ABCB

Australian Fire Engineering
Guidelines

2021

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The Institution of Fire Engineers
Australia Branch

ENGINEERS AUSTRALIA

abcb.gov.au

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Version history

Original

Publish date: Jul 2021
Print version: 1.0

Preface

The Australian Fire Engineering Guide (AFEG) has been developed by a team of specialist fire engineers (FE). The AFEG is part of the National Construction Code (NCC) support documents, and provides a guideline that meets the modern needs of the Australian fire engineering community. AFEG supersedes the International Fire Engineering Guidelines (IFEG).

AFEG Part 1 provides an insight to the issues that go beyond actual engineering, and a perspective on the role of engineering within the regulatory and non-regulatory systems. This portion of the AFEG is intended to link engineering practice with the state- and territory-based legal and regulatory system of choice.

The AFEG has been developed for use in the fire safety design of buildings. It will also be of use for appropriate authorities in carrying out their role of approving building designs. The AFEG is intended for use by competent and experienced FEs, as discussed in Section 1.1.2.

Acknowledgements

This document was made possible by the generous contributions of the team of specialist FEs involved in its development. Thanks to Dr Jonathan Barnett, Sarnia Rusbridge, Tobias Salomonsson and Kjetil Pedersen for donating your time and expertise. The expert team would like to acknowledge helpful feedback from members of the Engineers Australia Society of Fire Safety.

The AFEG development team is also grateful to Dr Brian Ashe for his guidance and comments.

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REMINDER

This guideline is not mandatory or regulatory in nature and compliance with it will not necessarily discharge a user's legal obligations. The guideline should only be read and used subject to, and in conjunction with, the general disclaimer at page i.

The guideline also needs to be read in conjunction with the relevant legislation of the appropriate state or territory. It is written in generic terms and it is not intended that the content of the guideline counteract or conflict with the legislative requirements, any references in legal documents, any handbooks issued by an administration or any directives by the appropriate authority.

1 Introduction

1.1 Introducing the AFEG

1.1.1 Evolution

The Australian Fire Engineering Guide (AFEG) supersedes the International Fire Engineering Guidelines (IFEG).

The objectives of the AFEG are to:

- provide a link between the regulatory system and fire engineering (Part 1)
- provide guidance about the process of fire engineering (Part 2)
- provide guidance on available methodologies (Part 3)
- describe the AFEG's philosophy of use (Part 4).

The AFEG is a process document. Its purpose as a National Construction Code (NCC) support document is to provide guidance. The use of a mandatory format was discussed before the development of both the first and second editions of IFEG, and again for the AFEG. It was concluded that fire engineering lacks the necessary array of validated tools and data to produce a mandatory document.

Fire engineering designs are complex and generally require extensive use of engineering judgement. So, in order to approve a fire engineering design, appropriate authorities need an understanding of the fire engineering process and what constitutes an acceptable fire engineering design. Therefore, guidance is required to improve both the standard of fire engineering applied by practitioners, and the ability of the appropriate authority to carry out their function of safeguarding the community.

The AFEG embraces worldwide best practice and draws upon previous and parallel work from many groups around the world. The documents considered include:

- *Application of Fire Safety Engineering Principles to the Design of Buildings – Part 0: Guide to Design Framework and Fire Safety Engineering Procedures,* PD 7974-0:2002, BSi
- *CIBSE Guide E, Fire Engineering,* Chartered Institute of Building Services Engineers (CIBSE), UK, 2019

- *Fire Engineering Guidelines (FEG),* 1st Edition, Fire Code Reform Centre Ltd Australia, 1996
- *Fire Engineering Design Guide,* 3rd Edition, University of Canterbury, Christchurch, New Zealand, 2008
- *Fire Safety Engineering Guidelines (FSEG),* Edition 2001, Australian Building Codes Board, Canberra, Australia, 2001
- *Fire Safety Engineering: The Methods Report,* The Warren Centre, Australia, 2019
- *Fire Safety Engineering: Comparison of FSE Guidance Documents and Assessment Criteria*, The Warren Centre, Australia, 2019
- *Fire Safety Engineering – General Principles – Part 1: General, ISO 23932-1,* International Organization for Standardization (ISO), 2018
- *Fire Safety Engineering, ISO/TR 13387: 1999, ISO, 1999*
    - Part 1: Application of fire performance concepts to design objectives
    - Part 2: Design fire scenarios and design fires
    - Part 3: Assessment and verification of mathematical fire models
    - Part 4: Initiation and development of fire and generation of fire effluents
    - Part 5: Movement of fire effluents
    - Part 6: Structural response and fire spread beyond the enclosure of origin
    - Part 7: Detection, activation and suppression
    - Part 8: Life safety – occupant behaviour, location and condition.
- *International Fire Engineering Guidelines (IFEG),* Australian Building Codes Board, Australia, 2005
- *International Fire Safety Standards Common Principles,* 1st Edition, International Fire Safety Standards Coalition, 2020
- *National Construction Code Volume One Amendment 1*; Australian Building Codes Board; 01 July 2019.
- *The SFPE Guide to Performance-Based Fire Safety Design,* Society of fire Protection Engineers (SFPE), Hurley, Rosenbaum. USA (2015)
- *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings,* Society of Fire Protection Engineers (SFPE), Bethesda, MD. USA (2000)
- *SFPE Guide to Fire Risk Assessment,* 2nd Edition (Draft), SFPE Task Group on Fire Risk Assessment, 2020
- *The Swedish National Board of Housing, Building and Planning's general recommendations on the analytical design of a building's fire protection,* BBRAD. Boverket, Karlskrona, Sweden, 2013.
- *Technical Building Works Regulations,* TEK17, Ministry of Local Government and Modernisation (KMD), Norwegian Building Authority (DiKB), Norway, 2017.

1.1.2 Scope

The AFEG provides information for the fire safety design of buildings under the NCC. It may also assist in assessing the adequacy of fire safety in existing buildings and upgrade strategies.

The concepts and principles discussed may also assist in the fire engineering design and approval of other structures such as ships, tunnels and rail platforms.

This document provides guidance to the fire engineering fraternity in designing fire safety systems to achieve acceptable levels of safety. The AFEG assumes that FEs have a level of competence and experience that would enable accreditation by an appropriate body. For example, accreditation to the Engineers Australia National Engineering Registry (NER) scheme.

FEs need use the AFEG as a tool for responsible fire engineering. The role of fire engineering with respect to fire safety and the term 'fire engineer' are discussed in 1.3 and 1.4 respectively.

The AFEG aligns with the UN ECE standard *International Fire Safety Standards Common Principles*, 1st Edition (IFSS-CP) published by the International Fire Safety Standards Coalition, which includes Engineers Australia.

1.1.3 Limitations

The AFEG has been written explicitly for dealing with life safety. It may be useful in property protection, business continuity and post-fire incidents, but only to the extent that these areas would be considered applicable by the stakeholders.

Fire and its effects on people and property are both complex and variable. Therefore, a fire safety system may not cope with all possible scenarios. The ideal concepts of 'absolute' or '100%' safety – as well as ‘zero’ or ‘no’ risk – are not attainable. This needs to be understood by designers, owners, occupiers, contractors, appropriate authorities and others in their assessment of fire-engineered solutions.

There will always be a finite risk of injury, death or property damage. Some of the guidance in the AFEG relates to the qualitative and quantitative methodologies available to evaluate such risks.

The AFEG should never be used as a 'recipe book' to allow inexperienced or unqualified people to undertake work that should be done by a professional FE.

1.2 The regulatory system

The intent of building regulations is to mitigate risks to a level tolerated by the community.

Building codes have been developed to provide the technical basis for such regulations. Traditionally, building codes have been prescriptive, however, such codes cannot cover emerging technologies and every combination of circumstances. Therefore, the constraints of prescriptive regulations may not be appropriate for every building considered.

In order to free designers from such constraints, increase innovation, and facilitate trade, building codes have become performance based. The NCC is a performance-based code.

1.2.1 The regulatory framework

The Australian regulatory system adopts the following generalised framework:

- **The Australian Constitution** enables the state and territory governments to legislate for building developments
- **Development/Building Acts** are administered by the state or territory governments to control building development
- **Building regulations** are given status by the Development/Building Acts and permit the government to include conditions on building developments. They regulate building work and set out detailed requirements and procedural matters for assessments, approvals, inspections, certification, appeals, penalties, and accrediting bodies.

The regulations or the law give authority for the use of the building code. This includes:

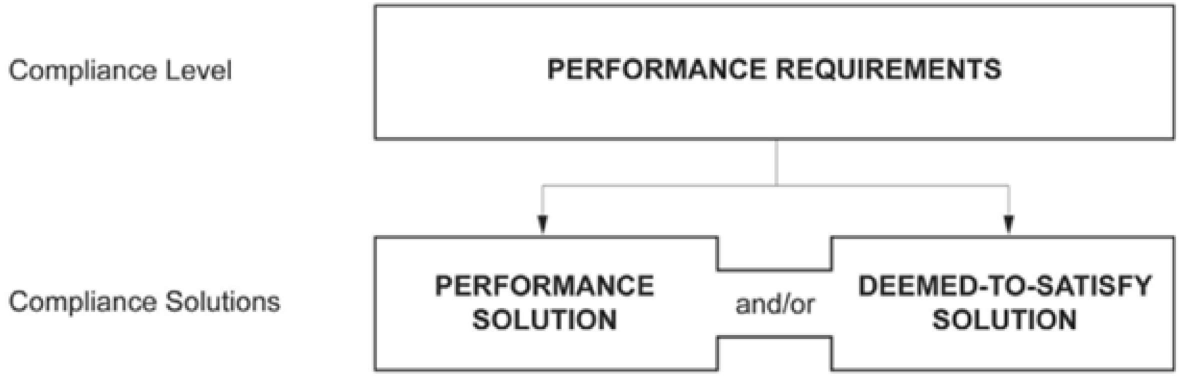
- **The NCC** which provides the technical content for the building regulations
- **Other legislation** which may include other acts, regulations, and standards.

1.2.2 The NCC

The NCC sets the minimum required level for the health, safety, amenity, accessibility and sustainability of certain buildings. It is a performance-based code which primarily applies to the design and construction of new buildings. One of the goals of the NCC is the achievement and maintenance of acceptable standards of fire safety and resistance. The Australian Building Codes Board (ABCB) seeks to ensure that NCC requirements have rigorously tested rationale, create benefits to society that outweigh costs and are not unnecessarily restrictive.

Compliance with the NCC requires compliance with the Performance Requirements as illustrated in Figure 1.2.1 (NCC 2019 Amendment 1).

Figure 1.2.1 The NCC hierarchy



Compliance with the NCC is achieved by complying with the Governing Requirements and the Performance Requirements of the NCC. Compliance with the Performance Requirements may be demonstrated by:

- a design that complies with a Performance Solution
- a Deemed-to-Satisfy (DTS) Solution
- a combination of both.

The NCC explains the various pathways to compliance. This is outlined in Clause A2.2 of NCC Volume One (NCC 2019 Amendment 1):

A2.2 Performance Solution

(1) A *Performance Solution* is achieved by demonstrating—

(a) compliance with all relevant *Performance Requirements*; or

(b) the solution is at least *equivalent* to the *Deemed-to-Satisfy Provisions*.

(2) A *Performance Solution* must be shown to comply with the relevant *Performance Requirements* through one or a combination of the following *Assessment Methods*:

(a) Evidence of suitability in accordance with Part A5 that shows the use of a material, product, *plumbing* and *drainage product*, form of construction or design meets the relevant *Performance Requirements*.

(b) A *Verification Method* including the following:

(i) The *Verification Methods* provided in the NCC.

(ii) Other Verification Methods, accepted by the *appropriate authority* that show compliance with the relevant *Performance Requirements*.

(c) Expert Judgement.

(d) Comparison with the *Deemed-to-Satisfy Provisions*.

(3) Where a *Performance Requirement* is satisfied entirely by a *Performance Solution*, in order to comply with (1) the following method must be used to determine the *Performance Requirement* or *Performance Requirements* relevant to the *Performance Solution*:

(a) Identify the relevant *Performance Requirements* from the Section or Part to which the *Performance Solution* applies.

(b) Identify *Performance Requirements* from other Sections or Parts that are relevant to any aspects of the *Performance Solution* proposed or that are affected by the application of the *Performance Solution.*

(4) Where a *Performance Requirement* is proposed to be satisfied by a *Performance Solution*, the following steps must be undertaken:

(a) Prepare a *performance-based design brief* in consultation with relevant stakeholders.

(b) Carry out analysis, using one or more of the *Assessment Methods* listed in (2), as proposed by the *performance-based design brief*.

(c) Evaluate results from (b) against the acceptance criteria in the *performance-based design brief*.

(d) Prepare a final report that includes—

(i) All Performance *Requirements* and/or *Deemed-to-Satisfy Provisions* identified through A2.2(3) or A2.4(3) as applicable; and

(ii) identification of all *Assessment Methods* used; and

(iii) details of steps (a) to (c); and

(iv) confirmation that the *Performance Requirement* has been met; and

(v) details of conditions or limitations, if any exist, regarding the *Performance Solution*.

1.2.3 Performance Requirements

The NCC Performance Requirements state the level of performance which a Performance Solution must meet, or a DTS Solution is deemed to meet.

1.2.3.1 Non-quantification of risk

As discussed in Section 1.2.2, the fire-related Performance Requirements of the NCC provide a benchmark with respect to the risk of fatality, injury and loss of adjacent structures through fire. It is not intended that this benchmark should be ‘absolute safety or ‘zero risk’ because these concepts are not achievable. The benchmark risk needs to take into account what the community expects and the cost to the community.

The level of safety provided by the NCC is not yet explicitly stated (quantification of the fire safety requirements is proposed for NCC 2022). This can lead to difficulties in interpreting the Performance Requirements (which are not yet quantified). When a fire engineering design is proposed, acceptance criteria must be developed in order to analyse the outcome of the design. The relationship between the acceptance criteria and the relevant Performance Requirements is often a matter of engineering judgement, and therefore can vary between individual practitioners and from project to project. Involving as many stakeholders as possible in developing the acceptance criteria can help minimise this variation. Stakeholder involvement will also form an important part of the performance-based design brief (PBDB) process described in 2.2.

When a fire engineering design is carried out, ‘design fires’ have to be developed in order to design the fire safety system under consideration. The selection of design fires and other design considerations rely, to some extent, on the application of engineering judgement and can therefore vary between individual practitioners and from project to project. This variation can be minimised by using the process detailed in the AFEG and with the involvement of stakeholders – as described in the PBDB process (2.2). The NCC is silent on the matter of fires set with malicious intent (arson and terrorist activities). The process described in Section 2.2.10 to develop design fires on the basis of a consideration of all potential fire scenarios encompasses such fires.

The interpretation of the terms ‘to the degree necessary’ and ‘appropriate to’ for any factor related to fire safety will vary according to the project being designed and subsequently analysed. This adds to the difficulty of setting the acceptance criteria. This issue can also be addressed using the PBDB process.

1.2.3.2 Relationship with DTS

Where a building does not meet particular DTS Provisions, the relevant Performance Requirement(s) need to be determined to develop a Performance Solution (see Section 2.2.9).

In the design of the Performance Solution, designers must carefully consider the relationship between the DTS Provision and Performance Requirements. This will often require input from other stakeholders – such as the appropriate authority and others conversant with the practical application of the NCC. This input is greatly facilitated by the PBDB process.

Just as the DTS Provisions of the NCC are interrelated in some cases, the Performance Requirements may be interrelated. Thus, it is not unusual for one design to result in a deviation to more than one DTS Provision, and therefore the need for two or more Performance Requirements to be addressed. A Performance Solution or design which deviates from the DTS Provision may relate to more than one section of the NCC. However, the analysis strategy for the fire engineering design would need to satisfy both Performance Requirements.

1.3 Fire engineering

The International Standards Organisation (ISO) defines fire (safety) engineering as:

> *"The application of engineering principles, rules and expert judgement based on a scientific appreciation of the fire phenomena, of the effects of fire, and the reaction and behaviour of people, in order to:*
>
> - *save life, protect property and preserve the environment and heritage;*
> - *quantify the hazards and risk of fire and its effects;*
> - *evaluate analytically the optimum protective and preventative measures necessary to limit, within prescribed levels, the consequences of fire."*

The NCC has the fire safety goals of life safety, facilitation of fire brigade intervention, and protection of other buildings from a fire in a building.

Fire engineering is an evolving and rapidly developing discipline. In comparison to the traditional, established engineering disciplines, it does not have well-codified methods of approaching and solving problems. Fire engineering has only become a possibility as a result of developments in fire science increasing the understanding of the many aspects of fires in structures. These developments include:

- how various materials ignite
- the manner in which fire develops
- the manner in which smoke (including toxic products) spread
- how structures react to fire
- how people respond to the threat of fire, alarms, and products of combustion.

Fire science has also provided tools that can be used to predict some of the above phenomena, such as:

- fire dynamics theory
- deterministic and probabilistic fire behaviour and effects modelling
- human behaviour and toxic effects modelling.

The practice of fire engineering has been facilitated by continuing advances in computing technology, digital models and the introduction of performance-based codes with specific provision for the acceptance of fire engineered solutions.

Despite these advances, fire engineering is still an emerging discipline. Our knowledge of fire science is developing. As a result, engineering judgement (or the use of engineering estimates) is a key part of fire engineering practice. **No fire engineering design can be developed without the use of engineering judgement;** based on data, experience, current knowledge and emerging understanding of fire science and human behaviour.

Fire engineers should be aware of their duty of care and that part of their role, amongst other things, is to protect the community and ensure the best practical solution is applied for the end users of the building.

1.3.1 Benefits

Fire engineering can be used for objectives other than those within the scope of the NCC, and has wider applicability and benefits beyond evaluating Performance Solutions.

The general objectives of the NCC are:

- to protect building occupants (including attending emergency services personnel)
- to facilitate the activities of emergency services personnel
- to protect other buildings from being affected by a fire in the building in question.

For some projects, the client or other stakeholders may have fire safety objectives in addition to those of the NCC. Examples of such objectives may include:

- limiting structural and fabric damage
- limiting building contents and equipment damage
- maintaining continuity of business operations and financial viability
- protecting corporate and public image
- protecting heritage in older or significant buildings
- limiting the release of hazardous materials into the environment

- safeguarding community interests and infrastructure.

In addition, the client may have various non fire-related objectives for the building design that impact on the fire safety of the building. For example, the client may require:

- extensive natural lighting
- an open plan layout
- the use of new materials
- sustainability
- flexibility for future uses
- low life-cycle costs.

When designing an integrated, resource-effective fire safety system, FEs may take these objectives into account, together with the mandatory requirements. The FE has a duty of care to draw the client’s attention to objectives relating to matters which might adversely affect the client or the community.

Fire engineering can have many other benefits. For example, it can provide:

- a disciplined approach to fire safety design
- a better appreciation of the interaction of the components that make up a building's fire safety system
- a method of comparing the fire safety inherent in Performance Solutions
- a basis for selection of appropriate fire safety systems
- resource-efficiency through the use of Performance Solutions
- guidance on the construction, commissioning, maintenance and management of a building's fire safety system
- assessment of fire safety in existing buildings when a building's use changes – especially with respect to NCC requirements
- solutions for upgrading existing buildings when required by regulatory authorities.

These benefits, and others, are discussed in the following sections.

1.3.2 Life-cycle fire engineering

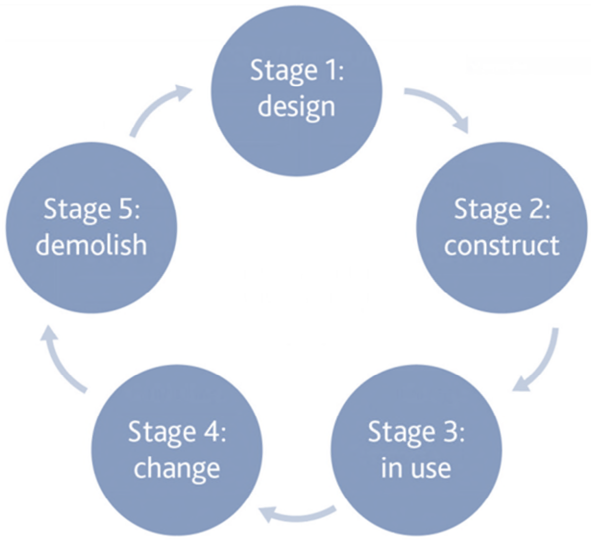
The design of a building to achieve an appropriate level of fire safety is only one element of the process of ensuring the achievement of fire safety for the life of the building. Figure 1.3.1 from the *International Fire Safety Standards Common Principles* (IFSS) shows the various stages representing the life-cycle of a building and the role that fire engineering can play in each of these stages.

In the design of a building, fire engineering can be integrated with the other professional disciplines. Fire engineering relates closely to building professions including architecture, building services engineering, structural engineering and project management.

The cost of insurance may also be a consideration. Some designs may be perceived as having a higher level of risk, which attract higher premiums and therefore may not be insurable at a reasonable cost.

The following sections discuss the role of fire engineering in each stage of the project life-cycle.

Figure 1.3.1 Potential fire engineering involvement at the various stages in the life-cycle of a building (from IFSS, p 15)



1.3.2.1 Design

The benefits of fire engineering are greatest if this discipline is involved early in the design process. Fire engineering can contribute to each stage of the design process.

For example, a preliminary report on potential fire safety systems can benefit a project feasibility study by providing flexibility in the use of fire safety systems that do not conform to the prescriptive DTS Provisions. In many cases, this delivers a more efficient design. Such a report may form a useful basis for discussions with the appropriate authority.

The PBDB, which is discussed in detail in 2.2, provides a consensus on the fire safety components of the designs and design options that need to be considered. The use of NCC Performance Solutions may lead to designs that are both more functional and economical.

Analysis of the trial design(s) identified in the PBDB may guide the design development by indicating which design(s) meet the Performance Requirements, and which components of the fire safety system need special attention. Conversely, design development may lead to other trial designs which require analysis.

The final fire engineering report will provide not only the justification for the fire safety system used, but also detailed requirements to ensure that the design documentation includes the necessary construction, commissioning, operation and maintenance requirements.

1.3.2.2 Construct: Construction

It is critical that the FE responsible for the design is involved in the construction stage to:

- facilitate the realisation of the design intent
- identify aspects that are crucial to fire safety
- develop a critical elements/functions register for fire safety systems.
- carry out supplementary analysis on required changes to the design, including liaison with relevant stakeholders (subject to local building regulations)
- determine that the necessary fire safety system components are installed as specified.

1.3.2.3 Construct: Commissioning

Proper commissioning is essential to realise the fire safety of the design and set a sound foundation for subsequent maintenance. Commissioning may be a requirement of Building Law, and reference should be made to the relevant legislation. For a performance-based design, involvement of the FE should almost always be required. The FE can:

- set system performance criteria for the fire safety system
- certify that the commissioning has proved compliance with the fire-engineered design.

For example, testing with heated artificial smoke ('hot smoke' tests) is a useful part of the commissioning process. This ensures the correct operation of equipment installed for smoke hazard management.

1.3.2.4 Construct: Final approval

This stage involves the issue of occupancy certificates (including related documents such as a certificate of compliance). In particular, the FE may be required to verify that:

- the conditions of the regulatory approval have been met
- construction and commissioning meet the approved design
- appropriate management and maintenance regimes are in place.

1.3.2.5 In-use: Management and use

The building management team's day-to-day commitment to safety will significantly affect the fire safety of a building. Management and use issues may be a requirement of Building Law, and reference should be made to the relevant legislation. Ideally, FEs should play a role in establishing management and use provisions which are appropriate to the fire-engineered design. The contributions made by FEs may include:

- contributing to the development of emergency evacuation procedures and associated training. These procedures need to be consistent with the fire engineering design, particularly in the method of warning occupants and the evacuation strategy (e.g. staged, horizontal)
- listing any limitation on fuel loadings and use of evacuation routes
- providing guidelines for housekeeping and other aspects of management for fire safety, including maintenance (Section 1.3.2.6).

Management and use issues should be addressed in the design stage (Section 1.3.2.1), refined during commissioning (Section 1.3.2.3) and be subject to final approval (Section 1.3.2.4).

1.3.2.6 In-use: Maintenance

The fire safety of a building depends on the ongoing functioning and efficacy of its fire safety system. Ideally, FE should be involved in defining the maintenance programs necessary to maintain design performance, taking into account relevant state or territory legislation, the NCC, and any relevant standards.

1.3.2.7 Change: Alteration and/or change of use

It is common for a building to be altered and/or change its use or classification during the course of its life. FE may be involved when buildings are altered or change their use because the alterations or additions may not meet the current DTS Provisions, or may compromise the original fire engineering design. FEs might:

- ensure fire-safety levels are maintained during refit and refurbishment activities
- contribute to obtaining the necessary approvals for the altered building
- examine a fire engineering design carried out on the existing building to determine if it still applies
- evaluate alterations to future use or occupancy change and include this in their PBDB for the client's attention.

1.3.2.8 Demolish

This final stage primarily focuses on the risk to site personnel and the structure on which they are working. The FE might be involved with all of the other tasks as applied to the building throughout its life.

1.3.3 Uniqueness of application

Fire engineering is building, structure, occupant and site specific in its application. This is both a strength and a weakness. Its strength is that it allows detailed consideration of the fire safety system most appropriate for the building, structure characteristics, occupants and site. This enables the benefits of the performance-based approach to be realised in the most cost effective and practical way. A weakness may arise when changes in the structure, occupants and site may require a re-evaluation of the fire safety system. This may not be necessary if the broader approach using a DTS Provision has been adopted.

From a fire engineering point of view, every building, structure – however similar it might be superficially – has subtle differences which may affect fire safety. Therefore, using one building, structure (or features of that structure) as a precedent for approval for another is generally not appropriate.

1.3.4 Third party review

Third party review is taken as encompassing both peer and specialist reviews. (see Definitions – Section 1.5.1). A third party review may be a requirement of Building Law, and reference should be made to the relevant legislation.

A third party review should be a constructive process which assists the appropriate authority in approving a design which is supported by a fire engineering report (FER). It may also assist the FE in ensuring that all matters, especially the justification of engineering judgement, are adequately addressed. A third party review should assist rather than hinder the approval of a given project. If this is not done, the process may be unduly protracted and jeopardise the worth of the third party review.

Those undertaking a third party review should understand a fire engineering design may vary according to the preferences of the FE, and a number of different approaches may be used in undertaking a fire engineering design. Professional detachment, flexibility and an open mind are essential characteristics of a good third party reviewer. As with fire engineers, third party reviewers should be aware of their duty of care and their responsibility to protect the community act in the best interest for the end users of the building. Direct discussion between parties during the review process should facilitate the resolution of any issues. Third party reviewers are obliged to maintain confidentiality of the review, including contents of the report and other documentation supplied.

Where a third party review is required by an appropriate authority, it is preferable that the third party reviewer be either recognised as an appropriate expert by the appropriate authority, or selected and appointed by the appropriate authority. It is also essential that the reviewer be independent of the project and project participants (see Definitions Section 1.5.1). The appropriate authority needs to determine whether a peer or specialist review is required (see Definitions Section 1.5.1).

Generally, a FE would not initiate a peer review, but might seek a specialist review of some aspects of the evaluation. On the other hand, the owner or project manager may commission a third party review of a fire engineering design in order to substantiate the conclusions.

Subject to the requirements of the appropriate authority the reviewer should:

- use the guidance of the AFEG as the benchmark for the review
- ensure the decisions made in the PBDB process have been followed in the analysis and conclusions
- carry out calculation checks as appropriate to determine the quality of the analysis
- ensure that the report conforms to the requirements of the AFEG and includes the appropriate items from Part 2.

In general terms, a review process may have a number of outcomes:

- The report adequately documents the evaluation of the design and supports the Performance Solution
- Although the trial design appears to be acceptable, it is not adequately supported by the evaluation. In this case, it should be relatively straightforward for the FE to satisfy the requirements of the reviewer
- The design has fundamental flaws or the wrong analysis strategy has been adopted. In such cases, the PBDB and the analysis need to be repeated in whole or part before the acceptability of the trial design can be determined
- The PBDB process has not been adequately carried out and therefore the design is unsound or not sufficiently justified. The whole fire engineering design including the PBDB and analysis may need to be redone.

The conclusions of a third party review should be documented. The report from the reviewer needs to be explicit and constructive in its approach, so that any deficiencies in the design and FER can be remedied expeditiously. In particular:

- assertions and assumptions need to be substantiated and referenced in the manner that the AFEG suggests for the FER itself
- check calculations should be sufficiently detailed to enable comprehension and evaluation
- the suggested remedial actions need to be clearly identified.

1.4 Fire engineers

A person practising in the field of fire engineering should have appropriate education, training and experience to enable them to:

- be skilled in using and supporting engineering judgement
- apply scientific and engineering principles to evaluate and design strategies to protect people and their environment from the consequences of fire
- be familiar with the nature and characteristics of fire and the associated products of combustion
- understand how fires originate and spread inside and outside buildings and structures
- understand how fires can be detected, controlled and/or extinguished (manual and automatic suppression)
- be able to anticipate the behaviour of materials, structures, machines, apparatus and processes related to the protection of life and property from fire
- understand how people respond and behave in fire situations with respect to the evacuation process
- understand and participate in the design process for buildings and other facilities
- understanding of the fire safety rationale of building codes, fire system testing and certification methods.
- understand building regulatory legislation and associated issues
- be able to balance obligations to the client and the community
- be able to negotiate with the client in developing instructions that are appropriate to the work to be undertaken, and to decline where the objectives are unacceptable.

There are objectives other than those of NCC that may be appropriate for a given project and the FE should draw these to the attention of the client and explain the benefits. Such objectives may include limiting building damage, maintaining building operation, and limiting environmental damage as discussed in Sections 1.3.1 and 2.2.5 of the AFEG.

As discussed in 1.3, fire engineering is an evolving discipline, with fewer well-proven and well-understood tools than other engineering disciplines. Therefore, engineering judgement plays a greater role in the discipline of fire engineering than in most other engineering disciplines and engineering judgement must play a part in **every** fire engineering design.

ISO defines engineering judgement as:

> *"The process exercised by a professional who is qualified by way of education, experience and recognised skills to complement, supplement, accept or reject elements of an engineering analysis."*

1.4.1 Related disciplines

There are several specialisations amongst engineers working with fire-related issues. The names of these specialisations are not necessarily consistent, and may vary from state to state.

In addition to FE, there are other related specialists (some FE are able to do these as well), such as:

- A **building services engineer,** who may be skilled in many different engineering services within a building, and may also be skilled in certain aspects of fire-related measures. For example, an electrical building services engineer may be skilled at designing an emergency intercom network, and a hydraulic engineer may be skilled at designing fire water supplies
- A **fire services or fire systems engineer**, who may be skilled in the design, installation and maintenance of fire detection, warning, suppression, and communication equipment
- A **structural engineer,** who may be skilled in structural fire engineering design.

1.4.2 Accreditation

Accreditation is a necessary step to ensure the competence and integrity of fire engineering practitioners. This is particularly important because fire engineering is a relatively new discipline.

Reference should be made to the appropriate building legislation for definitions of competent persons, as well as acceptable accrediting bodies and criteria for accreditation or registration as a FE.

1.5 Definitions, acronyms and information sources

1.5.1 Definitions

Table 1.5.1 below includes a selection of definitions relevant to the AFEG. Those italicised in the table are a NCC defined term and have been enhanced for the purpose of guidance. NCC definitions can be found in Schedule 3 of the NCC and the Guide to NCC (NCC 2019 Amendment 1).

Table 1.5.1 Definitions

Term	Definition
Approval	The granting of a statutory approval, licence, permit or other form of consent or certification by an appropriate authority. Approval may incorporate assessment of Performance Solutions.
Appropriately qualified person	*A person recognised by the appropriate authority as having qualifications and/or experience in the relevant discipline in question.*
Assessment Method	*A method that can be used for determining that a Performance Solution or DTS Solution complies with the Performance Requirements.*
Appropriate authority	*The relevant authority with the statutory responsibility to determine that the particular matter satisfies the relevant Performance Requirement. This is typically the building surveyor or building certifier charged with the statutory responsibility to determine building compliance and issue the building permit/approval and occupancy certificate/approval.*
Available safe egress time (ASET)	*The time between ignition of a fire and the onset of untenable conditions in a specific part of a building.*
Boundary conditions	A set of constraints for mathematical models.
Building Solution	A solution that complies with the Performance Requirements of a building code and is a Performance Solution, a solution that complies with the DTS Provisions, or a combination of both.
Certification	The process of certifying compliance of a particular design, design component, or design system with the technical provisions of the building code, standard or other approved assessment method and criteria. Certification may only be carried out by an appropriately qualified person.
Cue	A cue is usually in the form of a stimulus that may or may not elicit a response depending on a number of factors

Term	Definition
	associated with the respondent, event type, clarity of information and the situation. In a fire situation, the cues may be automatic, related to the combustion products of the fire, or given by other people.
Deemed-to-Satisfy (DTS) Provisions	*The DTS Provisions make up the bulk of the NCC. The DTS Provisions are deemed to satisfy the Performance Requirements and may be used as a benchmark for compliance.* *Note: complying with the DTS provisions may or may not result in a design that actually complies with the performance requirements of the NCC.*
Design	This process is carried out by the FE and may involve analysis, evaluation and engineering – with the aim of meeting the objective of the particular building or facility.
Design fire	The description of a representation of a fire within the design scenario.
Design scenario	*The specific scenario of which the sequence of events is considered and a fire engineering analysis is conducted against.*
Deterministic method	A methodology based on physical relationships derived from scientific theories and empirical results. For a given set of conditions, a specific deterministic method will always produce the same outcome.
Engineering judgement	Process exercised by a professional who is qualified because of training, experience and recognised skills to complement, supplement, accept or reject elements of an engineering analysis.
Evacuation	The process of occupants becoming aware of a fire-related emergency and going through a number of behavioural stages before and/or while they travel to reach a place of safety.
Evaluation	For the purposes of this document, the process by which a FE reviews and verifies whether a Performance Solution meets the appropriate Performance Requirements.
Expert judgement	*The judgement of an expert who has the qualifications and experience to determine whether a Performance Solution or DTS Solution complies with the Performance Requirements.* *Expert judgment is distinct from engineering judgement and involves the application of specific technical expertise that has been accumulated through experience in a sub-set of a field of engineering*
Field model	A model that divides a building enclosure into small control volumes and simulates the emission phenomena, movement of smoke and concentrations of toxic species in various

Term	Definition
	enclosures. This allows estimation of times of critical events – such as detection of fire and the development of untenable conditions. Use and evaluation of a field model always requires extensive engineering judgement.
Fire	The process of combustion.
Fire model	A fire model can be a set of mathematical equations or empirical correlations that – for a given set of boundary and initial conditions – can be applied for predicting time-dependent parameters such as the movement of smoke and the concentrations of toxic species. Use and evaluation of a fire model always requires extensive engineering judgement
Fire (safety) engineer (FE)	An appropriately qualified and experienced practitioner who, through sound and robust engineering practice, provides services that achieve reductions of risk for life for people in structures, reduction in property and environmental damage from structure fires, and the implementation of fire safety codes and regulations.
Fire engineering	See 1.3.
Fire engineering report (FER)	Final documentation of the AFEG process applied to a building.
Fire hazard	The danger in terms of potential harm and degree of exposure arising from the start and spread of fire, and the smoke and gases that are thereby generated.
Fire safety system	*One or any combination of the methods used in a building to facilitate fire safety, including but not limited to:* *(a) warn people of an emergency* *(b) provide for safe evacuation* *(c) restrict the spread of fire* *(d) control or extinguish a fire* *and includes both active and passive systems.*
Fire brigade intervention	All fire service activities from the time of notification up to the completion of fire attack and handover of the site back to the owner/occupier, with consideration of management of reignition potential and the environmental impact of fire mitigation.
Fire scenario	The ignition, growth, spread, decay and burnout of a fire in a building as modified by the fire safety system of the building. A fire scenario is described by the times of occurrence of the events that comprise the fire scenario.
Flaming fire	A fire involving the production of flames (including flashover fires).
Flashover	*The rapid transition from a localised fire to the combustion of all exposed combustible (usually cellulosic) surfaces within a room or compartment.*

Term	Definition
Fuel load	The quantity of combustible material within a room or compartment measured in terms of calorific value.
Hazard	The outcome of a particular set of circumstances that has the potential to give rise to unwanted consequences.
Heat release rate (HRR)	*The rate at which heat is released by a fire.*
Peer review	A third party review undertaken by a person accredited as a FE or a person with the equivalent competencies and experience.
Performance-based design brief (PBDB)	*A documented process that defines the scope of work for the fire engineering analysis and the basis for analysis as agreed by stakeholders.*
Performance Requirement	*A requirement which states the level of performance which a Performance Solution or DTS Solution must meet.*
Performance Solution	*A method of complying with the Performance Requirements other than by a DTS Solution. This used to be called an Alternative Solution.*
Place of safety	A place outside of the building which is not under the threat of fire from which people may safely disperse after escaping the effects of fire to a road or open space. Note: For specific occupancies (such as prisons, high care hospitals) the place of safety may be within the building. This approach requires specific consideration in consultation with stakeholders.
Prescriptive provisions	See DTS Provisions.
Qualitative analysis	Analysis that involves a non-numerical and conceptual evaluation of the identified processes.
Quantitative analysis	Analysis that involves numerical evaluation of the identified processes.
Required safe egress time (RSET)	*The time required for safe evacuation of occupants to a place of safety prior to the onset of untenable conditions.*
Risk	The product of the probability of an event occurring and the consequence of that event.
Sensitivity analysis	A guide to the level of accuracy and/or criticality of selected individual parameters determined by investigating the response of the output parameters to changes in these individual input parameters.
Smoke	The airborne solid and liquid particles and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.

Term	Definition
Smouldering fire	The solid phase combustion of a material without flames, but with smoke and heat production.
Specialist review	A third party review limited to a consideration of particular aspects of a fire engineering evaluation and carried out by a person with appropriate specialist knowledge.
Sub-system (SS)	A part of a fire safety system that comprises fire safety measures to protect against a particular hazard (e.g. smoke spread). Note: The AFEG defines six sub-systems (see Section 2.1.1).
Stakeholder	A person or organisation who has a share or interest in the design process and the successful completion of a building project, and/or person or organisation that is likely to be affected by the consequences of a fire should it occur in the building.
Third party review	A review of fire engineering reports, documents and supporting information carried out by a person who is independent of the organisation preparing the report, and is independent of those assessing and approving the report. See also peer and specialist review.
Trial design	A fire safety system that is to be assessed using fire engineering techniques.
Untenable conditions	Environmental conditions associated with a fire, in which human life is not sustainable

1.5.2 Acronyms

Table 1.5.2 Acronyms

Acronym	Meaning
ABCB	Australian Building Codes Board
AFAC	Australasian Fire and Emergency Service Authorities Council
AFEG	Australian Fire Engineering Guidelines
AS	Australian Standard
ASET	Available safe evacuation time
DTS	Deemed-to-Satisfy
ERL	expected risk to life
FCE	Fire cost expectation
FBIM	Fire Brigade Intervention Model (developed by AFAC)

Acronym	Meaning
FCRC	Fire Code Reform Centre Ltd
FE	Fire engineer
FER	Fire Engineering Report
HRR	Heat release rate
IAFSS	International Association for Fire Safety Science
IFE	The Institution of Fire Engineers, UK
IFEG	International Fire Engineering Guidelines
IFSS	International Fire Safety Standards
ISO	International Organization for Standardization
NCC	National Construction Code
NER	National Engineering Register
NFPA	National Fire Protection Association, USA
PBDB	performance-based design brief
RSET	Required safe evacuation time
SFPE	Society of Fire Protection Engineers, USA
SFS	Society of Fire Safety (Engineers Australia)
SS	Sub-system

1.5.3 Further information sources

The guidance in the AFEG is expected to remain constant over time. However, it is anticipated that the list of external information sources will be regularly updated to reflect continuously evolving research and best practice. The recommended use of the AFEG and other information sources is discussed in Part 4.

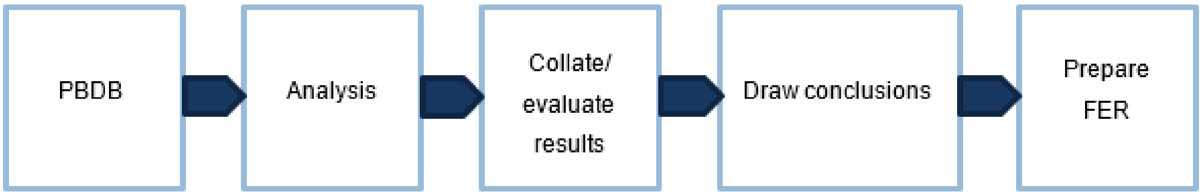
2 Process

2.1 Overview

2.1.1 The fire engineering process

The typical fire engineering process normally goes through five stages, as shown in Figure 2.2.1.

Figure 2.1.1 Typical fire engineering process



The first step is preparing a PBDB. This fundamental task is important and forms the basis of the fire engineering process. Although a PBDB process is required for every project, the outcome of that process may vary depending on the size and nature of the project. Therefore, not all PBDB processes and outcomes need to be documented in a separate comprehensive PBDB report. The PBDB process is discussed further in 2.2.

In any building, there are many features that combine to create an overall fire safety system for the building. To assist in the analysis of the fire safety system, it is convenient to consider it as comprising six sub-systems, each of which is shown below (for further discussion of these sub-systems, Appendix A). Each sub-system needs to be considered, but not all sub-systems need an in-depth analysis.

Table 2.1.1 Sub-system descriptions

Icon	Sub-system	Description
	**Sub-system A** SS-A Fire initiation & development & control (see Appendix A.1)	Sub-system A (SS-A) is used to define design fires in the enclosure of fire origin as well as enclosures to which the fire has subsequently spread, and how fire initiation and development might be controlled.
	**Sub-system B** SS-B Smoke development, spread & control (see Appendix A.2)	Sub-system B (SS-B) is used to analyse the development of smoke, its spread within the building, the properties of the smoke at locations of interest, and how the development and spread might be controlled.
	**Sub-system C** SS-C Fire spread, impact & control (see Appendix A.3)	Sub-system C (SS-C) is used to analyse the spread of fire beyond an enclosure, the impact a fire might have on the structure, and how the spread and impact might be controlled.
	**Sub-system D** SS-D Fire detection, warning & suppression (see Appendix A.4)	Sub-system D (SS-D) is used to analyse detection, warning and suppression for fires. This process enables estimates to be made of the effectiveness of suppression.
	**Sub-system E** SS-E Occupant evacuation & control (see Appendix A.5)	Sub-system E (SS-E) is used to analyse the evacuation of the occupants of a building. This process enables estimates to be made of the times required for occupants to reach a place of safety.
	**Sub-system F** SS-F Fire services intervention (see Appendix A.6)	Sub-system F (SS-F) is used to analyse the compatibility of the standard intervention activities of fire brigade services with a fire according to the FBIM.

Careful collation and evaluation of the results from the analysis is vital, and this is discussed in 2.4. Drawing conclusions requires engineering judgement, as discussed in Section 2.4.2. If the conclusions reveal the particular trial design is unsatisfactory, the analysis has to be repeated on a different trial design. This process is repeated until an acceptable trial design is found.

The overall fire engineering process (preparing a PBDB, carrying out the requisite analysis, collating the results, and drawing conclusions) is of little use unless the FER documents it in a transparent manner that is responsible, accurate and aimed at helping the ultimate decision maker and user of the report. This essential process is discussed in 2.5.

2.1.2 Application of the process

All fire engineering studies will be a mixture of design and evaluation. To that end, the FE needs to understand that as the design moves from early concept or scheme design through design development and into detailed design, the project design options are reduced, and costs are refined continually. If further fire engineering analysis is required during the construction stage, there may be further limitations to solutions and cost implications. Once the FE has completed the evaluation of the fire safety strategy and design solution, the other designers still have to complete the design of components, such as sprinklers and detection and smoke control systems. Therefore, it is critical that any fire safety evaluation is completed before the design or cost estimate of the project is finalised.

The fire engineering process outlined in Section 2.1.1 may be carried out in many different ways. As discussed in 2.2, the knowledge and skills of a FE are needed to determine the most effective way of devising a fire engineering analysis strategy and carrying out the evaluation. The AFEG provides guidance for FEs to select an analysis and evaluation strategy appropriate to the project in hand.

2.2 Preparing a fire engineering PBDB

For each project, the FE must prepare a PBDB. This section provides guidance on issues which should be addressed in the PBDB. A PBDB follows a process that defines the scope of work for the fire engineering analysis. Its purpose is to set down the basis on which the fire safety analysis will be undertaken. Note that the outcome of this process may vary depending on the size and nature of the project, and may therefore not be required to be documented in a separate PDBD report.

The PBDB is an essential part of the fire engineering process. Where appropriate, it may allow broader community aspirations to be taken into account during the development and evaluation of Performance Solutions, while ensuring that acceptable levels of safety are maintained.

In the case of a fire engineering analysis that considers a simple departure from a DTS Provision, the PBDB might be a short document (written, printed or electronic, which could include email communication). However, for large and/or complex projects, the PBDB could be a comprehensive report.

The PBDB process should be developed collaboratively by all the relevant stakeholders, but this may vary according to the particular circumstances of the project, as discussed in Section 2.2.2. All stakeholders must make best endeavours to provide input / feedback in a timely manner in order to deliver projects in the public interest.

The flow chart in Figure 2.2.1 illustrates the process for developing the PBDB, and refers to the relevant sections of the AFEG. However, the process will vary for any particular project and steps may be reordered or omitted. In some cases, an iterative process may be introduced. The FE should ensure that the process followed is appropriate for the design or evaluation.

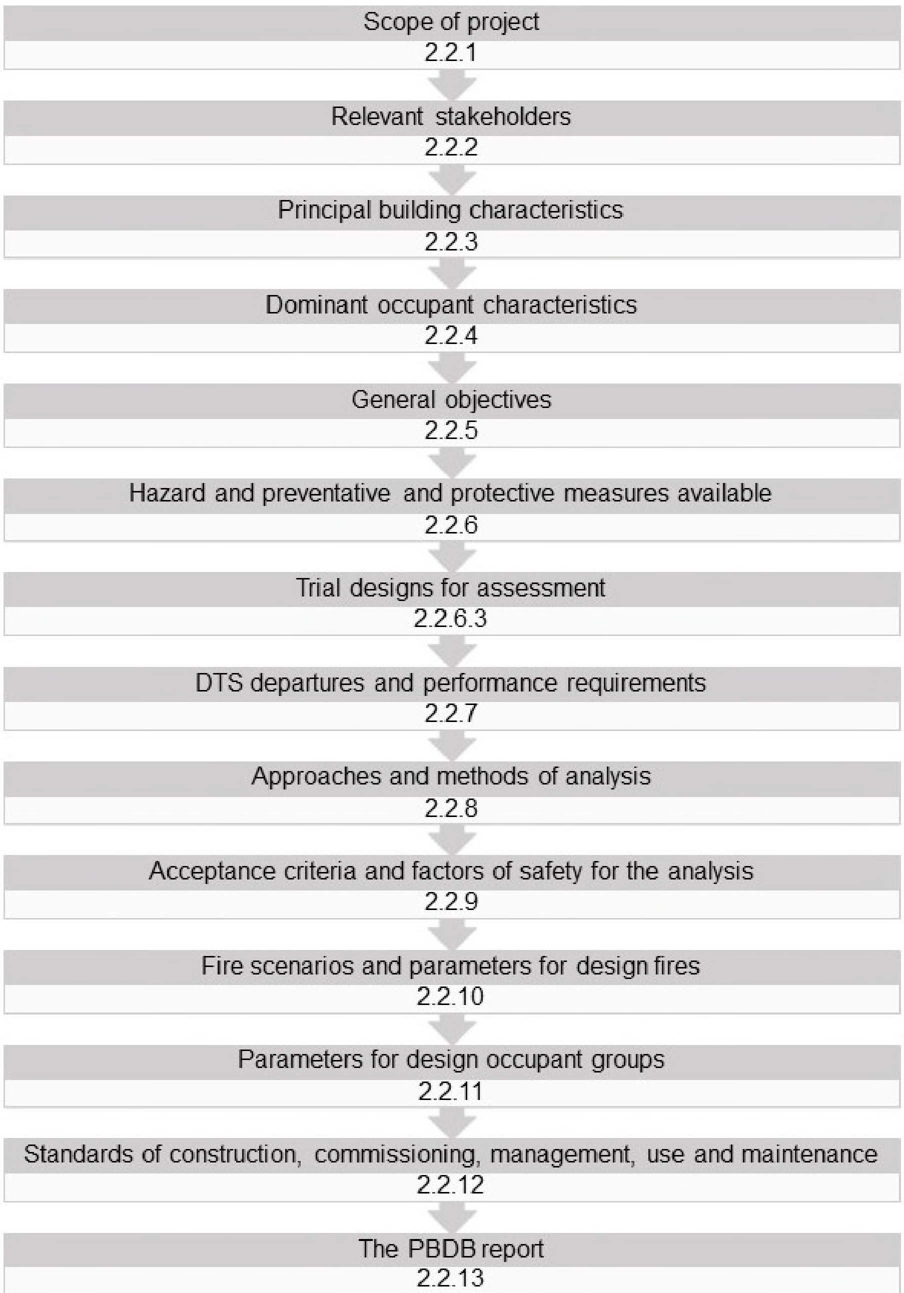
In principle, the proposed trial designs, analysis methods and acceptance criteria are agreed before the analysis commences. However, in practice, preliminary calculations may be carried out to establish the likelihood of success before trial designs are proposed and the full analysis carried out.

Where a trial design is found (through analysis) to be unacceptable (it does not meet the Performance Requirements) the PBDB process is revisited and a further trial design developed.

It is appropriate to invite stakeholder comments and input on the trial design, assessment criteria, and objectives. The 'final' PBDB will be incorporated into the overall report (2.5).

Each step in the flow chart (Figure 2.2.1) is discussed in Sections 2.2.1 to 2.2.13.

Figure 2.2.1 A process for developing a PBDB



2.2.1 Scope of the project

In order to help stakeholders contribute effectively to the PBDB process, the FE should explain the scope and intent of the project and invite questions and ongoing contact. Some topics that might be explained are discussed below.

2.2.1.1 Regulatory framework

It is important for the PBDB team to understand, right from the outset, the regulatory framework in which the building is to be designed and constructed. Questions might include:

- Are there any relevant legislative requirements relating to the building project?
- What is the process of accepting a performance-based solution as an alternative to a prescriptive design?
- Who are the appropriate authorities for the building permits / approvals?
- Which other stakeholders should be consulted?
- What timeframes can be expected for the various regulatory approval options available?

In some cases, there may be no applicable regulatory framework. For example, when an owner or tenant voluntarily upgrades all or part of an existing building to meet their own risk management requirements. Nevertheless, in this situation, the owner or tenant should give due regard to the regulatory environment to ensure there is not regulatory impact.

Alert:

Upgrade works may not be required under legislation to be submitted to the local fire authority but where a performance solution relates to equipment required to be used by the fire authority, it is considered prudent that they be included as a stakeholder irrespective of the size of the development.

2.2.1.2 Project schedule

Time constraints dictated by the project schedule may also affect the fire engineering process. For example:

- If a project is urgent, there may not be time to prepare a performance-based fire engineering analysis. Therefore, a standard DTS design may have to be adopted, although a performance-based solution may offer cost savings, flexibility and design innovation.
- Project schedules incorporating staged occupation of the building may affect the design of the fire safety system.

It is also important to understand the time required for the various stages of the regulatory process, including the fire engineering analysis.

2.2.2 Relevant stakeholders

Consultation and active engagement with stakeholders is a fundamental component in the process of formulating an appropriate scope of work and consequently, the brief and all that flows from it.

The PBDB must be developed collaboratively by the relevant stakeholders in the particular project. The following parties may be involved:

- Client or client's representative (such as project manager)
- Fire engineer
- Architect or designer
- Various specialist consultants
- Fire service (public or private)
- Appropriate authority (Authority Having Jurisdiction – subject to state legislation)
- Tenants or tenants representative for the proposed building (if available)
- Building operations management (if available)
- representative of owner's insurance company.

Conducting a simple stakeholder analysis can be used to determine who must be involved in the PBDB process. This analysis must identify stakeholders with a high level of interest in the design process, and/or likely to be affected by the consequences of a fire should it occur in the building. This stakeholder analysis should be included in the PBDB Report and the Fire Engineering Report.

Selection and engagement of the relevant stakeholders will often happen in conjunction with scoping the proposed solution. Identification of relevant stakeholders will stem from initial scoping of the attributes and parameters of the project and also the relevant parts of the building that are to be subject to a performance-based design approach. Within the proposed scope, the stakeholders can provide advice on appropriate acceptance criteria, NCC Assessment Methods (suitable for the acceptance criteria), potential risks and mitigation strategies.

As the design, assessment, and construction of any proposed work will normally involve more than one stakeholder, the process will require collaboration and negotiation to achieve a mutually acceptable performance-based outcome.

Consultation with an appropriate authority should be initiated as soon as possible to ensure the proposed acceptance criteria can be accepted in support of the approval process. However, the stage at which consultation is commenced is a decision for the person responsible for managing the brief process and may be influenced by the complexity of the project. Legislation may also dictate when this must occur.

The complexity of the project will influence:

a. the suitability of qualified and experienced individuals; and/or
b. the need for, and breadth of, stakeholder consultation.

A primary benefit of early consultation is that stakeholders, who will be required to contribute to decision making processes during the course of the project, have an opportunity to express their needs. This could be regarding preferred processes, technical methodologies, and the scope of documentation to support future decision making.

In practice, a draft PBDB is often prepared by the FE, submitted for comment to the other stakeholders, and refined. The circumstances of each project and its method of regulatory approval will generally dictate the precise process of stakeholder consultation, including how many meetings are held and if appropriate, any meeting forum (e.g. face-to-face, telephone, or video conferencing).

Alert:

It is crucial that the appropriate authority is not asked to provide design advice. It is a conflict of interest for those with regulatory responsibility to assess aspects of a design that they have contributed to the development of.

2.2.3 Principal building characteristics

In order to evaluate or design a building's fire safety system, it is important to understand the building's characteristics and its normal mode of functioning. The principal characteristics should be identified early in the PBDB process to facilitate decision-making and resolution of any issues (see Figure 2.2.1). The information available will vary for each stage in the design process. Table 2.1.1 includes a list of some characteristics (and examples of each) which may be appropriate.

Table 2.2.1 Example of principal building characteristics

Characteristics	Examples
Occupancy	Building classification Usage, particularly unusual uses
Location	Proximity to other buildings and boundaries Proximity to buildings of high importance (e.g. buildings used for post-disaster recovery) Proximity to other hazards Proximity to fire station(s) Fire services access
Size and shape	Number of floors Area of each floor General layout
Structure	Construction materials Hidden voids Openings, shafts and ducts Ventilation and air movement Unusual features
Hazards	See Section 2.2.6.1
Fire preventive and protective measures	See Section 2.2.6.2
Management and use	Regular inspections of preventive and protective measures Training of occupants
Maintenance	Frequency and adequacy of maintenance regimes Availability of parts and personnel for repairs
Environmental conditions	Ventilation and prevailing internal air currents Prevailing patterns of wind and snow

Characteristics	Examples
Value	Capital Community Infrastructure Heritage
Other	Environmental impact of a fire Fire-fighting concerns

2.2.4 Dominant occupant characteristics

Understanding the likely nature of the building's occupants is an important element of the PBDB process. There are many characteristics that may be identified, which makes complete characterisation difficult. For a given fire engineering evaluation, a limited number of dominant occupant characteristics may affect the outcome. Table 2.2.2 gives some examples of dominant occupant characteristics which may be relevant.

Table 2.2.2 Examples of dominant occupant characteristics

Characteristics	Examples
Distribution	Number Gender Age Location
State	Awake or asleep Intoxicated or sober Unconscious or fully conscious
Physical attributes	Mobility Speed of travel Hearing ability Visual ability
Mental attributes	Level of understanding Potential emergency behaviour Ability to interpret cues Ability to make and implement decisions independently
Level of assistance required	Requires full assistance Requires some assistance Does not require assistance
Level of assistance available	Shift schedules Staff numbers and type

Characteristics	Examples
	Staff to patient / child etc. ratio.
Emergency training	Trained Untrained
Occupant (group) roles	Parent or child Teacher or student Nurse or patient Staff or customer
Activity at the outbreak of fire	Asleep or awake Working in a noisy environment Watching a performance
Familiarity with the building	Unfamiliar Relatively familiar Familiar

Table 2.2.2 should be considered in identifying the design occupant groups for the building. The concept of design occupant groups is explained in Section 2.2.11 of the AFEG.

The dominant occupant characteristics chosen for the analysis may impose limitations on potential future uses of the building. Therefore, it may be prudent to consider potential future building occupancies as well as those planned for the immediate future.

2.2.5 General objectives

The PBDB should define the agreed fire safety objectives for the project in order to define the objectives. As stakeholders may have differing objectives, it is useful to consult with a range of relevant stakeholders. Project objectives can be divided into three broad categories: building regulatory objectives, other regulatory objectives, and non-regulatory objectives. These three categories are discussed in Sections 2.2.5.1, 2.2.5.2 and 2.2.5.3 respectively.

2.2.5.1 Building regulatory objectives

The building regulatory objectives for the project will normally be the broad objectives set out in the building legislation and/or building codes. These may include, but are not limited to:

- protecting building occupants
- facilitating the activities of emergency services personnel
- protecting the property
- preventing the spread of fire between buildings.

2.2.5.2 Other regulatory objectives

The other regulatory objectives for the project will normally be the broad objectives set out in other legislation. These may include, but are not limited to:

- environmental protection
- occupational health and safety
- fire services
- dangerous goods
- land use and other planning matters.

2.2.5.3 Non-regulatory objectives

The non-regulatory objectives for the project may include other objectives set by the client or other stakeholders (e.g. the insurer) such as:

- limiting structural and fabric damage
- limiting building contents and equipment damage
- maintaining continuity of business operations and financial viability
- safeguarding community interests and infrastructure
- protecting corporate and public image
- protecting heritage in older or significant buildings
- limiting the release of hazardous materials into the environment.

The client may also have various non fire-related objectives for the building design that impact the fire safety of the building. For example, the client may require:

- increased security
- extensive natural lighting
- an open-plan layout
- the use of new materials
- measures to improve energy efficiency and sustainability above NCC requirements

- flexibility for future uses
- low life-cycle costs.

2.2.6 Hazards and preventive and protective measures

A systematic review should be conducted to establish potential fire hazards (both normal and special) of the building. The information gathered when determining the principal building characteristics (see Section 2.2.3) forms the basis for this review. Section 2.2.6.1 provides examples of potential fire hazards.

The next step in the process is identifying which preventative and protective measures are in place or planned to address the hazards, and which additional measures could be used. Examples of preventative and protective measures are listed in Section 2.2.6.2.

2.2.6.1 Hazards

Table 2.2.3 lists some examples of factors which may be considered when determining likely hazards.

Table 2.2.3 Examples of factors to be considered when determining likely hazards

Factors	Examples
General layout	Long dead end corridors Unusual egress provisions Location of hazardous materials/processes Exposures to external radiant sources Building/architectural features Innovative construction methods
Activities	Repair and maintenance Process and construction Disregarding safety procedures
Ignition sources	Smoking materials Electrical equipment Heating appliances Unusual ignition sources

Factors	Examples
Fuel sources	Amount of combustible materials Location of combustible materials Fire behaviour properties Dangerous goods and explosives

2.2.6.2 Preventative and protective measures

Table 2.2.4 lists examples of preventative and protective measures for each of the fire safety sub-systems used in the AFEG.

Table 2.2.4 Examples of preventative and protective measures

Sub-system	Measures
SS-A – Fire initiation, development and control	Limitation of ignition sources Limitation of nature and quantity of fuel Arrangement and configuration of fuel Separation of ignition sources and fuel Management of combustibles including housekeeping measures Electrical safety equipment Regular plant maintenance Adherence to procedures for 'hot work' (e.g. welding)
SS-B – Smoke development, spread and control	Smoke barriers Natural smoke venting Mechanical smoke management
SS-C – Fire spread, impact and control	Separation of fuel Separation of buildings Fire resistive barriers Fire resistive structural elements Fire resistive air-handling ducts Fire resistive dampers Exposure protection
SS-D – Fire detection, warning and suppression	Automatic and manual detection equipment Automatic and manual warning equipment Surveillance equipment Automatic suppression equipment Manual suppression equipment

Sub-system	Measures
SS-E – Occupant evacuation and control	Evacuation plans Occupant training Emergency communications Egress signage Egress routes (including fire-isolated elements)
SS-F – Fire services intervention	Type of fire services available (full-time/permanent or volunteer) Characteristics of fire services' capability and resources Fire services' access to the site and the building Water supplies and infrastructure

2.2.6.3 Trial designs for evaluation

As the architectural and engineering drawings develop, the design team (including the FE) should incorporate measures which are expected to achieve an acceptable level of fire safety. The PBDB team should select one or more trial designs for detailed analysis as described in 2.3. Examples of factors which may be considered when developing trial designs may include: aesthetics, cost, ease of everyday use, speed of construction, and the importance of maintenance. The trial designs may incorporate measures which are not required by the relevant DTS Provisions.

In addition, trial designs should incorporate sensitivity, redundancies and uncertainties to compensate for potential failures of components of the trial design's fire safety system (see Section 2.2.8.5).

Additional trial designs will need to be developed if the selected trial designs do not meet the required performance criteria.

Each trial design considered should be clearly identified. All of its features, including those relating to fire safety, should be described. This description needs to be sufficiently detailed to allow the essential features of the design to be readily identified for analysis and future reference.

2.2.7 DTS departures and Performance Requirements

After defining the general objectives (Section 2.2.5), the next step in the process is determining which Performance Requirements will be used to evaluate the trial designs. A necessary precursor is for the PBDB team to determine where the trial designs do not meet the relevant DTS Provisions. This will identify the issues that need to be addressed in the analysis of the trial design (see 2.3).

In cases where there are no DTS Provisions, the relevant Performance Requirements need to be identified directly (Section 2.2.7.2), and the determination of non-compliance issues (Section 2.2.7.1) omitted.

It is important that the FE clearly identifies whether the trial design is being evaluated in terms of equivalence to the DTS Provisions, or according to the Performance Requirements (see Section 2.2.7.2).

2.2.7.1 DTS departures

For most structures, the majority of the design adopts the DTS Provisions. Each DTS departure needs to be identified, assessed and documented by comparing the trial designs with the relevant provisions. The FE may be involved in assisting in identifying the fire safety related DTS departures, but must have access to adequate information to do so. The building surveyor and appropriate authority will also need to be involved.

As more DTS Provisions are adopted, the scope of the fire engineering evaluation will generally decrease. This is because the analysis is limited to addressing the DTS departures.

2.2.7.2 Performance Requirements

The determination of the Performance Requirements is based upon the identified DTS departures, and the required general non-regulatory objectives (Section 2.2.5.3).

It is important to note that a single DTS departure may relate to more than one Performance Requirement. In addition, the departure and Performance Requirements may not be in the same section of the NCC.

2.2.8 Approaches and methods of analysis

Having determined the DTS departures and/or the relevant Performance Requirements, the next step is to select the approaches and methods of analysis which will be used to determine whether the trial design meets the acceptance criteria (see Section 2.2.9.1).

A consideration of the total analysis strategy (2.3) may be needed for this process. DTS departures may be grouped for analysis where they are evaluated using the same (or similar) approaches and methods.

A number of decisions need to be made when selecting the analysis approaches for grouped or single issues identified in the analysis strategy. The analysis may be carried out in a comparative or absolute manner – applying qualitative or quantitative methodologies and using deterministic or probabilistic tools.

These approaches are discussed in the following sections, together with guidance on the use of sensitivity and uncertainty studies and the selection of methods of analysis.

2.2.8.1 Comparative or absolute approach

Comparative (equivalence to DTS) or absolute (Verification Method) approaches may be adopted in the analysis strategy.

Comparative approach

A comparative approach aims to determine whether the Performance Solution is equivalent to (or better than) the DTS or prescriptive design. The comparative approach is often referred to as an “equivalence” approach.

For more guidance on comparative analysis, see the Handbook: Fire Safety Verification Method (ABCB, 2020) and for specific guidance on the derivation of a reference building see Section 6.6. Other methods of comparative analysis may be utilised subject to consultation and agreement with stakeholders.

Absolute approach

When an evaluation is carried out on an absolute basis, the results of the analysis of the trial design are matched, using the agreed acceptance criteria (see Section 2.2.9.1), against the objectives or Performance Requirements without comparison to DTS or prescriptive or "benchmark" designs.

2.2.8.2 Qualitative or quantitative approach

Both qualitative and quantitative approaches may be adopted in the analysis strategy. The methods chosen needs to be appropriate to the approach used.

Qualitative approach

Qualitative analysis aims to identify qualities that lead to increased risk compared to a structure satisfying the DTS Provisions. This means that uncertainty is partially addressed by identifying all negative impacts.

The basis (logic) for selecting this approach should be documented with appropriate references.

The qualitative approach is often based on engineering judgement, but may also involve simple calculations, comparisons, or use of data.

A 'Delphi' approach may also be appropriate in certain circumstances. For example, where a group of expert professionals reach consensus regarding the suitability of a particular solution.

A qualitative approach will likely be suited to simple performance solutions with minimal interactions with other building elements, deemed-to-satisfy fire safety components or performance solutions. Where possible, a quantitative or semi-quantitative approach should be adopted.

Quantitative approach

A quantitative approach entails the use of one or more of the many analysis methods available. Section 2.2.8.4 lists various forms of quantitative analysis methods and their desirable attributes. The results of quantitative methods are usually supported by additional qualitative arguments. Qualitative arguments arise from logical deductions that make use of empirical evidence, calculations, testing or other data and / or methods. Engineering judgement and experience normally informs these discussions to supplement any limitations in quantitative analyses.

Engineering judgement may be utilised by an engineer to fill knowledge gaps in fire science or human behaviour and supplement a quantitative analysis.

2.2.8.3 Deterministic or probabilistic approach

Both deterministic and probabilistic approaches may be adopted in the analysis strategy. The methods chosen will be appropriate to the approach used.

Deterministic approach

Deterministic methods are based on physical relationships derived from scientific theories and empirical results. For a given set of initial boundary conditions, a deterministic methodology will always produce the same outcome. However, deterministic methods do not indicate the probability of that outcome being realised.

Deterministic methods are more commonly used than probabilistic methods. This is because they are better developed, less complex, and less demanding on data and analysis. There is also a wide range of deterministic methods to suit various analysis requirements.

An analysis using deterministic methods generally adopts a timeline approach, where the times of occurrences of a number of events is calculated and compared.

Probabilistic approach

Probabilistic approaches use a variety of risk-based methodologies (see 3.2). These methods generally assign reliabilities to the performance of fire protection measures and assign frequencies of occurrence to events. They may analyse and combine several different scenarios as part of a complete fire engineering evaluation of a building design. The use of multiple scenarios and their combination through probabilistic techniques is the key feature of some probabilistic methods.

Probabilistic methods require significant amounts of statistical data which is rarely available. Due to their complexity, they may involve time-consuming calculations.

Furthermore, their validity may be more difficult to demonstrate, as this may require numerous experiments and a detailed examination of fire statistics.

An example of a probabilistic method using multiple design fire scenarios combined in event trees is below.

Example: Probabilistic event tree approach

A procedure for this kind of analysis may comprise the following steps:

- Develop multiple design fire scenarios using event trees
- Quantify the design fire scenarios in terms of:
  - the times of occurrence of the events comprising each scenario (as for deterministic method) using the appropriate sub-system analysis
  - the probability of occurrence of the events.
- Estimate the consequences of each design fire scenario in terms of the expected number of deaths for a given population and for the entire design life of the building
- Estimate the expected risk to life (ERL) which is the sum of the risks over all fire scenarios, where:

$$ERL = \frac{Expected\ number\ of\ deaths}{Number\ of\ occupants\ \times\ design\ buliding\ life}$$

- Compare the ERL estimated with the acceptance criteria for the analysis. For acceptance, ERL estimated should be ≤ ERL acceptance. The value of ERL acceptance may be a specified number (an absolute-type evaluation) or that of a design for the building that confirms to the DTS Provisions (a comparative-type evaluation).

2.2.8.4 Methods of analysis

If a quantitative approach has been selected for the analysis, suitable methods need to be chosen. These analysis methods will reflect the approaches selected for the analysis strategy (comparative or absolute, deterministic or probabilistic).

There are many forms of analysis methods. Examples may include:

- formulae, equations and hand calculations
- spreadsheet calculations
- statistical studies
- experiments with physical-scale models

- full-scale experimental tests (such as fire tests or trial evacuations of real buildings)
- computer simulation of fire development and smoke spread
- computer simulation of people movement.

The methods chosen should:

- be well documented (especially their limitations and assumptions) either in the literature or by the FE
- be well calibrated
- be well validated
- be suitable for the task
- generate outputs that can be compared with the acceptance criteria agreed for the analysis (see Section 2.2.9)
- have clearly defined limitations and assumptions that are well documented.

The PBDB report should record, as appropriate, the above information for each method chosen. Information about some methodologies is given in Part 3.

2.2.8.5 Sensitivity, redundancy and uncertainty studies

Fire engineering analyses require critical assessment of inputs, processes and outputs in order to achieve a high level of confidence in the outcomes. Sensitivity studies, redundancy studies, and uncertainty studies should be incorporated into the analyses and are described below. The nature and extent of these studies may be influenced by the approaches and methods selected.

Sensitivity studies

Example: Sensitivity studies

Typical examples may include:

- a design fire with a rate of growth chosen to be the most credible might be modified to have a different rate of growth
- the capacity of smoke management equipment might be reduced to assess partial failure
- the movement time component of an evacuation study may be estimated using significantly lower travel speeds

- a building complex may have a variety of egress options such as fire stairs, fire passageways, main exits, and exits to parking areas. The movement time component of an evacuation study may be conducted using only a limited number of exits. This would examine the robustness of the trial design with regard to alternative means of egress.

Sensitivity studies measure the impact of changing one or more key input values (singly or in combination) on the results of analyses. This is especially useful if there is some doubt about their quantification. The PBDB should state the nature and extent of the sensitivity studies that will be undertaken.

Redundancy studies

Redundancy studies are similar to sensitivity studies but examine the redundant measures of a trial design that essentially fulfil the same function. The PBDB should state the nature and extent of the redundancy studies that will be undertaken. In particular, designers should not expect each redundant component will deliver exactly the same performance. Instead, designers should look for single points of failure, and what redundant systems will be available to provide backup if that failure eventuates.

Uncertainty studies

Uncertainty studies often follow or complement a sensitivity study. An uncertainty study determines how input data and uncertainties inherent in the methods used are reflected in the outputs of the analysis. Some indication of the uncertainties associated with the methods may be obtained using a number of appropriate methods and comparing outputs. The uncertainties may be due to poor conceptualisation of the problem being investigated, or due to inadequate formulation of the conceptual or computational model used. Calculation and documentation errors may also lead to uncertainties. The PBDB team should determine whether an uncertainty study is appropriate for the chosen analysis strategy.

2.2.9 Acceptance criteria and factors of safety for the analysis

The next steps in the process are setting acceptance criteria and associated factors of safety for the analysis (see 2.3), and collating and evaluating the results (see 2.4).

These acceptance steps are necessary to determine whether the results of the analysis are equivalent to a structure adopting the DTS Provisions (comparative approach), or meet the Performance Requirements (absolute approach).

2.2.9.1 Acceptance criteria

The acceptance criteria need to be:

- appropriate to the general objectives, the Performance Requirements, and the analysis methods used
- numerical when a quantitative approach is adopted
- realistic (e.g. zero risk is not possible, and therefore is not an appropriate criterion).

Example: Typical acceptance criteria parameters for the analysis grouped according to general objectives (see Section 2.2.5)

General objectives	Criteria considerations
Protect building occupants	ERL ASET/RSET margin Smoke layer height Temperature of hot layer Radiant heat from hot layer Convective temperature Toxicity Smoke optical density
Facilitate fire services intervention	Access/Condition/equipment Radiant heat from hot layer Convective temperature Visibility Structural failure Water supply Resources at fire source
Protect adjacent property	Radiant heat from fire Flame impingement
Limit damage	Monetary loss Smoke release
Maintain business operation	Monetary loss Corrosive gases
Protect heritage	Monetary loss

	Hot layer gas temperature
Limit environment effects	Toxicity of effluent gases Impoundment of water

It may be convenient to express the acceptance criteria in terms of a number of relevant parameters which may be used singularly or in conjunction with each other.

For an equivalence approach, the same criteria should be used for both the structure adopting the DTS Provisions and the structure being evaluated.

For an absolute approach, the criteria should take into account any uncertainties in the analysis and the factors of safety employed. For the purposes of sensitivity studies, less rigorous acceptance criteria may be appropriate. These acceptance criteria should be agreed during the PBDB process in order to avoid overly conservative outcomes.

2.2.9.2 Factors of safety

The magnitude of the factors of safety adopted should be based on a consideration of:

- the extent of redundancy in the trial design
- the reliability of the various components of the fire safety system
- the analysis methods used
- the assumptions made for the analysis
- the results of an uncertainty analysis
- the acceptance criteria used
- the consequences of a fire.

As some of these considerations may not be quantified until the analysis has been completed, the values for the factors of safety may not be finalised at the PBDB stage. If the FE considers that the numerical values should be changed following analysis, the FE should go back to the stakeholders to obtain agreement and should document the process in the report.

To avoid overly-conservative outcomes, factors of safety should only be applied at the end of a calculation sequence, and not throughout the analysis steps.

For the purposes of sensitivity studies, less rigorous factors of safety may be appropriate in order to avoid overly-conservative outcomes.

2.2.10 Fire scenarios and parameters for design fires

Just as in structural engineering (for example) the structural loading needs to be specified in order to carry out the evaluation of the structural safety of the building, design fires need to be specified in order to carry out a fire engineering evaluation. The selection of appropriate design fires is therefore a crucial step. The validity of the data obtained by analysis and the conclusions drawn in the fire engineering evaluation rely upon the validity of the design fires.

In order to specify the design fires that are to be used in a fire engineering evaluation, three steps should be undertaken:

1. Determine potential fire scenarios (see Section 2.2.10.1).
2. From these possibilities, select the design fire scenarios to be used for developing the design fires (see Section 2.2.10.2).
3. For each of these design fire scenarios, specify a design fire (see Section 2.2.10.3).

2.2.10.1 Potential fire scenarios

A fire scenario is a description of a fire through all the relevant stages such as ignition, growth, spread, decay and burnout. A fire scenario will take account of factors such as:

- the nature, quantity, arrangement and burning behaviour of combustibles in each enclosure
- enclosure geometry
- number of enclosures and their relationship
- connections between enclosures
- the fire protection measures in the building and their effect on the fire.

The first task is to determine and justify potential fire scenarios. This can be done by a variety of techniques, such as:

- using some or all of the fire scenarios identified in CV4 (Fire Safety Verification Method) (Schedule 7 of NCC 2019 Volume One, Amendment 1)
- reviewing information assembled for the PBDB, especially that obtained from the hazard analysis (Section 2.2.6)

- examining data in the published literature
- reviewing fire statistics
- drawing on experience and knowledge.

2.2.10.2 Design fire scenarios for analysis

A fire engineering analysis can only take into account a limited number of the potential fire scenarios which might occur in a subject building. The number and nature of fire scenarios selected for analysis will depend on factors such as the number of DTS departures being addressed, methods of analysis used, and the characteristics of the building itself.

From the potential fire scenarios, the PBDB team has to decide which scenarios are to be subjected to analysis. Usually, a number of severe scenarios which have a reasonable probability of occurrence and significant potential for loss (e.g. life, property) are selected for analysis. Care and judgement should be used to avoid unnecessarily analysing events with a very low probability of occurrence. However, where the scenario may have very high adverse consequences, due consideration should be given – if not for the primary analysis at least in the sensitivity studies.

At PBDB stage, any design scenario considered should always include a preliminary description of the fire brigade intervention strategy. At PBDB stage, any design scenario considered should always include a preliminary description of the fire brigade intervention strategy following the SS-F presented in Appendix A6 using the FBIM, or other methods subject to consultation and agreement with stakeholders. This is needed also for those fire scenarios with low probability of occurrence but high adverse consequences because in principle the fire brigade will always intervene and therefore needs to know the fire scenario conditions at arrival in any case.

The preliminary description of the fire brigade intervention strategy enables and drives collaboration with the fire brigade during the PBDB to ensure that a building design is compatible with fire brigade standard operations. A collaborative approach in the public interest is expected.

The process undertaken in Section 2.2.10.1 may indicate there are potential fire scenarios which involve malicious ignition (arson). Such scenarios should be dealt with in a similar fashion to scenarios involving accidental ignition in selecting design fire scenarios for analysis. However, recognition should be given to the fact that the fire safety system may not have the scope or capacity to respond adequately to some large-scale arson attacks and terrorist events. Other measures need to be put in place to deal with these situations.

2.2.10.3 Design fires

In order to carry out a fire engineering analysis, it is usual to formalise the fire scenarios being considered as 'design fires'. At the PBDB stage, the task is to define and describe (to the extent possible without involving calculation) the design fires which will be used during the analysis.

A design fire shall be described in terms of the fire development in either qualitative terms (for qualitative analysis) or quantitative terms (for deterministic and quantitative analysis). A quantitative description of a design fire can include the incipient phase, growth phase, fully developed phase, decay phase and extinction depending on the design fire scenario being evaluated. A design fire can also include the effect of measures (such as sprinkler activation) or actions (such as fire brigade intervention) influencing the development of the fire, however this should be carefully considered, appropriately justified and discussed with the stakeholders.

2.2.11 Parameters for design occupant groups

A building may contain more than one type of occupant group and each group may contain a diverse range of individual occupants. The recommended approach is to identify the most common, influential or vulnerable occupant groups and base the analysis on these groups. The selected occupant groups are referred to as design occupant groups.

Dominant characteristics that may be considered in identifying design occupant groups are listed in Section 2.2.4 of the AFEG. To avoid excessive complexity, only the most critical, relevant or significant characteristics should be considered for a given group. The decision as to which characteristics need to be considered may be based on the literature, engineering judgement, and discussions between all interested parties.

Numbers should not be the main criterion in selecting the design occupant groups. If any of the occupant groups have characteristics which would influence the outcome of a fire scenario, they should be considered for identification as a design occupant group. In some cases, the design occupant group may consist of only one person.

There may be more than one design occupant group for an evaluation. In some cases, each design occupant group may play a dominant role at a different stage of the evacuation process.

The PBDB team should identify the design occupant group(s) to be used for the analysis and, if appropriate, describe which group will be used in each step of the analysis of the evacuation process.

Example: Design occupant groups

In a hospital, examples of design occupant groups are the staff and the patients. As the design fire used for the evaluation should be based on a likely severe fire scenario (e.g. fire occurring at night) other possible occupant groups such as visitors may be ignored. The staff may be used as the design occupant group to assess the detection and pre-movement phases. However, it will be the patients, as a design occupant group, who will determine the movement time. The detection and pre-movement times for the staff occupant group can be adopted as the universal times for the whole or part of a hospital. The time for all patients to move to a place of safety will be determined by the type of patient (e.g. intensive care, surgery) and this may vary from ward to ward.

2.2.12 Standards of construction, commissioning, management, use and maintenance

Real-life fire safety over ensuing decades will be highly dependent on elements other than the approved design. Such elements include:

- construction – how the design is transformed into reality
- commissioning – how the building is commissioned to become a working entity
- management and use – how the occupants and the fire hazards are managed and how the building is used
- maintenance – how the building and its fire safety system are maintained.

The PBDB should consider any measures addressing the question of how high, or how low, one can prudently expect standards for the elements listed above to be maintained over the life of the building.

Where possible and practical during the preparation of the PBDB, all relevant stakeholders should be aware of – and have input into – what standards should be assumed for these elements. They may also have input into how these standards might best be:

- incorporated into working documentation
- achieved during construction and commissioning
- achieved throughout the life of the building.

2.2.13 The PBDB report

The PBDB team should prepare a report at the end of the PBDB deliberations and before the analysis commences. This report should:

- summarise the discussions, assumptions and factors that lay behind each decision – especially those decisions based on engineering judgement
- record the parameters of the analysis to be carried out
- be suitable for inclusion in the final report on the fire safety evaluation of the design.

A typical PBDB report might include:

- Executive summary
- Introduction
- Scope of the project
- Relevant stakeholders
- Principal building characteristics
- Dominant occupant characteristics
- General objectives
- Hazards and preventative and protective measures available
- Trial designs for evaluation
- DTS departures and Performance Requirements
- Approaches and methods of analysis
- Acceptance criteria and factors of safety for the analysis

- Fire scenarios and parameters for design fires
- Parameters for design occupant groups
- Standards of construction, commissioning, management, use and maintenance
- Conclusion.

For further guidance refer to Section 3.2 of the ABCB Handbook Performance Solution Process.

2.3 Analysis

Preparing the PBDB is the essential precursor to the actual analysis of the trial design(s). Generally, all the major decisions necessary to allow the analysis to be carried out will have been made during the PBDB process and duly recorded. This process will have also provided most of the input data required for the analysis. Variations to the design should be documented via a PBDB process as applicable to the issue, which may or may not require an update to the PBDB document.

This chapter gives general guidance on the analysis process, but each project needs to be considered individually and the analysis strategy varied accordingly (see 2.2).

2.3.1 The fire safety sub-systems

As discussed in 2.1, in any building there are many features that combine to create an overall fire safety system. To assist in analysis, it is convenient to consider the system as comprising six sub-systems, which are introduced in Section 2.1.1, and expanded in Appendix A.

There are interactions between the sub-systems, as is evidenced by the inputs and outputs from one sub-system to another. Many computer-based fire engineering methods operate simultaneously over two or more sub-systems. For example, a fire and smoke development method may encompass SS-A, SS-B, SS-C, and SS-D.

The sub-systems used in the analysis strategy are chosen on the basis of:

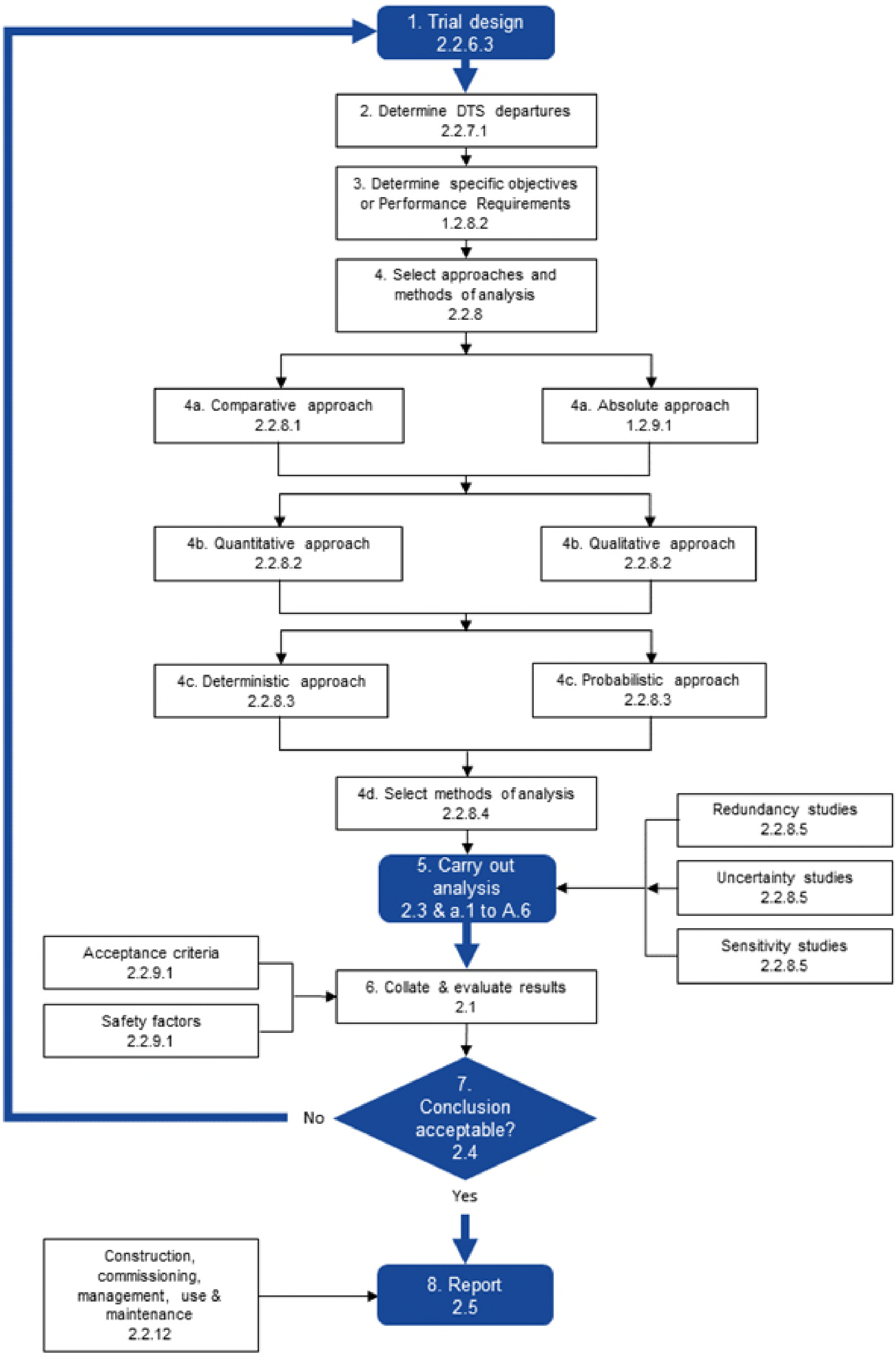
- the DTS departures (see Section 2.2.7.1)
- the Performance Requirements (see Section 2.2.7.2)
- the inputs and outputs of the sub-systems (see Appendix A)
- the approaches and methods of analysis selected (see 3.2)

2.3.2 Conducting the analysis

Typically, each building project is unique and similarly, each fire engineering evaluation is unique. It is not sensible, therefore, to set down detailed guidance on how the fire safety analysis should be undertaken. Instead, it is the responsibility of the FE to plan the analysis for the particular project, based on the decisions taken during the preparation of the PBDB as discussed in 2.2.

Figure 2.3.1 shows the factors which will influence the analysis strategy, and which will have been agreed upon in the PBDB process. The figure also shows that the analysis process is iterative when one or more trial designs are shown to be unacceptable – that is, they do not meet the acceptance criteria set for the analysis.

Figure 2.3.1 Analysis of trial designs



In the following paragraphs, each step in Figure 2.3.1 is discussed with reference to the PBDB and later chapters of the AFEG.

Step 1

The trial design is analysed, recognising the agreements reached in the PBDB process. Where more than one trial design has been identified, each may be analysed, or only the preferred design analysed, provided it meets the acceptance criteria set for the analysis.

Step 2

The DTS departures of the trial design need to be established in order to identify the issues to be addressed.

Step 3

The Performance Requirements are determined from the DTS departures identified in Step 2.

Step 4

The approaches and methods of analysis to be used are selected using the following sub-steps:

- **Step 4a** – select comparative or absolute approach
- **Step 4b** – select qualitative and/or quantitative approach
- **Step 4c** – select deterministic or probabilistic approach
- **Step 4d** – select analysis methods.

Step 5

The steps above, together with data from the PBDB, provide the basis for carrying out the analysis (using the sub-systems identified in Section 2.3.1).

Step 6

Although the sub-systems may be used in the order presented in the AFEG, the analysis process often requires the order to be changed. This is because data from later sub-systems may be required for the analysis of a preceding sub-system.

Other factors from the PBDB which need to be taken into account during the analysis are the sensitivity studies (including consideration of redundancies) and uncertainty studies that were determined to be necessary.

After the analysis has been carried out, the results need to be collated and evaluated. This step is discussed in 2.4 and requires consideration of the acceptance criteria and factors of safety for the analysis. In some cases, further sensitivity studies (including consideration of redundancies) and uncertainty studies may also need to be carried out.

Step 7

If the conclusion is that the results of the analysis do not meet the acceptance criteria with the required factors of safety and redundancy, the trial design is discarded or modified and the analysis of another trial design is required as discussed in 2.4.

Steps 7 and 8

Alternatively, if the conclusion (Step 7) is that the results indicate the trial design is acceptable, the results should be reported (Step 8) as discussed in 2.5**.**

2.4 Collating and evaluating the results and drawing conclusions

When one or more trial designs have been analysed, it is necessary for the FE to collate and evaluate the results, and to draw conclusions.

This chapter provides guidance on these processes, but each project needs to be considered individually and the processes varied accordingly. The steps for the process are shown in Figure 2.4.1.

Figure 2.4.1 Flow chart for collating and evaluating the results and drawing conclusions

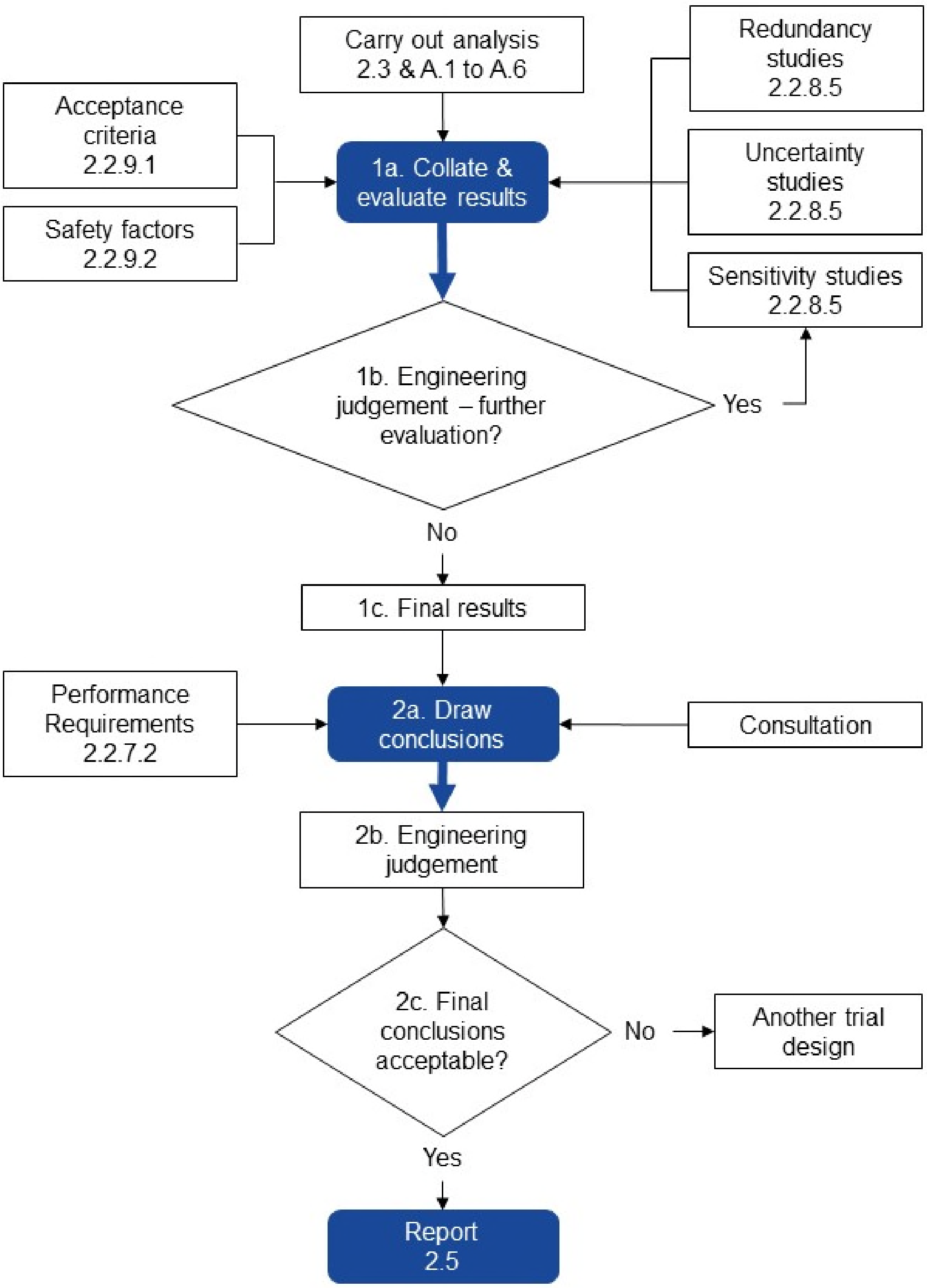


Figure 2.4.1 illustrates:

- collating and evaluating the results (Section 2.4.1)
- drawing conclusions (Section 2.4.2).

These processes generally involve the use of engineering judgement in collating and evaluating the results and drawing conclusions.

This use of engineering judgement emphasises the need for evaluations to be conducted by a FE with the necessary knowledge and experience.

2.4.1 Collating and evaluating the results

Step 1a

The results obtained from the analysis (according to 2.3) should be collated for evaluation. Not all sub-systems will necessarily have been involved, but the outputs of all relevant sub-systems need to be assembled for evaluation.

The evaluation needs to take into account:

- the acceptance criteria for the analysis set according to Section 2.2.9.1
- the safety factors set according to Section 2.2.9.2 – which are to be applied in determining whether the results meet the acceptance criteria
- whether the agreed redundancy (see Section 2.2.8) has been demonstrated by the redundancy studies (see Section 2.2.8.5)
- the results of the uncertainty studies carried out according to Section 2.2.8.5
- the results of the sensitivity studies carried out according to Section 2.2.8.5.

Step 1b

The FE should apply engineering judgement to the collated and evaluated results in order to determine if further evaluation (e.g. further sensitivity studies) or adjustments to the results are required – in the light of the FEs knowledge and experience. Such engineering judgement should be adequately justified, and the logic used explicitly stated in the report (2.5).

Step 1c

When the FE is satisfied that the results have been properly evaluated and no further manipulation is required, the final results are tabulated.

2.4.2 Drawing conclusions

Step 2a

The conclusions of the evaluation need to be drawn based upon the final results and taking into account the Performance Requirements for the evaluation as determined during the PBDB process (see Section 2.2.7.2). These outcomes may require further consultation with other professionals.

Step 2b

The FE should apply engineering judgement to the conclusions in order to assess their soundness and appropriateness to the evaluation taking into account:

- the PBDB deliberations;
- the assumptions used in the evaluation; and
- any limitations or requirements associated with the conclusions.

Again, the justification for and the logic used in applying engineering judgement should be fully reported (2.5).

Step 2c

If the final conclusions indicate that the trial design is acceptable, the FER can be completed. But if this is not the case, it may be appropriate to analyse another trial design. Additional trial designs may have been identified during the PBDB process. If this is not the case, further consultations and modification of the PBDB is necessary. Where more than one trial design has been assessed and found acceptable, a choice may have to be made. This choice could be made on grounds such as cost, ease of construction, and aesthetics.

2.5 Completing the FER

When the fire engineering analyses and evaluations have been carried out and conclusions reached, the FER can be completed. The FER is a major and significant output of the fire safety evaluation and should be a self-explanatory document.

The information contained in the final report forms the basis for construction, commissioning, management, use, maintenance, audits, alteration/extension, or change of use of the building.

2.5.1 Report format

There are many possible formats for a report, but the framework should follow the fire engineering process described in Section 2.1.1. In the case of electronic reports, the format should inhibit subsequent alteration.

The following headings provide a possible format:

- Executive Summary
- Introduction
- PBDB
- Analysis
- Collating and Evaluating the Results (with annotated drawings)
- Conclusions
- References
- Appendices.

3 Methodologies

3.1 Preparing a PBDB

This chapter describes a selection of methodologies that may be used in preparing a PBDB. This does not preclude the use of other methodologies that might be chosen by the FE. The methodologies described do not cover all aspects of preparing a PBDB.

3.1.1 Acceptance criteria for analysis

As indicated in 2.2, there are a number of acceptance criteria that may be used for the analysis. Typical acceptance criteria parameters are set out in the example box in Section 2.2.9.

3.1.2 Fire scenarios

3.1.2.1 Identification and definition of fire scenarios

Each fire scenario represents a unique occurrence of events, and is the result of a particular set of circumstances associated with the fire safety system. Accordingly, a fire scenario represents a particular combination of outcomes or events related to:

- types of fires that are generated upon ignition
- the development of the fire
- external environmental conditions.

Identification and definition of significant fire scenarios in the PBDB enables them to be described in a manner suitable for the analysis.

The types of fires that may be generated upon ignition may be categorised as:

- smouldering fires
- flaming (non-flashover fires)
- flashover fires.

Fire development may be influenced by:

- size and type of ignition source
- distribution and type of fuel
- fire load density
- location of the fire (with respect to walls and ceilings)
- ventilation conditions
- stack effect
- building construction and materials
- air-handling equipment characteristics.

External environmental conditions may be influenced by:

- the season (e.g. summer or winter)
- wind speed and direction

A fire scenario can be defined by specifying a particular combination of outcomes or events for each of the fire safety sub-systems. This requires the systematic combination of feasible outcomes or events for each of the six sub-systems.

Some of the different outcomes or events that may be considered are listed below by sub-system.

Fire initiation, development and control (SS-A):

- smouldering, non-flashover or flashover fires.

Smoke development, spread and control (SS-B):

- smoke management – operation or non-operation
- if operative – successful or not
- doors or dampers – open or closed
- door or damper smoke seals – fitted or not
- leakage through barriers – controlled or not.

Fire spread, impact and control (SS-C):

- doors open or closed
- barriers – successful or not
- external spread via openings – yes or no.

Fire detection, warning and suppression (SS-D):

- detector activation – successful or not
- sprinkler – operation or non-operation
- if operative – successful or not.

Occupant evacuation and control (SS-E):

- awake or asleep
- response to cues – successful or not (implications also for time of occurrence)
- if not initially successful, subsequent response to other cues – successful or not
- different times for evacuations.

Fire service intervention (SS-F):

- rescue – successful or not
- extinguishment – successful or not
- different times for arrival and set up.

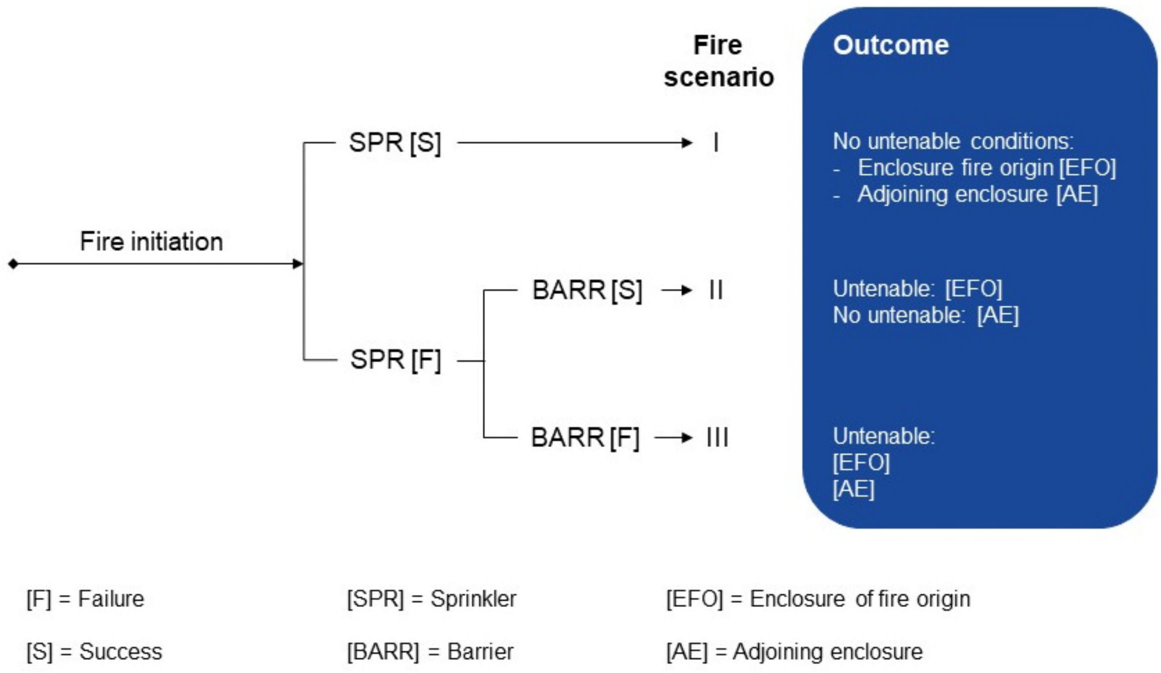
A simple representation of the possible events associated with a fire safety system (including both sprinklers and barriers) for the case of a potential flashover fire, is shown in Figure 3.1.1. From these events, it is possible to characterise three fire scenarios: Fire Scenarios I, II and III. These scenarios are briefly described below.

- **Fire Scenario I.** Control of fire growth in the enclosure of fire origin, because of successful operation of the sprinklers.
- **Fire Scenario II.** Control of fire growth to the enclosure of fire origin, because of the success of the barriers in preventing the spread of fire when the sprinklers have failed to control the growth of the fire.
- **Fire Scenario III.** Spread of fire to the adjoining enclosures, because of the failure of the sprinklers to control the growth of the fire, and the failure of the barriers to control the spread of fire to adjoining enclosures.

Once the events associated with each fire scenario have been defined, for a quantified analysis, it is possible to quantify the occurrence of the fire scenario by defining the times of occurrence of key events along a timeline.

Further information on the systematic development of fire scenarios, based on the use of event trees, is presented in Section 3.2.2.

Figure 3.1.1 Event tree representation of the possible events associated with a fire safety system including sprinklers and barriers



3.1.2.2 Development of event trees for scenario identification

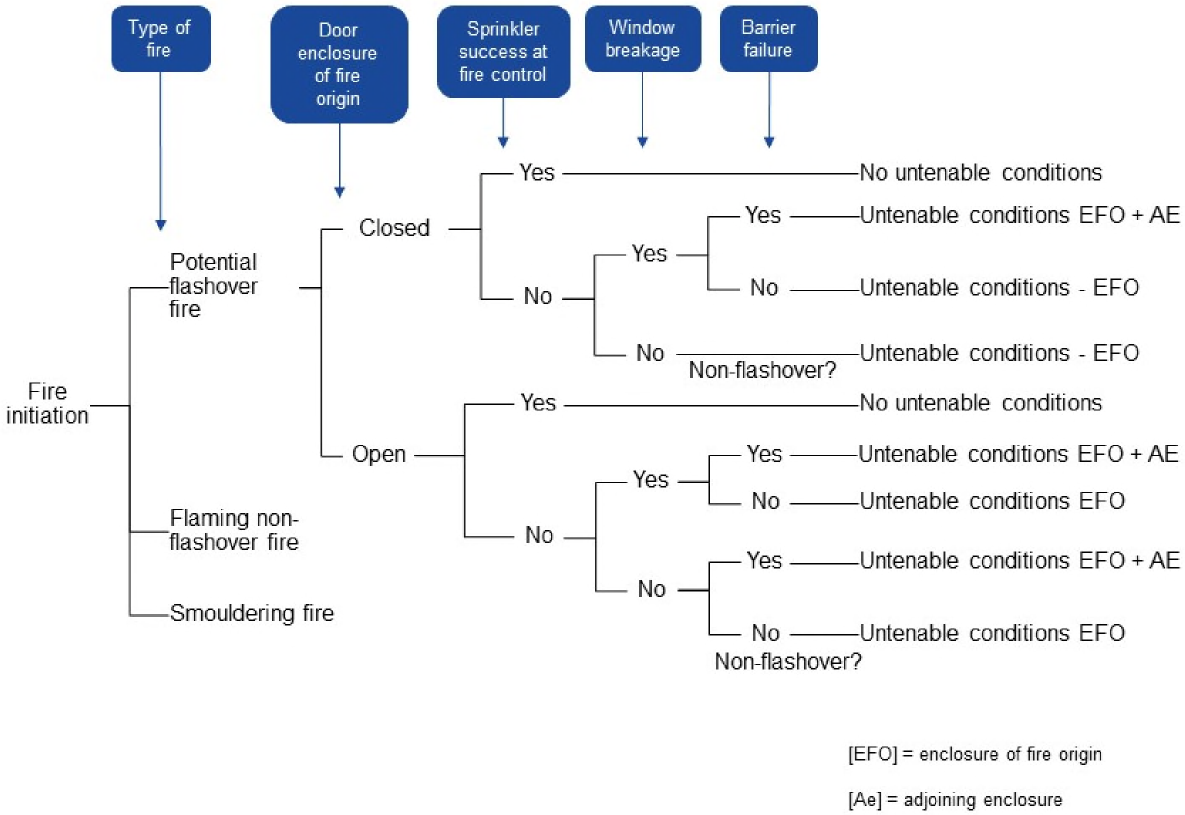
When undertaking a probabilistic analysis, the use of event trees is recommended to assist in the systematic identification and definition of multiple scenarios. Event trees provide a simple method to represent the full range of fire scenarios that can occur.

In a probabilistic analysis, a probability is calculated for each scenario – based on individual event probabilities. Where event probabilities are not available, fault trees may be used to calculate and assign probabilities to specific events. Fault tree analysis permits the hazardous incident (top event) frequency to be estimated from a logic model of the failure mechanisms of a system. A number of publications describe methods for constructing fault trees.

A path in an event tree is represented by a particular continuous combination of branches (that is, events) and starts with the initiating event and finishes with a final event. There are many paths in an event tree. A fire scenario is defined by a particular path in the event tree.

An outline of some of the fire scenarios that can develop in an enclosure is shown in Figure 3.1.2. These scenarios are based on the event tree approach.

Figure 3.1.2 Fire scenarios using an event tree approach



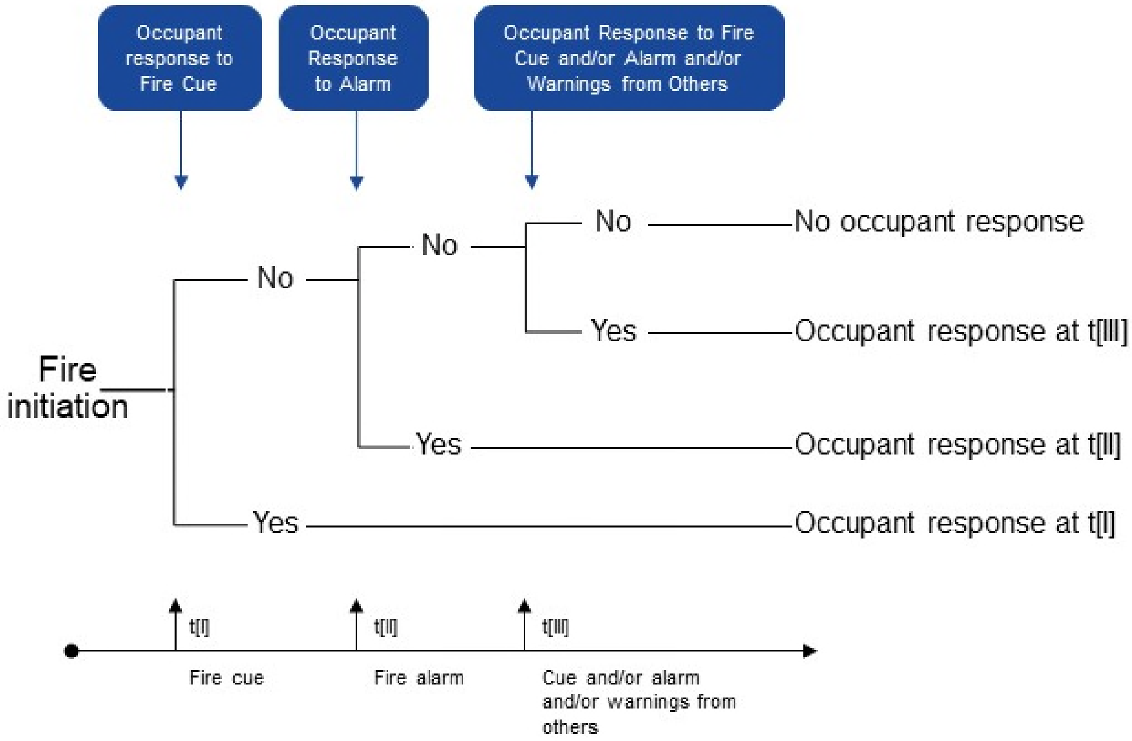
When developing fire scenarios, it is also appropriate to develop scenarios for occupant detection using an event tree approach. The occupant detection scenarios are based on the following assumptions.

- **Occupant Detection I.** Occupants are assumed to be able to detect the presence of fire by visual, olfactory and other sensory means.
- **Occupant Detection II**. Occupants are assumed to be able to detect the presence of fire by an alarm triggered by some form of smoke or thermal detector.
- **Occupant Detection III.** Occupants are assumed to be able to detect the presence of fire by new visual, olfactory and other sensory responses, response to an alarm (not previously responded to), or response to warnings issued by others.

Figure 3.1.3 shows the four assumed occupant detection responses, together with the associated timeline for such responses.

It should be noted that the above conditions are the result of some gross assumptions; other assumptions could be readily justified.

Figure 3.1.3 Occupant responses based on an event tree formulation plus associated timeline



Each of the above four occupant detection response scenarios, as shown in Figure 3.1.3, should be combined separately with each of the fire scenarios identified in Figure 3.1.2.

3.2 Analysis

This chapter describes a selection of methodologies that may be used to undertake analysis. This does not preclude the use of other methodologies chosen by the FE. The methodologies do not cover all aspects of an analysis.

3.2.1 Deterministic approaches

The deterministic approach to a problem involves the definition of a scenario and the use of analytical methods – which, if applied repeatedly, would lead to identical outcomes. Zone and some field model programs and common evacuation modelling programs may fall into this category. The methodologies presented in the subsequent chapters of this part of the AFEG are generally deterministic.

The deterministic approach is the primary analytical approach to many fire engineering problems. However, probabilistic concepts are often involved in the interpretation and application of the analytical results of this approach. The deterministic approach is sometimes combined with the probabilistic approach in assessing fire engineering designs.

3.2.2 Probabilistic approaches

There are a number of methodologies by which the probabilities of fire safety systems functioning, or occupant response occurring as designed, can be incorporated into an analysis to establish risk levels associated with the fire safety system design.

The probabilistic approach provides a means by which an overall level of risk based on critical parameters may be established. Typically, these risks relate to life safety or property loss. Other issues could be introduced as the principal parameters if desired.

This section outlines one approach that may be adopted to introduce probabilistic outcomes into an evaluation.

This method of evaluation is appropriate where an alternative fire safety system trial design is composed of essentially different elements to those in the DTS design (as specified in the regulations) and where the cost-effective combination of such elements is not immediately obvious.

This method of evaluation involves the consideration of multiple quantitative fire scenarios that are defined with the aid of event tree analysis. The quantitative results are then weighted with the probabilities associated with the fire scenarios and combined to obtain the risk parameters.

First, develop event trees for the fire scenarios and occupant detection response as described in Section 3.1.2.2.

Associated with each scenario, it is possible to define two consequences for the occupants – occupant safety or occupant number of deaths:

- **Occupant safety.** When no occupants are exposed to the occurrence of untenable conditions for the particular enclosure under investigation.
- **Occupant number of deaths.** The number of occupants remaining in the enclosure under investigation at the time of occurrence of untenable conditions.

To estimate the expected number of fatalities for each scenario (required for the life-risk analysis), two parameters must be obtained for each scenario considered:

- probability of occurrence of the fire scenario
- number of people exposed to untenable conditions.

These two parameters are combined to give the expected number of deaths, END_j, which may be estimated from:

$$END_j = Pj \times Nj$$

Where:

P_j is the probability of occurrence for the events of the specified fire scenario developing following ignition

N_j is the number of deaths and is represented by the number of occupants exposed to untenable conditions.

There will generally be more than one way in which a fire at a specified location may develop and pose a threat to the occupants. The risk associated with a particular fire is, therefore, the sum of the risks over all fire scenarios and all potentially threatened enclosures – rooms or spaces – within a building (target locations).

The overall risk to life safety associated with a particular building design can be estimated from the sum of the risks associated with each fire scenario considered in the analysis:

$$END = \sum_j ENDj = \sum_j PjNj$$

The ERL safety parameter is defined below:

$$ERL = \frac{Expected\ number\ of\ deaths\ during\ the\ design\ life\ of\ building}{Buildling\ population \times Design\ life\ of\ building}$$

which can be expressed in the following equation:

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

Where:

ELLB is the expected number of deaths over design life of building

OP is the number of occupants defined to be in the building at the commencement of a fire

t_D is the design building life (years).

To produce an exhaustive measure of the risk to life, it would be necessary to consider every possible fire scenario within the building. However, the computational effort required increases with the number of scenarios. The simplification of the problem by the PBDB team (see 2.2) is therefore an essential precursor to carrying out a comprehensive probabilistic risk assessment. The design life of a building is not always known and the fire safety team should make an assumption in such cases.

The same methodologies can be employed to develop other outcomes such as the Fire Cost Expectation (FCE).

Using the procedures presented in this section, it is also possible to estimate the extent of damage that may result from a fire. This information may then be used to estimate potential monetary losses and enable a cost benefit study to be carried out to establish the value of installing additional fire protection measures. In this case, monetary losses are used as the measure of potential consequences.

When using such considerations, it is recommended that the overall fire cost associated with a particular design be estimated. The FCE (present value) is:

$$FCE = \text{Capital cost} + Annual\ costs + Expected\ cost\ of\ losses$$

Where:

Capital cost is capital cost associated with active and passive fire protection

Annual costs are annual costs for inspection and maintenance of fire equipment

Expected cost of losses is expected cost of building and contents fire losses.

4 Philosophy and intent

4.1 Information sources

Because fire engineering is an emerging discipline, research is ever evolving and approved methods constantly updating. As discussed in 1.3, there are very few well-codified methods of approaching and solving problems. The key issues that FE need to have an in-depth knowledge of include:

- how various materials ignite
- the manner in which fire develops
- the manner in which smoke (including toxic products) spread
- how structures react to fire
- how people respond to the threat of fire, alarms, and products of combustion.

The dilemma for the FE is where to locate appropriate knowledge and guidance.

As with other emerging disciplines, there is a variety of information sources available.

1. State and territory based legal requirements

   Examples:

   - Building Act
   - Building Regulation

     The NCC as adopted by each state and territory and the Australian Standards (AS) which are referenced documents within the NCC

     Examples:
   - NCC 2019 Amendment 1
   - AS 1670.4 Fire detection, warning, control and intercom systems – System design, installation and commissioning- Emergency warning and intercom systems. 2018.

2. Australian Standards not adopted by the NCC

3. The Engineers Australia’s Society of Fire Safety (EA – SFS) Practice Guides

   Examples:

   - *Society of Fire Safety Practice Guide Facade/External Wall Fire Safety Design*; SFS Facade Fire Safety Design Committee, Engineers Australia; 15 March 2019

4. International standards and guides such as the International Standards Organisation (ISO) and the Society of Fire Protection Engineers (SFPE) standards

   Examples:

   - SFPE S.01 Standard on Calculating Fire Exposures to Structures. Society of Fire Protection Engineers; Gaithersburg MD, 2011.
   - SFPE S.02 Standard on Calculation Methods to Predict the Thermal Performance of Structural and Fire Resistive Assemblies. Society of Fire Protection Engineers; Gaithersburg MD, 2015.
   - ISO 23932-1:2018. Fire safety engineering — General principles — Part 1: General. ISO/TC 92/SC 4. 2018.
   - CIBSE Guide E, Fire Engineering, 3rd Edition, Chartered Institute of Building Services Engineers (CIBSE), UK, 2010

5. National standards such as New Zealand, European, UK, USA

   Examples:

   - BS 9999: Code of practice for fire safety in the design, management and use of buildings. British Standards Institution (BSI). 2020.
   - NFPA 13: Standard for the Installation of Sprinkler Systems. National Fire Protection Association. 2019.

6. Published subject matter textbooks and handbooks

   Example:

   - *SFPE Handbook of Fire Protection Engineering*, 5th Edition. Society of Fire Protection Engineers; Gaithersburg MD, 2016.

7. Refereed journals and symposia and proceedings

   Examples:

   - Asiaflam Fire Science and Engineering Conferences
   - IAFSS Symposia
   - Interflam Fire Science and Engineering Conferences
   - International Conferences on Performance Based Design and Fire Safety Design Methods
   - International Symposia on Human Behaviour in Fire.

8. Refereed university publications

Example:

- *Fire Engineering Design Guide, 3rd Edition,* University of Canterbury, Christchurch, New Zealand, 2008;

9. Publications from recognised national laboratories

10. Non-refereed university publications

11. Publications from recognised private laboratories

    Examples

    - UL 10B. Standard for Fire Tests of Door Assemblies (Ed. 10). Underwriters Laboratory. 2020.
    - FM4880. Evaluating the Fire Performance of Insulated Building Panel Assemblies and Interior Finish Materials. FM Global. 2017.

12. Non-refereed Symposia and proceedings

APPENDICES

Appendix A Fire safety sub-systems

A.1 Fire initiation, development and control – SS-A

SS-A is used to define design fires in the enclosure of fire origin as well as enclosures to which the fire has subsequently spread. The design fires are normally described in terms of three types (see discussion in Section 3.1.2):

- smouldering fire
- non-flashover flaming fire
- flashover fire.

For the purposes of the AFEG, an enclosure typically is a single volume and may take many forms such as a room, a corridor, a shaft, an atrium, a warehouse or a stadium arena.

This appendix provides guidance on how to:

- consider the initiation of a fire in a fire engineering context
- quantify design fires (developed during the PBDB process, Section 2.2.10.3) in terms of:
  - HRR
  - toxic species yield
  - smoke yield
  - time to key events, particularly flashover.
- consider measures to control fire initiation and development in a fire engineering context.

This appendix also discusses the relationships between this sub-system and other sub-systems.

Although this appendix provides guidance on the analysis of SS-A in the general analysis context discussed in 2.3, each project needs to be considered individually and the analysis varied accordingly.

A.1.1 Procedure – SS-A

A.1.1.1 Fire initiation and development

Within a typical fire engineering evaluation, the normal assumption is that fire initiation has occurred. Thus analysis of fire initiation is not generally an issue.

However, in some fire engineering evaluations it is appropriate to incorporate a probabilistic analysis of ignition based on statistics for fire starts.

The flow chart in Figure A.1.1 illustrates how fire development can be analysed. Discussion of the figure can be found in the following sections:

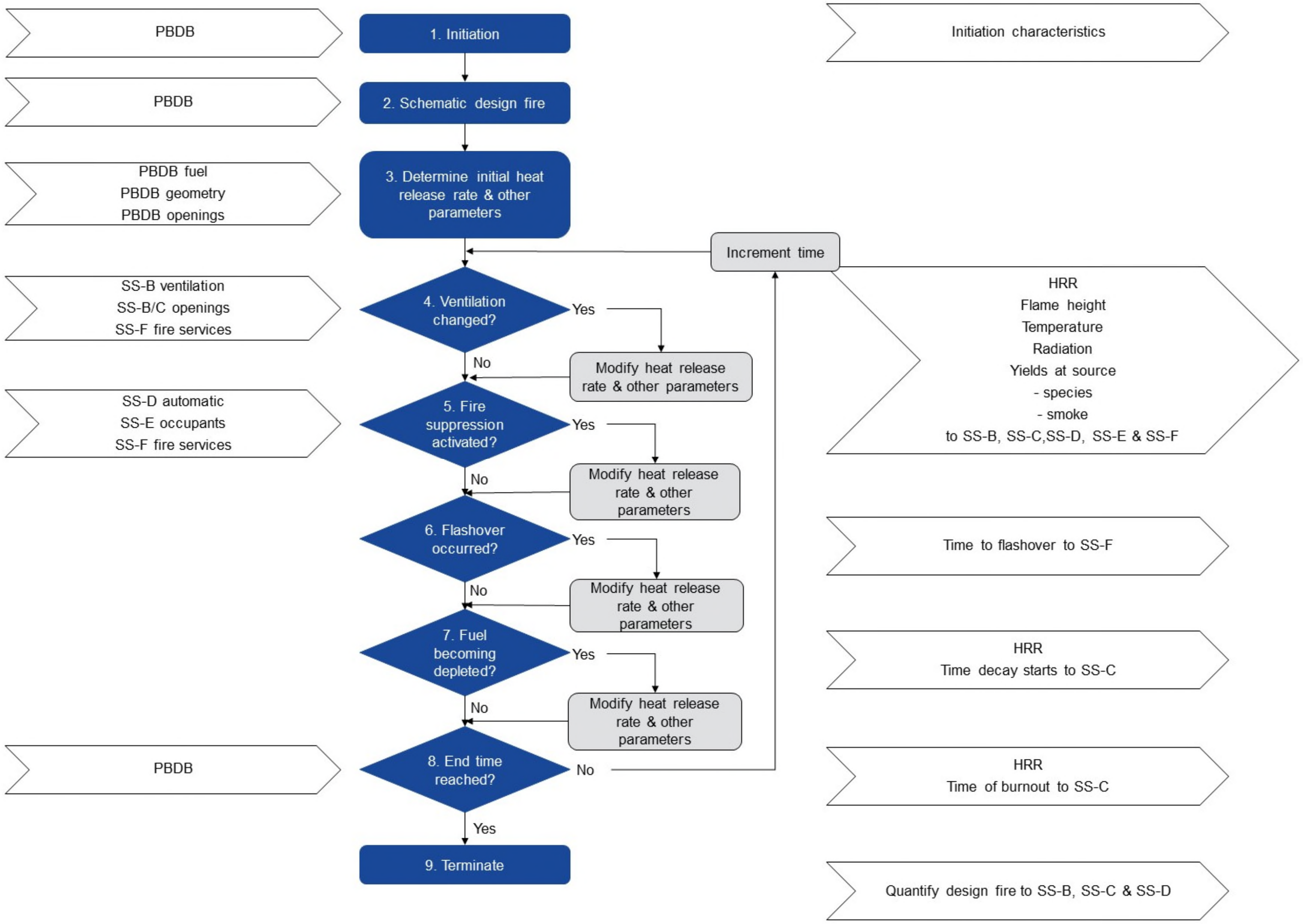
- Section A.1.2 Outputs
- Section A.1.3 Inputs
- Section A.1.4 Analysis.

An analysis needs to be undertaken for each design fire specified by the PBDB.

Where the PBDB decision is to undertake an analysis that includes consideration of probabilities of various events and scenarios occurring should be undertaken, the flow chart can assist the FE in identifying those factors that may be taken into account during the probability analysis.

The flow chart provides guidance but does not necessarily cover all the factors which may be relevant to a particular fire engineering analysis.

Figure A.1.1 Flow chart for fire initiation and development analysis



A.1.1.2 Control of fire initiation and development

The control of fire initiation and development may be used to improve fire safety as an alternative to (or an addition to) those measures provided by other sub-systems and these are discussed in Section 2.1.1.

A.1.2 Outputs – SS-A

The **principal outputs** from SS-A may be quantified relationships of the heat release rate (HRR) versus time for the design fires (smouldering, non-flashover flaming, and flashover – as appropriate). These relationships will indicate:

- time to flashover (if it occurs)
- time to start of fire decay
- time to burnout.

The outputs may be used as inputs to SS-B, SS-C, SS-D and SS-F, and if required for a probabilistic analysis, should have associated probabilities of occurrence.

Other possible outputs from SS-A include:

- initiation characteristics
- flame height at each time interval
- temperature at each time interval
- radiant heat emission at each time interval
- species yield at the fire source at each time interval
- smoke yield at the fire source at each time interval.

These outputs may be used as inputs to SS-B, SS-C, SS-D, SS-E and SS-F, and if required for a probabilistic analysis, should have associated probabilities of occurrence.

A.1.3 Inputs – SS-A

The following input data may be required:

- material and product ignitability data for enclosure linings and contents
- design fires from the PBDB

- fuel characteristics from the PBDB
- occupancy characteristics from the PBDB
- building characteristics from the PBDB, including:
    - geometry of enclosures
    - location, status (open or closed) and nature (fire rated or not), and size of openings such as doors, windows and roof vents
    - changes in ventilation condition (e.g. due to windows breaking or smoke dampers closing). Data on window breakage and dampers closing may also be calculated (see SS-C and SS-B respectively)
    - thermal properties of internal linings (including thermal properties of building envelope (e.g. EPS panel construction)
    - leakage rates through doors and barriers.
- activation of smoke management equipment (SS-B):
    - when
    - the effect on smoke/hot layer parameters.
- activation of suppression (SS-D):
    - when
    - the effect on HRR.
- fire fighting activities of occupants (SS-E) or fire services (SS-F):
    - when
    - with what effect (e.g. on HRR).

If a probabilistic analysis is being carried out, some of these inputs will have associated probabilities of occurrence and/or reliabilities.

A.1.4 Analysis – SS-A

A.1.4.1 Analysing fire initiation and development

As discussed in Section A.1.1.1, fire initiation is not normally subjected to analysis. However, in some instances, it may be appropriate to carry out calculations on a particular aspect of fire initiation.

Once ignition has occurred (or assumed to have occurred), the analysis of fire development (in order to define a design fire) is normally carried out using an iterative process in which the parameters of the fire are determined at each time increment – taking into account factors that may affect fire development.

The analysis need only be carried out as far as is necessary to provide a design fire for input to the other sub-systems. A separate analysis is required for each design fire identified in the PBDB. The typical process of analysis is shown in Figure A.1.1 and the steps are discussed below.

Step 1

If fire initiation has not been assumed, analysis may be carried out to determine:

- the probability of initiation, particularly for the development of event trees for probabilistic analysis (see discussion in Section 2.3.2)
- how a fire may spread into a second (or subsequent) compartment by ignition of material in that compartment.

Step 2

Obtain design fires from the PBDB process (see Section 2.2.10.3). The required types (smouldering, non-flashover flaming, and flashover) and numbers of design fires will be decided during that process.

Qualitative decisions on the effect of ventilation and suppression on the design fires may also be made during the PBDB process. The analysis of this sub-system will quantify such effects.

Step 3

For each design fire, an initial HRR and the initial yields of specific combustion products need to be established. The basis for choosing these initial characteristics will be agreed upon during the PBDB process, and in some cases, may even be quantified.

As discussed in the PBDB, the heat release rate profile should take account of the design fire scenario being considered, and typically it should be derived from test data and statistical analysis. As the selection of a design fire can dominate the result of an analysis, due care must be exercised in selecting appropriate fires. Commonly, for a flaming fire, growth is assumed to occur as a t^2 fire (from zero time) that best matches the design fire scenario, up to the maximum heat release rate of the fuel or to flashover.

Generally, fire engineering analysis is carried out by adopting a broad-brush approach to the burning of fuel, assuming that fuel will burn as a single unit. Occasionally, however, it may be appropriate to analyse in greater detail how fire may spread, for example, how fire may spread from one individual object to another, in order to define the initial heat release rate in more detail.

For smouldering fires, it is difficult to calculate with certainty how long it may be before the transition to flaming might occur. Because many fires do not have a smouldering phase, a flaming fire is commonly assumed not to have a smouldering phase.

The initial characteristics of the design fire will be changed by various factors, the major ones being those shown in Figure A.4.2. Their influences need to be determined as discussed in the following steps.

Step 4

One of the most important factors affecting the HRR is the ventilation available to the fire. Two possible regimes are generally identified as:

- a fuel-controlled fire
- a ventilation-controlled fire.

Calculations can be carried out to determine:

- which regime predominates (and is therefore limiting the HRR)
- what modifying effect may be applicable to the design fire.

During the course of the fire, the ventilation may change for a variety of reasons. These may include:

- glass breaking (SS-A, SS-B or SS-C)
- the operation of air handling or smoke extraction systems (SS-B)
- doors or other partitions burning through (SS-C)
- openings created by fire service intervention (SS-F).

Therefore, it is necessary to determine the times at which these factors change the available ventilation and the magnitude of the change, in order to determine their effect on fire development. The analysis process described in the appropriate sub-systems should be used.

Step 5

Determine whether suppression has been activated or commenced so that the design fire can, if appropriate, be modified accordingly. This requires input from other sub-systems:

- SS-D which covers automatic suppression equipment. The qualitative effect on the design fire will be decided during the PBDB process and SS-D will quantify that effect
- SS-D and SS-E which cover likely occupant fire fighting activities. In a fire engineering analysis, it is customary to assume that occupants will not engage in effective fire fighting activities. However, if there is good reason to believe that occupants will contribute to effective fire fighting (e.g. a trained hospital fire intervention team), and this has been recognised in the PBDB, such action may be taken into account
- SS-D and SS-F which cover fire service suppression activities (this also includes private industrial fire crews). The qualitative effect of these activities will be agreed during the PBDB process and SS-F will quantify that effect.

Step 6

Determine if the conditions are appropriate for flashover to occur.

The criteria used for determining the onset of flashover will depend on the method of analysis used, and on the engineering judgement of the fire engineer, and may have been agreed during the PBDB process.

To simplify design, the growth period between flashover and the maximum HRR is usually ignored and it may be assumed that when flashover occurs, the HRR instantaneously increases to the maximum value. This assumption is conservative.

Once flashover has occurred, the fire is said to be fully developed and is commonly assumed to have a constant HRR at a level determined by the ventilation conditions (see Step 4).

Step 7

Determine whether the fuel is becoming depleted (i.e. whether the decay phase is starting). The criteria, in terms of the relative amount of fuel consumed, may have been set in the PBDB process or set (and justified) by the FE using engineering judgement.

If the decay phase has started, then the HRR should be decreased in the manner agreed in the PBDB process or determined by the FE.

Step 8

Determine if the end time has been reached. This is when:

- all the fuel has been calculated to have been consumed
- the stage of the design fire agreed to in the PBDB process, has been reached
- in the engineering judgement of the FE, sufficient analysis has been carried out to justify the trial design under consideration.

If the end time has not been reached, the next iteration is undertaken and the analysis continued until the end time has been reached.

Step 9

The analysis of SS-A is terminated.

A.1.4.2 Analysing control of fire initiation and development

It may be determined during the analysis, or in drawing conclusions (2.4), that it would be beneficial to control fire initiation and development as a means of meeting the Performance Requirements. In such cases, other measures noted below (in addition to those shown in Figure A.1.1) may be considered, subject to the issues discussed in Section A.4.5:

- elimination or control of ignition sources
- changing the configuration of fuel items (e.g. from rack storage to palletised storage and storing items horizontally rather than vertically)
- reducing the ignition and fire spread characteristics of the fuel load, which includes the building contents (e.g. furnishings), linings, and combustible structure. This may be accomplished by testing, selection, control of purchasing, and use.
- separating fuel from ignition sources by using protective storage
- education and training of occupants.

These measures form the basis for traditional fire prevention activities, which may be addressed by fire prevention codes and standards. Although they are not addressed in most building codes to any significant degree (except for the third bullet), they can be incorporated usefully into a fire engineering design strategy (see also 2.2.6).

A.1.5 Construction, commissioning, management, use and maintenance – SS-A

The development of the design fires for the analysis in this sub-system relies on various assumptions regarding:

- ignition sources
- the nature of the fuel and its disposition
- the enclosure characteristics
- the intervention of various protective measures.

It is essential that these assumptions are not negated during the construction phase and are verified during commissioning. The greater challenge is to ensure the assumptions continue to hold true during the management, use, and maintenance of the building through documented procedures and schedules. This applies particularly to the ignition sources and fuels, which are not generally the subject of building regulation – but fundamental to a fire engineering analysis. It may be possible to ensure this verification through the essential safety provisions for buildings that may apply in some jurisdictions.

A.2 Smoke development, spread and control SS-B

SS-B is used to analyse the development of smoke in an enclosure, its spread within the building, and the properties of the smoke at locations of interest. This process enables estimates to be made of the times of critical events.

For the purposes of the AFEG:

- smoke is considered to include both visible and invisible products of combustion or pyrolysis and entrained air
- an enclosure is typically a single volume, and may take many forms such as a room, a corridor, a shaft, an atrium, a warehouse, or a stadium arena.

This appendix provides the guidance on quantifying:

- the development of smoke within the enclosure of fire origin
- the spread of smoke to enclosures beyond the enclosure of fire origin
- the characteristics of the smoke (particularly those that lead to untenable conditions)
- how smoke management equipment may minimise smoke accumulation and spread
- The ASET, where appropriate.

This appendix also discusses the relationships between this sub-system and others.

Although this appendix provides guidance on the analysis of SS-B in the general analysis context discussed in 2.3, each project needs to be considered individually and the analysis varied accordingly.

A.2.1 Procedure – SS-B

A.2.1.1 Smoke development and spread

Figure A.2.1 illustrates how smoke development and spread within a building can be analysed. Discussion of the figure can be found in the following sections:

- Section A.2.2 Outputs
- Section A.2.3 Inputs
- Section A.2.4 Analysis.

An analysis needs to be undertaken for each design fire specified by the PBDB and quantified using SS-A.

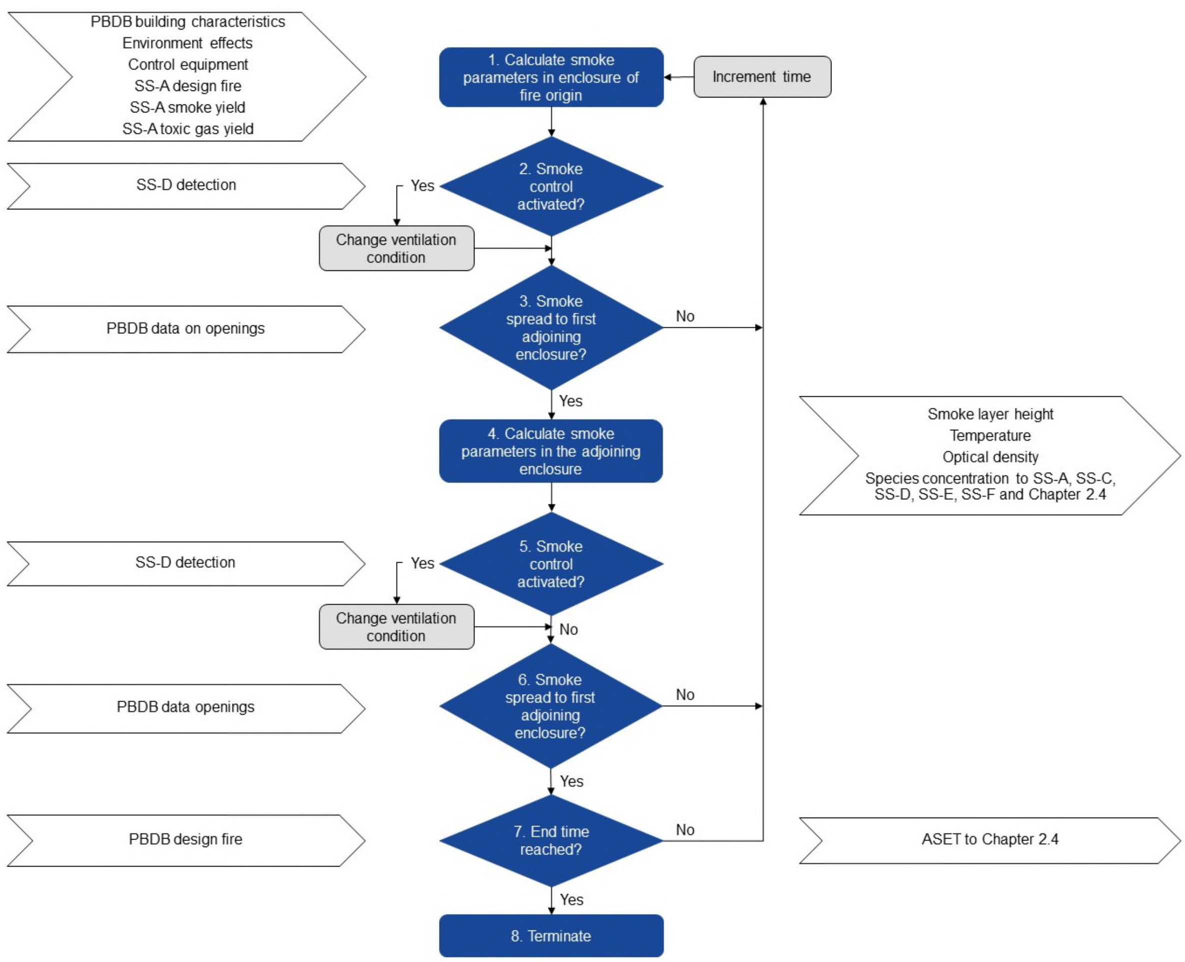
Where the PBDB decision is that an analysis that includes consideration of probabilities of various events and scenarios occurring should be undertaken the flow chart can assist the FE in identifying those factors to be taken into account during the probability analysis.

The flow chart provides guidance but does not necessarily cover all the factors which may be relevant to a particular fire engineering analysis.

A.2.1.2 Control of smoke development and spread

The control of smoke development and spread may be used to improve fire safety as an alternative (or in addition) to these measures provided by other sub-systems and those discussed in Section A.2.4.

Figure A.2.1 Flow chart for smoke development and spread analysis



A.2.2 Outputs – SS-B

Depending on the analysis tools used, the following parameters are generally available as outputs from SS-B.

Smoke layer interface height

This parameter may be used to:

- evaluate the effect of smoke on occupant behaviour in SS-E,
- evaluate the effect of smoke on fire services activities in SS-F, and
- form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating results and evaluating and drawing conclusions). It may be coupled with smoke temperature, smoke optical density, and species concentration to determine ASET.

Smoke temperature

This parameter may be used to:

- establish the expected times of heat detector and sprinkler activation (SS-D)
- evaluate the effect of smoke on occupant behaviour in SS-E
- evaluate the effect of smoke on fire services activities in SS-F
- form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating and evaluating results and drawing conclusions) and may be coupled with smoke layer height, smoke optical density and species concentration to determine ASET
- evaluate buoyancy effects on smoke spread and the 'stack effect' (SS-B)
- establish the time of failure of smoke management equipment components, e.g. exhaust fan motor (SS-B)
- determine the likelihood of fire spread to unignited fuel items (SS-A) and spread through barriers (SS-C).

Smoke optical density

This parameter may be used to:

- establish the expected times of activation of smoke detectors and consequent commencement of operation of smoke management equipment in SS-D
- evaluate the effect of smoke on occupant behaviour in SS-E
- evaluate the effect of smoke on fire service activities in SS-F

- form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating results and evaluating and drawing conclusions) and may be coupled with smoke layer interface height, smoke temperature and species concentration to determine ASET.

Species concentration

This parameter may be used to:

- evaluate the effect of smoke on occupant behaviour in SS-E
- evaluate the effect of smoke on fire services activities in SS-F
- form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating results and evaluating and drawing conclusions) and may be coupled with smoke layer interface height, smoke temperature and smoke optical density to determine ASET.

Where the acceptance criteria are related to life safety, toxic species, such as carbon monoxide, carbon dioxide and hydrogen cyanide (and low oxygen concentration) are often considered. Where property protection is of concern, corrosive species (such as hydrogen chloride) and smoke particles are often considered.

ASET

This parameter is used in a timeline analysis. When compared (see 2.4) with RSET, obtained from SS-E, provides a criterion for acceptability (see Section 2.2.9) of that design.

ASET may be determined using the outputs above, on the basis of the acceptance criteria (see Section 2.2.9).

A.2.3 Inputs – SS-B

The required input parameters to SS-B are determined by the analysis methods used. They may include the parameters described below.

Building characteristics

The following parameters are usually relevant and should be available from the PBDB:

- geometry of enclosures

- position and size of openings such as doors, windows and roof vents
- changes in ventilation condition (e.g. due to windows breaking or smoke dampers closing)
- thermal properties and flammability of internal linings
- leakage rates through doors and barriers.

Heat release rate profile

Heat release rate versus time is obtained from SS-A.

Smoke yield

The yield of smoke from the source of the fire is obtained from SS-A. (How the smoke entrains air in a smoke plume will normally be considered within SS- B)

Toxic gas yield

The yield of toxic species, for example carbon monoxide, is obtained from SS-A.

Characteristics of smoke management equipment

When smoke management equipment is involved, its characteristics should, as far as possible, be specified in the PBDB. The following characteristics are likely to be relevant:

- flow rates of exhaust fan and make-up air
- delay in the activation of fans from detection time
- delay in opening of natural ventilation from detection time
- delay in changing the configuration of flow-control devices, such as doors, dampers and retractable screens
- locations and sizes of inlet vents
- locations and sizes of exhaust vents
- leakage rates through elements of construction
- conditions under which the system is assumed to fail
- reliability and efficacy of the system (this is of particular relevance to a probabilistic analysis or to sensitivity studies).

Time of smoke detection

This input is obtained from SS-D. Coupled with the delay in activation of the smoke management equipment, it gives the time at which smoke management commences.

Environmental effects

The PBDB should establish which environmental effects are to be considered in the analysis. The following effects may be relevant to SS-B:

- velocities and prevailing direction of wind where this may cause adverse pressures at vent and inlet locations
- temperature of internal and external air
- internal air movements caused by the smoke management equipment that might affect smoke flow and the performance of smoke detectors.

A.2.4 Analysis – SS-B

SS-B is generally used in one of two situations.

- When the characteristics of any smoke management equipment are known. The aim of the calculations is to predict for each fire scenario how smoke will spread over time and to determine ASET. In some cases there will be no installed smoke management equipment to affect the development and spread of smoke.
- When a building geometry is set and the required ASET has been established, the aim of the analysis is to calculate the appropriate characteristics for smoke management equipment.

A.2.4.1 Analysing smoke production and spread

Whether smoke management equipment is installed or not, the typical process of analysis is presented in Figure A.2.1.

The analysis of smoke spread is normally carried out using an iterative process in which at each time increment, the parameters of the fire and the smoke generation are changed appropriately to match the assumed development of the fire. When the conditions reach the activation point for any smoke management equipment, the effect of that management equipment is taken into account in the analysis.

Step 1

Calculate how much smoke (including entrained air) is expected to be generated, and how thick the smoke layer in the upper part of the enclosure of fire origin, is expected to be. At the same time, the expected smoke layer temperature, optical density and the concentrations of various toxic species may be calculated.

Step 2

Where smoke management equipment has been installed, data from SS-D will indicate at which time increment smoke detection occurs. When this happens, the time to activation of the equipment is calculated taking into account any characteristic delay time of the equipment (fan, damper, vent, etc.). When the smoke management equipment has been activated, calculation of the changed ventilation conditions should be carried out.

It should be noted that, in some cases, mechanical smoke management may not have been provided and passive smoke management has been used.

Step 3

The next step is to determine whether smoke spreads from the enclosure of fire origin into the first adjoining enclosure. This normally occurs when the smoke layer in the enclosure of fire origin has descended below the level of an opening to the adjoining enclosure in question.

Step 4

If smoke spreads into the first adjoining enclosure, calculate the smoke parameters for that enclosure.

Step 5

This step is the same as Step 2 for the two enclosures considered, if activation of the smoke management equipment has not occurred for smoke development in the first enclosure or where activation in the second enclosure is independent of the first enclosure.

Step 6

This step is the same as Step 3 and examines the possibility of smoke spread to the next adjoining enclosure.

Step 7

Determine whether the end time has been reached. This is when:

- smoke has ceased to spread and all the smoke management equipment has been activated
- all the adjoining enclosures have been examined
- the stage of the design fire (agreed to in the PBDB process) has been reached
- in the engineering judgement of the fire engineer, sufficient analysis has been carried out to justify the trial design under consideration.

If the end time has been reached and if required by the analysis strategy, calculate the ASET based upon the criteria for ASET set in Section 2.2.9.

If the end time has not been reached, the next iteration is undertaken and the analysis continues until the end time has been reached.

Step 8

The analysis of SS-B is terminated.

A.2.4.2 Analysing control of smoke development and spread

There are a number of ways to control the development and spread of smoke as discussed below:

- Controlling the materials comprising the fuel load – so that only those materials that have a low smoke potential or are difficult to ignite and burn slowly if ignited are used (see SS-A). This would form part of a fire prevention strategy.
- Designing smoke management equipment to limit the development and spread of smoke to a predetermined level. This uses the same basic elements of Figure A.2.1 as the analysis process described in Section A.2.4.1. It enables the quantification of those characteristics of the smoke management equipment (see Section A.2.3) that enable the attainment of the relevant acceptance criteria for the analysis (as determined in the PBDB process) used in 2.4 (Collating the results and drawing conclusions).

Although the design fires from SS-A should be used, the process may be simplified to (conservatively) use the maximum HRR from the design fires for these calculations. The simplified approach may not be valid for fires in large, single compartment buildings.

A.2.5 Construction, commissioning, management, use and maintenance – SS-B

Smoke management equipment often comprises a complex assembly of many interactive components and requires close attention in order to be reliable. Incorporating smoke management equipment into systems which occupants use daily for comfort (e.g. air conditioning) may improve the probability of the successful operation of smoke management equipment.

In order to achieve the required performance of the equipment (assumed or calculated during the analysis), attention needs to be paid to construction, commissioning, management, use and maintenance as assumed or required by the fire engineering evaluation (as articulated in the Report – see 2.5). It may be possible to ensure that the required maintenance is done through the essential safety provisions that may apply in some jurisdictions.

Particular attention should be paid to the commissioning procedures and the performance required. Normal commissioning procedures should be followed (e.g. measurement of airflows and pressure gradients) but these need to be supplemented for a fire-engineered design.

Testing with heated artificial smoke (hot smoke tests) is sometimes carried out as part of the commissioning process to evaluate the correct operation of smoke management equipment.

A.3 Fire spread, impact and control – SS-C

SS-C is used to analyse the spread of fire beyond an enclosure, the impact a fire might have on the structure and how the spread and impact might be controlled.

For the purposes of the AFEG:

- spread beyond a fire enclosure is deemed to have occurred when any material outside that enclosure ignites and another fire is initiated. Therefore, flames projecting from openings do not constitute spread unless they ignite another material (existing or potential) outside the enclosure.
- an enclosure is typically a single volume and may take many forms such as a room, corridor, shaft, atrium, warehouse or stadium arena.

Fire spread from the enclosure takes place through openings that initially exist or are created by the impact of fire. Fire severity and the ability of the barriers forming the enclosure to withstand the fire determine whether openings are created by the impact of the fire. Openings that allow the spread of fire both horizontally and vertically, internally and externally to the building should be considered.

The impact of the fire is also considered when the time to failure of structural components is being assessed with respect to occupant evacuation, protection of adjoining property, or fire service intervention.

This appendix provides guidance on how to:

- determine whether and at what rate fire may spread to an adjoining enclosure or to an adjacent building
- quantify how fire spread and its impact can be controlled.

This appendix discusses the relationships between this sub-system and others.

Although this appendix provides guidance on the analysis of SS-C in the general analysis context (discussed in 2.3), each project needs to be considered individually and the analysis varied accordingly.

A.3.1 Procedure – SS-C

A.3.1.1 Fire spread and impact

Figure A.3.1 illustrates how fire spread between enclosures and its impact on the enclosures can be analysed. Discussion of the figure can be found in the following sections:

- Section A.3.2 Outputs
- Section A.3.3 Inputs
- Section A.3.4 Analysis.

An analysis needs to be undertaken for each design fire specified by the PBDB.

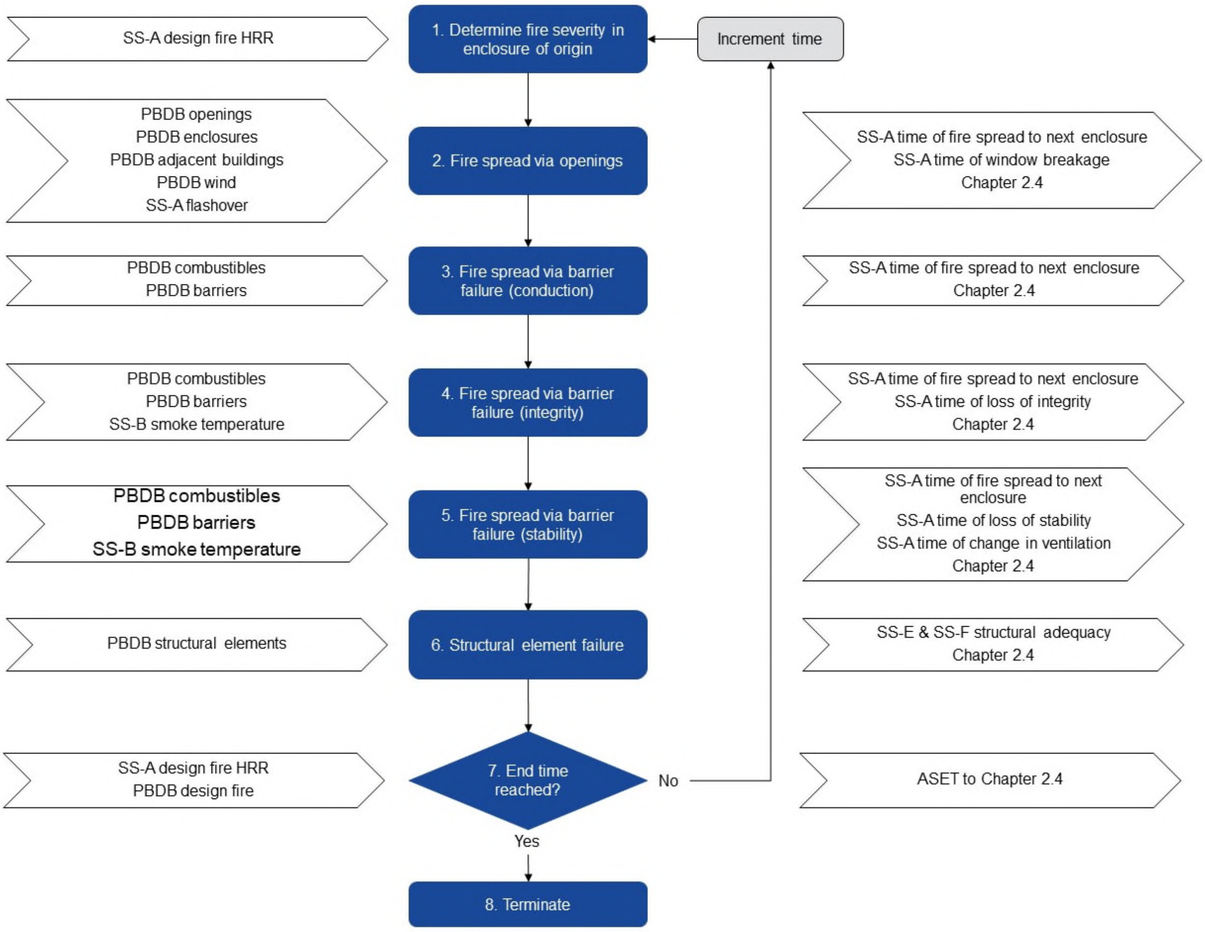
Where the PBDB decision is that an analysis should be undertaken that includes consideration of probabilities of various events and scenarios occurring, the flow chart can assist the FE in identifying those factors to be taken into account during the probability analysis.

The flow chart provides guidance but does not necessarily cover all the factors which may be relevant to a particular fire engineering analysis.

A.3.1.2 Control of fire spread and impact

The control of fire spread and its impact may be used to improve fire safety as an alternative (or in addition) to those measures provided by other sub-systems. This is discussed in Section A.3.4.

Figure A.3.1 Flow chart for fire spread and impact analysis



A.3.2 Outputs – SS-C

Depending on the analysis tools used, the following parameters are generally available as outputs from SS-C.

Time of fire spread to the next enclosure

This parameter not only provides information about time to fire spread but may also be used:

- in SS-A to indicate when the design fire for the next enclosure is initiated
- in SS-E to assess evacuation of occupants
- in SS-F to assess fire fighting activities
- to form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating and evaluating results and drawing conclusions) and may also be used to determine ASET.

Time of loss of integrity of a barrier

This parameter not only provides information about time to fire spread (see above), but may also be used:

- in SS-A to assess changes in ventilation
- in SS-E to assess evacuation of occupants
- in SS-F to assess fire fighting activities
- to form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating and evaluating results and drawing conclusions) and may also be used to determine ASET.

Time of loss of stability of a barrier

This parameter not only provides information about time to fire spread (see above), but may also be used:

- in SS-A to assess changes in ventilation,
- in SS-E to assess evacuation of occupants,
- in SS-F to assess fire fighting activities, and
- to form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating and evaluating results and drawing conclusions) and may also be used to determine ASET.

Time of failure of a structural element

This parameter not only provides information about structural adequacy but may also be used:

- in SS-E to assess evacuation of occupants,
- in SS-F to assess fire fighting activities, and
- to form the basis for one of the acceptance criteria for the analysis, as determined in Section 2.2.9 and used in 2.4 (Collating and evaluating results and drawing conclusions) and may also be used to determine ASET.

ASET

This parameter is used in a timeline analysis. When compared (see 2.4) with RSET, obtained from SS-E, provides a criterion for acceptability (see Section 2.2.9) of that design.

ASET may be determined using the above outputs on the basis of the acceptance criteria (see Section 2.2.9)

A.3.3 Inputs – SS-C

The required input parameters to SS-C are determined by the analysis methods being used and may include:

- **Characteristic fire profile.** The fire profile is obtained from SS-A and may be expressed in terms of HRR or heat flux or temperature as a function of time.
- **Time of flashover.** This parameter is obtained from SS-A and may be used (see Section A.4.4.1), in certain circumstances, as the time for fire to spread to an adjacent enclosure.
- **Smoke temperature.** This parameter is obtained from SS-B and may be used to determine ignition of combustibles in an adjacent enclosure.
- **Building characteristics.** The following parameters are usually relevant and should be available from the PBDB:
  - geometry of enclosures
  - number, location, size and dimensions of openings
  - physical properties of barriers and structural elements
  - location and ignition characteristics of combustibles (especially in adjacent enclosures)
  - proximity and ignition characteristics of adjacent building facades or of potential building development.
- **Wind effects.** Wind velocity and direction may influence the extent of fire projection from windows and heat losses from the enclosure. The effect of wind is likely to be more significant when there are openings on both the windward and leeward sides of the building.

Depending upon the burning characteristics of the building and its contents, the potential distribution of flying brands and embers may also be a necessary consideration if fire spread to adjoining property is to be limited. This may have design implications in areas prone to bushfires.

A.3.4 Analysis – SS-C

SS-C is generally used in one of two situations:

- When the characteristics of any building are known and the aim of the calculations is to predict for each fire scenario how fire will spread and impact on the building over time (see Section A.4.4.1) and, in some cases, to determine an ASET (see 2.4).
- When the degree of fire spread and impact and required ASET have been established, the aim of the analysis is to determine the appropriate characteristics for the building with respect to control of fire spread and impact (see Section A.5.4.2).

A.3.4.1 Analysing fire spread and impact

Fire spread beyond a fire enclosure takes place through openings in the boundaries of the fire enclosure (either existing or created by the impact of the fire). The evaluation may need to consider:

- existing openings such as open doors and windows
- openings resulting from breakage of glazed openings or doors opened by occupants evacuating the building
- openings due to non-existent fire stopping, failure of inadequately fire-stopped penetrations or damage to elements such as service pipes or cable trays
- openings resulting from loss of integrity of the barrier (e.g. walls, floors and closures in the closed position) due to cracks, fissures or structural collapse.

Certain building features will provide ready avenues of spread if directly connected to the enclosure or if the separation between the feature and enclosure is breached. Features that facilitate flame spread in this way may include:

- vertical shafts such as stairways, elevator shafts, large service ducts and architectural voids
- concealed spaces such as ceiling voids, spaces within hollow construction and spaces under floors and behind exterior cladding on the inside of building facades.

These features are treated as enclosures for the purpose of analysing fire spread and impact. The features of interest and the potential routes of spread should be defined during the PBDB. For a given fire location, there may be more than one potential route for fire to spread – and this may require several sets of analyses to be carried out. Combinations of openings, which may be either opened or closed, may also be investigated to determine the worst likely conditions for fire spread.

As indicated at the beginning of this appendix, spread beyond a fire enclosure is deemed to have occurred when material outside that enclosure ignites. For the purposes of analysis, a number of simplifying assumptions may be made:

- Spread through an opening in an enclosure occurs when flashover has taken place. This assumption may also be applied to closed windows if the glazing is of ordinary window glass but not toughened or wired. The rationale for this assumption is that the heat release of a fire in the pre-flashover stage is limited and not likely to cause spread through openings. However, such possibilities (including glass breakage) may be required for some analyses.
- Barrier failure equates with ignition of combustibles in the adjacent enclosure and fire spread.
- Non fire-rated barriers may be considered to remain intact until flashover in the enclosure. The rationale for this assumption is that the impact on barriers is low during the pre-flashover stages and barrier failure will commonly occur after flashover. Direct flame contact on the barrier may negate this assumption.

Step 1

Determine the fire severity in the enclosure of origin. This is generally achieved using input from SS-A on the design fire. The characteristic fire profile, expressed as HRR as a function of time, can be used to give fire severity in terms of:

- heat flux versus time
- temperature versus time
- time equivalence.

The fire severity can also be determined independently of SS-A using information from the PBDB on the combustibles in the enclosure and the enclosure characteristics and methodologies devised for this purpose.

Step 2

Determine the possibility and time for fire spread by way of the existing openings in the enclosure of fire origin. The spread to an adjacent enclosure, building or property boundary may occur by means of:

- burning embers and other debris
- radiation
- direct flame contact.

As discussed above, the 'adjacent enclosure' includes vertical shafts and concealed spaces as well as rooms on the floor of fire origin and floors above that of fire origin. In the latter case, the fire may spread by way of flames projecting through windows.

For adjacent buildings, fire spread may occur through the glass of fixed or closed windows by radiation, without glass breakage occurring.

In the case of fixed or closed windows, the time of glass breakage may be determined, based on the fire severity, and this event used to determine fire spread as well as to modify the ventilation for the design fire in SS-A. Alternatively, as noted above, the time to flashover from SS-A may be used as the time to glass breakage (as with the time for fire spread through all openings).

For closed doors, the time of opening may be obtained from the analysis of occupant evacuation in SS-E.

Step 3

Determine the possibility and time of spread due to conduction through the boundaries ('barriers') of the enclosure of fire origin. Barrier failure due to conduction of sufficient heat through the barrier to meet failure criteria can occur without loss of integrity and stability of the barrier. Whether ignition of combustibles occurs in the next enclosure depends on their ignitability and disposition (obtained from PBDB) but, as discussed above, barrier failure alone may be taken as the criterion for flame spread into the adjacent enclosure.

Step 4

Determine the possibility and time of spread due to loss of integrity of the boundaries (barriers) as discussed in of the enclosure of the fire origin. Barrier failure due to loss of integrity involves the formation of cracks and fissures and the failure of firestopping. The ignition of combustibles in the adjacent enclosure may be due to radiation from hot gases and flames, depending on the nature and disposition of the combustibles. Information on the combustibles may be obtained from the PBDB and smoke temperatures from SS-B. However, as discussed above, barrier failure alone may be taken as a criterion for flame spread into the adjacent enclosure.

Step 5

Determine the possibility and time of spread due to the loss of stability of the boundaries (barriers) of the enclosure of fire origin. Barrier failure due to loss of stability involves the collapse of the barrier that may or may not be a structural element of the building. The ignition of combustibles in the adjacent enclosure may be due to radiation from hot gases and flames and the factors discussed in Step 4 apply. However, barrier failure alone may be taken as a criterion for flame spread into the adjacent enclosure.

Step 6

Determine the possibility and time of failure of structural elements of the building due to the impact of the fire in the enclosure of fire origin based on information from the PBDB.

Structural adequacy and the time to failure of structural components should be evaluated in terms of stability if their continued function is required for occupant evacuation or fire service intervention or to prevent collapse or impact on adjacent buildings or structures" Consideration to impacts on other items should also be given, such as people who may be walking past the building on the street, etc.. The extent and sophistication of the analyses applied to the structural elements in the presence of fire should be established during the preparation of the PBDB. The evaluation of the collapse mechanisms of complex and redundant structures may require input from structural engineers.

Barriers that are supported by structural elements, or are structural elements themselves supported by other elements, may also fail when the supporting element fails. Thus, the time of failure of the structural element should be evaluated to ensure that the barrier it is supporting does not fail prematurely. If the analysis proceeds past the failure of the structural element, then the consequence of the failure of the element on other barriers (or elements) needs to be considered.

Step 7

Determine if the end time has been reached. This is when:

- the fire has extinguished

- there is no further spread or loss of stability for the enclosure of fire origin
- all the enclosures have been examined
- the stage of the design fire, agreed to in the PBDB process, has been reached
- in the engineering judgement of the fire engineer, sufficient analysis has been carried out to justify the trial design under consideration.

If the end time has been reached, and if required by the analysis strategy, calculate the ASET based upon the criteria for ASET set in Section 2.2.9. If this end time has not been reached, the next iteration is undertaken and the analysis continued until the end time has been reached.

Step 8

The analysis of SS-C is terminated.

A.3.4.2 Analysing control of fire spread and impact

There are a number of ways to control fire spread and impact. These include:

- Controlling the materials comprising the fuel load so that only those materials that have a low HRR or are difficult to ignite and burn slowly if ignited are used (see SS-A). This would form part of a fire prevention strategy.
- Designing barriers and protection of openings to limit the fire spread and impact to a predetermined level. This uses the same basic elements of Figure A.3.1. It enables quantification of those characteristics of the barriers and protection of openings that enable the attainment of the relevant acceptance criteria for the analysis (as determined in the PBDB process) used in 2.4 (Collating the results and drawing conclusions).

A.3.5 Construction, commissioning, management, use and maintenance – SS-C

The principal issues with regard to construction and commissioning of fire spread and impact control measures are:

- the integrity of the barriers
- materials and components are to specification
- operable systems, such as auto-closing fire doors, work as required
- appropriate operation and maintenance manuals are available.

Passive components of a fire safety system, such as fire rated walls, are prone to be overlooked in building repairs and modifications subsequent to the original construction. Management procedures designed to ensure the ongoing identification and integrity of these fire safety components need to be considered as an essential part of the use of the building.

In general, passive fire protection barriers require little routine maintenance. Active barriers, such as automatically closing fire doors, require a maintenance schedule that should include operational tests. Inspection to preserve the integrity of fire spread control features should be part of the requirements of a maintenance program. Documents should define the maintenance requirements and record the outcomes. It may be possible to ensure that this is done through the requirements for essential safety provisions for buildings that may apply in some jurisdictions.

A.4 Fire detection, warning and suppression – SS-D

SS-D is used to analyse detection, warning and suppression for fires. This process enables estimates to be made of times of critical events and the effectiveness of suppression.

Although the analysis of fire detection generally involves automatic devices, detection by building occupants (audio, olfactory, visual or tactile) may also be considered, providing appropriate criteria are used.

It should be recognised that a sprinkler head has a heat-sensitive element, and therefore behaves very similarly to a heat detector and may be used to detect fires.

While the analysis of fire suppression generally involves automatic equipment, suppression by building occupants (using extinguishers and hose reels), public fire services (permanent or volunteer), and private fire crews (particularly in industrial complexes) may also be considered – providing appropriate criteria are used. In the case of the fire services, suppression activities are analysed in SS- F.

This appendix provides guidance on quantifying:

- the detection of fire
- the activation of various types of fire detectors
- the activation of various types of smoke management and suppression equipment
- the time of activation of warning (for warning occupants and communication to fire services)
- the effectiveness of suppression.

This appendix also discusses the relationships between this sub-system and others.

Although this appendix provides guidance on the analysis of SS-D in the general analysis context discussed in 2.3, each project needs to be considered individually and the analysis varied accordingly.

A.4.1 Procedure – SS-D

A.4.1.1 Fire detection, warning and suppression

Figure A.4.1 outlines the process of analysing fire detection, warning and suppression in a building. Discussion of the figure can be found in the following sections:

- Section A.4.2 Outputs
- Section A.4.3 Inputs
- Section A.4.4 Analysis.

An analysis needs to be undertaken for each design fire specified by the PBDB.

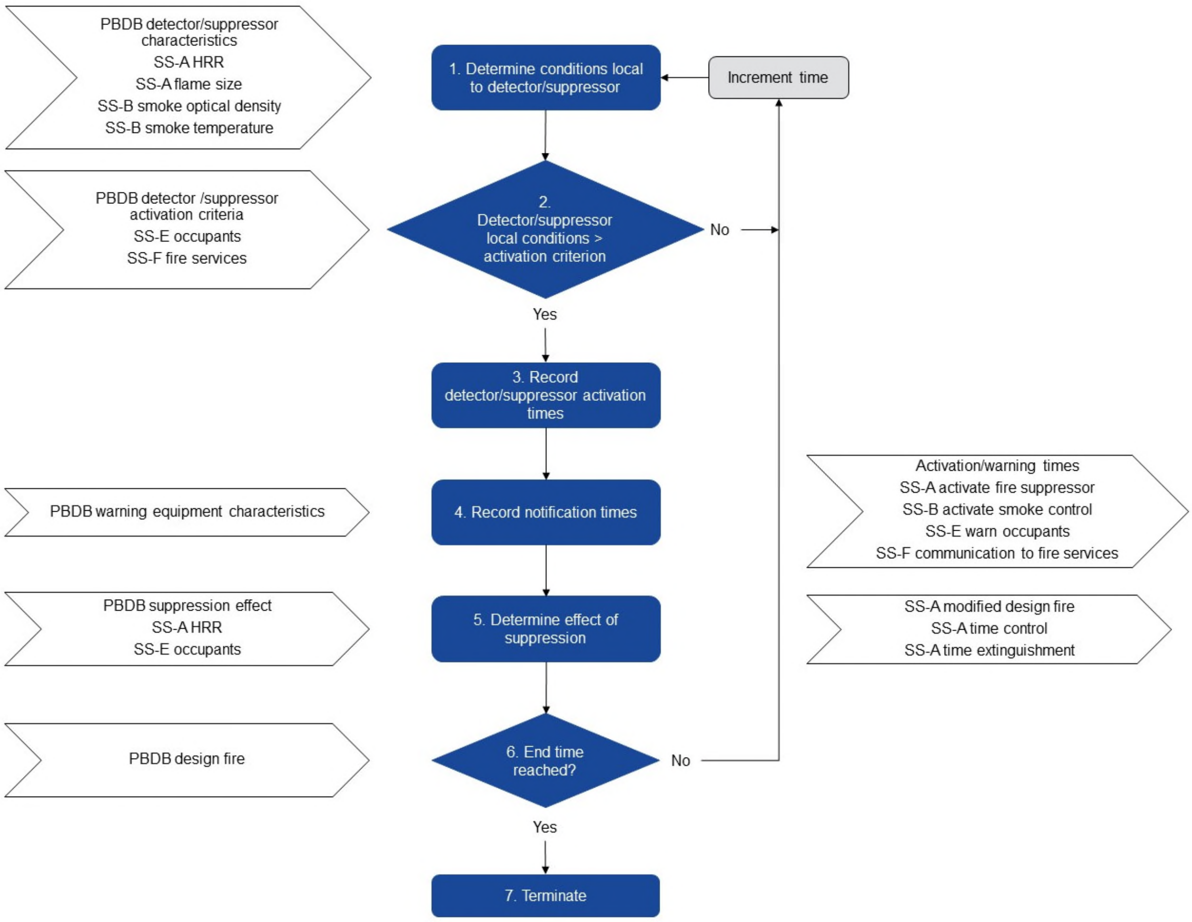
Where the PBDB decision is an analysis that includes consideration of probabilities of various events and scenarios occurring should be undertaken, the flow chart can assist the FE in identifying those factors to be taken into account during the probability analysis.

The flow chart provides guidance but does not necessarily cover all the factors which may be relevant to a particular fire engineering analysis.

A.4.1.2 Enhancement of fire detection, warning and suppression

Enhanced fire detection, warning and suppression may be used to improve fire safety as an alternative (or in addition) to the measures provided by other sub-systems, and these are discussed in Section A.4.4.2.

Figure A.4.1 Flow chart for detection, warning and suppression analysis



A.4.2 Outputs – SS-D

A.4.2.1 Outputs for fire detection and warning

The outputs will vary according to:

- the type of fire detectors
- the means of activation, namely, automatic or manual
- whether the output is an electronic signal, an audible alarm or a visual alarm
- the manifestations of the fire used for detection (noise, smell or obscuration).

Typical outputs are discussed below:

- **Time to activate smoke management equipment.** This excludes delays in the equipment becoming effective and is an input to SS-B.
- **Time to alert occupants.** As indicated above, the alarm may take a number of forms and the time includes any time delays inherent in automatic equipment but excludes the time for occupants to react to the alarm (see SS-E).

- **Time to alert fire services.** This includes delay time discussed in Step 4 of the analysis in Section A.4.4.1. This provides input to SS-F.

A.4.2.2 Outputs for suppression

The following outputs apply whether the suppression is by automatic equipment, occupants or fire fighters:

- **Time of commencement of activation or commencement of suppression.** In the case of automatic equipment, this will be the activation time, whereas for human intervention this is the commencement of fire fighting activities. This provides input to SS-A and SS-F.
- **Modified HRR versus time.** This reflects the effect of suppression. It is generally categorised by the following factors to provide input to SS-A and SS-F:
  - no effect
  - control
  - extinguishment.
- **Time to control.** If the effect of suppression is only to 'control' the fire, the time to control may be taken as the time to activation or the commencement of suppression (and used in SS-A and SS-F).
- **Time to extinguishment.** If the effect of suppression is 'extinguishment', the time at which the fire is finally extinguished may be determined as an input to SS-A and SS-F.

A.4.3 Inputs – SS-D

A.4.3.1 Inputs for fire detection and warning

Typical inputs may include:

- **Detector and warning characterisation:** Information is required on the location, type and actuation criteria of the detectors and alarms from the PBDB. The actuation criteria will vary from one type to another and will determine the other inputs required. In principle, detectors include automatic suppressors as well as occupants of the building (see SS-E).
- **Fire conditions:** A number of fire parameters may be used to determine detector activation according to the type of detector. These may include:
  - HRR from SS-A
  - flame size and temperature from SS-A

- carbon monoxide concentration from SS-A
- smoke optical density from SS-B
- smoke temperature from SS-B.

A.4.3.2 Inputs for fire suppression

Typical inputs may include:

- **Suppressor characterisation.** Information on the location, type, actuation criteria, and suppressing agent characteristics of the suppression equipment are obtained from the PBDB. The actuation criteria will vary from one suppressor type to another, and will determine the other inputs required. Suppressors include automatic suppressors, occupants, and fire services.
- **Fire conditions:** A number of fire parameters may be used to determine the suppressor activation times and the effect of suppression:
  - HRR from SS-A
  - smoke optical density from SS-B
  - smoke temperature from SS-B
  - nominated suppression effectiveness from the PBDB.

A.4.4 Analysis – SS-D

A.4.4.1 Analysing fire detection, warning and suppression

The process of analysis is shown in Figure A.4.1. The initial four steps are similar for both detectors and suppressors, although the necessary input data will vary according to the actuation criteria.

Step 5 deals only with suppression by automatic equipment and building occupants. Suppression by the fire services is covered by SS-F.

Step 1

Determine the conditions local to the detector or suppressor. The parameters that are relevant will depend on the type of detector/suppressor, its characteristics, and activation criteria.

Step 2

Compare the conditions local to the detector or suppressor with the activation criteria. If the criterion has been exceeded by the local conditions, the device may be considered to have activated. If the criterion has not been exceeded, the time should be incremented, and the situation should be re-examined.

Step 3

Record the activation times.

Step 4

Modify the activation times to obtain the notification times by adding any delay times appropriate to the equipment associated with the detector or suppressor. Generally, delay times inherent in the detector or suppressor will have been included in the characteristics of the detector or suppressor used in the analysis, or otherwise included in the analysis method.

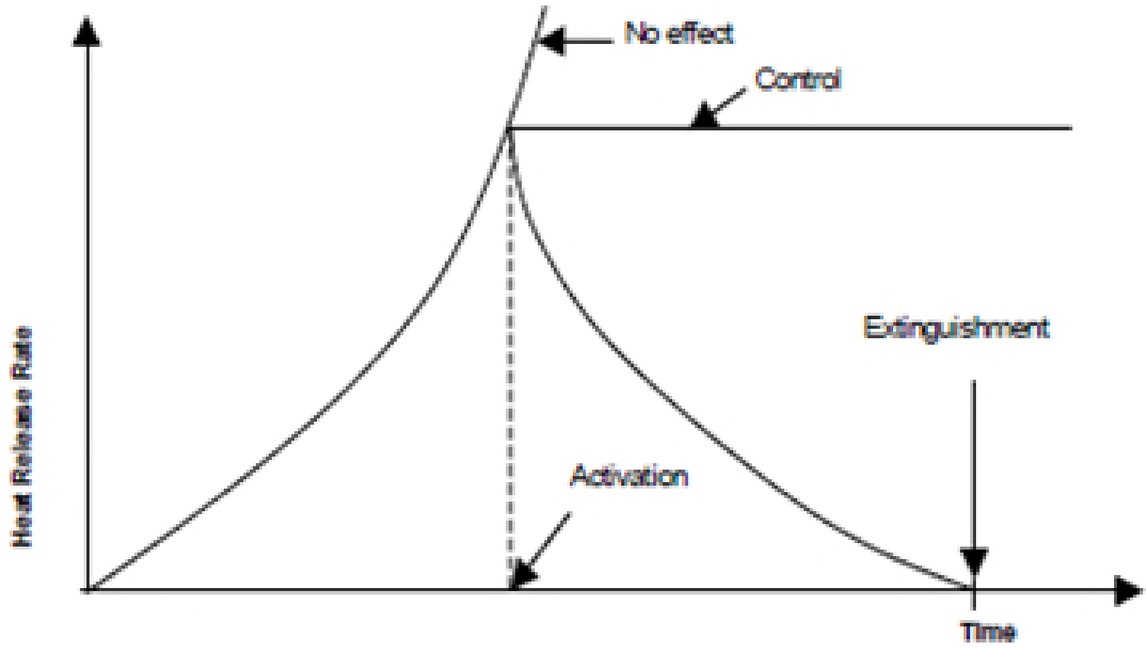
The delays may be due to:

- detector signal interrogation, verification and processing by associated equipment
- the time required for a signal to sound an alarm
- time required for the transmission of signals. For example, signals sent to fire stations through automatic equipment, alarm monitoring companies or manual alarms
- time for coincident detector operation
- time for occupant evacuation before the release of a suppression agent that is harmful to humans.

Step 5

If a suppressor has been installed and activated, Step 5 is to determine the effect of the equipment on the design fire (from SS-A). The effect of the suppressor is illustrated in Figure A.4.2.

Figure A.4.2 Possible effects of suppression on a design fire



As shown in Figure A.4.2 the possible effects of suppression can be expressed as one of three possible outcomes:

- **No effect.** Although this is an unlikely outcome, it is sometimes used as a conservative assumption. This is based on those cases where the suppressor may be inoperative or a fire has developed beyond flashover and is thus difficult to extinguish.
- **Control.** This outcome is represented by a steady HRR from the time at which suppression begins. It is assumed that the control situation represents the extent of the suppressor's capability and that extinguishment is only achieved when all the fuel is consumed. This may be a conservative assumption in a fire engineering analysis, and is often used when the fire is shielded from the suppressor. However, the intent of the design of the suppressor should be taken into account as not all designs are for extinguishment.
- **Extinguishment.** In addition to the time of extinguishment, the FE can calculate the rate at which the fire decays. Sometimes, arbitrarily, the decay phase is assumed to be a mirror image of the growth phase.

The outcome(s) used in the analysis will generally be decided qualitatively during the PBDB process, but may require input from SS-E for likely-occupant fire fighting activities. In a fire engineering analysis, it is customary to assume that occupants will not engage in effective fire fighting activities unless they are part of a specially-trained site emergency response crew. However, if there is good reason to believe that occupants will contribute to effective fire fighting, such action may be taken into account and the time such activities commence determined. Decisions on these matters should be made during the PBDB process.

Suppression by fire services is covered by SS-F.

Step 6

Determine if the end time has been reached. This is when:

- the fire has ceased to burn either due to suppression or lack of fuel
- the stage of the design fire agreed to in the PBDB process has been reached
- in the engineering judgement of the FE, sufficient analysis has been carried out to justify the trial design under consideration.

If the end time has not been reached, the next iteration is undertaken and the analysis continued until the end time has been reached.

Step 7

The analysis of SS-D is terminated.

A.4.4.2 Analysis of enhanced fire detection, warning and suppression

Enhancement of this sub-system may be achieved by designing (or choosing) fire detection, warning and suppression equipment that performs to a predetermined level. This process uses the same basic elements of Figure A.4.1 as well as the analysis process described in Section A.4.1.1). It enables the quantification of those characteristics of the detection and suppression equipment (see Section A.4.3) that enable the attainment of the relevant acceptance criteria for the analysis (as determined in the PBDB process used in 2.4 (Collating the results and drawing conclusions).

A.4.5 Construction, commissioning, management, use and maintenance – SS-D

Fire detection, warning and suppression equipment ('active' fire protection measures) often use complex electronic components, and therefore need particular attention in order to ensure that:

- they are properly installed during construction of the building
- commissioning confirms the performance assumed or required by the fire engineering evaluation
- management and use is in accordance with any requirements of the fire engineering evaluation
- maintenance is carried out in accordance with the relevant codes, standards, manufacturers' literature and specific maintenance requirements recommended by the FE. It may be possible to ensure that this is done through the essential safety provisions that may apply in some jurisdictions.

A.5 Occupant evacuation and control – SS-E

SS-E is used to analyse the evacuation of the occupants of a building. This process enables estimates to be made of the events that comprise evacuation – in order to determine the time from fire initiation required for occupants to reach a place of safety. This time is generally referred to as RSET.

RSET comprises a number of components that are shown in the detection and evacuation timeline of Figure A.5.1

The actual times, and hence the quantitative timeline, may vary according to the location of the occupants with respect to the fire.

This timeline includes the following events (in order of occurrence):

- **Fire initiation (t_0).** Time zero for the analysis of the fire, evacuation, and determination of RSET.
- **Occurrence of cue (t_c).** The time of a cue that indicates the occurrence of a fire. The cue may be from an automatic alarm device, aspects of the fire itself, or people warning others.
- **Recognition of cue (t_r).** The time at which occupants, having received a cue, recognise it as an indication of a fire.
- **Initiation of movement (t_d).** The time at which occupants begin the evacuation movement. This may occur after a delay during which occupants carry out other actions (including 'no action').
- **Completion of movement (t_m).** The time when occupants reach a place of safety.

All these events or points in time are separated by time periods that comprise the components of RSET.

These event times are used to define the components of RSET as shown in:

- **cue period (P_c)**
- **response period (P_r)**
- **delay period (P_d)**
- **movement period (P_m).**

Various phases may be identified to represent one or more of the above periods as shown in Figure A.5.1:

- **detection phase = P_c**
- **pre-movement phase = $P_r + P_d$**
- **movement phase = P_m**
- **evacuation phase = $P_r + P_d + P_m$**
- **RSET = $P_c + P_r + P_d + P_m$.**

In the event of a fire in a building, traditional practice has been to commence occupant evacuation in response to fire alarms based upon evacuation management plans.

In high-rise buildings with an emergency warning and intercommunication system, the evacuation may be cascaded – with occupants on floors furthest from the fire placed initially on alert, and each floor/area evacuated progressively starting from the fire floor.

In particular types of buildings, the concept of a fire safe refuge – where occupants go to a special fire compartment to await support from the fire service to evacuate – is sometimes used. This may be appropriate for specific buildings such as ultra-high rise buildings or hospitals, however requires very careful consideration and consultation with all relevant stakeholders including the fire service. Internationally, the ‘protect in place’ concept has been used for some buildings, however this strategy is being reconsidered.

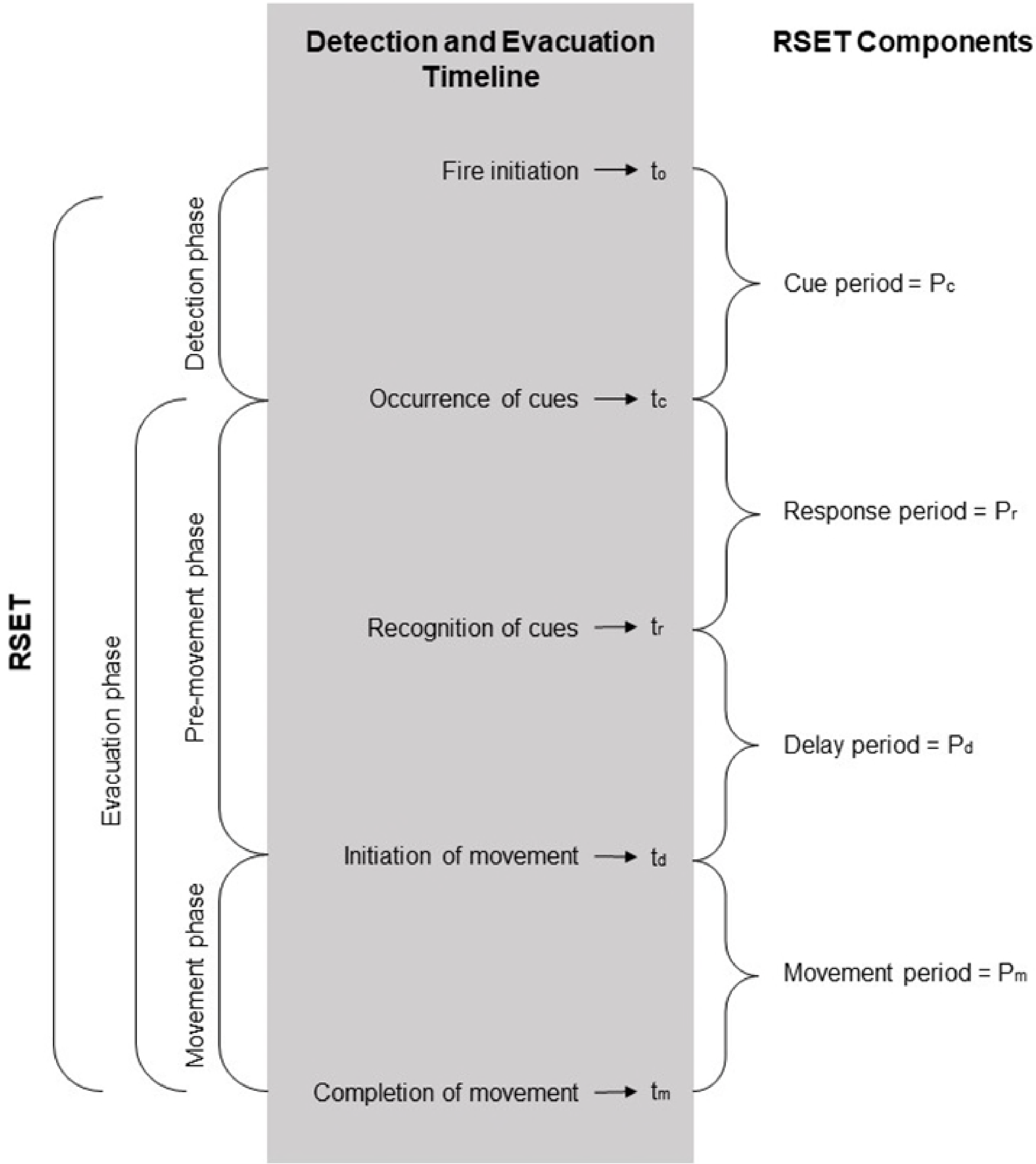
Occupants should be provided with a safe means of evacuating from the building to a road or open space. In all buildings, FE should consider safety for people with disabilities or other mobility impairments. The use of elevators for evacuation or providing refuges are examples of possible options.

This appendix provides guidance on quantifying the times, components and phases described above. In particular, the RSET period is quantified so that it may be compared with ASET (see 2.4 Collating results and drawing conclusions).

This appendix also discusses the relationships between this sub-system and others.

Although this appendix provides guidance on the analysis of SS-E in the general analysis context discussed in 2.3, each project needs to be considered individually and the analysis varied accordingly.

Figure A.5.1 Detection and evacuation timeline

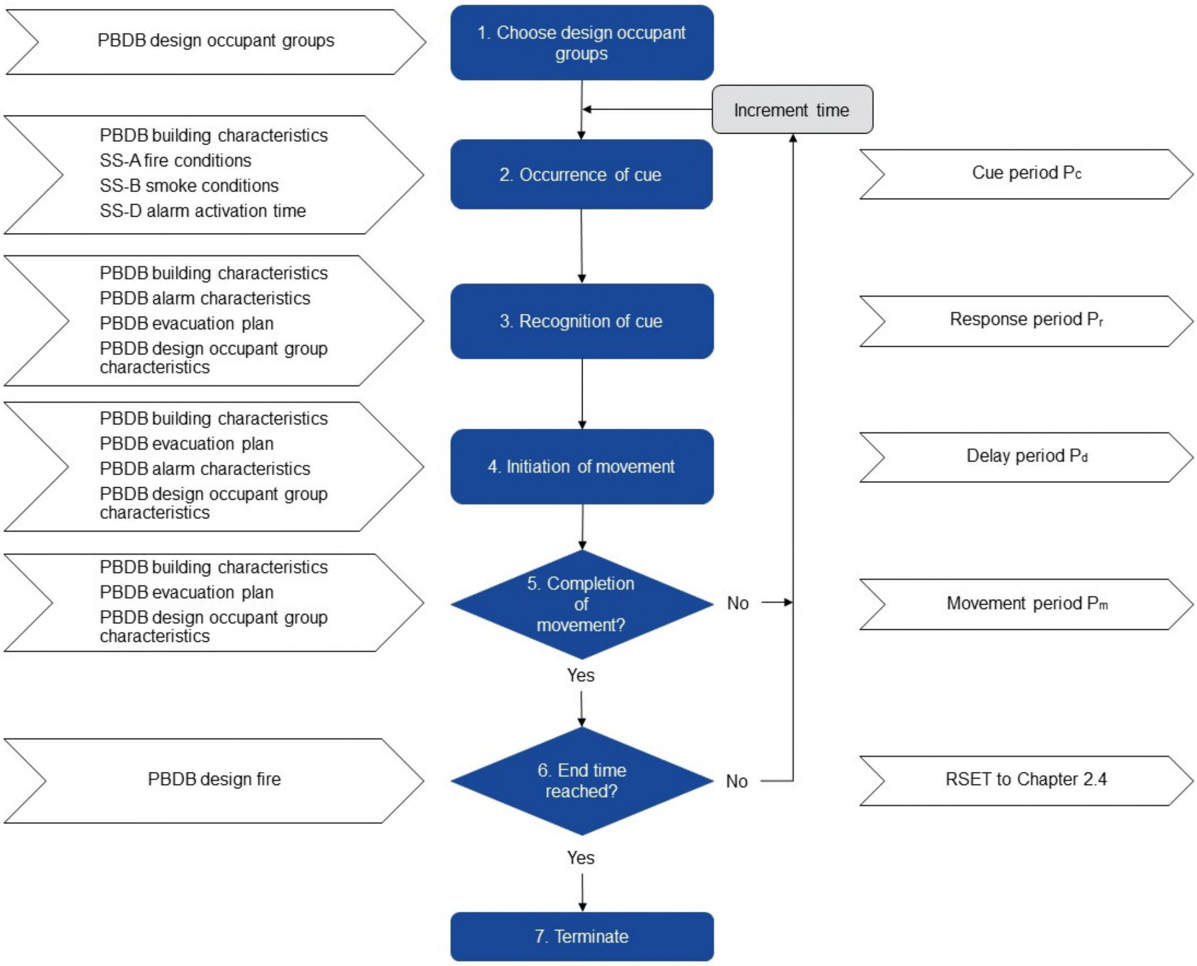


A.5.1 Procedure – SS-E

A.5.1.1 Occupant evacuation

Figure A.5.2 illustrates how occupant evacuation can be analysed.

Figure A.5.2 Flow chart for occupant evacuation analysis



Discussion of the figure can be found in the following sections:

- Section A.5.2 Outputs
- Section A.5.3 Inputs
- Section A.5.4 Analysis.

Figure A.5.1 is supplemented by other flow charts presented in the analysis section (Section A.5.4). An analysis needs to be undertaken for each design occupant group specified by the PBDB.

Where the PBDB decision is an analysis that includes consideration of probabilities of various events and scenarios occurring should be undertaken, the flow chart can assist the FE in identifying those factors to be taken into account during the probability analysis.

The flow chart provides guidance but does not necessarily cover all the factors which may be relevant to a particular fire engineering analysis.

A.5.1.2 Control of occupant evacuation

The control of occupant evacuation may be used to improve fire safety as an alternative (or in addition) to those measures provided by other sub-systems, and these are discussed in Section A.5.4.2.

A.5.2 Outputs – SS-E

Depending on the analysis tools used, the following parameters are generally available as outputs from SS-E:

- **cue period (P_c).** This is the period from fire initiation to the occurrence of a selected cue.
- **response period (P_r).** The occupants may not immediately associate the cue available to them with a fire-related emergency. The PBDB should have set the criteria by which the analysis will determine whether the occupants recognise the various cues. The time span between the occurrence and recognition of cues is referred to as the response period.
- **delay period (P_d).** The occupants may carry out a wide variety of delay-causing actions (including 'no action') once they have recognised the fire cues (and become aware of a fire- related emergency) – but before they initiate their movement towards a place of safety. The time span between the recognition of cues and the initiation of the movement towards safety is referred to as the delay period.
- **movement (travel) period (P_m).** The time span between the initiation and completion of the movement to a place of safety is referred to as the movement period.
- **RSET.** The sum of the cue period, response period, delay period and movement period is known as the RSET. This time is used in the collation of the results and in drawing conclusions as discussed in 2.4.

A.5.3 Inputs – SS-E

The required input parameters to SS-E are determined by the analysis methods used. They may include:

- **Building characteristics.** These should be available from the PBDB. Relevant parameters may include:
    - building type and use
    - physical dimensions

    - geometry of enclosures
    - number of exits
    - location of exits
    - geography and layout.
- **Evacuation plan.** The features of any evacuation plan for the building need to be identified. Although fire services assistance may be included in the evacuation plan, such assistance may not be used in the analysis in some evaluations. Features may include:
    - whether evacuation is controlled or uncontrolled
    - for controlled evacuations, what the evacuation type is (e.g. full, zone or staged).
- **Design occupant groups and characteristics.** The design occupant groups and their characteristics to be used for the analysis would have been determined during the PBDB process (2.2.11). As a number of groups may be analysed separately or used for different components of RSET, the relevant characteristics for each group are required
- **Time of occurrence of cues.** These may include cues such as:
    - the activation of an automatic alarm (audio or visual), obtained from SS-D
    - fire-related cues (audio, olfactory, visual and tactile), based on information from SS-A and B
    - warnings (in the form of actions or word of mouth) from other people, based on information from the PBDB or this sub-system.

A.5.4 Analysis – SS-E

The analysis of occupant evacuation (particularly the pre-movement phase) is made difficult by the lack of validated analysis methods. Where a suitable method is not available the FE can use:

- data from the literature, field studies or simulated evacuations
- engineering judgement.

The data needs to be well documented and the engineering judgement well substantiated (as described in 2.5, Completing the FER).

A.5.4.1 Analysing occupant evacuation

The process of analysis is shown in Figure A.5.2, and supplementary flow charts are given in Figure A.5.3, Figure A.5.4, Figure A.5.5 and Figure A.5.6. The analysis should be carried out for each of the enclosures (e.g. a room or mall) or group of enclosures (e.g. a floor or a whole building).

Step 1

Choose the design occupant group. Design occupant groups should be identified and described in the PBDB. The design occupant group recognised as being the most critical for the analysis is generally chosen, but it may be appropriate to carry out the analysis a number of times for different design occupant groups or to use different design occupants groups for various steps in the analysis.

Step 2

Determine cue occurrence and quantify cue period. The flow chart in Figure A.5.3 explains the steps involved in determining cue occurrence and the quantification of the cue period (P_c).

In the majority of cases, automatic alarms are the preferred choice for cues (notification). An automatic alarm may be activated in many different ways such as by smoke detectors, thermal detectors, suppressors, ultraviolet detectors and infrared detectors.

Fire-related cues are generally detected in the enclosure of fire origin. However, depending on the spread of smoke and fire, they may be detected in other enclosures. The cues may be:

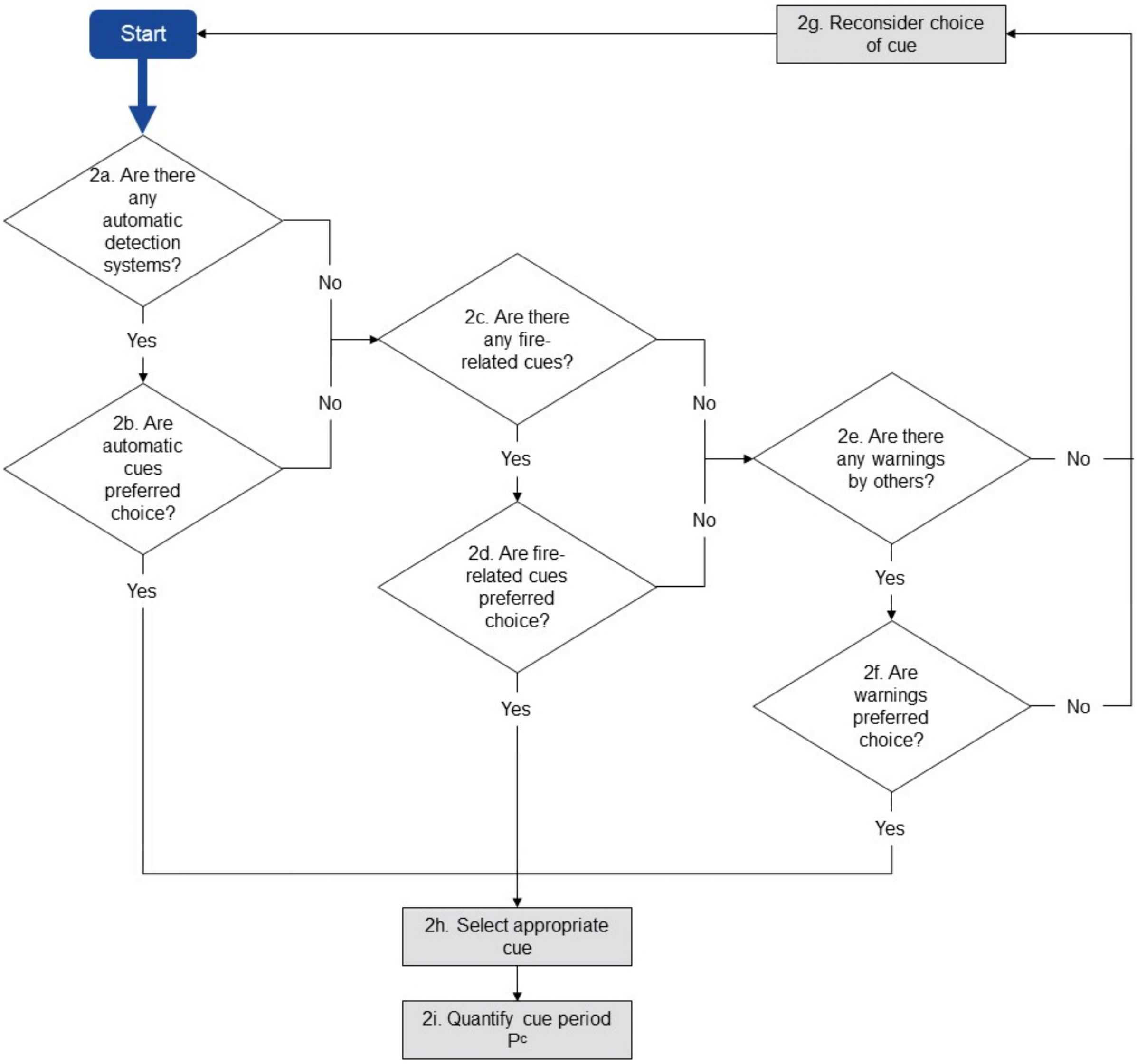
- audio, for example, the sound of the fire or burnt objects falling
- olfactory, for example, the smell of smoke
- visual, for example, the sight of smoke or flames
- tactile, for example, a change in air temperature or radiated heat from the fire.

In some cases, people who have heard or observed an automatic or fire-related cue may alert other people.

In using the option of warning by others, it should be noted that those who are doing the warning not only need to have recognised a cue, however would also have needed to have received a cue. This would need to be factored into the timing.

Figure A.5.3 illustrates the quantification of the cue period (P_c).

Figure A.5.3 Flow chart for determining the cue period (P_c)



The steps set out in Figure A.5.3 are described in more detail below.

Steps 2a and 2b

Assess automatic cues. The presence of automatic detection equipment should be established in the PBDB. If they are present, a decision needs to be reached on whether to include them in the analysis. If automatic detectors are used in the analysis, proceed to **Step 2h.**

Steps 2c and 2d

Assess fire-related cues. If automatic cues are not present or a decision has been reached not to include them in the analysis, fire-related cues may be considered. If fire-related cues are used, proceed to **Step 2h**.

Steps 2e and 2f

Assess cues from people warning others. These may be considered using information on the characteristics of the design occupant groups being used in the analysis. Generally, those warning others will have recognised a cue (see **Step 3**). If warning by others is used, proceed to **Step 2h**.

Step 2g

Re-consider choice of cue. If the FE has not chosen to consider any of the available cues, the analysis cannot progress any further. The FE needs to re-consider the choice of cues by returning to the start of the process.

Step 2h

Select appropriate cue. Where the above process has identified more than one possible cue for the analysis, select the most appropriate cue (for example, one of several possible automatic cues). In all cases, the reasons for choosing the cue should be documented.

Step 2i

Determine cue period. The information needed to determine the cue time (and hence the cue period) will be available from various sources according to the type of cue. For example:

- for automatic cues, SS-D
- for fire related cues, SS-A and B
- for warnings by others, **Step 3.**

After obtaining the information, determine the cue time, and then the cue period.

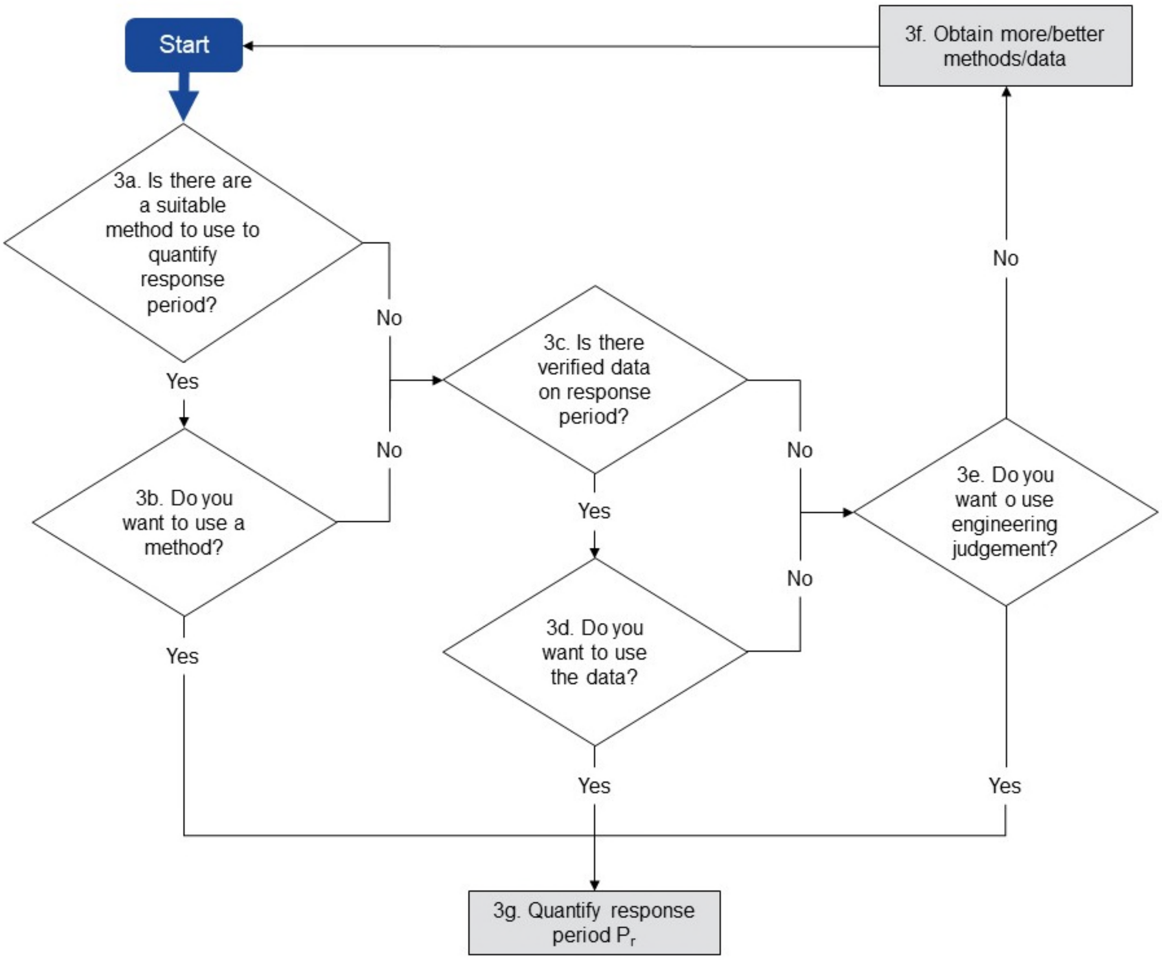
Step 3

Determine cue recognition and quantify response period. Figure A.5.4 explains the steps involved in determining cue recognition and quantification of the response period (P_r).

Cue recognition may be defined as the process of occupants receiving cues, defining the situation and identifying the cues as an indication of a fire-related emergency.

The time period over which these events take place is identified as the response period.

Figure A.5.4 Flow chart for determining response period (P_r)



The following steps comprise the quantification of response period as set out in Figure A.5.4.

Steps 3a and 3b

Establish the availability of a suitable method and decide whether to use it. The FE needs to establish the availability of a suitable method to quantify the response period. The decision on whether to use the method will depend on the suitability of the method and the availability of input data.

Steps 3c and 3d

Establish the availability of verified data and decide whether to use it or not. The FE needs to establish the availability of verified data to quantify the response period. The decision on whether to use the data will depend on the applicability of the data to the scenario being assessed.

Step 3e

Use of engineering judgement. Where valid methods or verified data are not available or not appropriate, engineering judgement may be used. However, all quantification based on engineering judgement needs to be justified in detail (see 2.5 Completing the FER).

Step 3f

Obtain other methods or data. Where the methods and data considered are not appropriate and engineering judgement cannot be used, the FE needs to obtain other methods or data in order to quantify the response period.

Step 3g

Quantify response period. Quantify the response period using methods, adopting data, or by applying engineering judgement.

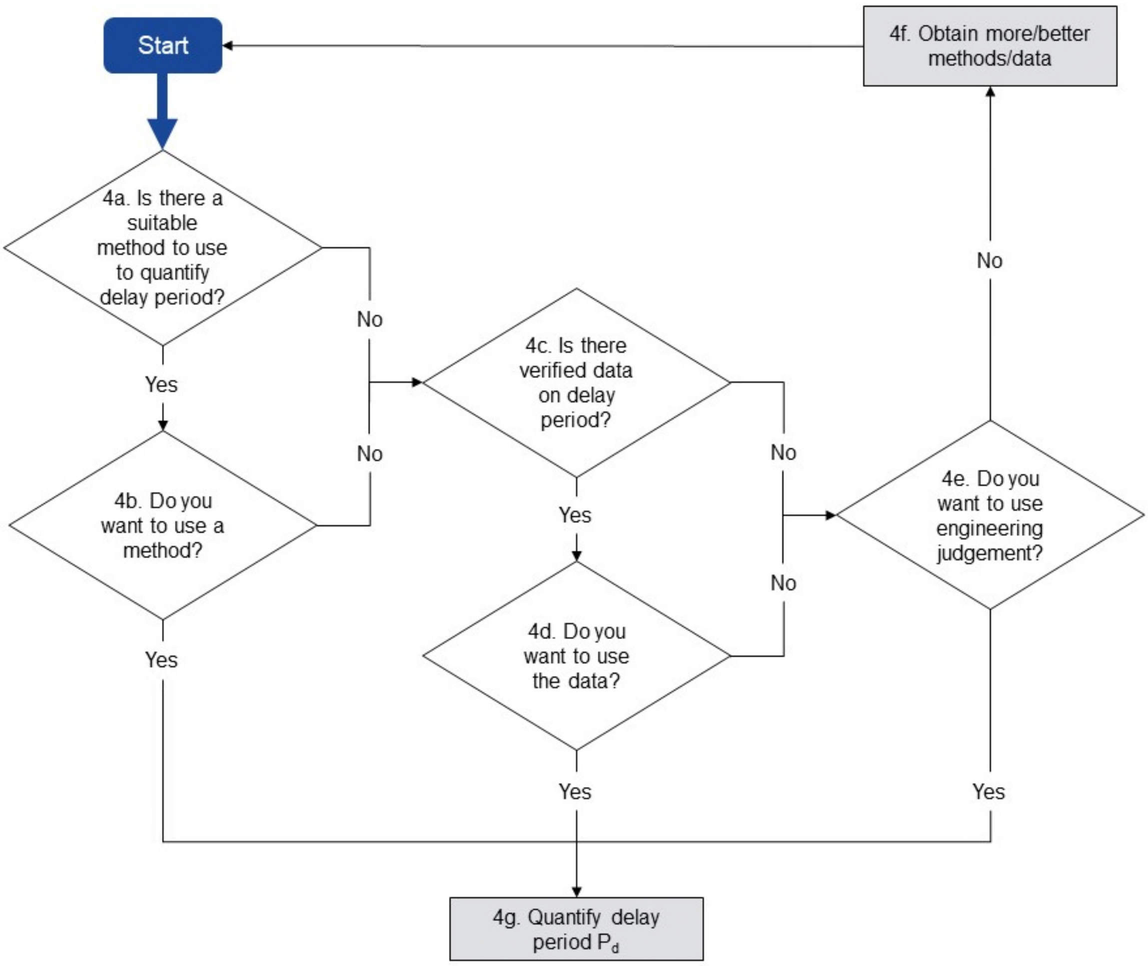
Step 4

Determine time of initiation of movement and quantify delay period (P_d). The flow chart in Figure A.5.5 explains the steps involved in determining initiation of movement and quantification of the delay period (P_d).

After cue recognition, there is generally a delay period before movement towards a place of safety is initiated. During this delay period, occupants may carry out a wide variety of actions (including ‘no action’) which may vary according to the design occupant group considered.

Figure A.5.5 illustrates the steps that comprise the quantification of the delay period (P_d).

Figure A.5.5 Flow chart for determining the delay period (P_d)



The following steps comprise the quantification of delay period as set out in Figure A.5.5.

Steps 4a and 4b

Establish the availability of a suitable method and decide whether to use it. The FE needs to establish the availability of a suitable method to quantify the delay period. The decision on whether to use the method will depend on the suitability of the method and the availability of input data.

Steps 4c and 4d

Establish the availability of verified data and decide whether to use it. The FE needs to establish the availability of verified data to quantify the delay period. The decision on whether to use the data will depend on the applicability of the data to the scenario being assessed.

Step 4e

Use engineering judgement. Where valid methods or verified data are not available or not appropriate, engineering judgement may be used. However, all quantification based on engineering judgement needs to be justified in detail (see 2.5 Completing the FER).

Step 4f

Obtain other methods or data. Where the methods and data considered are not appropriate and engineering judgement cannot be used, the FE needs to obtain other methods or data to quantify the delay period.

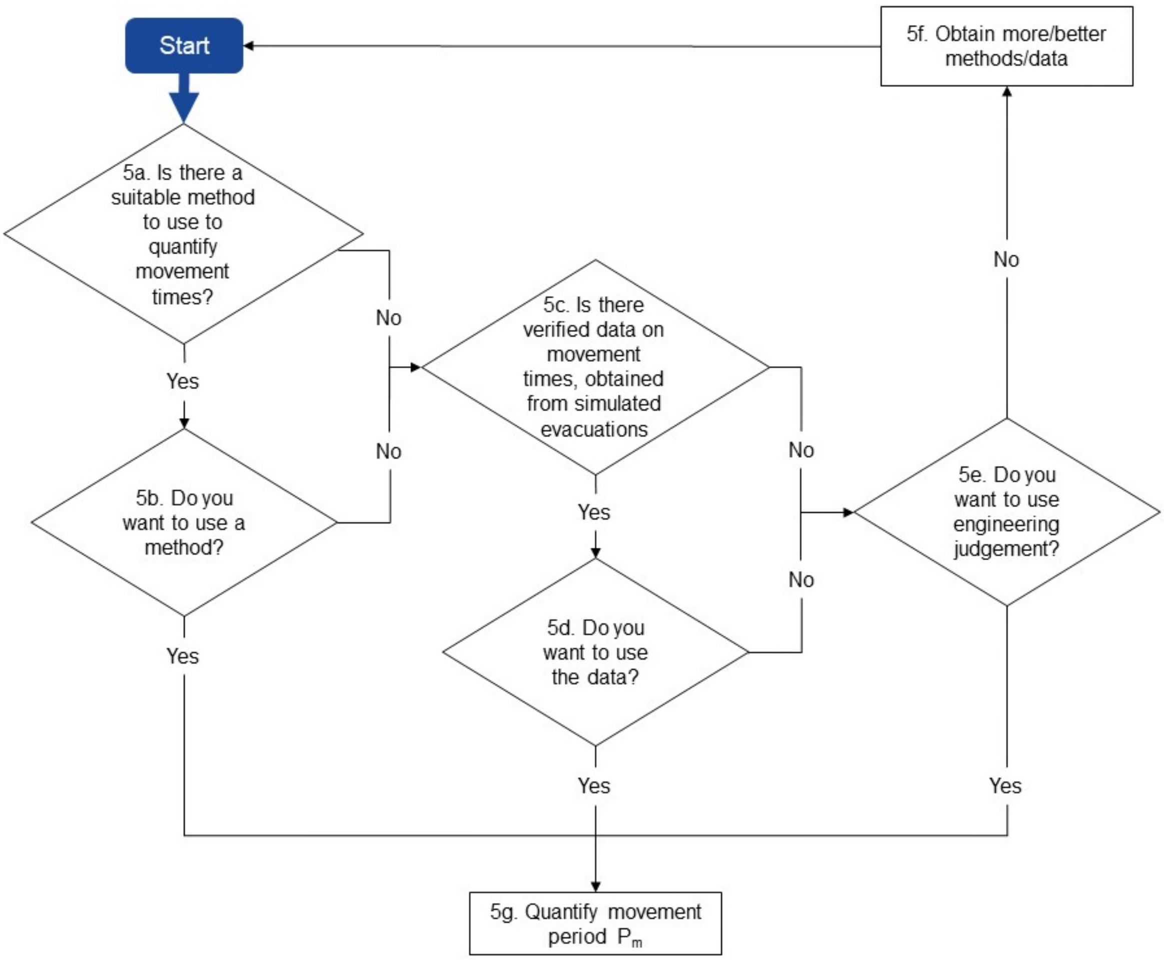
Step 4g

Quantify delay period. Quantify the delay period using methods, adopting data, or by applying engineering judgement.

Step 5

Determine completion of movement and quantify movement period (P_m). Figure A.5.6 explains the process for determining completion of movement and quantification of the movement period (P_m).

Figure A.5.6 Flow chart for determining the movement period (P_m)



The following steps comprise the steps set out in Figure A.5.6.

Steps 5a and 5b

Establish the availability of a suitable method and decide whether to use it. The FE needs to establish the availability of a suitable method to quantify the movement period. The decision on whether to use the method will depend on the suitability of the method and the availability of input data.

Steps 5c and 5d

Establish the availability of simulated evacuation data and decide whether to use it. The FE needs to establish the availability of simulated evacuation data to quantify the movement period. The decision on whether to use the data will depend on the applicability of the data to the scenario being assessed.

Step 5e

Use of engineering judgement. Where valid methods or simulated evacuation data are not available or not appropriate, engineering judgement may be used. However, all quantification based on engineering judgement needs to be justified in detail (see 2.5 Completing the FER).

Step 5f

Obtain other methods or data. Where the methods and data considered are not appropriate and engineering judgement cannot be used, the FE needs to obtain other methods or data in order to quantify the movement period.

Step 5g

Quantify movement period. By using methods, adopting data or by applying engineering judgement, the movement period should be quantified.

Step 6

Determine the end time has been reached. This is when:

- the analysis has been carried out for all the occupant groups identified in the PBDB
- all the occupants have reached a place of safety
- all the relevant enclosures have been analysed
- the stage of the design fire, agreed to in the PBDB process, has been reached
- in the engineering judgement of the FE, sufficient analysis has been carried out to justify the trial design under consideration.

If the end time has been reached, calculate the RSET by adding the cue period (P_c), response period (P_r), delay period (P_d) and movement period (P_m). If the end time has not been reached, carry out the next iteration and continue the analysis until the end time has been reached.

Step 7

The analysis of SS-E is terminated.

A.5.4.2 Analysing control of occupant evacuation

There are a number of ways of reducing the RSET in order to improve the performance of a building's fire safety system. The time periods that constitute RSET can be reduced individually or collectively by varying the factors that influence the magnitude of these periods.

The factors that could influence the relevant periods may include:

- response period:
    - additional cues and information
    - less ambiguous cues
    - more trained personnel.
- delay period:
    - training programs
    - more information related to an emergency
    - more trained personnel and directives.
- movement period:
    - additional and better signage
    - more trained personnel and directives
    - improvement of egress path location and dimensions
    - improved egress path design
    - egress path illumination
    - contra flow integration.

The possibility of achieving a given RSET value may be analysed by varying one or more of these factors and using the processes described in A.5.4.1 to quantify a modified RSET.

A.5.5 Construction, commissioning, management, use and maintenance – SS-E

The evacuation measures that contribute to a building's fire safety system comprise both physical measures (e.g. egress paths, fire corridors and exits, signage) and emergency organisation and procedures (e.g. emergency planning committee, emergency control organisation, emergency procedures, evacuation plans, education and training, testing and maintenance).

These aspects should be addressed during the design and construction phase. The emergency procedures for new buildings should be developed by (or with input from) the fire engineering team. For existing buildings, the existing emergency plan may need to be modified to reflect the assumptions and recommendations of the fire engineering study. Again, this should be carried out by, or receive input from, the FE.

Comment: Evacuation procedures

Documented evacuation procedures may include:

- recommended procedures for the controlled evacuation of buildings, structures and workplaces during emergencies
- guidelines on the appointment of an emergency planning committee and an emergency control organisation
- setting up of an emergency control organisation, the preparation of emergency plans and procedures
- the role and authority of emergency control organisation personnel while executing their duties
- an education and training program.

During commissioning, the physical provisions, emergency organisational structure, and emergency procedures need to be critically assessed – a cause/consequence analysis may be appropriate. This may result in some refinements to the organisation and procedures to better reflect the building as constructed.

Once a structure and procedures have been adopted, building management is responsible for establishing the emergency planning committee, emergency control organisation, appointments, education and training programs, and testing procedures. Building management is also responsible for reviewing and amending organisations and procedures as necessary.

Maintenance is another building management responsibility. It includes:

- Maintenance of the physical measures. The building management should ensure, through regular checks, that egress paths are kept clear of any obstructions, all doors operate as required, and all signage is in good condition.
- Maintenance of the emergency organisation and procedures. Building management should ensure that the organisation meets at appropriate times; training sessions are carried out; evacuation exercises are carried out;

emergency procedures are reviewed, tested and updated; all trained personnel positions are filled; and records are kept.

It may be possible to ensure that these measures are maintained through the essential safety provisions for buildings that may apply in some jurisdictions.

A.6 Fire services intervention – SS-F

SS-F is used to analyse the effects of the intervention activities of fire services on a fire. This process enables estimates of various events that comprise the intervention as well as the effectiveness of suppression activities.

This sub-system includes public and private fire services such as those that might belong to an industrial complex.

In many fire engineering evaluations, the effect of fire services intervention on the fire is not taken into account, the building fire safety system is evaluated on the basis of the other five sub-systems. The fire brigade intervention strategy is to be developed in consultation with the fire brigade during the PBDB process, and may need to be validated using the FBIM. The analysis of the evacuation of occupants to a place of safety should not rely on fire services intervention.

However, this does not mean that the fire engineering evaluation should discount the needs of fire services carrying out their intervention activities. This appendix provides guidance on quantifying the time of:

- the arrival of the fire services at the fire scene
- investigation by the fire services
- fire services set up
- search and rescue
- fire services attack
- fire control
- fire extinguishment.

Relevant aspects of the fire safety strategy, including elements such as the RSET and the ASET for particular fire scenarios may be represented with the FBIM to articulate the overall fire safety strategy with the fire brigade intervention strategy and therefore facilitate stakeholder conversation during the PBDB stage. This may be illustrated using Gantt Charts or the like.

This appendix also discusses the relationships between this sub-system and others.

This appendix provides guidance on the analysis of SS-F in the general analysis context discussed in 2.3. However, each project needs to be considered individually and the analysis varied accordingly. In some cases, environmental and other issues may be of concern, and these would need to be taken into account in analysing the activities of the fire services. It should be noted that this sub-system may vary over the life of the building due to changes in fire service location, budgets, equipment, and changes in traffic density.

A.6.1 Fire Brigade Intervention Model (FBIM)

The objectives of the NCC require, amongst other things, that the design allows for fire service intervention. AFAC has developed a universal model that quantifies the time taken by a fire service to undertake its activities. The FBIM is an event-based methodology that encapsulates standard fire service activities from time of notification to control and extinguishment.

The FBIM employs a structured decision-based framework necessary to both determine and measure fire service activities on a time-line basis. The model interacts with the outputs of Sub-systems A to E as needed for analysis and is applicable to most fire scenarios. It will be necessary to utilise the expertise of the local fire service to validate many of the decision-based input parameters used. The FBIM is pertinent to most service types, crew sizes and resource limitations.

To support fire brigade intervention activities, adequate fire fighting facilities must be provided (for example, adequate vehicular access and firefighting water supply) as determined by the interaction of Sub-systems A to F.

Fire services commonly have a responsibility to conduct activities relating to:

- search and rescue of building occupants
- fire containment
- fire extinguishment
- protection of property from damage due to fire and its products
- protection of the environment and the community from the products of fire and dangerous substances, including the effects of fire service intervention (for example, fire fighting water run off from a chemical warehouse into the environment)
- minimising business interruption and adverse affects on the community.

The FBIM relies on the systematic utilisation of up to 16 modules (flow-charts) to calculate the total time required for the fire service to undertake its activities. Each module represents a distinct component of fire service intervention. Many fire service actions are undertaken concurrently and the total time to complete fire service intervention is not necessarily the successive addition of individual task activity times. Each fire safety analysis will individually determine how many flow charts are required to quantify the necessary fire service actions.

A.6.1.1 The basic FBIM strategy

The FBIM analysis initially requires an output from Sub-system A. The elapsed time from start of fire until the fire service is notified. A typical calculation would include the time taken for a smoke detector to operate plus any delay associated with an alarm verification process or third party monitoring the fire alarm system.

The fire service will then usually dispatch a predetermined number of fire fighters and vehicles to the fire location. Dispatch times, travel times and initial set up time 'kerb-side' (e.g. donning breathing apparatus and gathering basic safety equipment) can be calculated using the FBIM.

At this time, the conditions at the fire scene (provided by Sub-systems A, B, C & D) will determine the appropriate fire service action (e.g. enter a building to check for trapped occupants or determine the need for more fire service resources at the scene).

A common fire service tactic is for some firefighters to enter the building, locate and assess the severity of the fire at the same time as other firefighters are deployed to check for trapped occupants in areas close to the fire. The FBIM calculates the time taken for these activities. The possibility of successfully completing these actions will be determined principally by conditions inside the building as predicted by Sub-systems A, B, C and D. These systems will need to be interrogated regularly to check their impact on the FBIM time line.

Fire containment or suppression activities may then be attempted to provide additional time for other firefighters to conduct an interior search of the rest of the building. If adequate facilities are provided, suppression activities will significantly modify the output of Sub-system A and have flow-on effects to the other sub-systems.

For a growing fire, the effectiveness of the intervention strategy will depend principally on the fire growth rate, tenability and the rate of fire services resources building up at the fire scene. The number of fire fighters, type of fire appliance and distance of travel will all influence the effectiveness of operations at the fire scene. Fire service equipment and procedures vary and discussion with individual fire services will be necessary to obtain correct information.

If there is insufficient water supply or an insufficient number of fire fighters at the fire scene to handle interior fire fighting needs, the strategy may change from offensive (fight the fire) to defensive (stop fire spread to adjoining buildings/compartments).

A.6.1.2 FBIM application

The FBIM can be used as a whole or in part to enable and drive stakeholder discussion at PBDB stage. It may be used to generate information with respect to aspects such as the following:

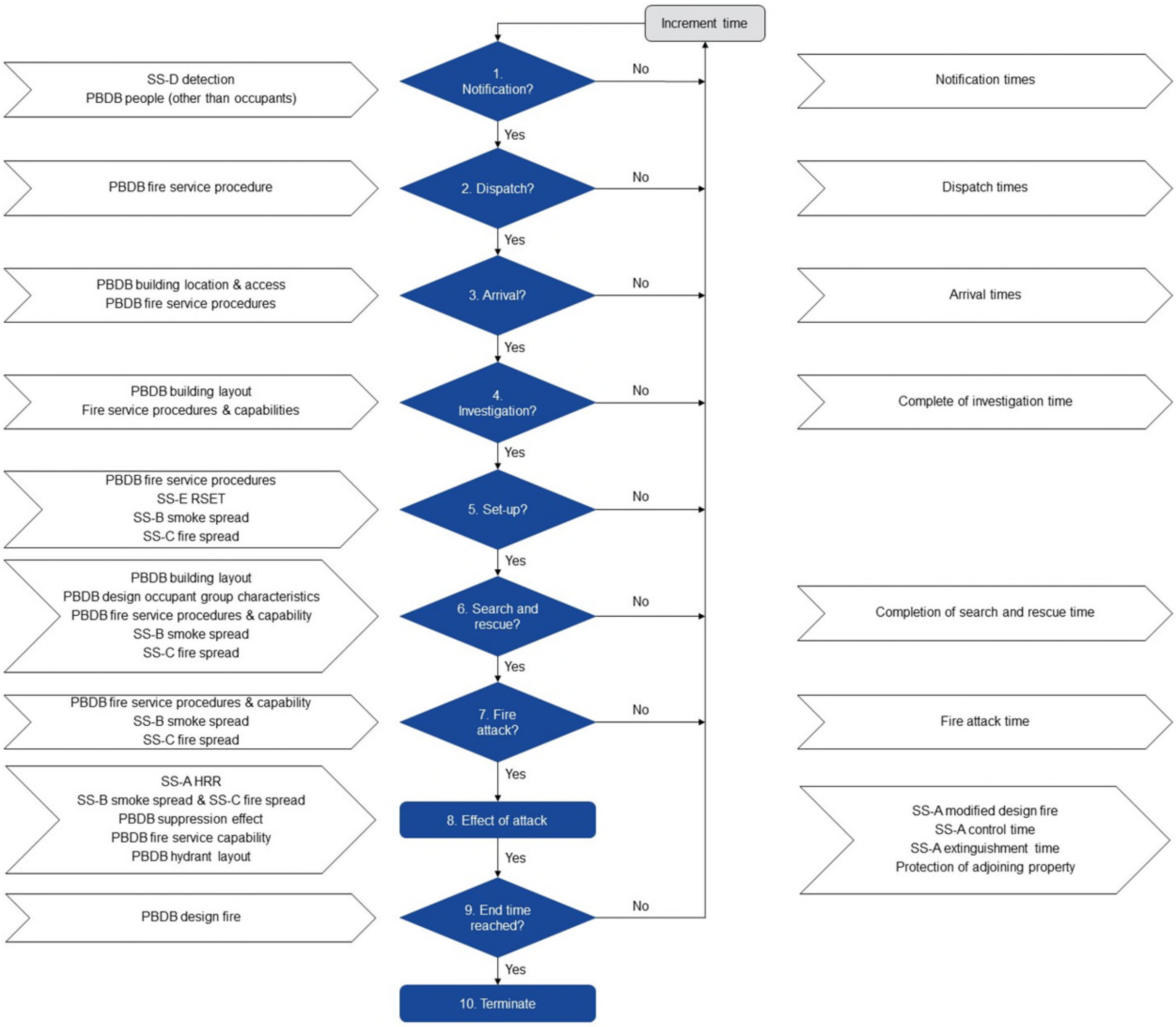
- the time taken for fire service personnel to reach a particular location in a building
- the required water flow rate and building separation necessary to prevent fire spread to adjoining property
- the time fire service personnel will be inside a building for search and rescue activities during which fire fighter tenability and structural stability should be maintained
- the robustness of a fire-engineered solution

Refer to the FBIM Manual for a complete description on how to use the FBIM.

A.6.2 Procedure – SS-F

Figure A.6.1 illustrates a procedure for analysing fire services intervention. It should be noted that the FBIM Manual should also be consulted in undertaking the analysis.

Figure A.6.1 Flow chart for fire services intervention analysis



Discussion of the figure can be found in the following sections:

- Section A.6.3 Outputs
- Section A.6.4 Inputs
- Section A.6.5 Analysis.

An analysis needs to be undertaken for each design fire specified by the PBDB.

Where the PBDB requires an analysis that includes consideration of the probabilities of various events and scenarios occurring, the flow chart can assist the FE in identifying the factors to take into account during this analysis.

The flow chart provides guidance but does not necessarily cover all the factors which may be relevant to a particular fire engineering analysis.

A.6.3 Outputs – SS-F

Outputs from an analysis of fire services intervention include a number of operational times, as well as times for fire control and extinguishment. Only some of these times may be relevant outputs for a particular fire engineering evaluation. Both RSET and ASET may be included on this timeframe.

The outputs of the fire services intervention analysis are set out below:

- **Notification time.** The time at which the fire service becomes aware of an alarm. In the case of automatic detection equipment, this will generally be the warning time calculated in SS-D. In the case of alarms raised by people, this may occur at a later time.
- **Dispatch time**. The time from notification of alarm until the fire service vehicles leave the fire station. This may vary with fire service type. For example, a fire station with full time paid fire fighters is likely to respond faster than one operated by volunteers. The dispatch system used (for example, radio, phone, automatic or manual) will also affect dispatch time.
- **Arrival time**. The time when the fire service reaches the site.
- **Time to complete investigations**. This will include location of the fire – determined using information from installed fire safety equipment, occupants, and observations of smoke and flames.
- **Time to set up**. Vehicles, hoses and other equipment may need to be moved into position in order to set up search, rescue and fire intervention activities. This activity may be affected by fire-induced environmental conditions in (or adjacent to) the building.
- **Time to complete search and rescue.** The time taken to search, assist evacuation (if necessary) and rescue any people injured and having difficulty evacuating. This activity may be affected by fire-induced environmental conditions in the building and the physiological demands of the activities.
- **Time for other property protection.** These modules consider the impact of the fire in the burning building upon other buildings. Activities include the time to mobilise and set up necessary resources (e.g. aerial or pump appliance, hand-held hose streams) or to undertake salvage operations to minimise damage.
- **Time of fire attack**. The time at which the fire service commences suppression activities. The attack may be the application of water on a fire (an offensive strategy), the operation of hose streams to protect adjoining property (a defensive strategy), or both. This activity may be affected by fire induced environmental conditions in or adjacent to the building. The time of fire attack provides input to SS-A.

- **Modified HRR versus time.** This reflects the effect of suppression that provides input to SS-A. It is generally categorised as:
    - no effect
    - control
    - extinguishment.
- **Time to control.** If the effect of suppression is only to 'control' the fire, the time to control may be taken as the time to commencement of suppression (used in SS-A). If control of the fire is beyond the capability of the available fire service resources, prevention of fire extension to other properties may be achieved, but this will have no impact on SS-A.
- **Time to extinguishment**. If the effect of suppression is 'extinguishment', the time at which the fire is finally extinguished may be determined as an input to SS-A.
- **Time for environment protection**. Environmental impact is an issue of importance to fire brigades and industry. Where protection of the environment is within the design brief this needs to be considered.

The outputs time to control, modified HRR, and time to extinguishment may also be calculated during the analysis of SS-D. Therefore, a choice needs to be made as to which sub-system will include this part of the analysis of fire services intervention.

A.6.4 Inputs – SS-F

The required input parameters to SS-F are determined by the analysis methods used. They may include:

- **Building characteristics.** The following parameters are usually relevant and should be available from the PBDB:
    - location and access affects the time to arrive from a fire station
    - type and use affects the investigation, search and rescue as well as fire suppression activities
    - size, layout and signage affects the investigation, search, rescue and fire fighting
    - location of hydrants, fire indicator panels and other fire service facilities (which affects the efficiency of fire suppression activities).
- **Fire service operational procedures and capability.** Much of the input information is related to the level of fire service cover and operational practices. It is important at the PBDB stage that fire services intervention is considered and the strategy is discussed with the relevant fire service. . The principal factors that govern the capability of fire services may include:

- the number and location of fire stations with respect to the building under consideration
- the resources contained within those fire stations
- the time required to dispatch the resources from the fire stations
- the resources available at the fire scene (installed systems and amount of available fire fighting water)
- the fire ground conditions (e.g. air temperature, humidity, radiant heat)
- fire services crew equipment (e.g. protective clothing, breathing apparatus).

- **Detection time.** Fire engineers should take into account the time at which the alarm call is received at the fire station. Detection may be by an automatic fire alarm system or by a person. Data may be obtained from SS-D.
- **RSET.** The calculations of RSET from SS-E may indicate that occupant evacuation is complete before fire services' arrival. This information may be included in the FBIM overlapping the Fire Brigade Intervention Gantt Chart to enable discussion with the fire brigade during the PBDB stage However, in practice, the fire service may undertake a search for any trapped or injured occupants.
- **HRR.** The effectiveness of fire suppression by the fire service will be dependent on the HRR at the time of attack. Data on HRR as a function of time is provided by SS-A.
- **Effectiveness of attack.** This will be decided in the PBDB process in one of three forms for the subject building or prevention of spread with respect to an adjoining property**.** These forms are:
    - no effect
    - control
    - extinguishment.

A.6.5 Analysis – SS-F

Fire services intervention can be quantified using an evaluation of the necessary operational actions, based upon the predicted impact of the fire and supported by numerical data on the time taken for such actions. The FBIM should be used to assist with the analysis.

The process of analysis is shown in Figure A.6.1. It should be noted that some steps, e.g. Steps 4, 5, 6 and 7, may occur concurrently and result in the fire attack occurring earlier. However, a conservative approach would consider each step sequentially. Further guidance is given in the FBIM manual.

Step 1

Determine the time of notification of the fire service. The notification time is based on time of detection obtained from SS-D with additional time, where appropriate, for any delays (e.g. due to call handling, verification of calls).

Step 2

Determine time of dispatch.

Step 3

Determine the time of arrival.

Step 4

Determine the time at which investigation of the situation has been completed and sufficient information gathered to commence set up, search and rescue and fire attack.

Step 5

Determine the time at which set up of the fire service equipment is completed for fire attack and search and rescue. This activity may be affected by fire induced environmental conditions in or adjacent to the building.

Step 6

Determine the time at which search and rescue activities have been completed if they have been undertaken. These activities may include assisting in an evacuation process that has already commenced.

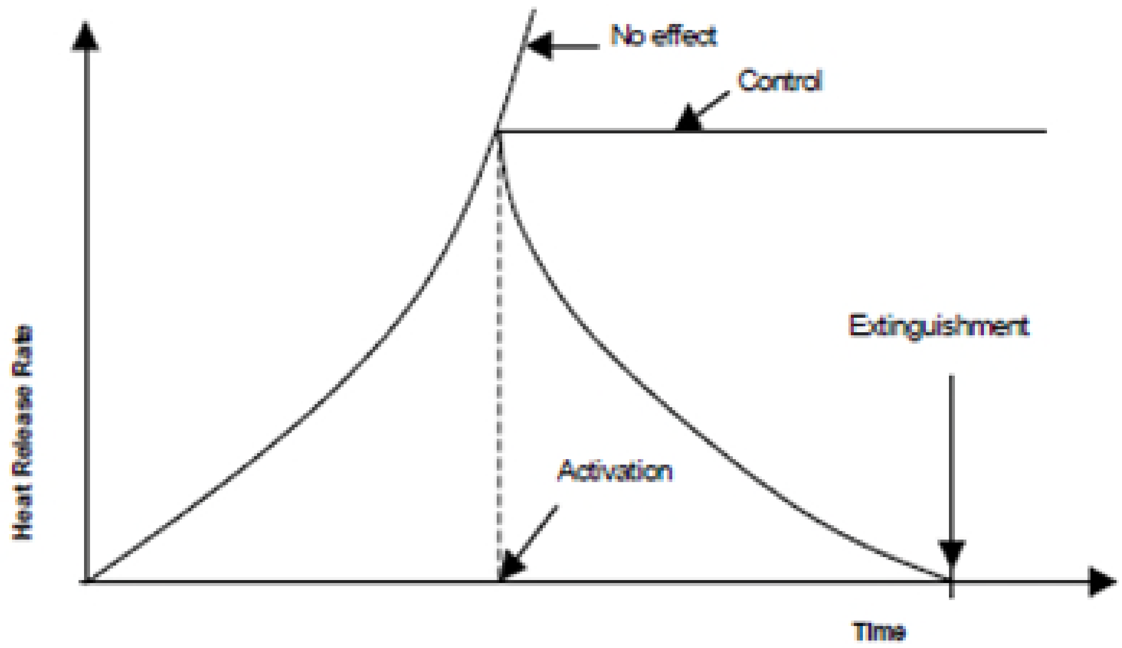
Step 7

Determine time of commencement of fire attack by the fire service on the subject and adjoining property if a fire attack is undertaken.

Step 8

Determine the effect of the fire service suppression activities on the design fire (from SS-A) or in preventing fire spread to adjoining property.

Figure A.6.2 Possible effects of suppression on a design fire



The effect of the suppression activities can be expressed, as illustrated in Figure A.6.2, as one of three possible outcomes.

- **No effect**. This is based on the fact that the fire service may arrive after the fire has passed its growth stage – and the difficulty in extinguishing a fire that has developed beyond flashover in the enclosure of origin.
- **Control.** This outcome is represented by a steady HRR from the time at which the attack begins. It is assumed that the control situation represents the extent of the fire service capability and that extinguishment is only achieved when all the fuel is consumed. This is a conservative assumption in a fire engineering analysis and is often used when access to the fire is limited.
- **Extinguishment.** In addition to the time of extinguishment, the rate at which the fire decays can be calculated. Sometimes, arbitrarily, the decay phase is assumed to be a mirror image of the growth phase.

Step 9

Determine if the end time has been reached. This may be considered to occur if sufficient analysis has been carried out to justify the trial design under consideration occur when :

If the end time has not been reached, the next iteration is undertaken and the analysis continued until the end time has been reached.

Step 10

The analysis of SS-F is terminated.

A.6.6 Construction, commissioning, management, use and maintenance – SS-F

There are some construction, commissioning, management, use and maintenance requirements directly related to fire services intervention. In particular, the design and maintenance of the following items is needed to facilitate effective fire services intervention:

- the perimeter roads for fire service access
- the egress and access paths and elevators that the fire service would use during intervention
- the fire protection measures that provide a safe environment for the fire service during intervention (e.g. structural stability, sprinklers, smoke management, emergency warning and intercommunications)
- all equipment that the fire service uses during intervention (e.g. hydrants).

It may be possible to ensure that the required maintenance is done through the essential safety provisions that may apply in some jurisdictions.