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EXECUTIVE SUMMARY

An independent technical review of Report No. JA18-00224 Final (Rev1) -'Fire Safety of Early Childhood Centres in High Rise Buildings in Australia', by RED Fire Engineers has been undertaken.

The focus was to be the absolute risk analysis with an emphasis on;

1) the data used to inform ignition probability (i.e. fire start frequencies).
2) the approach taken to derive individual and societal risk and tolerable risk criteria
3) the validation of the findings against fire statistics.
4) any other relevant observations in relation to the analysis and findings

Where necessary supplementary analysis of fire statistics has been undertaken to address items 1) to 3). Detailed checks on the calculations and modelling on which Report No. JA18-00224 was based, including re-running modelling, was excluded from the scope of the technical review.

This review was commissioned after completion of Report JA 18-00224, and therefore there was no opportunity to provide progressive feedback to the authors during preparation of their report and for them to take account of the feedback which would be normal practice for a Peer Review. Nor has there been an opportunity to clarify aspects of the report with the authors.

These limitations should be taken into account when considering the observations made.

Using the above numbering system, the following conclusions have been drawn

1) Data used to inform ignition probability

The assumed ignition probability (fire start frequency) was found to be consistent with other sources and reviewed fire statistics and is considered reasonable.

2) Approach taken to derive individual and societal risk and tolerable risk criteria

(i) The ABCB Draft Tolerable Risk – Internal Use Handbook [1] was used to derive the tolerable risk criteria.

(ii)The Building Class Group was correctly identified as BCG 3;

(iii) The corresponding Benchmark Safety Hazard Individual Risk for fire was correctly identified as 3.39×10^{-7} $year^{-1}$

(iv) The corresponding Benchmark Safety Hazard Societal Risk for fire stated in report JA18-00224 was not in accordance with the ABCB Draft Tolerable Risk – Internal Use Handbook. The difference between the tolerable societal risk prescribed by the handbook and that adopted in report JA18-00224 does not materially affect any other findings in this report.

(v) The method adopted in report JA18-00224 to calculate individual risk was not considered consistent with the definition of individual risk in the ABCB Draft Tolerable Risk – Internal Use Handbook. The equation used in report JA18-00224 would provide higher values for individual risk than the equation nominated in this technical review report, which is consistent with the individual risk definition in the Handbook. The magnitude of this difference will vary from case to case and it is not possible to quantify accurately, without access to the consequences for each branch of the event trees. If corrections to the individual risk calculations are made, it will only account for a relatively small proportion of the very high overestimates of losses.

(vi) The F-N plots or societal risk appear to be broadly consistent with the modelling results and event trees presented, but a more definitive comment cannot be provided without reviewing additional data

3) Validation of the findings against fire statistics

Estimates were based on US statistics (for two three-year intervals) during which there were only two events in which fatalities occurred. The first occurred just outside the sample period but has been included to provide a conservative estimate. In this event, the fatalities comprised three children and an adult. The second occurred in a family care facility (domestic dwelling style building) with the supervisory person absent at the time of the fire and therefore, is not representative of a centre based facility with multiple supervisory staff. No other fatalities were identified during these periods. Using both these events to calculate the risks in ECC would be expected to provide an overestimate of the risk. However, because the events are so rare it should be noted that the risk estimates would be sensitive to an individual event.

(i) The best estimate based on the limited statistics available indicated that the average individual risk of fatality /annum for an ECC would be expected to be of the order of 1.8×10^{-7}. This indicates that the ABCB Tolerable Risk Benchmark Safety Hazard Individual Risk for fire of 3.39×10^{-7} year^{-1} is attainable and appropriate. The estimated individual risk of fatality /annum for Design Case 1 (the single storey benchmark building) quoted in report JA18-00224 was 5.58×10^{-4} which is substantially greater than the historic risk based on fire statistics.

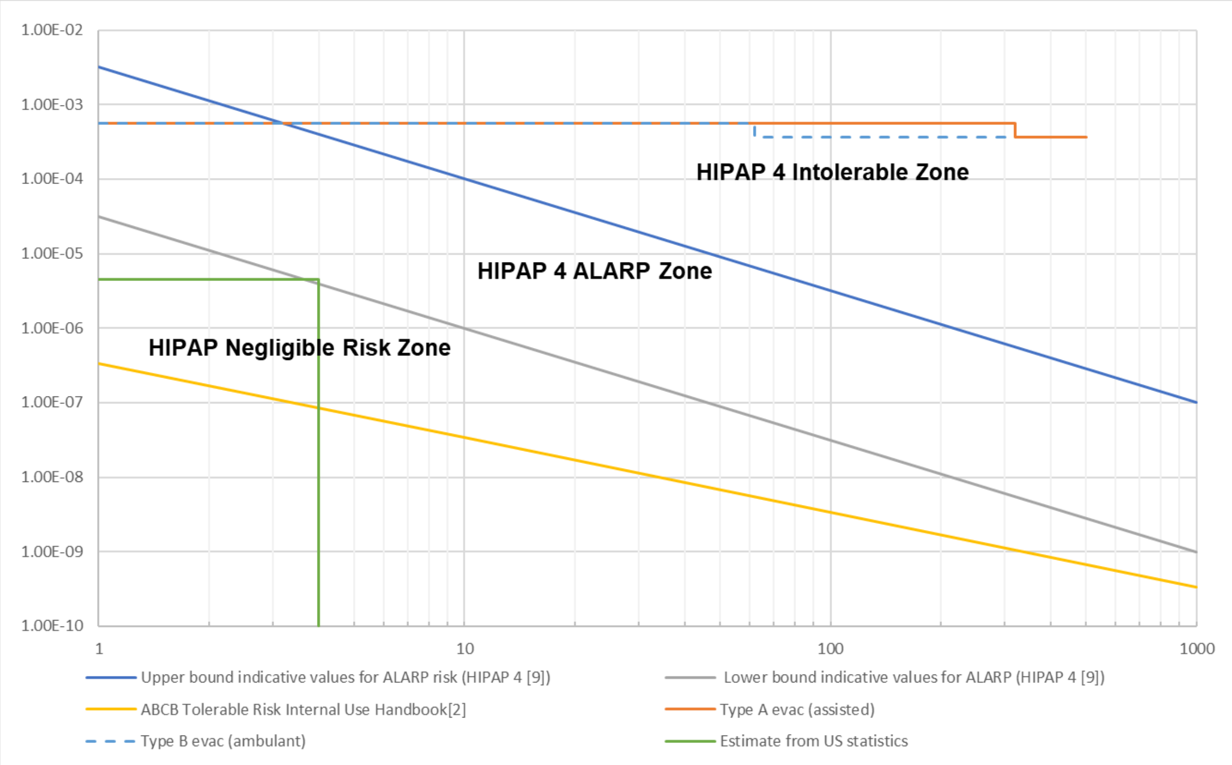
(ii) The frequency of occurrence of four or more fatalities per daycare centre per annum (assuming an average facility size of 100) was estimated to be 4.5×10^{-6} which provides a point on an F-N plot. This point sits on the lower bound indicative risk values for ALARP from NSW Risk Criteria (HIPAP4) [2] as shown in the following figure. This lower bound separates the negligible risk zone from the ALARP zone where measures should be considered to reduce the risk to a level that is “as low as reasonably practicable”.

The ABCB Tolerable Societal Risk Criteria requires a substantially lower frequency of less than 1×10^{-7} events involving four or less fatalities. Based on the statistics reviewed this may be difficult to achieve.

The F-N results presented in report JA19-0024 for a single storey facility indicated that

- For an ECC with Type A children (children that require carrying during evacuation), 500 occupants are exposed to untenable conditions at a frequency of approx. 4 x 10^{-4} / annum).
- For Type B children (children that are ambulant but require supervision during evacuation), 300 occupants are exposed to untenable conditions at a frequency of approx. 4 x 10^{-4} / annum).

These frequencies and the magnitude of losses substantially exceed the estimates based on statistics and both the ABCB Tolerable Risk Criteria and the HIPAP4 criteria as shown in the following figure;



Results from Single Storey Design Case 1 compared to Societal Risk Benchmarks and an estimate of societal risk based on US statistics.

The largest variance in the analysis from the societal risk benchmarks occurs where 10 or more fatalities occur in a single incident. Such incidents are very rare and no directly applicable data could be identified for more than 4 fatalities in the equivalent of ECCs.

Reference was therefore made to NFPA published statistics on multi-fatality fires from kindergarten to year 12 schools, with 10 or more deaths, which has some relevance the ECCs especially those with older Type B ambulant children. Ignoring two explosion related incidents there were six events with 10 or more fatalities between 1908 to 1958. In the 60-year period since 1958 there were no reported fire incidents in US schools that resulted in 10 or more fatalities.

It is therefore concluded that report JA18-00224 is substantially overestimating the risk in single storey ECC facilities compared to fire statistics.

4) Other Relevant Observations

(i) The arrangement of the report is logical and reasonable to follow with effort taken to explain the assumptions made. It would have been helpful for the outcomes (consequences) for each event tree branch to have been identified but it is acknowledged that there is a fine balance between too much and too little information.

(ii) It is not uncommon when undertaking an absolute QRA for the level of risk to be overestimated due to conservative assumptions being adopted particularly where there is some uncertainty regarding inputs and modelling methods. Whilst the report included some sensitivity analyses, the very high-risk levels predicted and variance from expected losses was not fully explained.

(iii) Undertaking a comparative analysis against a similar benchmark building, that provides an acceptable level of safety, is an appropriate, and established means of reducing the sensitivity to simplifications and assumptions. However, in this case substantial variations between the benchmark building and the other design cases, with respect to building height and fire safety systems for example, could not be avoided. Report JA18-00224 investigated the sensitivity of the outcomes to some simplifications and assumptions. The following observations therefore focus on other matters that could explain the overestimates of individual and societal risks, impact significantly on the comparative analysis results or may present additional hazards not addressed in the risk assessment.

(iv) A very large ECC (418 children) was adopted for the analysis compared to the average size of an ECC (60 children). This is expected to have had a very large impact on both the absolute and comparative risk levels predicted. The distribution of ECC sizes should be checked and an average size facility analysed. If there are significant numbers of large ECCs in high-rise buildings, it may be appropriate to consider additional requirements for large facilities such as additional compartmentation.

(v) Report JA18-00224 assumed that all flaming fires progressed to a maximum size of 20MW. A significant proportion of these would be likely to peak below 20MW. This assumption may have contributed to the overestimate of the absolute risk and may also affect the comparative risk by, for example, overestimating the impact of automatic suppression compared to detection and evacuation options.

(vi) In determining the location of design fires, the risk of ignition based on the usage of the functional areas was not considered. Instead it was assumed fires occurred in play areas, with 60% occurring in the main play area which in the selected building layout was on the path of travel to both exits. This assumption may significantly impact on the absolute and comparative risk results and lead to specific hazards not being identified. Statistical data could be used to identify high frequency locations for fire starts (e.g. kitchens) and help identify mitigation methods (e.g. fire separation of kitchen and laundry areas).

(vii) Fire Brigade intervention was not considered. This is expected to impact on the absolute analysis significantly and to some extent on the comparative analysis

(viii) Consistent with current fire engineering practices (particularly relating to deterministic designs) it was assumed that there was no incipient (smouldering) phase prior to the t-squared growth phase of the fire and generally conservative assumptions relating to the timing of the identification of fire cues and tenability criteria were adopted. These assumptions are expected to have contributed significantly to the overestimates of absolute risk.

(ix) Report JA18-00224 excluded the analysis of potential interactions with occupants from other floors of the building and fire brigade personnel within the fire isolated stairs during an emergency evacuation and acknowledged that this exclusion would underestimate the risk to occupants. It is considered that the interaction with occupants from other floors is a significant additional hazard introduced by locating ECCs in high-rise buildings and must be addressed. The likely impacts of the interactions include significant delays to the evacuation of ECC occupants and other occupants of the building which would have a significant impact on absolute and comparative risks. In addition, there are other hazards that need consideration including:
a. a crush resulting from the simultaneous evacuation of young slow moving children and other occupants.
b. abduction due to uncontrolled access to the children
c. inadequate security and safety for the children outside the building

(x) The following fire and smoke spread scenarios were not considered but may increase the risk to occupants from a fire on another floor;
- External fire spread between levels
- Smoke spread via lift shafts, service shafts from other levels
- Smoke spread through fire resistant doors in the closed position

(xi) For a very large ECC facility the proposed enhancements included in report JA18-00224 are considered a reasonable approach to significantly reduce the fire risk, particularly if the doors separating the compartments are also designed to restrict the spread of smoke. This approach would then have some similarity to Class 9c buildings provisions. Smoke spread via the lift shaft may also require some attention.

(xii) Consideration could be given in the ABCB Tolerable Risk Verification Method to the adoption of tolerable societal risk criteria that are not based on the tolerable individual risk to avoid confusion when using the method. In some cases, the required tolerable societal risks derived using the currently proposed method may be impractical to achieve.

(xiii) An example calculation of Individual risk based on QRA outcomes could be included in the ABCB Tolerable risk - Internal Use Handbook to assist users.

CONTENTS

1. Scope

The scope of the project is to provide an independent technical review of Report No. JA18-00224 Final (Rev1) -'Fire Safety of Early Childhood Centres in High Rise Buildings in Australia', by RED Fire Engineers.

The focus is to be the absolute risk analysis with a particular emphasis on;

- the data used to inform ignition probability (i.e. fire start frequencies).
- approach taken to derive individual and societal risk and tolerable risk criteria
- validation of the findings against fire statistics

Notwithstanding this any other relevant observations in relation to the RED report's analysis and findings were required to be included.

Where necessary supplementary analysis of fire statistics has been undertaken to address the above dot points.

2. Limitations

Detailed checks on the calculations and modelling undertaken including re-running modelling was excluded from the scope of this technical review.

This review was commissioned after completion of Report JA 18-00224.Final (Rev1) and therefore there was no opportunity for progressive feedback to the authors during preparation of their report to provide the opportunity for them to take account of comments which would be normal practice for a Peer Review. Nor has there been an opportunity to seek clarification of certain aspects of the report from the designers.

These limitations should be taken into account when considering the observations made in this report in particular the lack of opportunity for the authors to update the report.

3. Background, Objectives and Required Scope of Report JA 18-00224

The following information has been extracted from the Approach to Market Reference ID: ABCB RA/1-2018 issued by the ABCB which defined the objectives and scope of works for the Report JA 18-00224.

"Background

The ABCB is carrying out a detailed investigation into the fire safety of children particularly in early childhood centres in high rise buildings as part of the Holistic Review of Fire Safety (HRFS) Project.

With the requirements for outdoor play spaces, the high cost of ground and first floor retail spaces, and the density of city development, the most practicable available spaces are now often levels that are several storeys above ground and most commonly in high rise office buildings.

The NCC's fire safety provisions have evolved over the past 20 years in response to fire incidents and the changing nature of building occupation and use. There is some opinion that fire safety relating to early childhood centres now being located in high rise buildings may be inadequate.

As the locating of early childhood centres in high rise buildings is a relatively new phenomenon, the degree of fire safety provided is unknown. Also there is no body of evidence that can be relied upon to validate the concerns which have been raised. Therefore, it is suggested that quantitative risk analysis be used to inform whether the level of risk is tolerable and within an acceptable range.

The Project objectives are:

1. Review/confirm the adequacy of the current fire safety performance requirements and deemed to satisfy (DTS) provisions of the NCC with regard to children in Early Childhood Centres in high rise buildings in Australia.
2. Compare the current NCC provisions against international requirements of similar countries.
3. Review Commonwealth, State and Territory and other jurisdictional body administrative and operational procedures and guidance information as to its impact on the safety of children within Early Childhood Centres in NCC compliant buildings.

The Project Scope includes:

- Considering previous studies undertaken by the ABCB (including the “BCA Early Childhood Centres Review” by Ove Arup Pty Ltd;
- Considering trends in the performance-based design of buildings, changing technology and the use of buildings that can be applied to Early Childhood Centres;
- Considering international approaches to Early Childhood Centres in high-rise buildings;
- Carrying out a Quantitative Risk Assessment (QRA) on the NCC DTS provisions with regard to Early Childhood Centres in high rise buildings and compare with the ABCB tolerable risk guidelines. The base for comparison shall be a facility located at ground floor level. Cases at storey levels above and below 25 metres shall be considered;
- Examine whether jurisdictional administrative and operational provisions and the use of guidance material from other bodies are adversely affecting the current fire safety level of NCC provisions for these buildings; and
- Developing a final report for consideration by the ABCB.”

4. Supporting Documentation

The following supporting data relating specifically to this project has been considered where appropriate;

- Approach to Market ABCB RA/1-2018 for an assessment of the fire safety of Early Childhood Centres in NCC high rise buildings
- High Rise Buildings in Australia JA 18-00224 Final (Rev1)[3]
- BCA Early Childhood Centre Review – Consultancy Services to Evaluate Building Code of Australia Fire Safety Provisions Relating to Early Childhood Centres: Draft 2 by Ove Arup Pty Ltd.[4]
- ABCB Draft Tolerable Risk – Internal Use Handbook ABCB 2018[1]

5. Overview of Approach Documented in Report JA18-0024

A benchmark single-storey Early Childhood Centre (ECC) was defined (Design Case 1) together with the following additional design cases;

- Design Case 2: A 2-storey building with an ECC on the 2nd level connected to a ground floor library by means of stair with toughened glass elements separating the library from the stair
- Design Case 3: A 2-storey building with an ECC on both levels connected to a ground floor library by means of an open stair
- Design Case 4: A 8-storey (effective height less than 25m) building with the ECC on level 7.
- Design Case 5: A 8-storey (effective height more than 25m) building with the ECC on level 8.

All design cases were subsequently compared against the individual and societal risk criteria in the ABCB Draft Tolerable Risk – Internal Use Handbook and Design Cases 1. In addition, Design Cases 2 to 4 were compared against Design Case 1 (the benchmark case)

The literature review (Section 3) addressed the first three dot points of the brief through the inclusion of the following;

- A review of the previous study undertaken by Arup[4]
- A summary of State and Territory requirements for Early Childhood Centres
- A review of the BCA requirements
- A Review of other national codes (New Zealand Building Code, BBR Sweden and US - NFPA 101

Section 4 provides a more detailed characterisation of the Design Case Buildings and Occupant Characteristics and explains the basis of a number of assumptions made.

Section 5 provides an overview of the QRA process including the construction of event trees, description of interpretations relating to risk definitions and acceptance criteria.

Section 6 describes the Egress modelling approaches including assumptions and limitations, and derived inputs.

Section 7 - Consequence Assessment, includes details of the fire and smoke spread modelling undertaken to determine amongst other things ASET for the various branches of the event trees which is used in conjunction with the Egress modelling outcomes to determine the numbers of occupants exposed to untenable conditions for each of the event tree branches

Section 8 presents the results and Section 9 related sensitivity analysis.

The results are discussed in Section 10 and Conclusions and Recommendations drawn in Section 11.

Appendix A includes Analysis of recommended changes to the NCC.

The arrangement of the report is logical and reasonable to follow with effort being taken to explain the assumptions made.

It would have been helpful for the outcomes (consequences) for each event tree branch to have been identified, but it is acknowledged that there is a fine balance between too much and too little information. This data would have enabled scenarios with very high losses to be identified and investigated more easily.

6. DATA USED TO INFORM IGNITION PROBABILITY

6.1. ECC SIZE.

The estimate of ignition frequency was based on the floor area using the coefficients derived by Tillander [5] for what were considered the most relevant occupancies. The ignition frequency is therefore sensitive to the floor area of ECC adopted for the analysis. As the floor area was also used to derive the number of occupants the impact on societal risk would also be significant because of the increase in numbers exposed in some scenarios

A very large ECC was assumed (416 children and 84 staff) compared to an average facility which would be expected to cater for approximately 60 children. Table 1 derived from the 2016 Early Childhood Education and Care National Workforce Census [6] provides a summary of the average number of places at ECCs.

Table 1 Average Number of Places at ECCs

Average number of places	Long Day services	Outside School hours care	Vacation care services	Total
Average Maximum offered	61	56	59	59
Average Typically offered	56	46	50	52

A typical floor area was estimated to be approximately 500m^2 (potentially a high estimate) for an average facility housing 60 children and 12 staff (assuming the same children to staff ratios as Report JA 18-00224).

The adopted Tillander correlation was not stated but based on the stated frequency (1.07 x 10^{-2} per year included in the report) the institutional care correlation has been assumed for the estimates in Table 2

Table 2 Comparison of Parameters for an Average Facility and the Design Cases

Parameter	Estimated Average Case	JA 18-0022 Design Case
Floor area – m^2	500	2000
Number of children	60	416
Number of staff	12	84
Estimated frequency of fire starts / annum based on Tillander Institutional care coefficients	0.0029	0.011

It was not unreasonable to select a very high percentile floor area as a worse case for design purposes for a deterministic or comparative study, but it may have been more appropriate to select an average or median size particularly for the QRA for the benchmark single storey building to facilitate comparison of the modelling outcomes against available statistics to provide confidence in the outcomes. Ideally it would be of benefit to consider a range of sizes but within the project constraints it is understood that it was not feasible.

It would also be a valid risk management approach from a technical perspective to limit the maximum ECC size in high-rise buildings if practical outcomes can be obtained with numbers closer to a typical facility.

6.2. Other Data Sources

The report referenced other sources of information (generally design guides) for ignition frequencies and also undertook a sensitivity analysis since the rates from the guides can vary by orders of magnitude and the relevance of the occupancies in the guides to ECCs may be relatively limited. As expected, the outcomes are proportional to the frequency of ignition.

The ignition rates could also be compared with estimates derived directly from fire statistics. A study current being undertaken has estimated a frequency of fire starts for a 4000m^2 primary school with 360 students to be approximately 0.013 fires /annum based on fire statistics predominantly from the UK and US which is of the same order of magnitude as the estimate for the ECC with 416 children in Table 2.

The frequency of fire starts (or ignition probability) adopted in Report JA 18-00224 is therefore considered reasonable for the size of ECC adopted for the analysis

7. Derivation of Individual and Societal Risk and Tolerable Risk Criteria

7.1. Selection of Tolerable Risk Criteria from Tolerable Risk Handbook

The Building Class Group was correctly identified as BCG 3 and the corresponding Benchmark Safety Hazard Individual Risk for fire was also correctly identified as 3.39×10^{-7} year^{-1}.

The benchmark societal risk values were not derived in accordance with the procedure included in the Tolerable Risk Handbook which requires that;

“the Benchmark Safety Hazard Societal Risk for fire (and other hazards) is derived by assuming a tenfold decrease in the likelihood of a multiple fatality event for each tenfold increase in potential fatalities, as anchored against the Benchmark Safety Hazard Individual Risk for fire for the Building Class Group relevant to the subject building in accordance with VM V1.0”.

The values derived following this procedure for BCG 3 are presented in Table 3.

Table 3 Benchmark Safety Hazard Societal Risk for Fire for BCG 3

Fatalities (N)	Benchmark Safety Hazard Societal Risk for fire
N=1	3.39×10^{-7}
N=10	3.39×10^{-8}
N=100	3.39×10^{-9}
N=1000	3.39×10^{-10}

The values in Report JA 18-00224 appear to have been taken from an example in the Tolerable Risk Handbook representing typical QRA outputs for comparison against the Benchmark Safety Hazard for the Societal Risk for fire.

7.2. Calculation of Individual Risk

7.2.1. Assumed Periods of Occupancy

Report JA 18-00224 selected an option to calculate the Location Specific Individual Risk in section 5.1 which is appropriate and proposed the following definition;

“the annual probability of a hypothetical person located in the same location for an entire year becoming a fatality”.

The above definition is consistent with an assumption that was made in Report JA 18-00224 that the building was occupied and in use 24-hours per day 7 days a week. The report explained that this assumption was conservative however the assumption will over predict the number of fatalities / year and is not appropriate in an absolute analysis. It would also imply the building was effectively a residential type building occupied at all times by the hypothetical person.

An alternate definition that accounts for periods when the building is unoccupied is to consider a typical full time equivalent attendee could be as follows;

“location specific individual risk is the frequency at which a full time equivalent individual may be expected to become a fatality as the result of a fire when attending the ECC”.

Under this alternate definition there would be no fatalities of children that attend the ECC at times when the ECC is unoccupied (overnight and potentially weekends) and the risk estimates should be adjusted accordingly. This adjustment was suggested in report JA 18-00224 under these circumstances.

7.2.2. Calculation of individual risk from event tree outcomes

The following relationship was stated to have been used to calculate the individual risk in report JA 18-00224;

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

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

This relationship is only valid for scenarios where all the occupants are exposed to untenable conditions but is relevant to the calculation of the societal risk for 1 or more fatalities.

This is best demonstrated by the following example which assumes the risk of exposure to untenable conditions is the same for all occupants;

If half the occupants are exposed to untenable conditions during a scenario there would only be a 50% probability of a specific person being exposed to untenable conditions.

The following relationship is therefore suggested for the calculation of Individual risk for scenarios where the ECC is occupied.

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

where;
IR Individual Risk [$year^{-1}$]
F_i frequency of scenario *i* provided that $C_i \geq 1$ [$year^{-1}$]
C_i fatalities associated with scenario *i* [-]
n total number of scenarios [-]
p_i is the population of the ECC for scenario *i*

This will have an impact on the calculated Individual Risk values throughout the report

It is noted that report JA 18-00224 indicated that the Tolerable risk handbook did not include an equation for calculation of the Individual Risk. Also, the use of an Individual Risk Benchmark to anchor the societal risk implies there is a relationship between Individual risk and societal risk which tends to cause confusion. Consideration should be given to updating the internal draft handbook to include an example equation for Individual Risk and potentially modifying the Societal Risk Benchmark so that it is independent of the Individual Risk Benchmark to avoid confusion.

7.3. Calculation of Societal Risk

7.3.1. Assumed Periods of Occupancy

The comments made in Section 7.2.1 also apply to the calculation of Societal Risk.

7.3.2. Calculation of Societal Risk from event tree outcomes

Since the outcomes for the event tree branches are not provided it is not possible to draw any firm conclusions regarding the calculation methods for societal risk.

8. Comparison of the Findings with F-N Benchmarks and Fire Statistics

8.1. Comparison with F-N Benchmarks

The societal risk results are substantially higher than expected for all the design cases. Since the current NCC provisions focus on single storey-ECCs and the majority of existing NCC and similar facilities are single storey the results for the Design Case 1 (single-storey) will be compared against the ABCB tolerable risk criteria for BCG3 and the NSW Risk Criteria for Land Use Safety Planning Hazardous Industry Planning Advisory Paper No 4 (HIPAP4) [2]. These benchmark cases have been plotted as F-N curves with $\log_{10}$ scales in Figure 1 for children that require carrying during evacuation (Type A) and ambulant children that require supervision during evacuation (Type B).

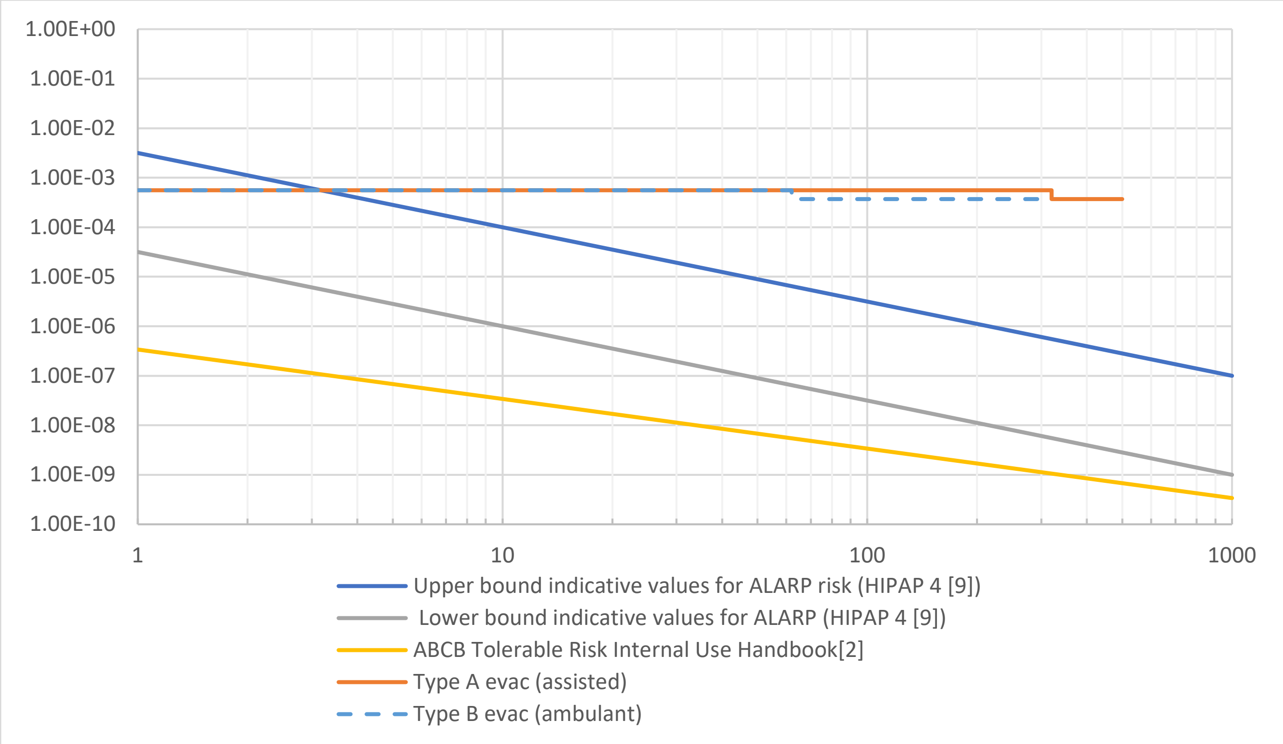


Figure 1 Results from Design Case 1 with Type A and B occupants (F-N results scaled from plots in report JA18-00224) compared to Societal Risk Benchmarks

It can be observed that for Type A (non-ambulant) children, scenarios occur in which all 500 occupants are exposed to untenable condition at a relatively high frequency (approx. 4 x 10^{-4} / annum).

For Type B (ambulant) children scenarios occur in which over 300 occupants are exposed to untenable conditions also occur with a similarly high frequency (approx. 4 x 10^{-4} / annum).

From a comparison with the NSW Risk Criteria for Land Use Safety Planning Hazardous Industry Planning Advisory Paper No 4 (HIPAP4), it could be argued that the draft ABCB Societal Tolerable Risk Criteria are conservative in this case and could be reviewed. The established HIPAP 4 indicative criteria have therefore been used for as a benchmark for comparison.

For the highest loss scenarios, the upper bound frequency limit from HIPAP 4 (above which the risk would be considered unacceptable) is approximately 1000 times lower than the F-N plots derived in report JA18-00224 for an ECC at ground level. The lower bound frequency from HIPAP 4 (below which the risk is considered negligible) is approximately 100,000 times lower than the F-N plots for the ECCs. To put this in perspective if automatic sprinklers were introduced the risk reduction would be likely to be less than a factor of 10.

8.2. Comparison of Individual Risk with Fire Statistics

Only limited fire statistics are available in the public domain in Australia and because of the relatively small population and low frequency of occurrence of injuries and fatalities in non-residential buildings the sample size is very low. Therefore, reliance needs to be placed on other sources.

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)[7].

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

- Preschools and daycares (ECCs and family daycares)
- Kindergartens
- Elementary schools (primary schools)
- Middle junior and high schools (secondary schools)
- Other non-adult schools

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 (family) day-care facility. The four fatalities yield an average of 1.33 fatalities / annum. Press reports indicate a fire in a day-care facility of domestic dwelling type construction (family 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 [8]) This situation is extremely unlikely to occur in centre based care facilities similar to Australian ECC facilities.

From Table 202.30 of the Digest of Education Statistics [9] 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 day care.

An approximate estimate of individual risk to children from fires in family day-care facilities (not ECC facilities) can be obtained by dividing the number of fatalities a year by the number of children attending the family day-care facilities.

There were an average of 1.33 fatalities / annum over the 3 year period that occurred in family day-care facilities with approximately 1,721,000 children exposed to the risk yielding an individual risk of fatality / annum for a child attending a family childcare facility of 7.72×10^{-7} which is greater than the Benchmark Safety Hazard Individual Risk for fire for group BCG 3 of 3.39×10^{-7} but family day-care facilities are generally adapted domestic residential buildings.

If the 1.33 fatalities / annum are apportioned across all centre based care facilities for children up to 5 years old (which are generally the equivalent of Australian ECCs) with a total of approximately 7,450,000 children the individual risk of fatality / annum for a child attending would be 1.79×10^{-7} which is less than the Benchmark Safety Hazard Individual Risk for fire for group BCG 3 of 3.39×10^{-7}.

Older data is available from the period 1996-1998 for Daycare Center Fires in the US[10] which are directly applicable to ECC type buildings. The key findings from the topical report were;

- An estimated 325 fires occur in daycare centers/facilities each year. These fires rarely injure or kill anyone—less than 10 injuries or fatalities each year—but they cause an average of $1.6 million in property loss.

- Cooking is the leading cause of daycare center fires. Children playing with fire are not a significant cause.
- Smoke alarms operate in 63% of daycare center fires—a much higher rate than in non-residential structures in general.
- Licensing regulations and building codes for daycare facilities emphasize fire prevention and protection.

The fire loss data for day care centres compared to all non-residential buildings for the period 1996 to 1998 is summarised in Table 4.

Table 4 Loss Measures for Day Centre Fires (3-year average (1996-98)) from Topical Research Series Volume 2, Issue 15 Daycare Centre Fires

Loss Measure	All Non-residential Structure Fires	Daycare Centre Fires
Dollar Loss/Fire	$21,878	$5,975
Injuries/1,000 Fires	22.1	23.9
Fatalities/1,000 Fires	1.7	0

The Topical Report[10] included the following details of a fatal fire that occurred just outside the sample period; In January 1999, a faulty clothes dryer ignited a daycare centre fire. The ensuing blaze killed the centre's owner and three children, ages 2, 1, and 3 months. A fourth child suffered permanent brain damage.

To obtain an estimate of the individual risk within day centres it is therefore reasonable to assume an average of one fatality / annum occurs. The number of Daycare centres in the US in 1999 would be less than the number in 2013. On this basis the average individual risk of a fatality /annum would be expected to be similar to the 1.79 x 10^{-7} estimate derived from the 2009-2011 data above which was based on 1.33 fatalities /annum occurring from an expected larger number of fatalities.

The limited statistical data available indicates that the ABCB Tolerable Risk Benchmark Safety Hazard Individual Risk for fire of 3.39 × 10^{-7} year^{-1} is attainable and appropriate.

The Individual Risk of fatality /annum for design case 1 with Type A or Type B children from report JA19-0024 was 5.58 x 10^{-4}. As noted in Section 7.2 the calculation method adopted reflected the societal risk of 1 or more fatalities and not the individual risk. It is expected that there would be a reduction in this value if the individual risk was calculated using the suggested approach but there would remain a very large variance from the Benchmark Safety Hazard Individual Risk for fire of 3.39 × 10^{-7} year^{-1} and the societal risk estimated from statistics of 1.79 x 10^{-7}.

8.3. Comparison of Societal Risk with Fire Statistics and Incidents

The review of data relating to individual risk identified two incidents with 3 or 4 fatalities that occurred during the periods 1996-1999 and 2009-2011. A potentially conservative estimate would assume 1 multiple fatality every 3 years in which there were 4 fatalities. Since no other fatalities occurred during the relevant periods the same frequency applies to one or more fatalities per fire.

A very approximate estimate (expected to be an overestimate) of the frequency of these events can be obtained if an average of approx. 100 children attend a facility yielding approximately 74,500 (7,450,000 / 100) centre based day care facilities in the US

Therefore, the frequency per centre based daycare centre / annum of a fire with four fatalities would be expected to be less than (1/3/74500) ≈ 4.5 x 10^{-6}.

Due to the limited statistics available this should be viewed as a best estimate and is sensitive to the occurrence of a single incident. Considering 1 of the two events used in this estimate was a family daycare facility rather than a centre based facility and a large average day centre population was assumed it is expected that this is likely to be a significant over-estimate of risk.

A large proportion of these facilities were provided with smoke detection / alarm systems. From Hall[11] for the educational property classification; 24% of properties where fires occurred between 1994 and 1998 were protected with automatic suppression systems compared with 40% for the period 2006 to 2010. Therefore, a proportion of these buildings are likely to have been sprinkler protected. These measures would reduce the risk from fires compared to the minimum NCC DTS provisions for a single storey building.

If the estimated risk is applied to an NCC DTS compliant single storey building the overestimate of risk based on the statistics would tend to be offset by the reduction in fire protection levels.

Based on the above discussion the frequency estimated from US statistics for four or more fatalities from a fire in a day care facility of 4.5 x 10^{-6} / annum is considered a reasonable estimate for single storey ECCs based on the limited data available and is plotted in Figure 2 for comparison with tolerable risk benchmarks and the societal risk estimates for Design Case 1 from report JA18-00224. For four fatalities the estimate based on statistics is closely aligned to the lower bound indicative value for ALARP.

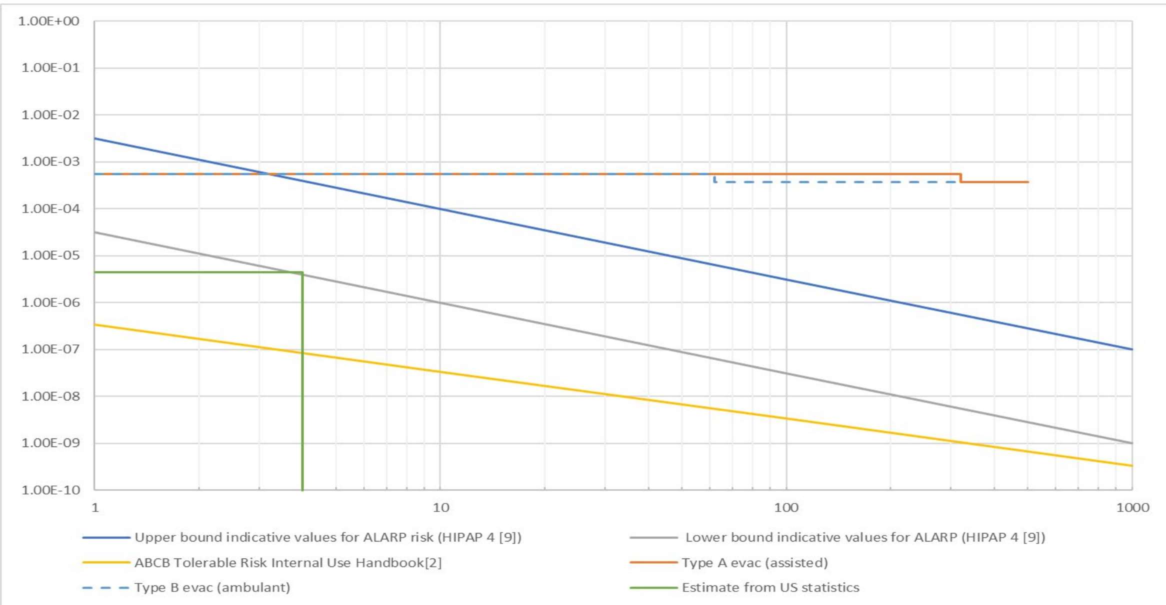


Figure 2 Results from Design Case 1 compared to Societal Risk Benchmarks and an estimate of societal risk based on US statistics.

The F-N results presented in report JA19-0024 for a single storey facility indicated that

- for Type A children (assisted evacuation) 500 occupants are exposed to untenable at a frequency of approx. 4 x 10^{-4} / annum).
- For Type B children (ambulant) 300 occupants are exposed to untenable conditions at a frequency of approx. 4 x 10^{-4} / annum).

The number of Childcare services in Australia is shown in Figure 3 which was approaching 12,000 in 2008 and in 1998 the number of services was approaching 9000.

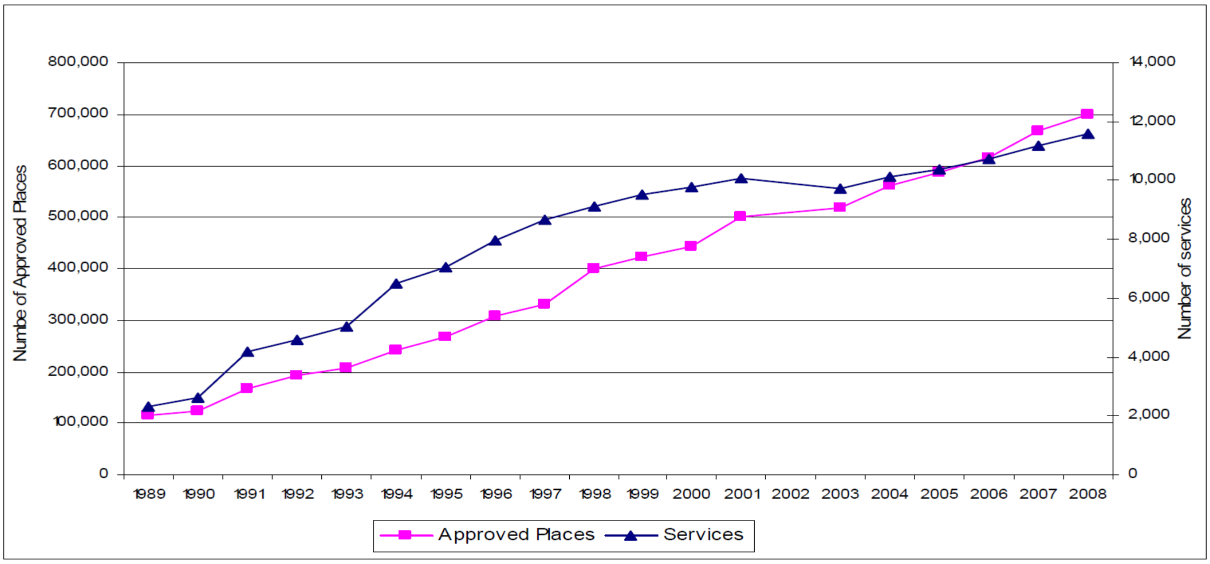


Figure 3 Growth in Childcare Services and Places 1989 -2008 from Senate Inquiry into Provision of Childcare [12]

It is a reasonable assumption that the average number of services would have been in excess of 10,000 for the 20-year period between 1998 and 2008 and during this period there have been no major incidents causing more than 10 fatalities and no evidence of any fatalities from fires in ECCs could be identified.

If there had been one incident involving multiple fatalities the frequency of a multi-fatality event occurring in a specific Childcare Service facility would have been 5 x 10^{-6}/ annum (1/10000/20) which is approximately two orders of magnitude less than the QRA results in JA19-0024 and similar to the estimated risk from US statistics for 4 fatality events.

The largest variance in the analysis from the societal risk benchmarks occurs where 10 or more fatalities occur in a single incident.

Such incidents are very rare and no directly applicable data could be identified. The NFPA publishes details of multi-fatality school fires from kindergarten to year 12 with 10 or more deaths which has some relevance the ECCs especially ECCs with older Type B ambulant occupants. The incidents published by the NFPA are summarised in Table 5 together with reports on the events extracted from various publications[13].

It is noteworthy that there were eight events with 10 or more fatalities two of which resulted in 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. Of the eight events one (Lakeview school) was a gas explosion and it was indicated that the explosion was not followed by a significant fire and the Bath Consolidated School event was a bombing. This leaves six fire events which are discussed in more detail in Appendix A.

Table 5 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

The most relevant case to the analysis of a single storey ECC was the Cleveland Hill School Cheektowaga, NY. The building was a single storey annex and 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. The music room was the only occupied room in the annex at the time. It was impossible to exit via a corridor and teachers broke windows and assisted all but 10 of the occupants to evacuate with a further five later dying in hospital as a result of the fire. The delayed detection of this fire was identified as the most significant factor in the NFPA Quarterly April 1954. This indicates that scenarios can occur which block escape routes in a common space but are usually associated with situations were evacuation is delayed and a fire grows undetected.

9. Other Observations

9.1. Estimation of Risk - Overview

It is not uncommon when undertaking an absolute QRA for the level of risk to be overestimated due to conservative assumptions being adopted particularly where there is some uncertainty regarding inputs and modelling methods. Where this occurs, it is useful to identify the reasons for the variations and supplement the analysis with a comparison against a benchmark building that is considered to provide an acceptable level of safety. By using a comparative approach, the sensitivity to many variables and assumption is reduced provided the benchmark building and proposed building solutions are sufficiently similar.

In this case the overestimate of the risk for the benchmark building (single-storey) compared to available statistics is very large and by necessity the benchmark building and nature of risks varies considerably from the other design cases due mainly to the impact of an increase in height of the building, introduction of open stairs for the two storey options and differences in the fire safety systems provided.

The following supplementary observations have therefore focused on factors that may have contributed to the overestimate of risk and the potential impact on the comparative analysis as well as the absolute analysis.

9.2. Frequency of Ignition

The absolute results will be affected proportionately by the frequency of ignition but if the same ignition frequency is assumed for all cases there will be no net effect on the comparative analysis. The selected frequency / unit area based on Tillander correlations is considered reasonable and was consistent with estimates based on statistics from other sources.

9.3. Size of Facility / Number of Occupants

The selected size was substantially greater than the mean size and median size of a facility and adopted the highest permitted occupant density. The following table was derived in Section 6.1

Table 6 Comparison of Parameters for an Average Facility and the Design Cases

Parameter	Estimated Average Case	JA 18-0022 Design Case
Floor area – m^2	500	2000
Number of children	60	416
Number of staff	12	84
Estimated frequency of fire starts / annum based on Tillander Institutional care coefficients	0.0029	0.011

The floor area adopted in JA 18-0022 was approximately 4 times the estimated average and the number of occupants 7 times. The impact of these variations is expected to be significant.

If the frequency of fire starts is 4 times greater it will increase societal risk and individual risk by four times.

The number of occupants is likely to have a significant impact on both the societal and individual risk results based on a preliminary review of the results presented in the report.

Although the NCC requires additional exit capacity for larger populations the minimum number of exits (2) from each floor was adopted and the width of exits increased accordingly to account for the population of 500 people.

The analysis assumed that the stair width had no impact on the egress of the Type B ambulant children. Therefore, effectively the same egress provision is assumed with no variation to account for the larger population. For Type B occupants in the high-rise buildings it is likely there would be a substantial reduction in individual societal and individual risks with a population of 72 compared to 500. Insufficient data is available to draw firm conclusions but for Type B configurations where scenarios indicate the numbers exposed to untenable conditions are less than approximately 420 it implies there was enough time to safely evacuate 80 people (i.e. the entire population of an average sized facility). Thus, the consequences of many if not all scenarios where less than 420 people were exposed could be reduced to zero.

On this basis it is therefore expected that there could also be a very large impact on the comparative risk results against a single storey benchmark building (without stairs) in addition to the absolute risk and on both the societal and individual risks.

9.4. Hours of Occupation

The analysis assumed that the building was always occupied . This is not expected to be the case because the facility would be effectively a residential building and not an education centre and additional NCC provisions would apply. Generally larger fires tend to occur in buildings when they are unoccupied, but these fires do not present a risk to life for the children attending whilst the property is unoccupied.

The design fire distributions could be adjusted to take this in account and branches added to the event trees for when the centre is unoccupied.

The impact of this could be of the order of a 25% reduction in the risks to occupants in absolute terms but not the comparative results unless there was a major change to the distribution of fire growth rates.

9.5. Selection of Design Fires

9.5.1. Location of Design Fires

Two locations were selected for design fires on the ECC floor. In the main play area (60% of fires) which is open to each of the fire exits and another in an adjacent room (40% of fires) that is open to the main play area at all times.

These locations would be expected to represent scenarios with the highest probability of multi-fatality outcomes by preventing access to emergency exits. These assumptions are expected to have a significant impact on the risk to life and may have contributed to the overestimate of individual and societal risks associated with ECCs.

Larger proportions of fire starts are expected in kitchen areas, for example, which may be enclosed to restrict access to the children.

The scenarios selected are a valid part of the comparative analysis but consideration of fires in other locations could impact on the outcomes and help identify appropriate solutions.

On other floors no specific locations were considered.

9.5.2. Fire Growth Rates and Maximum Fire Sizes

The analysis adopted the common fire engineering practice of ignoring any incipient or smouldering phase prior to commencing a growth phase for the design fires because of the difficulty in reliably quantifying the duration. This is a reasonable approach for a comparative analysis but may reduce the available safe egress time (ASET) and thus is likely to increase both the absolute values of the individual and societal risks obtained.

The selection of various growth rates based on the work of Holborn[14] is reasonable. However, the assumption that all fires other than smouldering fires progress to a size of 20 MW if there is no automatic intervention is very conservative and may have contributed to the overestimate of the risk to life.

This could be addressed by reviewing fire statistics relating the extent of damage from fires and estimating a proportion of fires that do not spread to involve multiple items.

This could impact significantly on the absolute risk estimates but would a smaller impact on the comparative analysis.

9.6. Fire Brigade Intervention

The impact of Fire Brigade Intervention has not been accounted for in the analysis. This would be expected to have a significant impact on the absolute risk values and on the comparative analysis. For example, the analysis assumes that if both fire stairs are blocked due to a fire on a lower level all the occupants in the ECC are exposed to untenable conditions. Under these circumstances Fire Brigade Search and Rescue in conjunction with firefighting activities would be expected to have a significant impact. This will influence significantly the comparative risk between the single storey and multistory scenarios. This would be offset to some extent in a comparative analysis due to the earlier commencement of search and rescue activities for a single storey building.

9.7. Identification of Fire Cues from the Fire

For design cases where there is no automatic detection and alarm system and for scenarios where the detection and alarm systems fail the time for identification of a cue from the fire and response to that cue is critical. Following “established practice” a smoke layer depth of 5% was adopted as the criteria. The results would be very sensitive to this assumption but there is a lack of data on which to base a suggestion for an alternative (or support the 5% depth criteria). This may have contributed to the high absolute risk estimates but the impact on the comparative analysis would be much less.

9.8. Egress Modelling

The egress modelling approach and inputs are reasonable and appropriately justified for applications where the ECC has exclusive use of fire stairs, but this is unlikely to be the situation unless mandated. The interaction with other building occupants and counterflow of fire brigade personnel and staff returning to evacuate further Type A children was not considered. The report highlighted these limitations and the likely under prediction of the risk.

Whilst this is a complex matter this is one of the most significant hazards introduced if an ECC is in a high-rise building and a shared stair introduces several additional hazards for young children particularly if the stair is crowded. The Emergency Management Organisation for the building has an important part to play in managing this risk which lies outside the scope of the NCC but appropriate assumptions and consequently recommendations should be made. With 416 children to evacuate the provision of a safe location after exiting the building is also an important consideration.

9.9. Tenability Criteria

The tenability criteria were based on established engineering approaches and represent a reasonable basis for the analysis. However, the tenability criteria will lead to a substantial overestimate of the number of fatalities since in some scenarios the time between visibility tenability limit being exceeded at a height of 2.1m and fatal exposure of a child (substantially below 2.1m) to smoke or heat may be substantial. This was identified and acknowledged in the report.

9.10. Evaluating the Consequences of fires on Other floors

The focus of this discussion is on Design Cases 4 and 5 which are not connected via open stairs or partially protected stairs to the ECC.

From a review of the event trees and information available in the report it is understood that the analysis considered that fire / smoke spread via the fire stair shafts was the only means by which the occupants of the ECC would be threatened by a fire occurring on another floor. If a flaming fire occurred (75.5% of fires) that was not suppressed by the automatic fire sprinkler system (if provided) and the stair pressurisation system for both stairs failed (if provided) and the fire doors to both stairs on the fire floor failed any remaining occupants on the ECC level were deemed to be exposed to untenable conditions.

This does not consider fire brigade intervention (search and rescue activities) and the protection provided by the doors at the ECC level. This may therefore substantially overestimate the risk from fires on other floors particularly for Case 4 (no sprinklers or stair pressurisation). This would impact on the absolute risk values for multi-storey buildings as well as the comparative risk between single and high-rise options.

The following items were not considered but may increase the risk to occupants from a fire on another floor.

- External fire spread between levels
- Smoke spread via lift shafts, service shafts from other levels
- Smoke spread through fire resistant doors in the closed position

Consideration of these items would tend to increase the risk to occupants in the ECC and impact on both the absolute and comparative risk.

In addition, the effectiveness of fire-resistant construction was assumed to be 100 % other than consideration of smoke/ fire spread through service penetrations and open /faulty fire doors to the fire stairs. Whilst the probability is low the consequences of a structural failure could be significant and expose any occupants remaining within the building to untenable conditions. This would impact on the absolute risk values for multi-storey buildings as well as the comparative risk between single and high-rise options.

9.11. Reliability of Efficacy of Fire Safety Systems

The reliability of the following fire safety systems was considered, and the adopted reliability ranges are reasonably;

- Sprinkler systems
- Smoke detection and alarm systems
- Stair pressurisation Systems
- Zone smoke control systems
- Fire isolated stairs and associated self-closing doors

Adopting a reliability of less than 100% for the effectiveness for structural fire protection, reinforced concrete and other fire-resistant elements should be considered.

9.12. Recommendations Made For Changes To the NCC in Report JA18-00224

A recommendation was provided in report JA18-00224 for all ECCs above ground to include the following enhancements to the current NCC requirements

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

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

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

The same methodology was stated to be applied but it could not be ascertained if a probability was assigned to the doors separating the two compartments being in the closed position at the time of the fire and whether smoke leakage around the door edges was considered.

For a very large ECC facility the proposed enhancements are considered a reasonable approach to significantly reduce the fire risk particularly if the doors separating the compartments are also designed to restrict the spread of smoke. This approach would then have some similarity to Class 9c buildings provisions. Smoke spread via the lift shaft may also require some attention considering the lengthy evacuation time required for Type A children. A candidate mitigation method if necessary could be a lift lobby. The floor plan shows a common lobby for one of the fire stairs and the lifts but is not indicated if this arrangement applies to all floors.

10. Conclusions

An independent technical review of the 'Fire Safety of Early Childhood Centres in High Rise Buildings in Australia', by RED Fire Engineers (Report No. JA18-00224 Final (Rev1) has been undertaken.

The focus was to be the absolute risk analysis with an emphasis on;

1) the data used to inform ignition probability (i.e. fire start frequencies).
2) approach taken to derive individual and societal risk and tolerable risk criteria
3) validation of the findings against fire statistics.
4) Any other relevant observations in relation to the analysis and findings were also to be provided.

Using the above numbering system, the following conclusions have been drawn.

1) Data used to inform ignition probability

The assumed ignition probability (fire start frequency) was found to be consistent with other sources and reviewed fire statistics and is considered reasonable.

2) Approach taken to derive individual and societal risk and tolerable risk criteria

(i) The ABCB Draft Tolerable Risk – Internal Use Handbook [1] was used to derive the tolerable risk criteria.

(ii)The Building Class Group was correctly identified as BCG 3;

(iii) The corresponding Benchmark Safety Hazard Individual Risk for fire was correctly identified as 3.39×10^{-7} $year^{-1}$

(iv) The corresponding Benchmark Safety Hazard Societal Risk for fire stated in report JA18-00224 was not in accordance with the ABCB Draft Tolerable Risk – Internal Use Handbook. The difference between the tolerable societal risk prescribed by the handbook and that adopted in report JA18-00224 does not materially affect any other findings in this report.

(v) The method adopted in report JA18-00224 to calculate individual risk was not considered consistent with the definition of individual risk in the ABCB Draft Tolerable Risk – Internal Use Handbook. The equation used in report JA18-00224 would provide higher values for individual risk than the equation nominated in this technical review report, which is consistent with the individual risk definition in the Handbook. The magnitude of this difference will vary from case to case and it is not possible to quantify accurately, without access to the consequences for each branch of the event trees. If corrections to the individual risk calculations are made, it will only account for a relatively small proportion of the very high overestimates of losses.

(vi) The F-N plots or societal risk appear to be broadly consistent with the modelling results and event trees presented, but a more definitive comment cannot be provided without reviewing additional data

3) Validation of the findings against fire statistics

Estimates were based on US statistics (for two three-year intervals) during which there were only two events in which fatalities occurred. The first occurred just outside the sample period but has been included to provide a conservative estimate. In this event, the fatalities comprised three children and an adult. The second occurred in a family care facility (domestic dwelling style building) with the supervisory person absent at the time of the fire and therefore, is not representative of a centre based facility with multiple supervisory staff. No other fatalities were identified during these periods. Using both these events to calculate the risks in ECC would be expected to provide an overestimate of the risk. However, because the events are so rare it should be noted that the risk estimates would be sensitive to an individual event.

(i) The best estimate based on the limited statistics available indicated that the average individual risk of fatality /annum for an ECC would be expected to be of the order of 1.8×10^{-7}. This indicates that the ABCB Tolerable Risk Benchmark Safety Hazard Individual Risk for fire of 3.39×10^{-7} year^{-1} is attainable and appropriate. The estimated individual risk of fatality /annum for Design Case 1 (the single storey benchmark building) quoted in report JA18-00224 was 5.58×10^{-4} which is substantially greater than the historic risk based on fire statistics.

(ii) The frequency of occurrence of four or more fatalities per daycare centre per annum (assuming an average facility size of 100) was estimated to be 4.5×10^{-6} which provides a point on an F-N plot. This point sits on the lower bound indicative risk values for ALARP from NSW Risk Criteria (HIPAP4) [2] as shown in Figure 4. This lower bound separates the negligible risk zone from the ALARP zone where measures should be considered to reduce the risk to a level that is “as low as reasonably practicable”.

The ABCB Tolerable Societal Risk Criteria requires a substantially lower frequency of less than 1×10^{-7} events involving four or less fatalities. Based on the statistics reviewed this may be difficult to achieve.

The F-N results presented in report JA19-0024 for a single storey facility indicated that

- For an ECC with Type A children (children that require carrying during evacuation), 500 occupants are exposed to untenable conditions at a frequency of approx. 4×10^{-4} / annum).
- For Type B children (children that are ambulant but require supervision during evacuation), 300 occupants are exposed to untenable conditions at a frequency of approx. 4×10^{-4} / annum).

These frequencies and the magnitude of losses substantially exceed the estimates based on statistics and both the ABCB Tolerable Risk Criteria and the HIPAP4 criteria as shown in Figure 4;

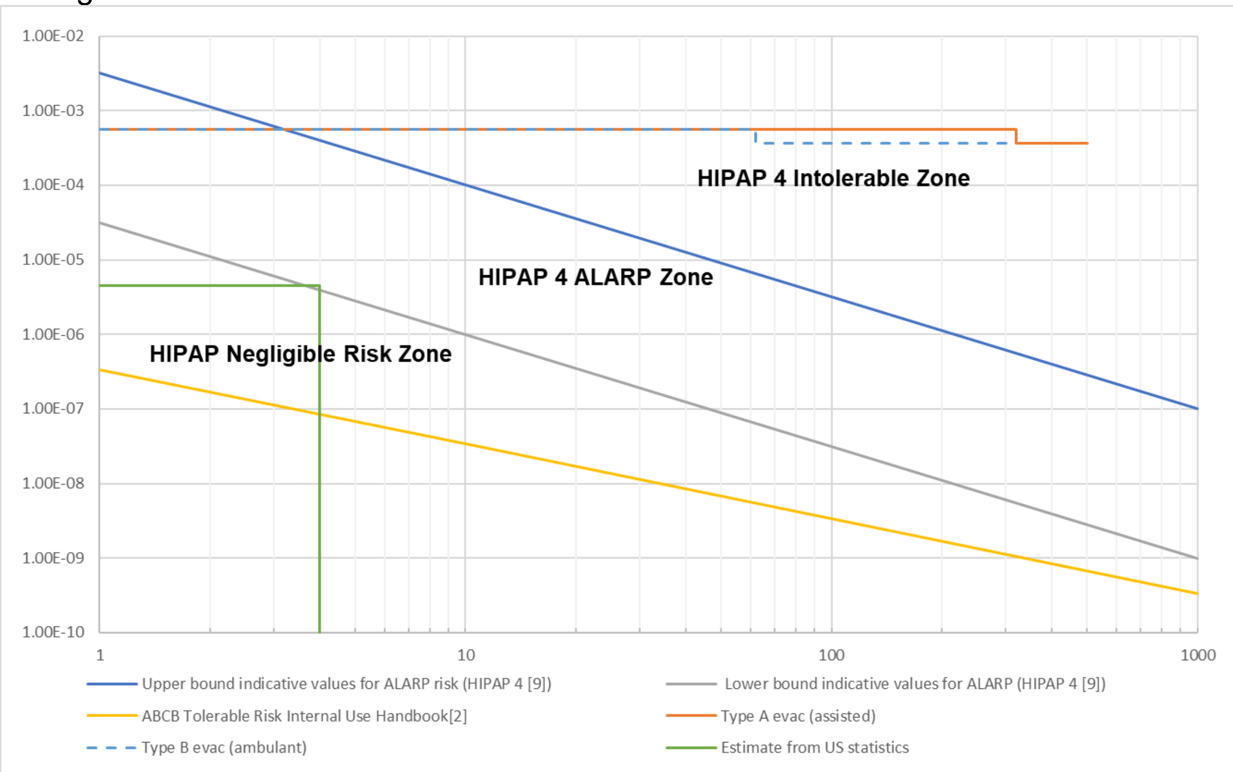


Figure 4 Results from Single Storey Design Case 1 compared to Societal Risk Benchmarks and an estimate of societal risk based on US statistics.

The largest variance in the analysis from the societal risk benchmarks occurs where 10 or more fatalities occur in a single incident. Such incidents are very rare and no directly applicable data could be identified for more than 4 fatalities in the equivalent of ECCs.

Reference was therefore made to NFPA published statistics on multi-fatality fires from kindergarten to year 12 schools, with 10 or more deaths, which has some relevance the ECCs especially those with older Type B ambulant children. Ignoring two explosion related incidents there were six events with 10 or more fatalities between 1908 to 1958. In the 60-year period since 1958 there were no reported fire incidents in US schools that resulted in 10 or more fatalities.

It is therefore concluded that report JA18-00224 is substantially overestimating the risk in single storey ECC facilities compared to fire statistics.

4) Other Relevant Observations

(i) The arrangement of the report is logical and reasonable to follow with effort taken to explain the assumptions made. It would have been helpful for the outcomes (consequences) for each event tree branch to have been identified but it is acknowledged that there is a fine balance between too much and too little information.

(ii) It is not uncommon when undertaking an absolute QRA for the level of risk to be overestimated due to conservative assumptions being adopted particularly where there is some uncertainty regarding inputs and modelling methods. Whilst the report included some sensitivity analyses, the very high-risk levels predicted and variance from expected losses was not fully explained.

(iii) Undertaking a comparative analysis against a similar benchmark building, that provides an acceptable level of safety, is an appropriate, and established means of reducing the sensitivity to simplifications and assumptions. However, in this case substantial variations between the benchmark building and the other design cases, with respect to building height and fire safety systems for example, could not be avoided. Report JA18-00224 investigated the sensitivity of the outcomes to some simplifications and assumptions. The following observations therefore focus on other matters that could explain the overestimates of individual and societal risks, impact significantly on the comparative analysis results or may present additional hazards not addressed in the risk assessment.

(iv) A very large ECC (418 children) was adopted for the analysis compared to the average size of an ECC (60 children). This is expected to have had a very large impact on both the absolute and comparative risk levels predicted. The distribution of ECC sizes should be checked and an average size facility analysed. If there are significant numbers of large ECCs in high-rise buildings, it may be appropriate to consider additional requirements for large facilities such as additional compartmentation.

(v) Report JA18-00224 assumed that all flaming fires progressed to a maximum size of 20MW. A significant proportion of these would be likely to peak below 20MW. This assumption may have contributed to the overestimate of the absolute risk and may also affect the comparative risk by, for example, overestimating the impact of automatic suppression compared to detection and evacuation options.

(vi) In determining the location of design fires, the risk of ignition based on the usage of the functional areas was not considered. Instead it was assumed fires occurred in play areas, with 60% occurring in the main play area which in the selected building layout was on the path of travel to both exits. This assumption may significantly impact on the absolute and comparative risk results and lead to specific hazards not being identified. Statistical data could be used to identify high frequency locations for fire starts (e.g. kitchens) and help identify mitigation methods (e.g. fire separation of kitchen and laundry areas).

(vii) Fire Brigade intervention was not considered. This is expected to impact on the absolute analysis significantly and to some extent on the comparative analysis

(viii) Consistent with current fire engineering practices (particularly relating to deterministic designs) it was assumed that there was no incipient (smouldering) phase prior to the t-squared growth phase of the fire and generally conservative assumptions relating to the timing of the identification of fire cues and tenability criteria were adopted. These assumptions are expected to have contributed significantly to the overestimates of absolute risk.

(ix) Report JA18-00224 excluded the analysis of potential interactions with occupants from other floors of the building and fire brigade personnel within the fire isolated stairs during an emergency evacuation and acknowledged that this exclusion would underestimate the risk to occupants. It is considered that the interaction with occupants from other floors is a significant additional hazard introduced by locating ECCs in high-rise buildings and must be addressed. The likely impacts of the interactions include significant delays to the evacuation of ECC occupants and other occupants of the building which would have a significant impact on absolute and comparative risks. In addition, there are other hazards that need consideration including:

a. a crush resulting from the simultaneous evacuation of young slow moving children and other occupants.

b. abduction due to uncontrolled access to the children

c. inadequate security and safety for the children outside the building

(x) The following fire and smoke spread scenarios were not considered but may increase the risk to occupants from a fire on another floor;

- External fire spread between levels
- Smoke spread via lift shafts, service shafts from other levels
- Smoke spread through fire resistant doors in the closed position

(xi) For a very large ECC facility the proposed enhancements included in report JA18-00224 are considered a reasonable approach to significantly reduce the fire risk, particularly if the doors separating the compartments are also designed to restrict the spread of smoke. This approach would then have some similarity to Class 9c buildings provisions. Smoke spread via the lift shaft may also require some attention.

(xii) Consideration could be given in the ABCB Tolerable Risk Verification Method to the adoption of tolerable societal risk criteria that are not based on the tolerable individual risk to avoid confusion when using the method. In some cases, the required tolerable societal risks derived using the currently proposed method may be impractical to achieve.

(xiii) An example calculation of Individual risk based on QRA outcomes could be included in the ABCB Tolerable risk - Internal Use Handbook to assist users.

Appendix A. Overview of Selected Multi-fatality U.S. School Fires

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.

On 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 and congestion further delayed egress. There were no automatic detection systems or suppression systems. A series of recommendations were made following an investigation by the detective and Fire Inspection Department of the District Police 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 and was being used for an event. At the time there were estimated to be 200 to 250 occupants. 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 preventing egress 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 as a result of the fire. The delayed detection of this fire was identified as the most significant factor in the NFPA Quarterly April 1954[15] 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[16] 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 with a floor area of approximately 600m^2. The fatalities were generally limited to the occupants of the second storey of the north wing.

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 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 occurred as the first fire appliances were reaching the site and prevented evacuation of the occupants of five classrooms evacuating 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 except for one classroom adjacent to the north wing that evacuated prior to the general building alarm being raised.

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 (note; 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

Appendix B. **References**

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