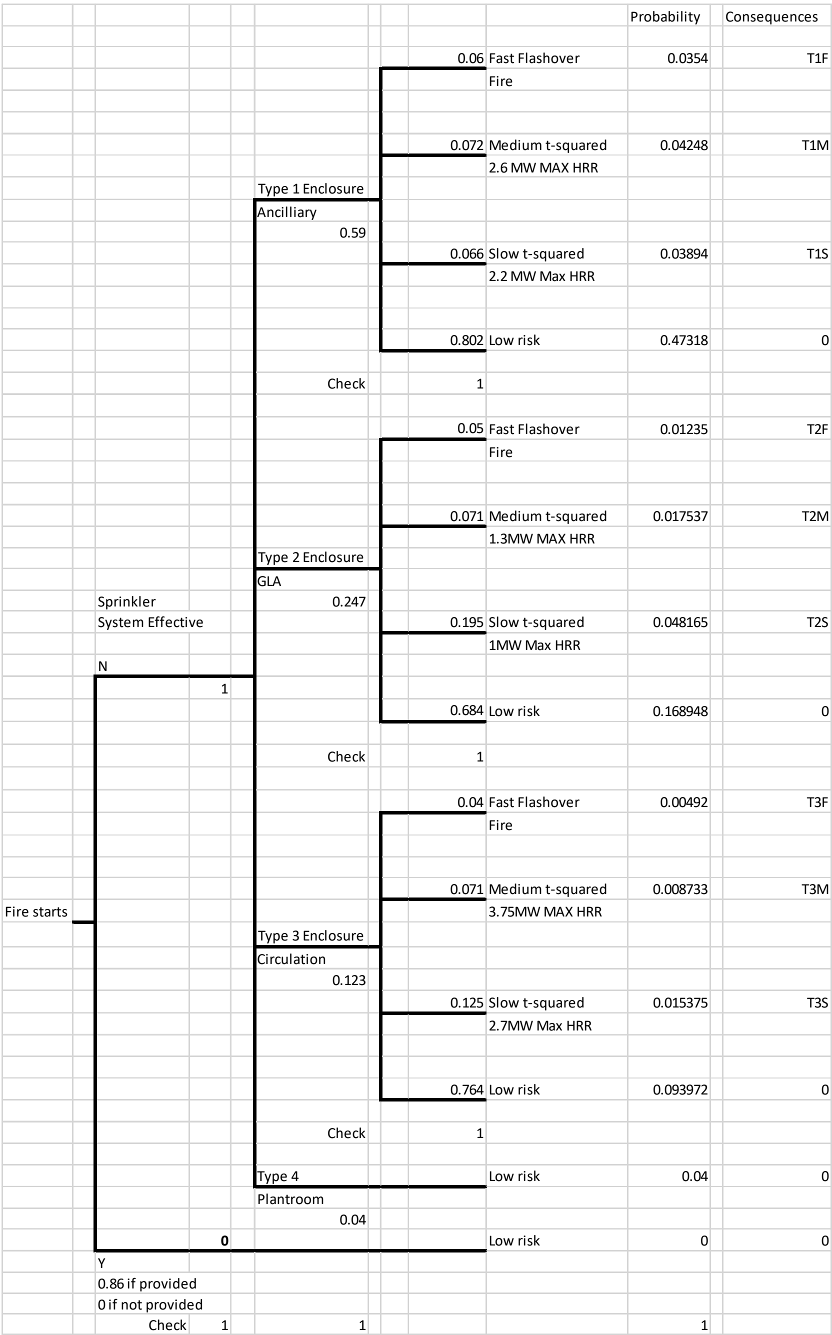


Figure 45 Consolidated Event Tree for Floor of Fire Origin

A series of simple event trees were developed to derive the consequences for each branch representative scenario taking into account;

- the type of alarm
    - o early manual detection and alarm assumed to be received before the automatic detection system raises the alarm, if provided and effective
    - o automatic detection and alarm system if provided and effective
    - o a delayed manual alarm where people are not in the vicinity of the fire
- the status of the door to the room of fire origin.

The outcomes from these sub event trees, which are shown in Figure 46, were then consolidated to derive distributions of consequences for each scenario group

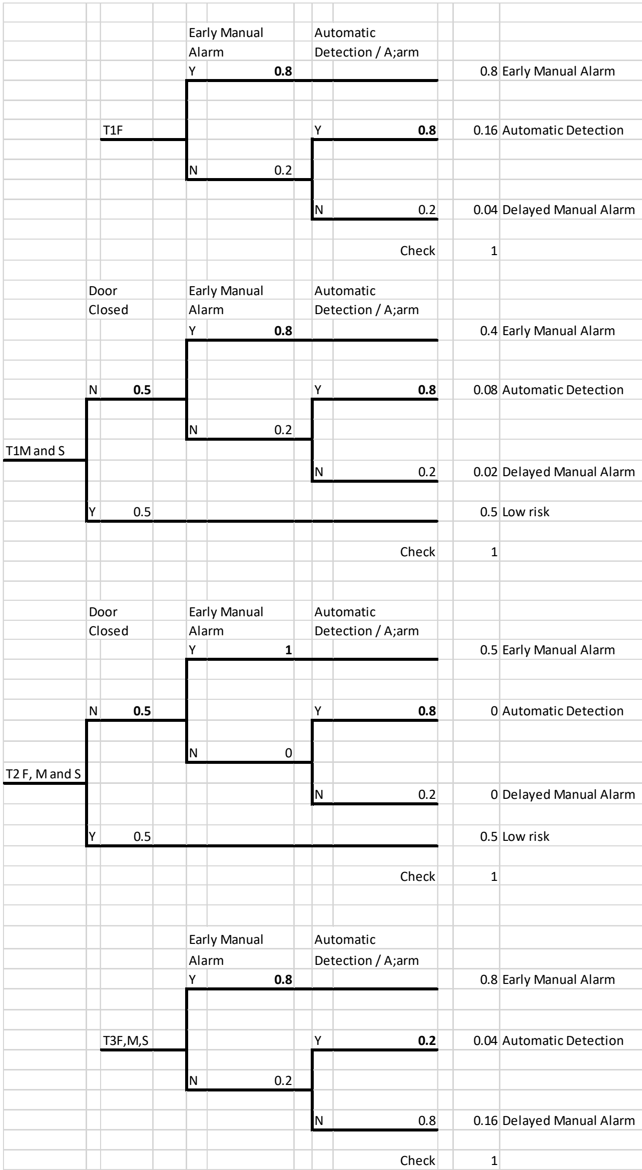


Figure 46 Event trees determining probability of Door Closure and means of fire detection alarm

The probability of an early manual alarm was estimated to be 0.8 for the ancillary and general circulation areas whilst the school is occupied and 1 in an occupied GLA (classroom) because of the large number of occupants that would be alert and wake.

The effectiveness of the detection and alarm system was assumed to be 0.8 if the system is provided and zero if not provided. The 0.8 effectiveness is a low estimate when compared to the values in ABCB FSVM Handbook Annex data sheets[14] but was selected to allow for variations in occupant awareness and response to the alarm. The probability of delayed manual detection was calculated on the basis that delayed manual detection would occur if early manual detection does not occur and an automatic detection system is not provided, or the system is not effective. The timing of delayed activation was estimated on the basis of the time that smoke will start entering the GLAs through the head of the door. A uniform distribution was therefore assumed based on the times the smoke layer interface fell to below 2m height in enclosures 6 and 7.

The probability of a door being closed to the enclosure of fire origin after evacuation or if the enclosure is unoccupied at the time of the fire was assumed to be 0.5 for the medium and slow growth rate fires occurring within an ancillary or GLAs. The probability of a door being closed was also assumed to be 0.5 for a fast fire in the GLA but taken as 0 for the ancillary areas since ancillary areas could be unoccupied at the time of the fire and the door is required to be open to provided sufficient ventilation to achieve flashover.

After flashover it was assumed that untenable conditions occur throughout the fire compartment of fire origin.

The distribution for each scenario group was then multiplied by the probability of occurrence of that scenario group and finally the consequences for all scenario groups was summed yielding a distribution of the probability of “n” occupants being exposed to untenable conditions per fire.

The results obtained were converted into the average number of fatalities per 1000 fires and the average individual risk from fires on the floor of origin were calculated based on the following:

- The frequency of fire / av school / annum - 0.013
- Max Number of students / floor / wing -120
- Effective rate of fire starts / floor / annum 0.00433
- Assumed effectiveness of sprinklers – 0.86

The outcomes are consolidated in Table 105 for both the Level 1 and Level 3 tenability criteria.

Table 105 Estimated fatalities /1000 and Individual Risk on the floor of fire origin

Parameter	Level 1 Tenability				Level 3 Tenability				
	Ref. 1 No detection	Ref 2 Detection	High-rise No Detection	High-rise Detection	Ref. 1 No detection	**Ref. 2 Detection**	High-rise No Detection	High-rise Detection	**High-rise Detect. & Sprinklers**
Fatalities / 1000 fires	2,586.69	941.05	3,174.54	1,760.12	31.34	**6.30**	220.68	44.23	**6.19**
Fat /floor / annum	0.0112	0.0041	0.01376	0.0076	1.36E-04	**2.73E-05**	9.56E-04	1.92E-04	**2.68E-05**
IR: 124 people / floor	9.04E-05	3.29E-05	1.11E-04	6.15E-05	1.10E-06	**2.20E-07**	7.71E-06	1.55E-06	**2.16E-07**
Low tolerable risk limit (TRL)	1×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-6}
High Tolerable risk limit (TRL)	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}
Ratio IR: Low TRL	90.4	32.9	111	61.5	1.1	**0.22**	7.71	1.55	**0.22**
Ratio IR: high TRL	0.90	0.33	1.1	0.62	0.011	**0.0022**	0.077	0.0155	**0.0022**

Reference Building 2 was adopted as the reference for comparison against the High-rise building with detection and sprinklers with respect to societal risk.

Appendix M. Analysis of Risk to Occupants on Floors other than the Floor of Origin

M1. Whole building evacuation

M1.1. Stair Design

The critical features and dimensions of the fire exit stairways are summarised below:

Riser (R): 140mm

Going (G): 280mm

2R + G = 560mm

Clear width 1.2m

12 steps per flight and 2 flights per floor (floor to floor height 3360)

1.2m wide landings with provision for a refuge at each building level

Travel distance per flight (measured along the gradient) 3.756m

Travel distance on each landing (travelling along circular arc) 1.89m

Therefore, travel distance between floors ≈ 11.3m

M1.2. Travel by Stair

It will be assumed that occupants will travel in single file with a minimum of 0.5m between occupants. Thus, a class group can be accommodated within 3 stair flights.

The fire will be assumed to occur on Level 2 (the lowest level with four classes accommodated).

A coordinated evacuation plan is assumed to be in place:

For the 5-storey primary school option the fire floor will evacuate first followed by the two levels above and finally the level below. Ground level is a separate “public area”.

It will be assumed that the evacuation of each floor commences once evacuation of the prior floor is complete which will allow for spacing between the various levels. The flow through each door to the fire stair will be assumed to be 1 person /second for the upper levels.

The primary school stairway travel speeds were calculated by applying the following age (reduction) factors:

Level 1 and 2 – Age factor 5

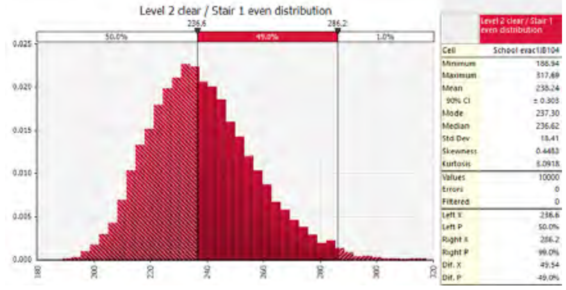
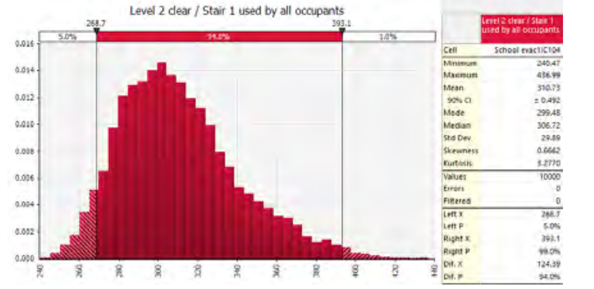
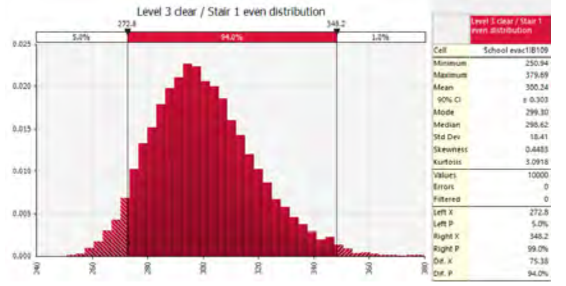
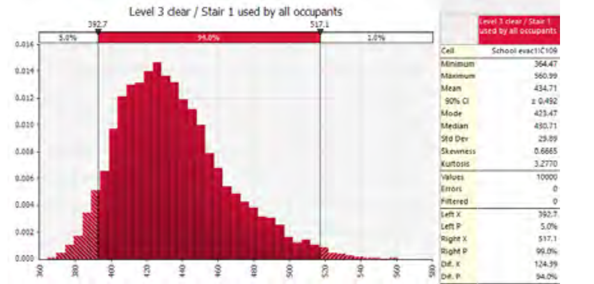
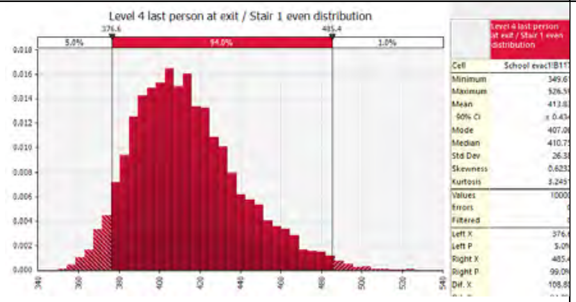
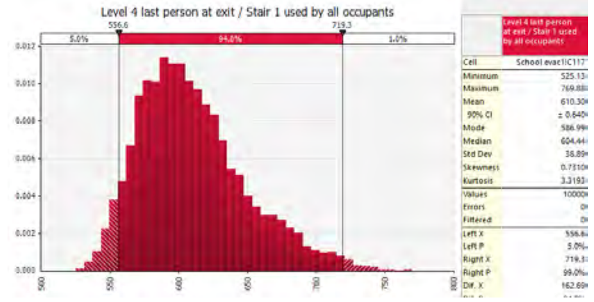
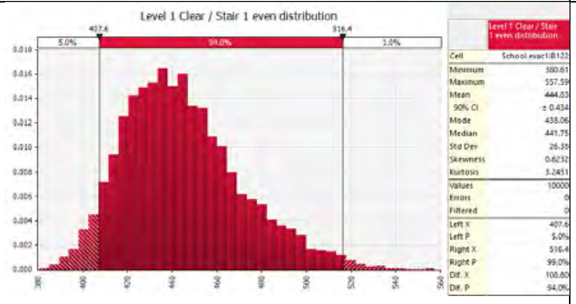
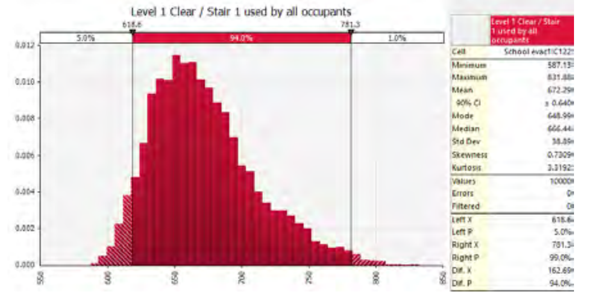
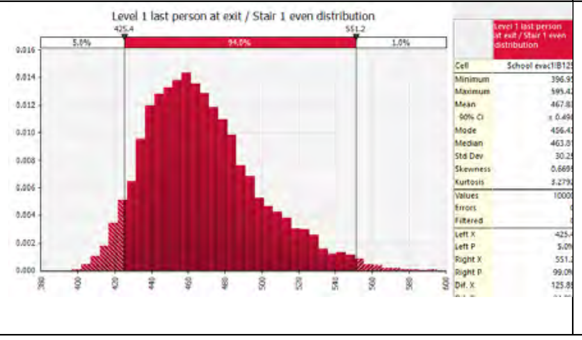
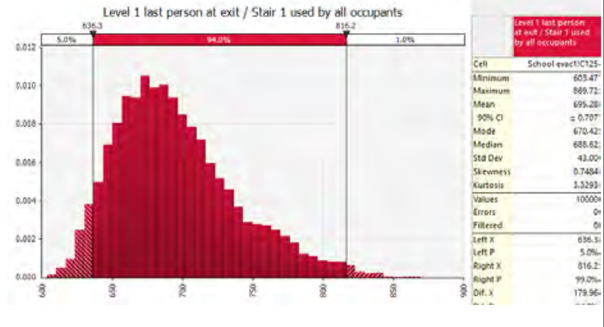
Level 3 - Age factor 7

Level 4 – Age factor 9

M1.3. Evacuation Distributions for 5-Storey Primary School Building

A multi-scenario analysis was undertaken to provide distributions of the evacuation times for each floor and to clear the building. The results are presented in Table 106.

Table 106 Evacuation Times for 5 Storey School

Level	2-stairs used	1-stair used
2		
3		
4		
1		
Last person leaves exit		

The evacuation time for the floor above the floor of origin assuming one exit is blocked has been estimated to be a maximum of 561s (9.4mins) and for the next floor 770s (12.8 minutes) from Table 106

M2. Risk to Occupants from Smoke Spread to Upper Levels

M2.1. Smoke Spread to upper levels via stair and lift shafts

Smoke spread to upper levels was modelled using B-Risk with the previously modelled configuration being extended to include two shafts and the main circulation areas two levels above the fire floor as shown in Figure 47. For occupants to be exposed to significant risk it is expected that a large fire would be required and therefore the representative design fire for smoke spread to the upper floors is a fast potential flashover fire.

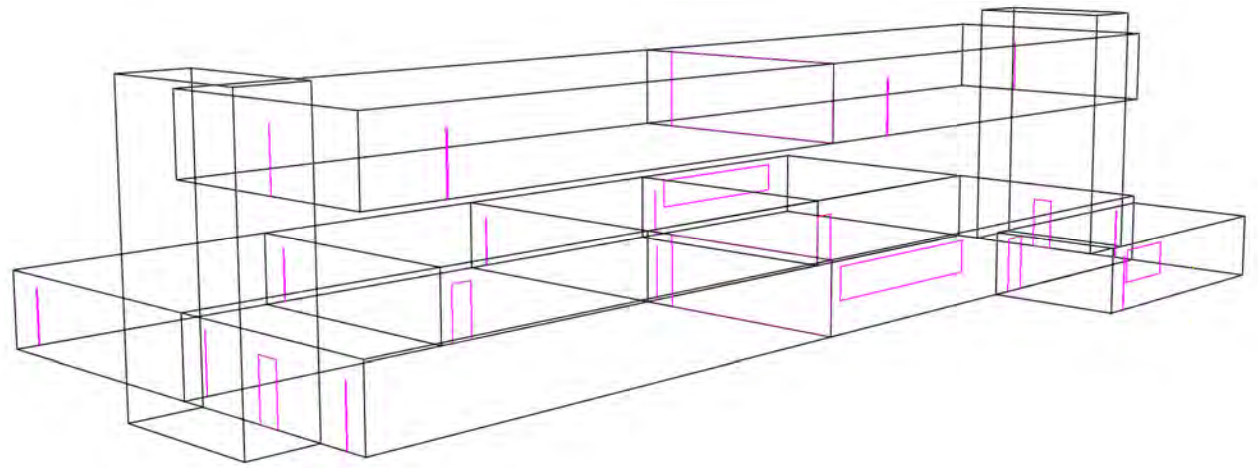


Figure 47 B-Risk Configuration for modelling smoke spread to other levels

Event trees were constructed to identify combinations of door states for the 5-storey building without stair pressurisation (Figure 48). A with stair pressurisation analysis is also presented in Figure 49 which was undertaken in case it was necessary to evaluate additional measures to improve fire safety levels above those provided by the proposed design. The outcomes were consolidated to identify cases for further modelling as indicated in Table 107 with the scenarios highlighted in red requiring further quantification

Table 107 Potential Outcomes in floors other than the floor of fire origin due to smoke spread via stairs when school is occupied - potential flashover fires.

Consolidated Scenario Clusters	No Stair pressurisation	Stair pressurisation
a) Early Suppression - Safety	0.86	0.86
b)2-stair evacuation -Safety - unassisted	0.1134	0.12635
c)1-stair evacuation -Safety - unassisted	0.02268	0.01197
Total unassisted - no time limit	**0.99608**	**0.99832**
d)1-stair evacuation ASET L1 565[1], L3 > 1800 - time limit	**0.00252**	**0.00133**
e) Rescue -required - no time limit if structure survives	0.001134	0.0002835
f) Rescue required -ASET L1 565 L3>1800	0.000252	0.000063
g) Rescue required -ASET L1 522 L3:1460	0.000014	0.0000035
Fire Brigade Rescue Required	**0.0014**	**0.00035**
Total proportion of potential flashover scenarios	**1**	**1**

The probability of a potential flashover resulting from a fire whilst the school is occupied can be calculated from the estimates in Figure 21 to be approximately 5.3% of reported fires as shown in Table 108 for the 5-Storey option (primary school only). The frequency of fires per primary school was estimated to be 0.013 fires per year, yielding a frequency of potential flashover fires whilst the school is occupied of 6.89 x 10^{-4} / annum.

Table 108 Estimate of probability of potential flashover fires whilst a school is occupied

Encl. Type	Enclosure Description	Fires %	Flashover fires whilst occupied %	Probability - flashover fire
1	Small rooms - stores, kitchen offices, amenities	59	6	0.0354
2	General Learning Area (classroom)	24.7	5	0.01235
3	Libraries / Flexible Learning / General circulation	12.3	4	0.00492
4	Plantroom	4	0	0
All	Total	100	-	0.05267

The configurations summarised in Table 109 were modelled in B-risk assuming a fully developed fire in an ancillary area. This was selected as a more likely fire location but there would be differences in smoke concentrations at the doors to the stair depending on the scenario selected. Having regard for the necessary assumptions and limited statistical data this was considered a reasonable approach to provide indicative estimates and identify significant risks.

Table 109 Summary of Smoke spread scenarios to upper floors

Ref	Shaft 1 lower door	Shaft 2 lower door	Shaft 1 upper door	Shaft 2 upper door	Description
Table 110	Closed	Closed	Closed	Closed	All stair doors closed
Table 111	Closed	Closed	Closed	Closed	All stair doors closed -increased leakage shaft 2 to simulate lift door
Table 112	Open	Closed	Closed	Closed	One stair open on fire floor
Table 113	Open	Closed	Open	Closed	Open upper and lower doors to one stair
Table 114	Open	Open	Open	Open	All stair doors open
Table 115	Open	Open	Closed	Closed	All stair doors on fire floor open, Doors on upper levels closed

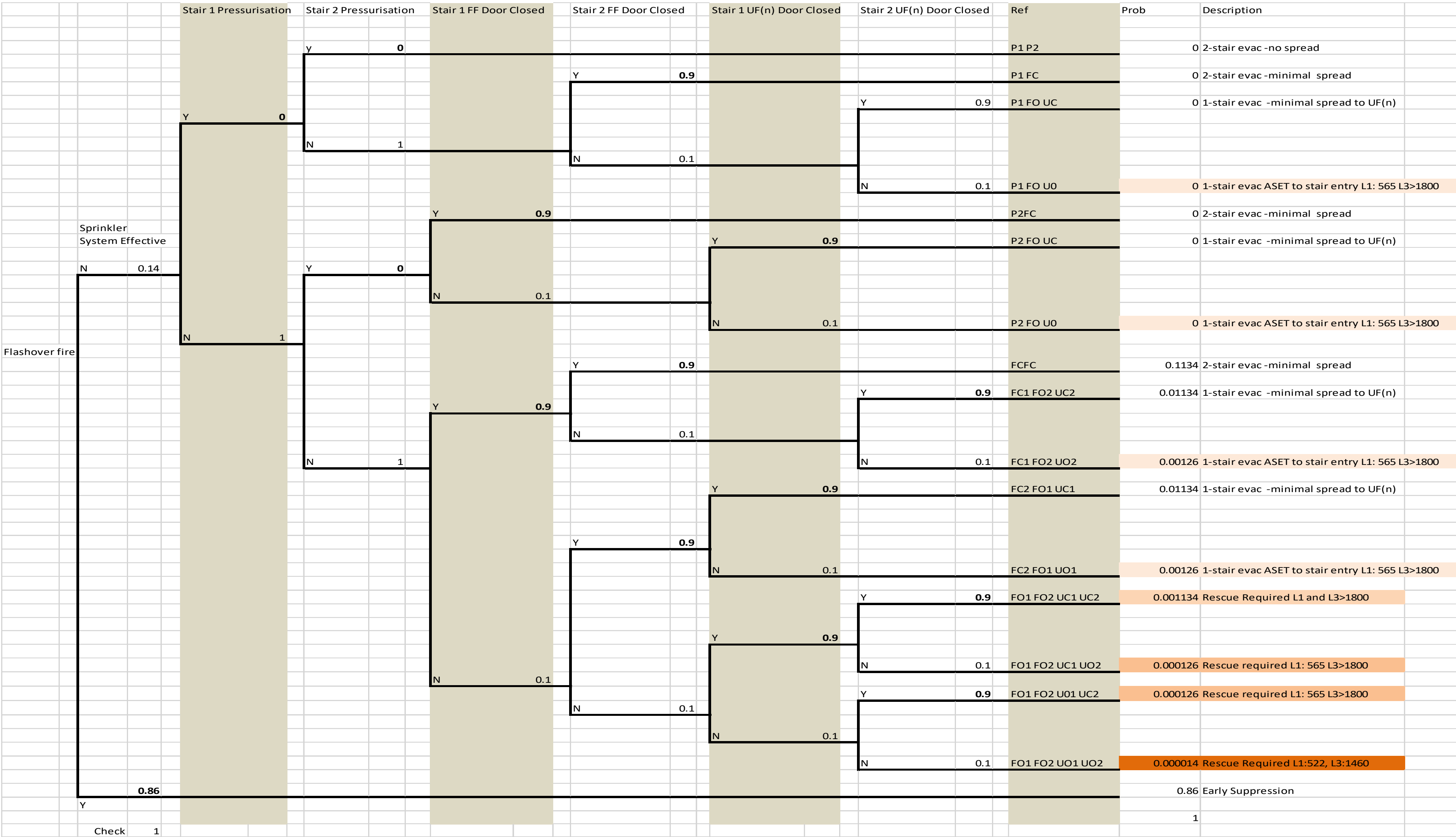


Figure 48 Event Tree for evaluation of smoke spread to upper levels via stair shafts (no stair pressurisation)

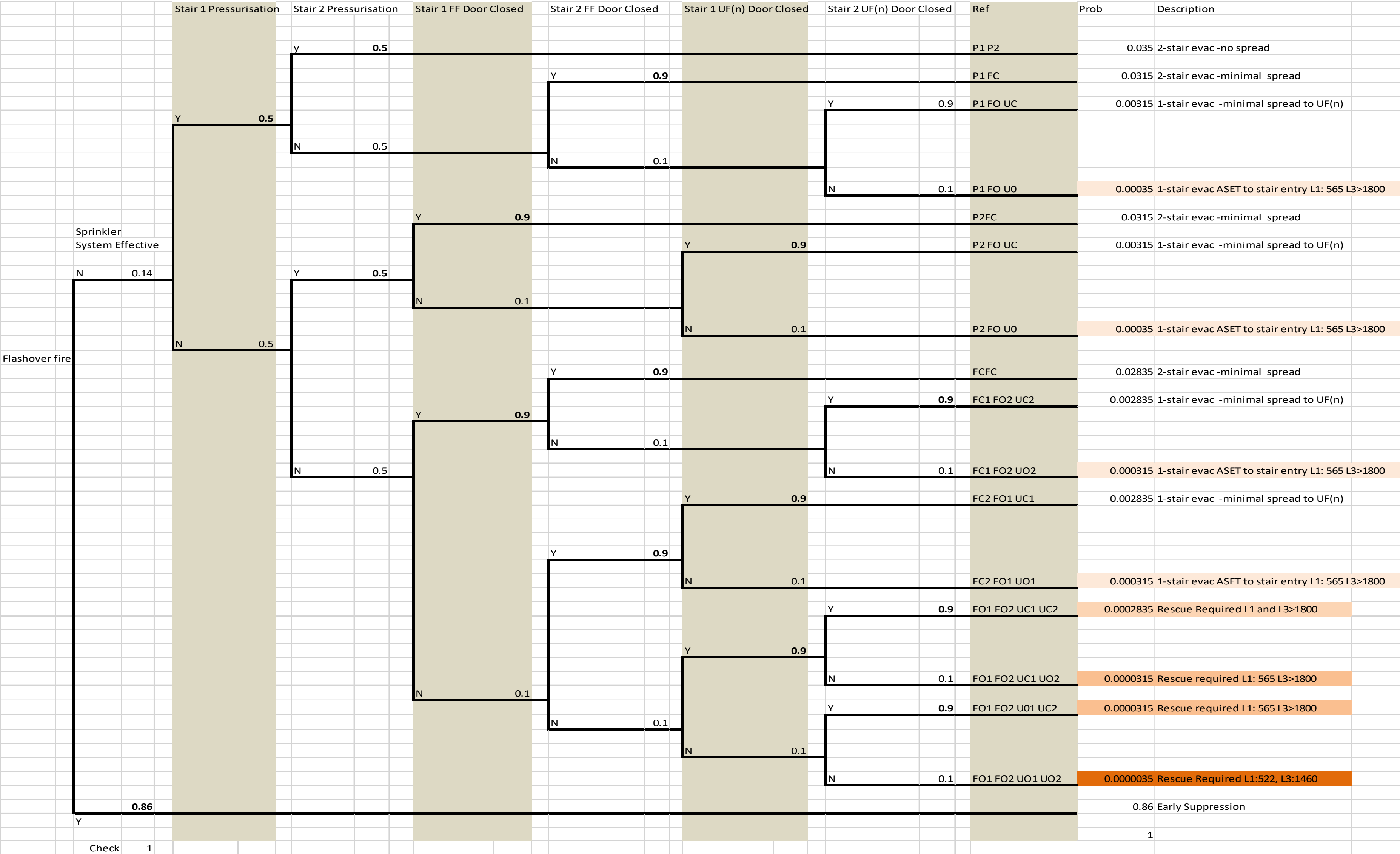


Figure 49 Event Tree for evaluation of smoke spread to upper levels via stair shafts with stair pressurisation

Table 110 Smoke Spread and Tenability Limits – spread to upper levels stair doors closed. (Ref FC/FC/UC/UC)

Parameter - units are secs(s) unless otherwise noted	Stairs		Upper level circulation		Ancillary	Circulation	
	Encl 8	Encl 9	Encl 10	Encl 11	Encl 5	Encl 6	Encl 7
Smoke Detector Activation					53	59	81
Sprinkler Activation -RTI 50					106		
Heat detector -RTI 30					86		
Window breakage - Cue 3					171		
Flashover					296		
Upper layer temps @1400s	21	21	20	20	810	134	105
Visibility 10m @2m	1110	>1400	>1400	>1400	33	126	129
Smoke layer 2m			>1400	>1400			
Smoke layer 1.75m			>1400	>1400			
Smoke layer 1.5m			>1400	>1400			
FED thermal - 0.3	>1400	>1400	>1400	>1400			
FED CO - 0.3	>1400	>1400	>1400	>1400			
Level 1 Tenability	1110	>1400	>1400	>1400			
Level 3 Tenability	>1400	>1400	>1400	>1400			

Enclosure 8 visibility at 1400s >5m

Table 111 Smoke Spread and Tenability Limits – spread to upper levels stair doors stair doors closed smoke spread via lift shaft check

Parameter - units are secs(s) unless otherwise noted	Stairs	Lift	Upper level circulation		Ancillary	Circulation	
	Encl 8	Encl 9	Encl 10	Encl 11	Encl 5	Encl 6	Encl 7
Smoke Detector Activation					53	59	81
Sprinkler Activation -RTI 50					106		
Heat detector -RTI 30					86		
Window breakage - Cue 3					171		
Flashover					296		
Upper layer temps @1400s	21	21	20	20	810	134	105
Visibility 10m @2m	1110	755	>1400	>1400	33	126	129
Smoke layer 2m			>1400	>1400			
Smoke layer 1.75m			>1400	>1400			
Smoke layer 1.5m			>1400	>1400			
FED thermal - 0.3	>1400	>1400	>1400	>1400			
FED CO - 0.3	>1400	>1400	>1400	>1400			
Level 1 Tenability	1110	755	>1400	>1400			
Level 3 Tenability	>1400	>1400	>1400	>1400			

Enclosure 8 visibility at 1400s >5.31m
Enclosure 9 (lift shaft) visibility at 1400s 2.60m

Table 112 Smoke Spread and Tenability Limits – spread to upper levels one stair door fire level open others closed (Ref FO/FC/UC/UC)

Parameter - units are secs(s) unless otherwise noted	Stairs	Lift	Upper level circulation		Ancillary	Circulation	
	Encl 8	Encl 9	Encl 10	Encl 11	Encl 5	Encl 6	Encl 7
Smoke Detector Activation					53	60	82
Sprinkler Activation -RTI 50					106		
Heat detector -RTI 30					86		
Window breakage - Cue 3					171		
Flashover					296		
Upper layer temps @1400s	69	21	20	20	814	129	101
Upper layer temps @1800s	75	21	21	21	837	135	106
Visibility 5m @2m	320	1335	>1800	>1800			
Visibility 10m @2m	282	950	>1800	>1800			
FED thermal - 0.3	1247	>1800	>1800	>1800			
FED CO - 0.3	580	>1800	>1800	>1800			
Level 1 Tenability	282	950	>1800	>1800			
Level 3 Tenability	580	>1800	>1800	>1800			

Table 113 Smoke Spread and Tenability Limits – spread to upper levels stair door fire floor and upper level open and smoke spread via lift shaft (Ref FO/FC/UO/UC)

Parameter - units are secs(s) unless otherwise noted	Stairs	Lift	Upper level circulation		Ancillary	Circulation	
	Encl 8	Encl 9	Encl 10	Encl 11	Encl 5	Encl 6	Encl 7
Smoke Detector Activation					53	59	81
Sprinkler Activation -RTI 50					106		
Heat detector -RTI 30					86		
Window breakage - Cue 3					171		
Flashover					297		
Upper layer temps @1400s	55	21	26	24	927	137	93
Upper layer temps @1800s	51	21	24	23	974	137	90
Visibility 10m @2m	287	1110	505	565			
Visibility 5m @2m	320	1450	638	707			
FED thermal - 0.3	1075	>1800	>1800	>1800			
FED CO - 0.3	561	>1800	1343	>1800			
Level 1 Tenability	287	1110	505	565			
Level 3 Tenability	561	>1800	1343	>1800			

Table 114 Smoke Spread and Tenability Limits - spread to upper levels both stair doors fire floor and upper level open (Ref FO/FO/UO/UO)

Parameter - units are secs(s) unless otherwise noted	Stairs		Upper level circulation		Ancillary	Circulation	
	Encl 8	Encl 9	Encl 10	Encl 11	Encl 5	Encl 6	Encl 7
Smoke Detector Activation					52	59	81
Sprinkler Activation -RTI 50					105		
Heat detector -RTI 30					86		
Window breakage - Cue 3					170		
Flashover					297		
Upper layer temps @1400s	88	25	28	26	787	109	77
Upper layer temps @1800s	90	25	29	26	799	109	78
Visibility 10m @2m	278	578	427	522			
Visibility 5m @2m	316	694	500	625			
FED thermal - 0.3	843	>1800	>1800	>1800			
FED CO - 0.3	538	1678	1460	1588			
Level 1 Tenability	278	578	427	522			
Level 3 Tenability	538	1678	1460	1588			

Table 115 Smoke Spread and Tenability Limits - spread to upper levels both stair doors fire floor open, upper level closed (Ref FO/FO/UC/UC)

Parameter - units are secs(s) unless otherwise noted	Stairs		Upper level circulation		Ancillary	Circulation	
	Encl 8	Encl 9	Encl 10	Encl 11	Encl 5	Encl 6	Encl 7
Smoke Detector Activation					52	59	81
Sprinkler Activation -RTI 50					105		
Heat detector -RTI 30					86		
Window breakage - Cue 3					170		
Flashover					297		
Upper layer temps @1400s	71	55	21	21	849	133	101
Upper layer temps @1800s	75	59	21	21	863	174	106
Visibility 10m @2m	285	297	>1800	>1800			
Visibility 5m @2m	323	342	>1800	>1800			
FED thermal - 0.3	1247	582	>1800	>1800			
FED CO - 0.3	582	640	>1800	>1800			
Level 1 Tenability	278	578	427	522			
Level 3 Tenability	538	1678	1460	1588			

M2.2. Fire Brigade Intervention for the 5-storey school with a fire on Level 2

The estimated distributions for the fire brigade to apply water to the fire and commence search and rescue activities on the floor of fire origin are shown in Figure 50

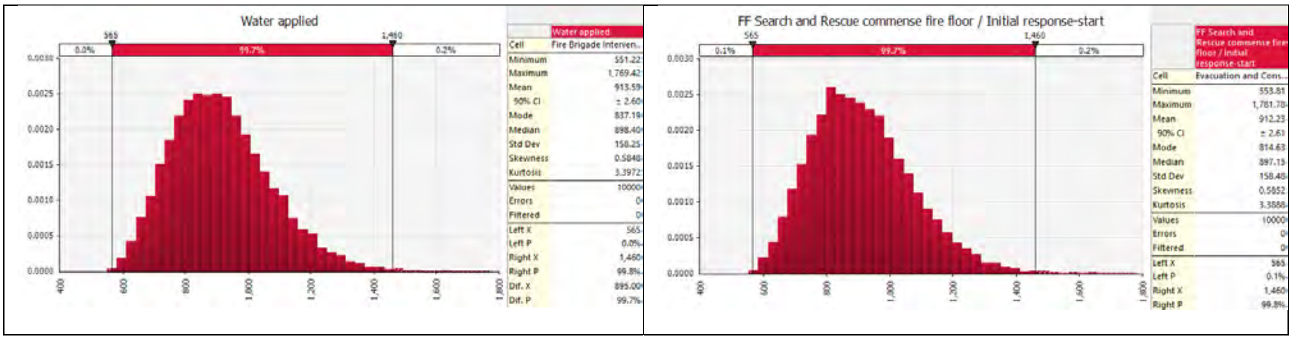


Figure 50 Fire Brigade – Time to apply water and commence search and rescue activities

The three scenarios requiring fire brigade search and rescue activities (from Table 107) are summarised below;

Scenario e) Occupants are trapped but not under immediate threat – fire brigade intervention would be successful.

Scenario f) Rescue required before 565s if L1 tenability criteria are applied and at some stage after 30 minutes (1800s) if L3 tenability criteria are applied.

Under L1 tenability fire brigade suppression and search and rescue activities are unlikely to commence prior to exposure. Under these criteria all occupants on the floor will be deemed-to-be exposed to untenable conditions.

Under L3 criteria suppression and search and rescue activities commence before 1800s in all scenarios analysed and therefore there is a high probability that search, and rescue activities would be successful, and it is assumed no occupants would be exposed to untenable conditions

Scenario g) is similar to scenario f) except that the level 3 tenability criteria are exceeded after 1460s. Whilst suppression and search and rescue activities were estimated to have commenced in 99.8% of cases before this time and the median value for commencement of search and rescue activities is approximately 900s there could be a significant risk to occupants if this scenario occurs. However, it is likely if smoke is entering the floor via an open door, attempts would be made to close the door and if unsuccessful the occupants would be likely to seek refuge within a classroom and close the classroom door. Quantifying the probability of success of these actions is difficult. A simplistic approach, which is considered to be conservative has been adopted, assuming that 50% of the occupants exposed to L3 tenability criteria whilst awaiting rescue will be exposed to untenable conditions (i.e. will not take avoidance measures such as sheltering in a room with closed doors).

If the Level 1 criteria are applied all the occupants on the floor would be assumed to be exposed to untenable conditions.

M2.3. **Risk from Smoke Spread via the stair and lifts shafts to occupants above the floor of fire origin for a 5 -storey primary school.**

The event tree shown in Figure 48 applies to one upper level floor, but it is not appropriate to simply multiply the risk for a typical floor by the number of floors above the fire since all the variables are not independent and the occupants of more than 1 floor can be exposed to untenable conditions in a scenario.

A review of the event tree indicates that the scenario clusters f) and g) require fire brigade intervention and are time sensitive and both scenarios require both stair doors on the fire floor to be left open. The probability of this occurring per fire scenario can be estimated from the event tree to be 0.0014.

The following approach was adopted to determine the mean probability of one door being open to a fire stair on one or more floors above the floor of fire origin for fires occurring on various levels.

a) a binomial distribution was applied to each door serving the levels above the fire with the probability of the door being closed of 0.9.
b) a multi-scenario analysis was undertaken to determine distributions of the number of floors with one door open to the stairway yielding the results shown in Table 116 (columns 2-5)
c) The mean probability for one door being open on (n) floors for fires occurring on all levels was calculated (column 6)
d) The mean probability for one door being open on (n) floors at the same time as both doors to the fire stairs on the floor of fire origin was calculated in column 7

The above process was repeated to determine the mean probability for two doors being open on (n) floors at the same time as both doors to the fire stairs on the floor of fire origin were open and the results are shown in Table 117

Table 116 Distribution of Floors above fire floor with one stair door open Scenario f)

1	2	3	4	5	6	7
No of floors (n)	Probability of 1 door being open on (n) floors above fire floor					Mean probability of one door to a stair being open and both doors on floor of fire origin
	Level 1 fire	Level 2 fire	Level 3 fire	Level 4 fire	Mean for fires on all levels	
0	0.5566	0.6759	0.8204	1	0.763225	0.001069
1	0.354	0.2888	0.1796	0	0.2056	0.000288
2	0.0828	0.0353	0	0	0.029525	4.13E-05
3	0.0066	0	0	0	0.00165	2.31E-06
Total	1	1	1	1	1	0.0014

Table 117 Distribution of Floors above fire floor with both stair doors open Scenario g)

1	2	3	4	5	6	7
No of floors (n)	Probability of 2 doors being open on (n) floors above fire floor					Mean probability of both doors to the stair being open and both doors on floor of fire origin
	Level 1 fire	Level 2 fire	Level 3 fire	Level 4 fire	Mean for fires on all levels	
0	0.97	0.9798	0.9898	1	0.9849	0.001379
1	0.0297	0.0201	0.0102		0.015	0.000021
2	0.0003	0.0001			0.0001	1.4E-07
3					0	0
Total	1	1	1	1	1	0.0014

For Scenario cluster d) (see Table 107) when applying Level 1 tenability criteria the floor directly above has sufficient time to evacuate but not the higher levels. The multi-scenario analysis was adjusted accordingly. In this scenario only the status of the door to the smoke-filled stair on each upper level is critical for this scenario cluster and the probability of one stair being smoke logged is 0.0252. The results are summarised in Table 118.

Table 118 Distribution of Floors above fire floor with one stair door open self-evacuation scenario (d)

1	2	3	4	5	6	7
No of floors (n)	Probability of the door to the smoke logged stair being open on (n) floors above fire floor					Mean probability of the door to the stair being open and the stair being smoke logged
	Level 1 fire	Level 2 fire	Level 3 fire	Level 4 fire	Mean	
0	0.8095	0.9	1	1	0.927375	0.02337
1	0.181	0.1	0	0	0.07025	0.00177
2	0.0095	0	0	0	0.002375	5.99E-05
3	0	0	0	0	0	0
Total	1	1	1	1	1	0.0252

Assuming a frequency of a potential flashover fire of 6.89×10^{-4} the contributions to the risk to occupants on the floors other than the floor of fire origin for this scenario have been estimated in Table 119.

Table 119 Outcomes from Analysis of Smoke Spread to Other Floors 5-Storey Building

Scenario	Floors exposed to risk	Probability of occurrence	Frequency of potential FO fire	Frequency of outcome	Exposed to L1	Exposed to L3
d)1-stair evacuation ASET L1 565, L3 > 1800 - time limit	1	0.0017703	6.89E-04	1.22E-06	124	0
	2	0.00005985		4.12E-08	248	0
e) Rescue -required - no time limit if structure survives		0.001069		7.37E-07	0	0
f) Rescue required -ASET L1 565 L3>1800	1	0.000288		1.98E-07	124	0
	2	4.13E-05		2.85E-08	248	0
	3	2.31E-06		1.59E-09	372	0
g) Rescue required -ASET L1 522 L3:1460	1	0.000021		1.45E-08	124	62
	2	1.4E-07		9.65E-11	248	124

The contribution to the average individual risk from these scenarios has then been calculated in Table 120 assuming the occupants at risk are the total number of occupants less those on the fire floor, i.e. 310 people. However, the individual risk will be higher for occupants located on the upper levels.

Table 120 Calculation of Contribution to Individual Risk and Inputs for Societal Risk 5-storey building

Frequency of outcome / annum	Number of occupants exposed to untenable conditions		Frequency x Consequences	
	L1 Criteria	L3 Criteria	L1 Tenability Criteria	L3 Tenability Criteria
1.22E-06	124	0	1.51E-04	0
4.12E-08	248	0	1.02E-05	0
7.37E-07	0	0	0	0
1.98E-07	124	0	2.46E-05	0
2.85E-08	248	0	7.07E-06	0
1.59E-09	372	0	5.91E-07	0
1.45E-08	124	62	1.80E-06	8.99E-07
9.65E-11	248	128	2.39E-08	1.24E-08
		Total	1.96E-04	9.11E-07
		IR (average)	6.32E-07	2.94E-09

M3. External Fire Spread to Upper Levels.

M3.1. Overview

Under the DTS provisions the external walls of the buildings are required to be non-combustible and comply with the required separation distances for any unprotected openings. The selected generic building layouts also do not include balconies. Therefore, the risk of an external ignition subsequently involving the building façade is very low. The most likely severe scenario is therefore likely to be a fully developed fire within the school breaking through the windows with flames projecting through the opening to such an extent that the windows to the floor above break facilitating fire spread to the next level and so on. Although there have recently been very many major fires involving fire spread over combustible facades, major fire spread over non-combustible facades is relatively rare but there have been some major fire incidents such as those summarised below derived from various sources including White[61] and Wade[62].

All the example incidents occurred in buildings or areas of buildings without sprinkler protection or where the sprinkler system was inoperative. Flame spread to the top of the building in five of the twelve example incidents as shown in Figure 51. In one of these cases fire spread was stopped by a sprinkler system that was operational on a higher level. In other incidents fire spread to the top of the building did not occur due to fire brigade intervention, relatively low fire load compared to the external fire separation between openings or a combination of these factors.

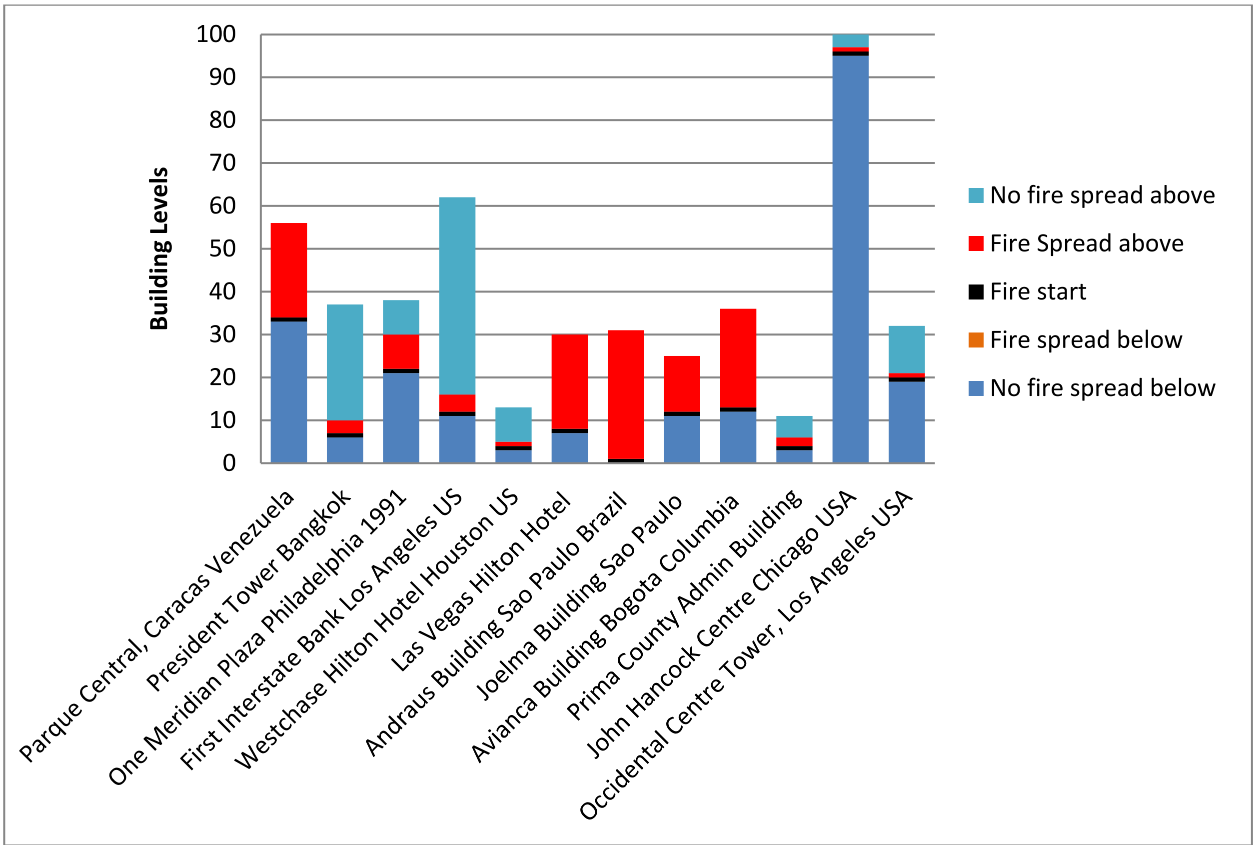


Figure 51 External Fire Spread in Buildings with non-combustible external walls

Further details are provided in Table 121.

Table 121 Fires involving non-combustible cladding

Location	Fire Date	Height (storeys) & use	Const. (initial / refurb)	External Wall Features	Fire Start	Fire spread	Fatalities /injuries	Sprinkler and Notes
Parque Central, Caracas Venezuela	2004	56		Non-combustible	34th floor East Tower	34-56 (top)	0/28	No functioning sprinkler system
President Tower Bangkok	1997	37 mixed incl hotel	1997 (close to completion)	Non-combustible	Level 7 internal explosion and fire	7-10		Sprinklers not operational, Fire stopping floor to floor compromised by cabling. External glazing withstood initial exposure but fractured and collapsed as they cooled
One Meridian Plaza Philadelphia 1991	1991	38-storey bank		Non-combustible	22 Floor internal fire broke through window	22-30		Partial sprinkler protection. Fire stopped when it reached sprinkler protected level
First Interstate Bank Los Angeles US	1988	62-storey bank		Non-combustible	12th floor internal fire start	12-16		Partial sprinkler protection but only at basement level. Flames extending from openings estimated to be 9m long. FB suppression limited spread
Westchase Hilton Hotel Houston US	1982	13-storey hotel		Non-combustible	Internal fire on 4th floor	4-5	12/3	Only waste chutes sprinkler protected. Substantial internal fire spread on 4th floor in addition to vertical external spread to 5th floor
Las Vegas Hilton Hotel	1981	30-storey hotel		Non-combustible 1m spandrel	Internal fire 8th floor	8-30	8/350	20-25 minutes to spread to the top. Postulated spandrel shape may have influenced spread. 3 fatalities in lift lobby on floor of fire origin. 4 in hotel rooms with open doors (check floor). No sprinklers
Andraus Building Sao Paulo Brazil	1972	31-storey store and office		Non-combustible Small spandrel / projection	4 floors of department store before breaking out	Whole facade	16	No sprinklers
Joelma Building Sao Paulo	1974	25-storey Office building		Non-combustible 900mm projection north & 600mm south wall	Internal 12th floor	12-25 on both facades	179/?	Assume no sprinkler intervention. Spread by igniting combustibles on each floor
Avianca Building Bogota Columbia	1973	36-storey office		Non-combustible – gap between slab edge and eternal cladding (glazing in aluminium frames with concrete mullions	Internal 13th floor	Spread to top of building	4/150	Assume no sprinklers. Spread a mix of external and via the gap between the floor and cladding. Two unoccupied floors were not significantly affected. Contents consumed over 12h period
Prima County Admin Building	1973	11-storey office		Non-combustible	Internal 4th floor	4-6	0	Assume no sprinkler intervention fire extinguished after approx. 45 minutes. Half 4th floor burned out minor damage to 5 and 6th floors
John Hancock Centre Chicago USA	1972	100		Non-combustible	96th	97th	?	Fire broke through windows to 97th floor but damage was limited due to relatively low fire load
Occidental Centre Tower, Los Angeles USA	1976	32		Non-combustible	20th floor	20-21	?	No sprinkler protection

If a sprinkler system operates and achieves its design objectives it is likely the fire will be controlled or suppressed prior to flashover or the occurrence of a large flaming fire. Therefore, external fire spread would be unlikely to occur except if the sprinkler system is ineffective in a building with non-combustible external walls, and a fully developed fire occurs.

This mode of fire spread has been investigated by numerous researchers including Oleszkiewicz and Delichatsios [63, 64] who have observed that vertical separation by means of spandrel panels is less effective than horizontal projections between openings and in many instances vertical separations within practical limits may not be effective.

Theoretical analysis tends to show that in a large proportion of cases fire spread will occur to the upper levels of a building, but fire statistics tend to indicate the frequency is substantially less.

Although a comparative analysis is being undertaken in this study the reference building is a single storey building, therefore there will be no cancelling effect of the impact of assumptions and simplifications relating to fire spread to the floors above. An approach drawing on statistical data and a previous analysis undertaken by Korhonen and Hietaniemi [4] has therefore been adopted. The Korhonen analysis undertook a theoretical study which was normalised against statistical data addressing the potential for large over-estimates regarding fire spread over non-combustible materials.

Although the focus was on residential buildings the fire loads considered were higher than those expected in schools and the range of ventilation conditions and enclosure configurations was such that the results can be reasonable applied to rooms within schools.

M3.2. Summary of Key Information from Korhonen [4]

This main focus of the report was the fire safety assessment and design concerning retrofitting of a wooden façade to a concrete-framed residential multi-storey building but as part of the study the risk of external fire spread over non-combustible external walls (concrete) was considered.

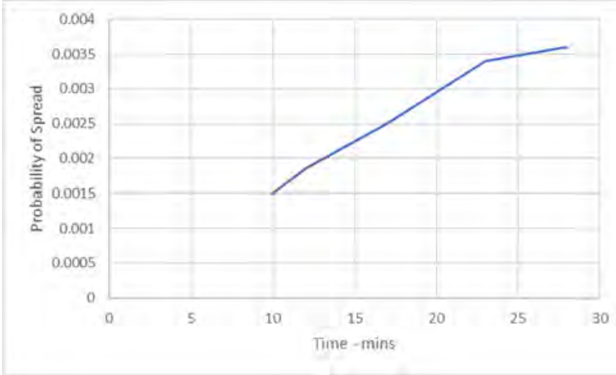
Relevant fire statistics were analysed comprising data spanning 6-years with an average of 425 fires / annum relating to multi-residential buildings.

Based on a theoretical analysis it was estimated that the probability of fire spread to the apartment above via the external façade was approximately 0.02 / annum for a concrete façade but this was an order of magnitude higher than the probability indicated by statistics and therefore a normalisation factor of 10 was applied in the study reducing this to approximately 0.002.

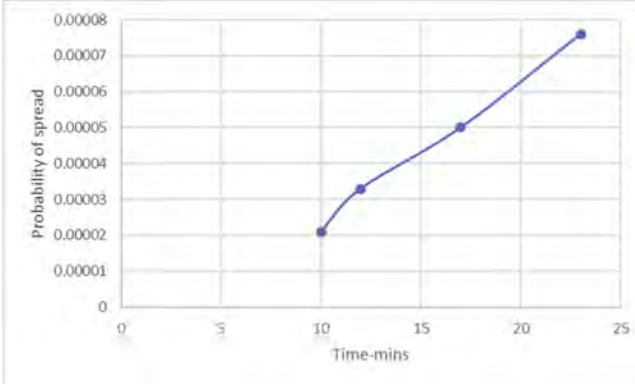
The analysis considered the timing of spread and fire brigade intervention and the results indicated that the probability of spread increases as the time to commencement of fire-fighting increases.

A review of the probability distributions derived in the report indicates that the timing of spread to the level above was estimated to occur between 10 to 15 minutes after ignition and between 18 minutes and 28 minutes to two levels above the fire floor but at a substantially lower probability.

Typical probability of spread estimates relative to the Fire Brigade Intervention time from Korhonen have been derived from the report (time from alarm to application of water) and are plotted in Figure 52.



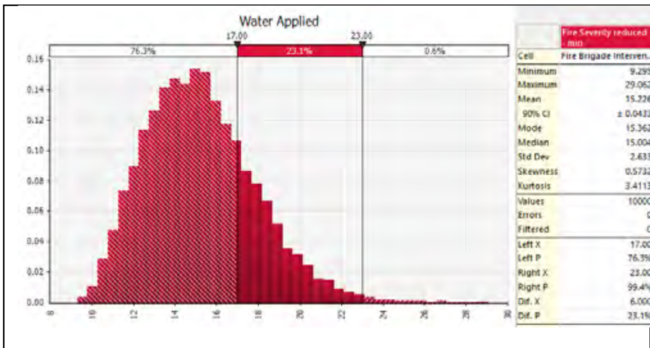
a) Probability of spread to one level above



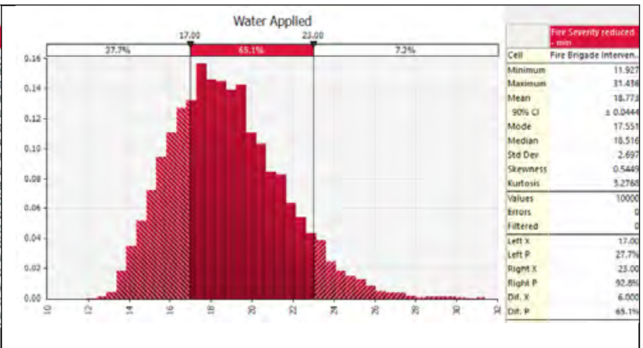
b) Probability of spread to two levels above

Figure 52 Probability of vertical fire spread versus time from alarm to application of water by the Fire Brigade derived from Korhonen [4]

The time for the fire brigade to apply water to a fire on the third floor was calculated using a multi-scenario implementation of the FBIM and the fire brigade response time based on the Report on Government Services. The distribution obtained is shown in Figure 53.



a) Fire Level 3



Fire Level 10

Figure 53 Distributions for the time for the Fire Brigade to apply water to the fire

Weighted probabilities were calculated to derive a single lumped probability of fire spread for fires on Level 3 of a building in Table 122.

Table 122 Calculation of lumped probability of fire spread

Time to FBI	Probability	L3 proportion	Weighted Probability L3
Below 17 minutes	0.002	0.763	0.001526
17-23 minutes	0.003	0.231	0.000693
Greater than 23	0.0035	0.006	0.000021
	Total	1	**0.00224**

M3.3. Calculation of Fire Losses

Windows are not full height and the separation between window openings on each floor will be typically between 900mm and 1500 and therefore it is considered reasonable to apply the results from Korhonen [4]. The fire safety strategy document will therefore require spandrels of minimum height 900mm, even though spandrels are not required for a sprinkler protected building under the NCC DTS provisions, because the presence of spandrels has been relied upon to demonstrate the metrics have been satisfied.

The frequency of fires for the 5-storey building was estimated to be 0.013 fires /annum but a fire on the top floor cannot spread upwards therefore for the purposes of calculating external fire spread for a 5-storey building a value of 0.01 fires / annum will be adopted (0.013 x 4/5).

The frequency of fire spread to the next level of a 5-storey building using the probabilities derived in Table 122 will be:

2.24×10^{-5} (.01 x 0.00224) assuming no sprinkler intervention.

The Korhonen [16] data used was based on apartment buildings. For a school building the proportion of fully developed fires whilst the building is occupied would be expected to be less than a residential building and therefore this is considered a high (conservative estimate)

The evacuation time for the floor above the floor of origin assuming one exit is blocked has been estimated to be a maximum of 561s (9.4mins) and for the next floor 770s (12.8 minutes) from Table 106. Since these are below the minimum time for spread to one level above of 10 minutes and two levels above of 18 minutes respectively evacuation will occur prior to the fire breaking into the floors unless both exits are blocked, and the occupants are relying on fire brigade intervention for assistance to evacuate.

The time available for fire evacuation to be undertaken by the fire brigade will be the time for the fire to break into the floor above (10-15 minutes) and then for untenable conditions to develop in positions where the occupants are sheltering typically another 5 to 10 minutes applying Level 1 criteria and substantially longer for level 3 criteria. Therefore, search and rescue would need to be completed between 15 and 25 minutes.

From an examination of the time to commence suppression which approximates to the time to commence search and rescue the outcomes are likely to vary from full evacuation to all occupants being exposed to untenable conditions for the 5-storey building. Due to the uncertainty of the outcomes a simplified approach has been adopted assuming there is a probability of 0.5 that 50% of the occupants on the floor will be exposed to untenable conditions under both the Level 1 and Level 3 criteria.

On this basis the following losses were estimated for external spread fires in the 5-storey primary school building:

Frequency of fire spread to the next level is 2.24×10^{-5} assuming no sprinkler intervention

Probability of people awaiting assistance to evacuate on the floor above is 0.0014 from Table 107 yielding a frequency of 3.136×10^{-8} fires per annum. The values in Table 107 were determined assuming the presence of sprinkler protection with an effectiveness of 86% and if the system is effective there are no losses, therefore no further adjustment for sprinkler intervention will be required.

Assuming 50% occupants exposed to untenable conditions in 50% of these scenarios yields 62 people exposed to untenable conditions at a frequency of 1.57×10^{-8} /annum.

Since the probability of spread to a further floor is 2-orders of magnitude less and there is a greater opportunity for fire brigade intervention no further evaluation of spread to two floors is required.

The average contribution to Individual Risk of exposure to untenable conditions / annum from the scenario of external fire spread would therefore be $62/310 \times 1.57 \times 10^{-8}$ /annum = 2.14×10^{-9}

M4. Internal Fire Spread and Structural Fire Resistance

M4.1. Method of Analysis and Inputs

Overview

The analysis of internal fire spread to the next level and structural fire resistance was undertaken using the Enclosure / Structural model together with a multi-scenario implementation of the Fire Brigade Intervention model incorporated in the EFT Multi-scenario Quantitative Risk Assessment Framework (England [60]).

A brief overview is provided below, and the relevant inputs described

The enclosure / structural multi-scenario model includes the following sub-models:

- Fully developed enclosure fire sub-model
- FRL (distribution) sub-model
- FRL conversion sub-model
- Simple Structural sub-model

Outputs from the model include localised failure times and major (global) structural failure times.

Fully developed enclosure fire sub-model

There are numerous closed form models that can be used to generate time / temperature regimes for post flashover (fully developed) compartment fires based on fuel load, ventilation and thermal properties of boundaries, many of which have been reviewed by Hurley[65].

The method presented in Annex A of EN 1991-1-2:2002[66] was selected because it has also been codified and used extensively.

The method adopts the following equation to define a heating regime based on variables such as thermal properties of the boundary, ventilation conditions, enclosure dimensions and fire load.

$$\Theta_g = 20 + 1\,325\ (\ 1 - 0{,}324\ e^{-0{,}2\,t^*} - 0{,}204\ e^{-1{,}7\,t^*} - 0{,}472\ e^{-19\,t^*}\ )$$

A linear relationship is assumed for the cooling phase. Refer to EN 1991-1-2:2002 for further details of the calculation method. No adjustment for combustion efficiency or combustion outside the fire enclosure is incorporated in the sub-model which will therefore tend to overestimate the fire duration / severity.

Typical inputs are described in the following sections;

Fire Load

A summary of primary school fire loads is included in Appendix I based on a study by Hadjisophocleous [38]and the following inputs were selected based on the total fire load density estimates for all rooms surveyed in primary schools

Mean fire load	426 MJ/m^2
Standard Deviation	152 MJ/m^2
Minimum	234 MJ/m^2

Maximum 948 MJ/m^2

The resulting distribution adopted is shown in Figure 54.

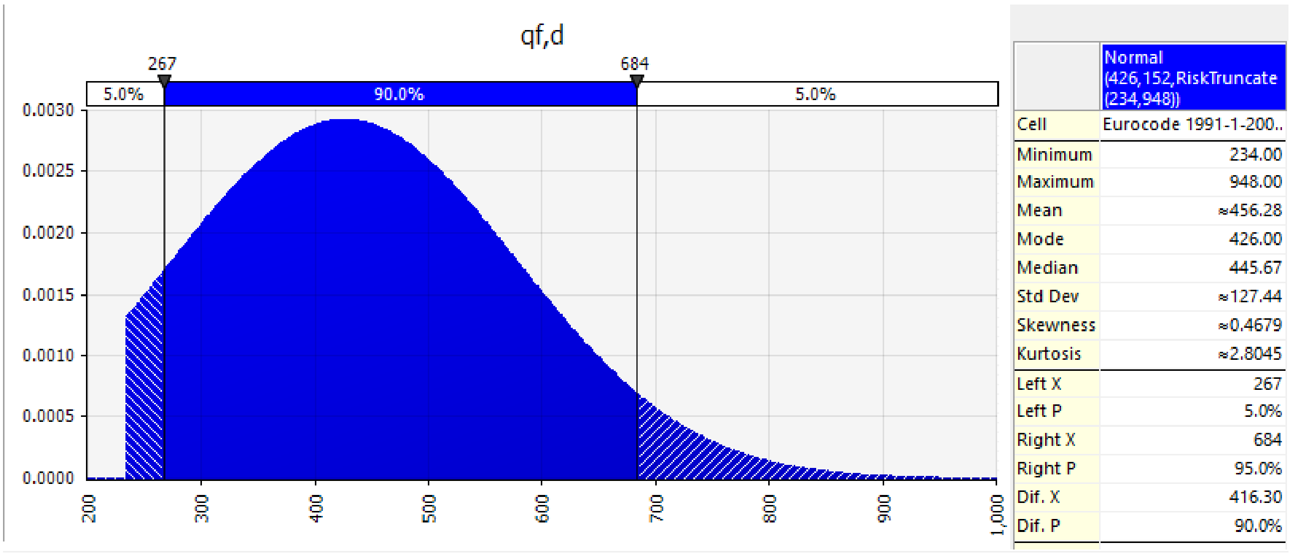


Figure 54 Fire Load Distribution

Floor Area

A summary of primary school room floor areas is included in Appendix I based on a study by Hadjisophocleous [38]. The following distribution was generated by assuming uniform distributions for the length and width of a room yielding a distribution that is similar to that obtained from the survey reported by Hadjisophocleous for all rooms.

The key parameters are listed below, and the distribution is shown in Figure 55.

Mean area	84.1 m^2
Standard Deviation	32.8 m^2
Minimum	24.4 m^2
Maximum	179.2 m^2

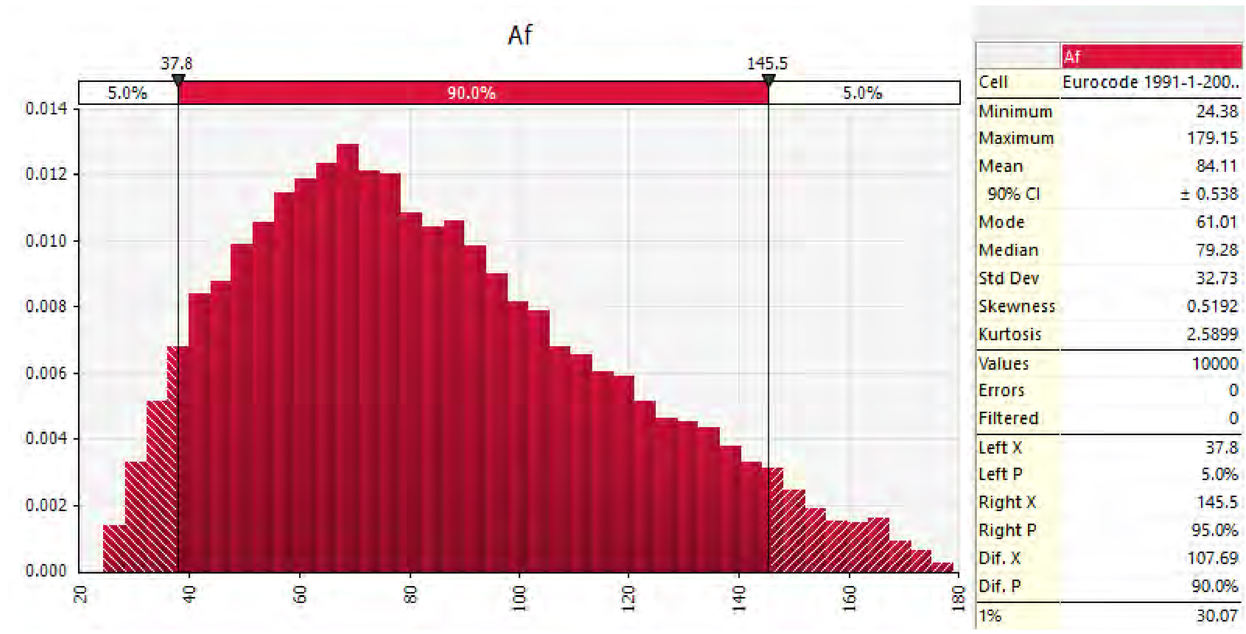


Figure 55 Floor Area Distribution

Room Heights

To address the most likely range of room heights a uniform distribution from 2.4m to 3.0m has been adopted for room heights.

Opening dimensions

A uniform (rectangular) distribution of openings areas from 25% to 41% of the floor area was adopted. The ventilation area was linked to the floor area to avoid generating very large ventilation openings in small enclosures which would generate unrealistic results.

The distribution obtained is shown in Figure 56 and the key parameters are listed below which are broadly similar to the survey results reported in Appendix I except for a reduction in the larger window areas to reflect a reasonable upper bound

Mean area	27.6 m^2
Standard Deviation	11.6 m^2
Minimum	6.6 m^2
Maximum	69.8 m^2

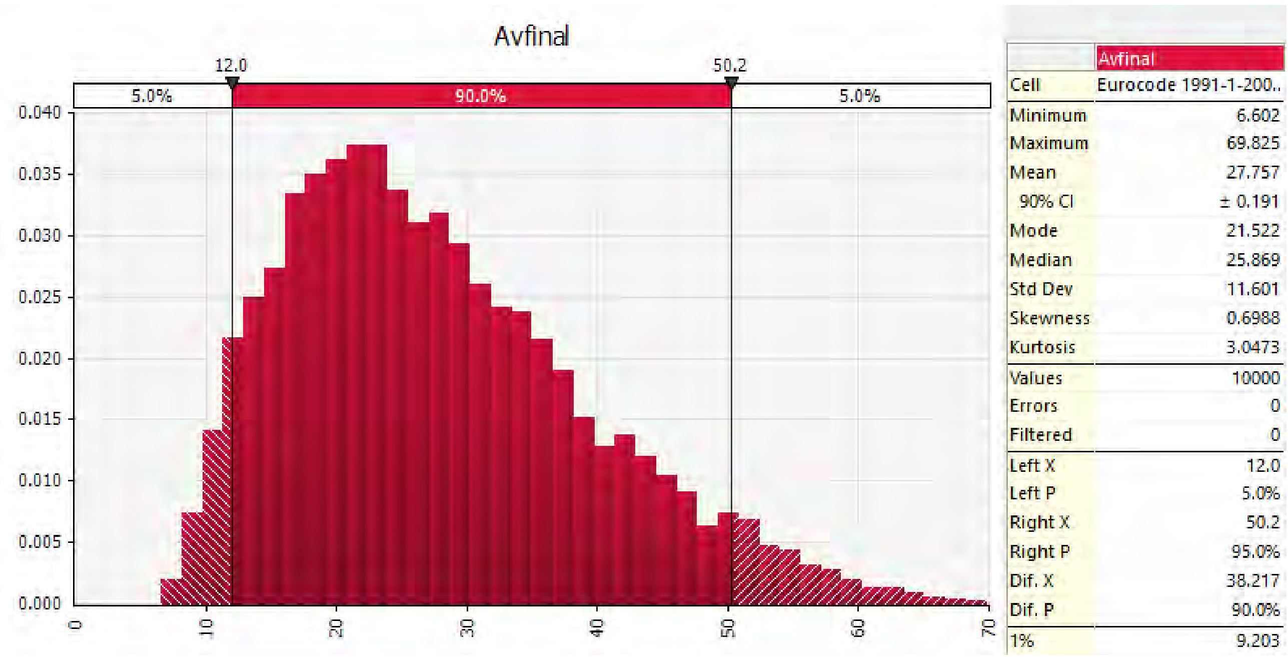


Figure 56 Distribution of Opening Areas

A Uniform Distribution varying from 0.6m to 2.1m was assumed for opening heights to address the range used in contemporary buildings.

Lining properties

The following lining properties are typical for plasterboard linings:

- Thickness – 26mm

- Thermal conductivity – 0.27 W/m.K
- Density 900kg/m^3
- Heat Capacity 2000 J/kg.K (allows for combined water)

Pre-flashover Growth Rate

A fast pre-flashover fire growth rate can be assumed to account for the impact of contents such as upholstered furniture / mattresses etc. however as the fires tended to be ventilation controlled this assumption is not critical.

FRL sub-model and Inputs

Effectiveness can be considered to be a combination of efficacy and reliability. It is practical to express efficacy in terms of the time to failure when exposed to a standard heating regime such as 1530.4, ISO 834 or ASTM E119 because these methods are used for regulatory purposes and there is a very large volume of existing test data. Reliability can be considered in terms of the probability of the design performance level being achieved.

There are many factors that can impact on the efficacy of passive fire protection systems. Examples are given in Table 123.

A common approach is to define a normal distribution to characterize the potential variation in FRLs due to the above factors; however, some factors such as gross defects can cause substantial reductions in performance. The two peak FRL characterization proposed by England[67] was therefore adopted for elements with prescribed FRLs. Essentially the FRL is characterized by combining two normal distributions.

The primary peak (mean) is centred on the prescribed FRL for the element with a standard deviation of 10% of the nominated FRL typically assumed to allow for normal material variations and minor installation variations. The secondary peak is centred on the performance estimated assuming a gross defect is present with a standard deviation of 10% of the estimated FRL of an element with a gross defect). There is little data available on the probability of a gross defect occurring, but a typical value is expected to be of the order of 0.005 based on the limited data available.

Table 123 Factors Affecting Efficacy of Passive Systems

Ref	Factors	Potential Impact	Est. Frequency
1	Gross defect (e.g. substitution of fire protective coverings with standard lining materials or gross fixing errors)	Minimal protection provided by applied protection - fire resistance approximates to the inherent fire resistance of underlying structure plus a minor contribution from the lining or in concrete structures substantial spalling occurs.	Relatively rare and unlikely to be systemic throughout a structure if adequate controls are in place
2	Normal variations in materials and installation practices	Typically manifests as a normal distribution of performance around the mean fire resistance.	Will occur with all systems.

3	Minor variations in method of fixing	Board systems tolerant of minor variations in fixing systems. Other systems such as masonry walls can be prone to premature failure due to construction errors[68].	Minor variations would occur frequently but impact on performance relatively low.
4	Sensitivity to Heating Regimes	Fire protective boards are normally resilient to variations in the heating rate but other systems such as glazing & intumescent coatings may be more sensitive.	Low frequency of major degradation in performance would be expected.
5	Aging	There is a risk of materials deteriorating with age. For board materials this impact is considered low.	Low frequency.
6	Unprotected large service penetrations	Could allow fire to spread through hole formed in barrier or fire spread to structural members by-passing fire protective coverings	

The main structure will be assumed to have an FRL of 120/120/120 with a standard deviation of 12 minutes but an FRL of 90/90/90 with a standard deviation of 10% will be assumed for floors to allow for application of NCC Specification C1.1 clause 3.3; Floor loading of Class 5 and 9b buildings: Concession.

An FRL of 26/26/26 with a standard deviation of 10% will be assumed for an element with a gross defect with a probability of occurrence of 0.005 for each member

Fire Resistance Levels to Scenario Time Conversion Model

In most instances the time to failure of an element of construction ascertained in a standard fire resistance test will differ from the failure time if the element is exposed to a real or simulated fire scenario (e.g. Annex A of EN 1991-1-2:2002) because the time temperature histories will differ depending of factors such as the nature, distribution and magnitude of the fire load, thermal properties of the boundaries and ventilation openings amongst other things.

If an element of construction comprises homogeneous materials with known thermal and mechanical properties at elevated temperatures (e.g. steel, concrete, timber) it is possible to determine the time to failure using simple correlations or more complex methods such as finite element analysis.

However many fire-resistant elements or components are too complex to model reliably such as fire doors, penetration seals, composite systems, connections, board fixings, adhesion of sprayed materials, spalling of high-strength concrete etc. and therefore a general method for conversion of fire resistance times to scenario times is considered appropriate for many comparative and generic studies where a broad range of elements of construction could be adopted for a particular application. This approach also addressed a further complication in that different models are likely to have varying degrees of conservatism generating further variables in the analysis.

A method based on an equal lumped thermal mass approach was implemented in which a “target protected steel element” with specified thermal properties was defined and the time temperature history calculated at a critical point based on exposure to the fire scenarios and the standard heating regime. Equivalent exposure was deemed to have occurred when the critical part of the element reaches the same temperature under the different heating regimes.

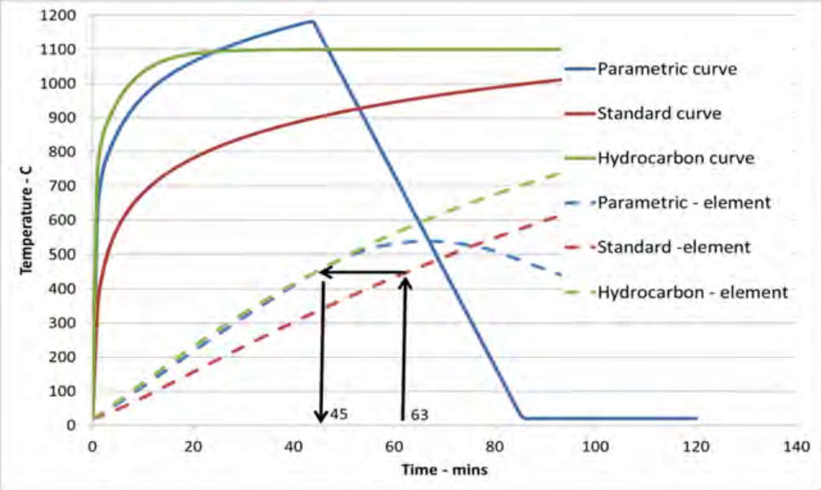


Figure 57 Conversion of Fire Resistance Period to Fire Scenario Time

The process is shown graphically in Figure 57. If it is required to determine the time to failure of an element that achieved an FRL of 63/-/- when exposed to the fire scenario (parametric curve) fire the following approach is adopted

- the target element attains a temperature of 454°C when exposed to the standard fire resistance test for 63 minutes
- the target element would need to be exposed to the fire scenario (parametric curve) for 45 minutes to attain the same temperature
- therefore, the fire scenario failure time would be 45 minutes

In this example the fire scenario is very similar to the hydrocarbon heating regime and the target element would also need to be exposed to the hydrocarbon heating regime for 45 minutes to attain 454°C.

A “target protected element” is defined with known thermal properties and the temperature at a critical point calculated when exposed to the fire scenarios and the standard heating regime. Equivalent exposure is deemed to have occurred when the critical part of the element reaches the same temperature under the different heating regimes. In this implementation a steel element was assumed to provide the lumped thermal mass and the mean temperature of the steel calculated using **Equation 5** from Milke[69]

$$\Delta T_s = \frac{k_i}{h}\left[\frac{(T_f - T_s)}{c_s\left(W/_D\right) + \frac{c_i \rho_i h}{2}}\right]\Delta t$$ **Equation 5**

Where;

T_s is the steel temperature - °C

T_f is the enclosure temperature - °C

k_i is the thermal conductivity of the insulation W/m.K

c_i is the heat capacity of the insulation – K/kg.K

ρ_i is the density of the insulation –kg/m^3

c_s is the heat capacity of steel – J/kg.K

W/D is the mass per unit length divided by the heated perimeter kg/m^2

Δt is the time step – s

Simple Structural Sub-model

In order to evaluate the risk of a major collapse of a structure or part of the structure it is first necessary to determine which structural elements or combinations of structural elements may initiate a major collapse. For mid and high-rise buildings many design codes require robust designs to address the risk of disproportionate collapse which can be achieved by incorporating redundancy in the design such that for collapse to occur more than one key structural element needs to fail.

When considering collapse of a structure exposed to fire the potential for defects to cause premature failures needs to be considered. However, the probabilities of more than one member having a defect may be sufficiently low that no additional special measures may be required. In other words, the risk associated with defects needs to be evaluated even if protection to structural members is specified to resist "full burnout" of a fire.

This can become even more significant under conditions where external fire spread leads to multiple fires within a building.

NCC performance requirement BP1.1 states;

"(a) A building or structure, during construction and use, with appropriate degrees of reliability,

must—

(i) perform adequately under all reasonably expected design actions; and

(ii) withstand extreme or frequently repeated design actions; and

(iii) be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage; and

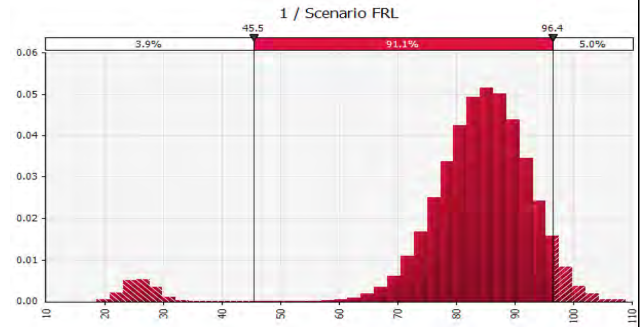
(iv) avoid causing damage to other properties, by resisting the actions to which it may reasonably expect to be subjected."

It is therefore considered reasonable to assume that the structure of the buildings will be designed in accordance with these provisions and that a level of redundancy will be provided in the design such that for collapse to occur more than one key structural element needs to fail.

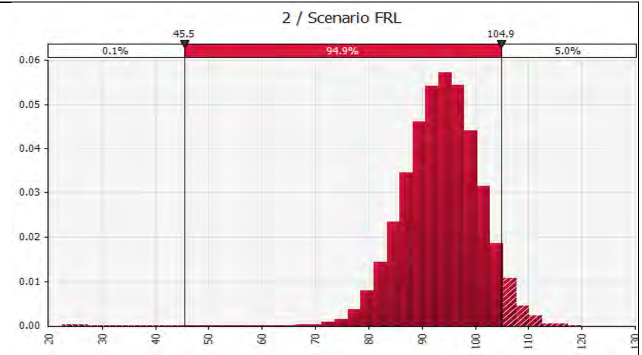
A simple structural layout for the steel framed building has been adopted whereby the structure within an enclosure can be represented as 6 columns and 2 floor units

It will be assumed that at least two major structural elements of the eight within the enclosure will have to fail before a global collapse of the structure occurs. This simplification is considered appropriate for a generic comparative analysis but for specific buildings a more detailed structural analysis may be appropriate.

A typical output is shown in Figure 58 from the two peak model showing the time for failure of one of the eight elements and two of the eight elements within an enclosure assuming a probability of a gross defect occurring in a single element of 0.01.



Combined distribution for premature failure due to failure of 1 element only (no redundancy)



Combined distribution for premature failure due to failure of at least 2 elements (1 level of redundancy)

Figure 58 Calculated combined distributions for Monte Carlo Simulations

Fire Spread Sub-model

Smoke spread and external fire spread to upper levels have been considered separately and therefore the risk of global collapse of the structure and a localised failure allowing fire spread to the level above will be evaluated.

If global collapse occurs, it will be assumed that all remaining occupants will be exposed to untenable conditions

If failure of one of the two elements providing fire separation to the floor above fails it will be assumed that all occupants remaining on that floor will be exposed to untenable conditions.

M4.2. Results from Multi-scenario Analysis

Multi-scenario analyses were undertaken with a fire on the 3rd floor to investigate the potential impact of defects in the fire protection, fire brigade intervention and evacuation of the building for 5-storey school buildings. Due to the very low frequency of these events and limited data for verification purposes the results should be viewed as indicative of the magnitude of the risk but will be very sensitive to key inputs such as the probability and nature of gross defects and the structural design of the building.

A summary of the outcomes is provided in Table 124.

Table 124 Multi-scenario results summary for Fire brigade Intervention Fire Spread and Structural Failure

Event	Parameter	5-storey Building (fire on third storey)
Commencement of fire fighting	Mean time-mins	15.2
	Max time -mins	31.1
	Min-time -mins	8.9
Major structural collapse	Probability if exposed to a fully developed fire	2.5×10^{-4}
	Time range - mins	11-17

Spread of fire to floor above	Probability if exposed to a fully developed fire	5.24×10^{-3}
	Time range - mins	9-18

The timing of fire spread to the level above is such that the occupants would have sufficient time to evacuate the floor if at least one of the two stairs is available, The probability of all exits being blocked, a major defect occurring with the floor and failure of the sprinkler system is considered very low compared to other means of fire and smoke spread and no further analysis was undertaken of this scenario.

Therefore, the focus will be on global collapse of the whole structure which was assumed to occur if two out of 8 structural members assumed to be fully exposed to the fire fail. The earliest global structural failure was estimated to occur 11 minutes (660s) after ignition of the fire.

To evaluate the consequences of the fire, mean evacuation rates have been used since the probability of global failure of the structure is relatively low and scenarios will be included where both exit options are blocked providing an evaluation of a broad range of scenarios.

The residual building population with respect to time for the critical period for global collapse have been calculated using the flow rates derived in Section M1.2.

Estimated losses

The mean evacuation times for the 5-storey building were estimated to be approximately 7-minutes if adequate visibility is maintained within both stairs and 9-minutes if adequate visibility is maintained in one stair. It is likely that evacuation would be completed prior to the estimated earliest time for global structural collapse. Therefore, the only scenarios where the occupants will not evacuate in time will be if both stairs are blocked (probability 0.0014) and the occupants are above the fire (assumed 50% of the scenarios). To take this into account when estimating the number of people exposed when both exits are blocked it will be assumed that half the building population is exposed.

The probability of global collapse if exposed to a fully developed fire was estimated to be 2.5×10^{-4} and the probability of a fully developed fire occurring whilst the school is occupied has been estimated to be 6.89×10^{-4} / annum.

It is therefore estimated that 217 people will be exposed to untenable conditions due to global collapse of the structure at a frequency of 2.41×10^{-10}. This will be included in a consolidated F-N plot of the Societal Risk

The Individual risk averaged over all the occupants of the building excluding the floor of fire origin will be: $2.41 \times 10^{-10} \times 217/310 = 1.69 \times 10^{-10}$

The frequency of global collapse of the structure would be approximately 2.41×10^{-8} (assuming an effectiveness of the automatic sprinkler system of 86%).

Appendix N. Consolidation of results for fires on the floor of origin and other floors.

N1. General Approach

The risk to occupants was calculated on the floor of origin and separately on the non-fire floor for the following scenarios relating to the high-rise options which were identified as presenting a significant risk:

- Smoke spread to other floors via shafts potentially blocking fire stairs
- External Fire Spread via the façade of the building
- Major Collapse of the Structure

The results have been consolidated below with respect to the individual risks and societal risks.

Based on the floor of fire origin results presented in Appendix L13 it was decided to adopt reference building 2 as the reference building (single-storey building with smoke detection throughout) and undertake the detailed analysis on the five-storey building that included a smoke detection system throughout and an automatic fire sprinkler system amongst other things.

N2. Individual Risk Consolidation

The average individual risk was calculated using the following relationship:

$$IR = \sum_{i}^{n} {(F_i \,.\, C_i)}/{p_i}$$

where;
IR Average Individual Risk [year^{-1}]
F_i frequency of scenario *i* provided that $C_i \geq 1$ [year^{-1}]
C_i number of occupants exposed to untenable conditions associated with scenario i [-]
n total number of scenarios [-]
p_i is the population exposed to scenario *i*

Therefore, when considering the floor of fire origin then $p_{i\ would}$ be the population of the floor of origin and not the entire building and F_i would be the frequency of the fire occurring on a floor

The Consolidated Individual Risk results for the various scenarios are shown in Table 125 applying the Level 3 tenability criteria.

Table 125 Consolidation and comparison of individual risk estimates applying level 3 tenability criteria

Scenario	Reference Building 1	Reference Building 2	5-storey high-rise
Floor / Module of origin	1.10E-06	2.20E-07	2.16E-07
Smoke Spread via stair and lift shafts to upper levels	0	0	2.94E-09
External Fire Spread to upper levels	0	0	2.14E-09
Fire Induced Collapse of Structure	0	0	1.69E-10
Total Individual risk from fire scenarios	1.10E-06	2.20E-07	2.21E-07
Normalised Against Reference Building 2	5	1	1.00

N3. Societal Risk Consolidation

The societal risks derived for floors other than the floor of origin have been consolidated for the 5-storey building in Table 126.

Table 126 Consolidation of people exposed to untenable conditions on floors other than the floor of fire origin 5-Storey School

Scenario	Num of people exposed	Frequency	Source
Smoke Spread via the stair and lifts shafts	62	1.45E-08	Table 119 Section M2.3
Smoke Spread via the stair and lifts shafts	124	9.65E-11	Table 119Section M2.3
External Fire Spread	62	1.57E-08	Section M3.3
Internal fire spread / Collapse	217	2.41E-10	Section M4.2

These were then added to the loss data for the floor of fire origin as determined for the various representative scenarios in Appendix N and presented as an F-N plot in Figure 59 and compared to a single storey reference building and various benchmarks.

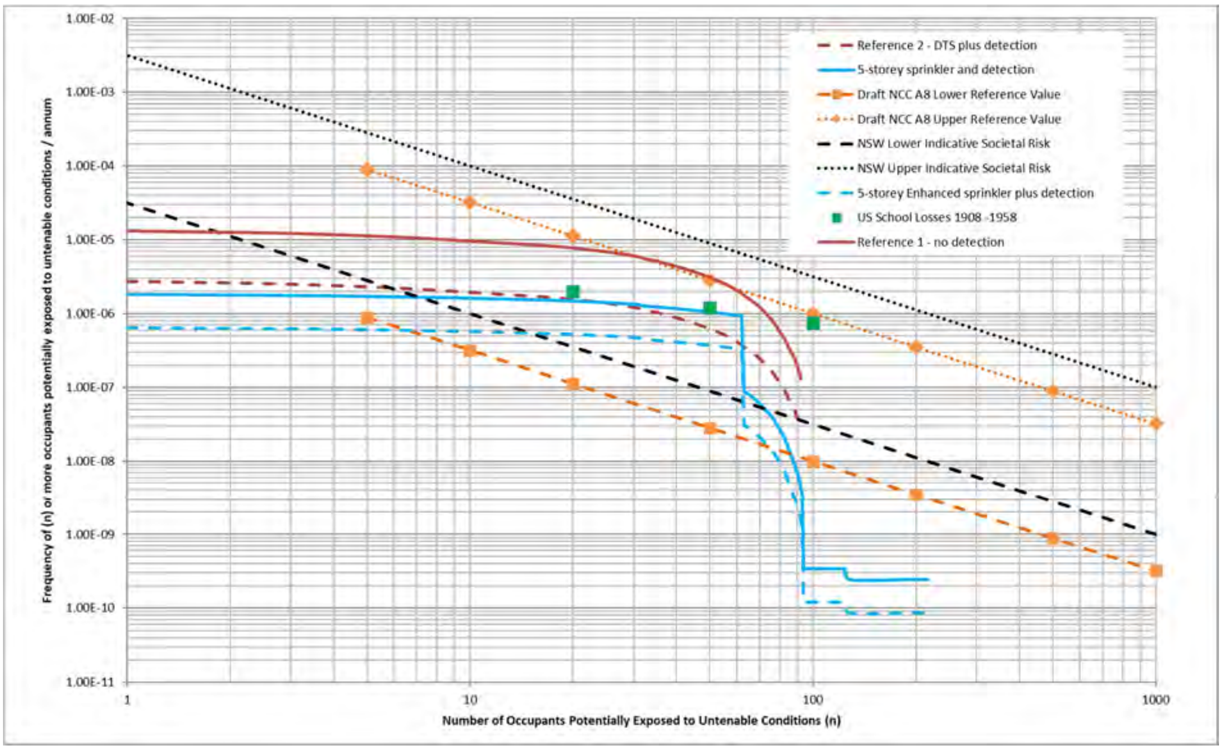


Figure 59 F-N Plot of Societal Risk of 5-storey building using Level 3 Tenability Criteria compared to various Benchmarks and a Reference building based on the DTS provisions with the addition of a smoke detection system

N4. Fire Spread between buildings

Since the buildings considered in the case studies are set within their own allotments and are not adjacent to any boundaries (>>6m away) a detailed analysis is not considered necessary and a simple calculation is provided as a precautionary check

Assuming 6m minimum separation the probability of imposing radiation greater than 10kW/m^2 on an adjacent structure is required to be less than 0.001

From Table 51 the proportion of flashover fires (including times when the building is unoccupied) would be expected to be approximately 11% for reportable fires for an unsprinklered school building. Therefore a 99 percentile flashover fire needs to be considered to check compliance.

For case study 2, sprinkler protection is provided with an assumed effectiveness of 86% reducing the fire severity required to be resisted to a 93.5 percentile fire.

The external façade of the building is non-combustible with a worse case façade comprising four, 3m wide windows typically 1.2m high separated by 4m. An allowance for some flame extension will be made by assuming a window height of 1.6m. A schematic of the façade is shown in Figure 60 with a quarter of the assumed average radiating surface shown.

Figure 60 Critical façade detail for evaluating fire spread between buildings.

In addition, a very conservative assumption was made that the fire will spread to all enclosures within a module or floor level and simultaneously burn at its maximum rate in all enclosures with average enclosure temperatures of 1200°C. (Note this conservative approach was adopted to allow simplifying assumptions to be adopted when undertaking the analysis in the knowledge that large safety margins were anticipated. More refined methods would be adopted for less conservative applications.

Source radiation can be calculated using

$E=\varepsilon\sigma T^4$

Where $\sigma=5.67 \times 10^{-11}$kW/m^2/K^4 and ε can be assumed to be approximately 0.85 yielding E= 227kW/m^2.

Based on the building configuration 41.7% of the wall within the enclosed area be radiating yielding an average source radiation of approx. 95 kW/m^2.

The configuration factor has been calculated using the configuration factor tables provided by Drysdale (Page 66)[18] with

$S= 1.6/14.4 =0.11$ and $\alpha= 1.6 \times 14.4 / 6^2= 0.64$

$\phi = 4x\ 0.063 = 0.252$

Therefore, the imposed radiant heat flux at a distance of 6m would be 24kW/m^2.

The applicable proposed criteria from the draft Part 8 of the NCC are:

A building must avoid the spread of fire between buildings such that:

(i) The probability of a *reportable fire* in a building causing heat fluxes greater than the values on the adjacent allotment at the prescribed distances listed in Table 127 must not exceed 0.001 and

(ii) The probability of a building not being able to *withstand* the heat fluxes prescribed in Table 127 for a period of 30 minutes must not exceed 0.01 at the nominated distances from the boundary ."

Table 127 Heat flux and Distance Limits for building separation distances

Maximum heat flux (kW/m^2)	Distance from Boundary (m)	Distance between buildings on the same allotment (m)
80	0	0
40	1	2
20	3	6
10	6	12

Since the incident heat flux on the boundary is estimated to be 18kW/m^2 (a safety factor of 4.44) it is expected that the limits would not be exceeded by 99 percentile of flashover fires and a more detailed analysis is not required. This conclusion can also be conservatively applied to the 5-storey sprinkler protected building which is sprinkler protected.

Note: if a more detailed analysis is required distributions of maximum compartment temperatures could be derived based on enclosure dimensions, thermal properties of walls, ventilation conditions and fire loads and dimensions of the fire plume and the 99 percentile case selected for detailed analysis

Since the building is located more than 6m from the boundary the façade is required to withstand a maximum heat flux of 10kW/m^2 for 30 minutes. The external façade of the building is of non-combustible construction with double glazed toughened glass glazing with pain thickness greater than 6mm and is therefore expected to withstand radiant heat fluxes in excess of 10kW/m^2 based on various experimental results (e.g. Klassen [5])

N5. Fire Spread via the external façade

The applicable proposed criteria from the draft Part 8 of the NCC are

> The probability that the external façade of a building cannot *withstand* the following exposures from *reportable fires* must not exceed 0.001:
>
> i. flames venting through an opening from an enclosure fire within the building;
>
> ii. burning items adjacent to the structure such as a vehicle, waste bin, collection of combustible rubbish depending on the use and access to adjacent areas;
>
> iii. a fire occurring on a balcony.

These requirements are assumed not to apply to the single storey building. (note: this should be clarified in the draft provisions). The following analysis will therefore focus on the 5-storey school building.

Burning items adjacent to the building will be expected to impact on the ground floor non-school parts which are required to be non-combustible. Therefore, the school area was evaluated for flames venting through an opening on the ground floor which is expected to inherently address small burning items likely to be located adjacent to the structure since the proposed building configuration does not have vehicular access in close proximity to the façade.

There are no balconies provided for the fire-storey school building and therefore analysis of balcony fires is not required.

From section M3.2 the probability of a reportable fire in an apartment building spreading to the floor above in a concrete building was estimated to be approximately 0.002 without sprinkler protection. Noting the rare occurrence of external spread between floors in high-rise buildings with non-combustible facades it is considered conservative to apply this value to the subject building if the impact of sprinklers is ignored since spandrel panels of at least 900mm are required to be provided as part of the building design.

Allowing for the impact of sprinklers with an assumed effectiveness of 86% the probability of external fire spread can be estimated to be:

0.002 x 0.14 =0.00028 which is substantially less than the nominated limit of 0.001 with a safety factor (approx. 3.6). Therefore, a more detailed analysis was not considered necessary and it was determined that the metric for fire spread via the façade had been satisfied.

N6. Internal Fire Spread

N6.1. Proposed requirements

The proposed requirements extracted from the draft Part 8 requirements are summarised below

> A building must avoid the spread of fire within the building such that when a reportable fire occurs, the probability of fire spread does not exceed-
>
> (i) 0.01 to spread outside of an SOU;
>
> (ii) 0.01 to spread between storeys; and
>
> (iii) the values in Table 128.

Table 128 Internal fire spread limits to manage fire spread

Building Classification	Floor Area	Volume	Maximum probability of spread beyond specified floor area and volume
5, 9b	**3000m^2**	**18000m^3**	**0.01**
6,7,8, 9a,9c	2000m^2	12000 m^3	0.01
5-9	18,000m^2	21000m^3	0.001
Class 9c & 9a patient care areas	1000m^2	-	0.01

N6.2. Single storey reference building

The internal fire spread criteria applicable to the reference buildings require the probability of spread beyond 3000m^2 not to exceed 0.01 for a reportable fire

For this to occur a large fire that can spread beyond the compartment of fire origin needs to occur. From Table 45 the proportion of flashover fires (including times when the building is unoccupied) would be expected to be approximately 11% for reportable fires for an unsprinklered school building.

For a fire to spread to cover an area in excess of 3000m^2

- a fire occurring in one of the school modules would need to spread to the central access hub develop to flashover within that enclosure and then spread to a further two school modules or
- a fire occurring in the central access hub would need to develop to flashover and spread to three of the four modules.

The interconnecting fire resistant walls are of plasterboard construction and will include service penetrations and fire doors with FRLs of -60/30. The event tree shown in Figure 61 was constructed using suggested values from FSVM data sheets [14] C6 and C7 where appropriate.

EFT Consulting

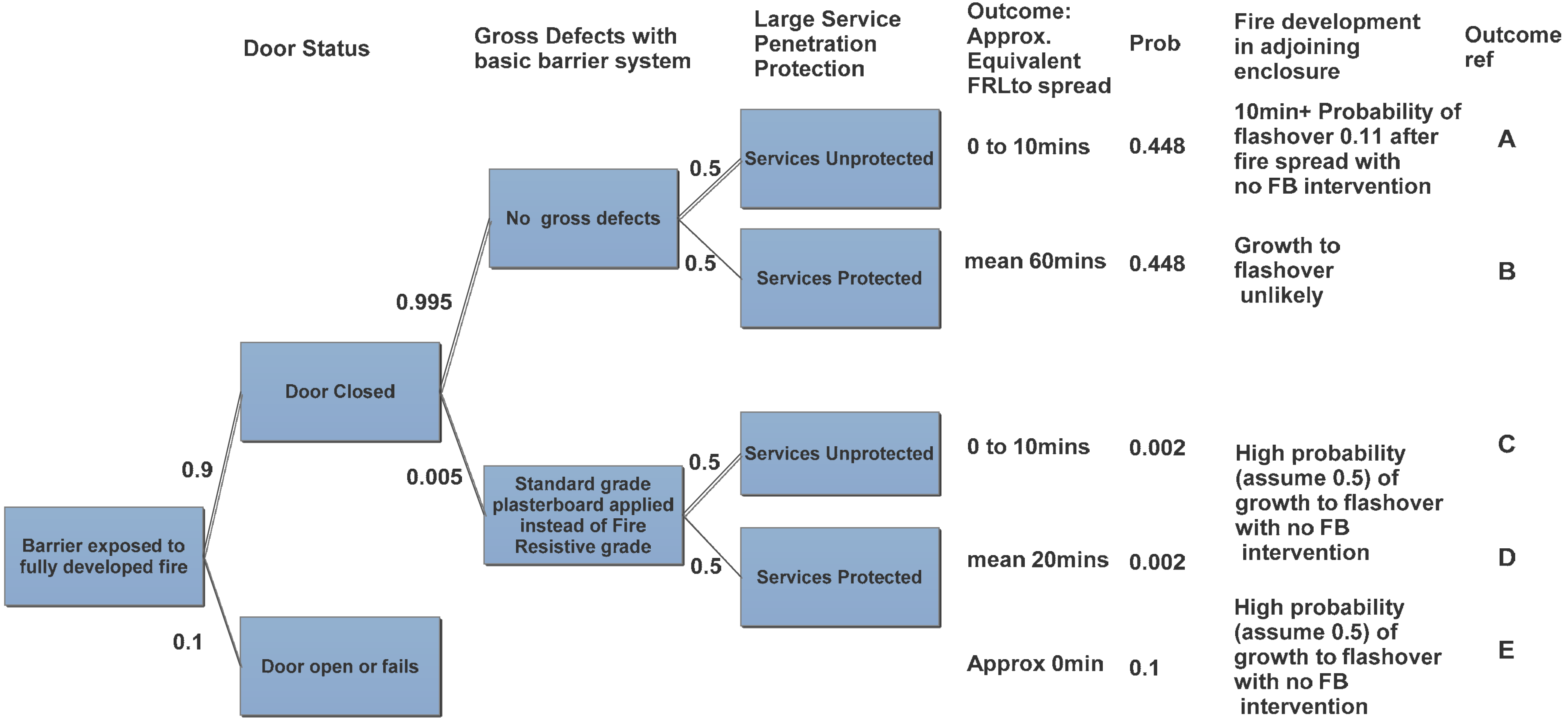


Figure 61 Event tree for fire spread through a fire resistant partition with a service penetration and self-closing fire door

The probabilities and timing of spread and subsequent fire development for each of the outcomes are summarised below

A. Probability of spread and flashover developing in an adjacent compartment estimated to be 0.049 (0.448 x 0.11) Time to spread estimated and subsequent flashover for a typical scenario estimated to be 10-15 mins
B. Spread to and flashover in adjacent compartment unlikely
C. Probability of spread and flashover developing in an adjacent compartment estimated to be 0.001 (0.002 x 0.5) Time to spread estimated and subsequent flashover for a typical scenario estimated to be 5-15 mins
D. Probability of spread and flashover developing in an adjacent compartment estimated to be 0.001 (0.002 x 0.5) Time to spread estimated and subsequent flashover for a typical scenario estimated to be 15-30 mins
E. Probability of spread and flashover developing in an adjacent compartment estimated to be 0.05 (0.1 x 0.5) Time to spread estimated and subsequent flashover for a typical scenario estimated to be 5-10 mins

The probability of a severe fire occurring (flashover fire) based on fire data was 0.11 and if this occurs the probability of the fire spreading to the next compartment and progressing to flashover would be the sum of the probabilities for outcomes A to E (i.e. 0.101)

Thus, the probability of the hub and one module becoming fully involved in the fire is estimated to be 0.011 (0.101 x 0.11) assuming no fire brigade intervention.

To exceed the 3000m^2 limit the fire needs to spread to three modules and the hub and the fire needs to spread throughout each of these modules and the hub. The probability of this occurring will therefore be substantially below the 0.01 limit ignoring fire brigade intervention and therefore no further analysis is considered necessary.

N6.3. **5-storey building**

The school building in defined as a Class 9b building.

The probability of internal fire spread between storeys needs to be maintained below 0.01 for a reportable fire.

The probability of a reportable fire achieving flashover based on fire incident data is approximately 0.11 and may occur when the building is occupied or unoccupied ignoring the impact of automatic sprinklers. The probability of the automatic sprinkler system being effective has been assumed to be 0.86 and if the system is effective it will prevent a fire progressing to a fully developed fire.

Therefore, the probability of a fire occurring that could threaten the fire separation between storeys is 0.0154 (0.11 x 0.14)

Assuming a high (conservative) probability of failure of 0.5 for the floor system due to the inclusion of services, construction joints etc the probability of fire spread would be 0.0077 which does not exceed the 0.1 limit and a more detailed analysis considering fire brigade intervention is not required.

It is also noted that if the effectiveness of the sprinkler system is increased to 91% the 0.01 probability limit will be satisfied although providing some redundancy is considered appropriate.

Appendix O. References

1. ISO, *ISO 16732-1 2015 — Fire safety engineering — Fire Risk Assessment — Part 1 General*. 2015, ISO: Switzerland.
2. Australasian_Fire_Authorities_Council, *Fire Brigade Intervention Model v2.2,*. 2004, Australasian Fire Authorities Council: Australia.
3. Productivity_Commission, *Report on Government Services 2018 Volume D, Chapter 9*, P. Commission, Editor. 2018: Canberra.
4. Korhonen, T. and J. Hietaniemi, *Fire safety of wooden façades in residential suburb multi-storey buildings.* VTT Building and Transport, 2005.
5. Klassen, M.S., et al., *Transmission through and breakage of multi-pane glazing due to radiant exposure.* Fire technology, 2006. **42**(2): p. 79-107.
6. England, J.P., *EFT 2604-6 Review of NCC Fire Safety Provisions for Primary Schools in High-rise buildings*. 2019, EFT Consulting: Melbourne.
7. ABCB, *Tolerable risk - Internal Use Handbook*. 2018, Australian Government and States and Territories of Australia: Canberra.
8. ABCB, *Handbook - Fire Safety Verification Method*. 2019, Australian Government and States and Territories of Australia: Canberra.
9. ABCB, *International Fire Engineering Guidelines Edition 2005*. 2005, Australian Building Codes Board: Canberra.
10. British_Standards_Institution, *PD 7974-7 Application of fire safety engineering principles to the design of buildings — Part 7: Probabilistic risk assessment*. 2019, British_Standards_Institution: UK.
11. Standards_Norway, *Fire Safety Engineering Guide for Probabilistic Analysis for Verifying Fire Safety Design in Buildings*. 2019, Standards_Norway: Norway.
12. Queensland_Independent_School_Block_Grant_Authority, *Learning Places and Spaces - Area guidelines for educational spaces*. 2017, QIS BGA: Queensland.
13. Wade, C., et al., *B-Risk Room Fire Simulator Software*. 2019, BRANZ: New Zealand.
14. ABCB, *Fire Safety Verification Method Data Sheets - Handbook annex*. 2019, Australian Building Coards Board: Canberra.
15. FEMA, *School Building Fires (2009-2011)*, in *Topical Fire Report Series*. 2014, U.S. Department of Homeland Security - FEMA: Emmitsburg, Maryland 21727.
16. England, J.P., *Draft - Supporting Guidance for the ABCB Fire Safety Verification Method - Group C Data Sheets Effectivness of Fire Safety Systems*. 2019, ABCB - Internal Use.
17. ISO, *ISO 13571:2012 — Life-threatening components of fire — Guidelines for the estimation of time to compromised tenability in fires*. 2012, ISO: Switzerland.
18. Drysdale, D., *An introduction to fire dynamics*. 2011: John Wiley & Sons.
19. ABS, *4221.0 - Schools Australia, 2018*, ABS, Editor. 2019, Australian Bureau of Statistics: Canberra.
20. ABS, *3101.0- Australian Demographic Statistics, Sep 2018*, A.B.o. Statistics, Editor. 2019: Canberra.
21. Pointer, S. and A. Tovell, *Hospitalised burn injuries, Australia, 2013–14*, in *Injury research and statistics series no. 102*. 2016, Australian Institute of Health and Welfare: Canberra.
22. Dowling, V.P. and G.C. Ramsay, *Building Fire Scenarios - An Analysis of Fire Incident Statistics*. 1996, CSIRO: Australia.
23. Castle, I., *4221.0 - Schools Australia, 1992*, ABS, Editor. 1992, Australian Bureau of Statistics: Canberra.
24. Snyder, T.D., C. De Brey, and S.A. Dillow, *Digest of Education Statistics 2017, NCES 2018-070.* National Center for Education Statistics, 2019.
25. V Apte, A.E., C Fleischmann, J Brian, C Wade, E Young, D Yung, *Design fires for apartment buildings - literature review, BRANZ Study Report 136*. 2005, BRANZ Ltd: NZ.
26. Campbell, R., *Structure fires in educational properties*. 2017: National Fire Protection Association, Fire Analysis and Research Division.
27. Department_of_Education_UK, *National pupil projections -future trends in pupil numbers:July 2018*, D.o.E. UK, Editor. 2018, HM Government: UK.

28. Coates, S., *Overview of the UK population:*. 2018, Office_for_National_Statistics.
29. Department_of_Education_UK, *Statistics of Education Schools in England 2002 Edition*, D.o.E. UK, Editor. 2002, HM Government: UK.
30. Department_for_children, s.a.f., *Building Design Bulletin 100: Design for fire safety in schools*, in *Department for Children, Schools and Families, EC2P 2EA, RIBA Enterprises Ltd (NBS), London*. 2007, Department for children, schools and families.
31. Department_for_Communities_and_Local_Government, *Fire Statistics: Great Britain April 2013 to March 2014 2010 to 2014*, U. Government, Editor. 2015: UK.
32. *Houston day care worker left children alone TWICE to go shopping on day of fire that killed 4 kids: prosecutors*, in *New York Daily News*. 2012, New York Daily News.
33. Holborn, P.G., P.F. Nolan, and J. Golt, *An analysis of fire sizes, fire growth rates and times between events using data from fire investigations.* Fire Safety Journal, 2004. **39**(6): p. 481-524.
34. Ahrens, M., *Reported Structure Fires by Extent of Fire Spread, Occupancy and Loss Rates.* 2013, NFPA: US.
35. Ahrens, M., *U.S. Experience with Sprinklers*. 2017, US: National Fire Protection Association.
36. Peacock, R.D., et al., *Defining flashover for fire hazard calculations.* Fire Safety Journal, 1999. **32**(4): p. 331-345.
37. Thomas, G., *Thermal properties of gypsum plasterboard at high temperatures.* Fire and materials, 2002. **26**(1): p. 37-45.
38. Hadjisophocleous, G. and Z. Chen, *A survey of fire loads in elementary schools and high schools.* Journal of fire protection engineering, 2010. **20**(1): p. 55-71.
39. Hall, J.R., *US Experience with sprinklers*. 2013: National Fire Protection Association. Fire Analysis and Research Division.
40. NFPA. *School fires with 10 or more deaths*. Jan 2013 [cited 2019 12 April 2019]; Available from: https://www.nfpa.org/News-and-Research/Data-research-and-tools/ARCHIVED/Fire-statistics/Fires-by-property-type/Educational/School-fires-with-10-or-more-deaths.
41. Stevens, R.E., *Flames Trap Fifteen in One-Storey School.* NFPA Quarterly, 1954. **47**(4): p. 331-337.
42. Babcock, C.I. and R. Wilson, *The Chicago school fire*. 1959: National Fire Protection Association.
43. International_Code_Council, *International Building Code 2018*, in *International Code Council, USA*. 2018, International_Code_Council.
44. HM_Government, *Approved Document B Volume 2 - Buildings Other Than Dwelling Houses*, in *Building Regulations 2010 Fire Safety*. 2006, HM_Government: UK.
45. HM_Government, *Ammendments to the Approved Documents*, in *Building Regulations 2010*. 2019, HM_Government: UK.
46. Ministry_of Buisness, I.a.E.N., *C/AS4 Acceptable Solution for Buildings with Public Access and Educational Facilities (Risk Group CA)*. 2017, Ministry_of Buisness,_Innovation_and_Employment NZ: NZ.
47. Ministry_of_Education, *Fire and safety design requirements for schools (July 2008)*, M.o. Education, Editor. 2018: New Zealand.
48. SEMC, *Emergency Management Framework for Vulnerable People*. 2015, State Emergency Management Committee (SEMC).
49. Page, I. and D. Norman, *The Prevelance and Fire Safety Implications of Early Childhood Centres in Multi-Storey Buildings.*, in *New Zealand Fire Service Commission Research Report*. 2015, New Zealand Fire Service Commission and BRANZ: New Zealand.
50. Taciuc, A. and A.S. Dederichs, *Determining self-preservation capability in pre-school children*. 2014: Springer.
51. Hamilton, G.N., P.F. Lennon, and J. O'Raw, *Human behaviour during evacuation of primary schools: Investigations on pre-evacuation times, movement on stairways and movement on the horizontal plane.* Fire Safety Journal, 2017. **91**: p. 937-946.
52. Lovreglio, R., et al., *A pre-evacuation database for use in egress simulations.* Fire Safety Journal, 2019. **105**: p. 107-128.

53. Australian_Curriculum_Assessment_and_Reporting_Authority, *School Students with Disability*. 2017.
54. and_Training_, D.o.E., *A summary of Statistics Victorian Schools*, S.o.V.D.o.E.a. Training, Editor. 2018: Victoria.
55. Swinburn, A., *Vertical School Design: Strategising the spatial configuration of a multi-storey typology to facilitate education in dense city environments.* Byera Hadley Travelling Scholarships Journal Series, 2017.
56. Gray, T., et al., *Vertical schools and green space: Canvassing the literature*. 2018, Western Sydney University. https://doi. org/10.26183/5bd93af6a3ca5.
57. Andrew Knox and H. Parry-Husbands, *Workplaces:Wellness + Wood = Productivity*. 2018, Pillinate: Australia.
58. England, J.P., *Draft - Supporting Guidance for the ABCB Fire Safety Verification Method - Group B Data Sheets Derivation of Design Fires*. 2018, ABCB - Internal Use.
59. Engineers_Australia_Society_of_Fire_Safety, *Practice Note for Tenability Criteria in Buildings*. 2014, Engineers Australia: NSW.
60. England, P., *WoodSolutions Technical Design Guide 38 Fire Safety Design of Mid-rise Timber Buildings. Basis for the 2016 changes to the National Construction Code.* 2016: Australia.
61. White, N. and M. Delichatsios, *Fire Hazards of Exterior Wall Assemblies Containing Combustible Components*, in *Fire Protection Research Foundation report*. 2014, NFPA.
62. C A Wade and J.C. Clampett, *Fire Performance of Exterior Claddings*. 2000, BRANZ.
63. Oleszkiewicz, I., *Vertical separation of windows using spandrel walls and horizontal projections.* Fire Technology, 1991. **27**(4): p. 334-340.
64. Delichatsios, M.A., et al. *Vertical safe separation distance between openings in multi-storey buildings having a fire resistant spandrel*. in *MATEC Web of Conferences*. 2016. EDP Sciences.
65. Hurley, M.J., *Evaluation of models of fully developed post-flashover compartment fires.* Journal of Fire Protection Engineering, 2005. **15**(3): p. 173-197.
66. British_Standards_Institution, *Eurocode 1: Actions on structures —Part 1-2: General actions — Actions on structures exposed to fire*. 2002.
67. England, J.P., *A Framework for a Risk Based Approach to the Fire Engineering Design of Structures*, in *10th International Conference on Performance-Based Codes and Fire Safety Design Methods*. 2014, SFPE: Gold Coast Australia.
68. J. Blackmore, et al., *Room and Furnace Tests of Fire Rated Construction*. 1999, CSIRO, BHP, VUT: Australia.
69. Milke, J.A., *Analytical methods for determining fire resistance of steel members*, in *SFPE handbook of fire protection engineering*. 2016, Springer. p. 1909-1948.