International Fire Engineering Guidelines

Edition 2005

INTERNATIONAL CODE COUNCIL®

NRC · CNRC

Department of Building and Housing
Te Tari Kaupapa Whare

ABCB

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International Fire Engineering

Guidelines

Edition 2005

This document has been produced through a collaborative venture between the following organizations (the collaborators):

- National Research Council of Canada (NRC)
- International Code Council (ICC), United States of America
- Department of Building and Housing, New Zealand (DBH)
- Australian Building Codes Board (ABCB)

The following organizations endorse the Australian parts of this document as describing an appropriate process for design and approval of fire safety in buildings by competent practitioners:

- The Australian members of the Australasian Fire Authorities Council (AFAC)
- Australian Institute of Building Surveyors (AIBS)
- The Institution of Engineers Australia (IEAust) Society of Fire Safety

The Insurance Council of Australia (ICA) supports the aims of this document.

The following organizations endorse the New Zealand parts of this document as describing an appropriate process for design and approval of fire safety in buildings by competent practitioners:

- The Institution of Professional Engineers New Zealand Inc (IPENZ)
- The New Zealand Fire Service (NZFS)

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The collaborators welcome any comments to assist the future development of this document. Please e-mail your comments to abcb.office@abcb.gov.au

Foreword

In November 2001 the ABCB published the Fire Safety Engineering Guidelines. These guidelines were primarily developed for use in Australia. Through the relationships developed within the Inter-jurisdictional Regulatory Collaboration Council (IRCC), the ABCB, together with the National Research Council of Canada (NRC), the International Code Council (ICC), United States of America and the Department of Building and Housing, New Zealand (DBH), decided to undertake a collaborative project to convert the Fire Safety Engineering Guidelines into an International Guideline for use within Australia, Canada, United States of America and New Zealand.

The International Fire Engineering Guidelines (IFEG) have been developed to meet the joint needs of the NRC, ICC, DBH and ABCB; they reference both nationally and internationally available standards, guides and associated documents, and use both imperial and SI units throughout.

The IFEG has been made suitable for use in Australia, Canada, USA and New Zealand through development of a separate Part 0 of the guideline for each collaborative country. Each Part 0 provides an insight to the issues that go beyond actual engineering, and provides a perspective on the role of the engineering within the regulatory and non-regulatory systems for the particular country. This portion of the guideline is intended to link engineering practice with the legal and regulatory system of choice. Parts 1, 2 and 3 contain information on the process, methodologies and data for fire engineering, and are applicable in Australia, Canada, USA and New Zealand.

Collaboration has allowed resources to be pooled so the amount of resources provided by each collaborator was only a percentage of what would have been required if the IFEG were developed by a single body. The project will act as a catalyst for future development on projects of mutual interest.

The IFEG have been developed for use in the fire safety design of buildings. They will also be of use for Authorities Having Jurisdiction (AHJ) in carrying out their role of approving building designs and are intended for use by competent practitioners.

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March 2005

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In particular the collaborators would like to thank the following:

- Members of the international editorial committee: - Beth Tubbs (ICC), Russ Thomas (NRC), Alan Moule (DBH), Brian Ashe (ABCB), Igor Oleszkiewicz (NRC), Noureddine Benichou (NRC)
- International editors: - Peter Johnson (Arup), Jim Mehaffey (Forintek), John Klote (John H. Klote inc.), Colleen Wade (BRANZ), George Hadjisophodeous (Carleton University), Jim Shields (University of Ulster), Paula Beever (New Zealand Fire Service), and Vytenis Baubrauskas (Fire Science and Technology Inc.)

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Table of Contents

These Guidelines comprise four parts, each of which is a separate entity. Part 0 is provided for each country. For a detailed table of contents, refer to the beginning of each part and each chapter.

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Part 0 - Australia
Introduction

International
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Table of Contents

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Chapter 0.1

Introducing these Guidelines

These Guidelines have four parts, each with its own table of contents, which have been designed for ease of use and cross-referencing with graphics as outlined below:

- **graphic identification** of sub-systems, as explained in Part 1
- **shaded boxes** containing examples or commentary
- **abbreviated flow charts** in the margins, with the relevant boxes shaded

This Part 0 provides background information and guidance that is integral to an understanding of the entire Guidelines within an Australian context.

Part 1 describes the process by which fire engineering is typically undertaken.

Part 2 describes a selection of methodologies that may be used in undertaking the fire engineering process.

Part 3 provides a selection of data that may be used in applying the methodologies of Part 2 or other chosen methodologies.

The Guidelines are paginated on a chapter basis in order to facilitate revision by replacement of individual chapters. It is envisaged that Part 0 and Part 1 will require less frequent revision than Part 2 and Part 3.

0.1.1 Evolution

The International Fire Engineering Guidelines (IFEG) represents the third edition of the guidelines and supersedes both the first and second editions published in 1996 and 2001 respectively. The 1996 and 2001 editions are therefore no longer current and should not be used or referred to.

The objectives of the Guidelines are to:

- provide a link between the regulatory system and fire engineering (Part 0);
- provide guidance for the process of fire engineering (Part 1); and
- provide guidance on available methodologies (Part 2) and data (Part 3).

This document has been written in the form of guidelines rather than in a mandatory or code format to reflect the current state of the art of fire engineering. The use of a mandatory format was discussed at length before the development of both the first and second editions (see below) of these Guidelines. It was concluded that fire engineering lacks the necessary array of validated tools and data to produce such a mandatory document.

Fire engineering designs are complex and generally require the extensive use of engineering judgement. In addition, those required to approve the output of fire engineering designs need an understanding of the fire engineering process and what constitutes an acceptable fire engineering design. Therefore, guidance is required both to improve the standard of application of fire engineering by practitioners and to improve the ability of the Authority Having Jurisdiction (AHJ) to carry out their function of safeguarding the community.

The following changes to the second edition have been incorporated into the IFEG:

- the concept and use of Evaluation Extent has been deleted and some consequential changes made to the steps of the Fire Engineering Brief (FEB) described in Chapter 1.2 of the IFEG
- dual units and conversion factors have been adopted in order to facilitate the international use of the document
- Part 3 has been re-organised to minimise repetition
- many of the commentary boxes have been eliminated in order to improve the compatibility of the document with overseas practice
- additional methodologies and data have been incorporated into Parts 2 and 3 respectively.

It should be noted that, in the preparation of the second (2001) edition of the Guidelines (Fire Safety Engineering Guidelines), the major changes included the incorporation of virtually all of the material of the first edition (Fire Engineering Guidelines) into four parts. These four parts are maintained in this edition. Another major change was the deletion of the methodology for occupant evacuation which formed the basis of Chapter 12 in the first edition. This methodology was deleted because it was considered invalid and it is not in any way endorsed. Valid methodologies are referenced in Chapter 2.8 of these international (third edition) Guidelines.

These Guidelines embrace worldwide best practise and draw upon previous work and parallel work from many groups around the world. The documents considered include:

- Fire Safety Engineering Guidelines (FSEG), Edition 2001, November 2001, Australian Building Codes Board, Canberra, Australia.
- Fire Engineering Guidelines ('FEG'), first edition, March 1996. Fire Code Reform Centre Ltd Australia (March 1996).
- Building Code of Australia 2005 — Volume 1', Class 2 to Class 9 Buildings, Australian Building Codes Board, Canberra, Australia.
- Fire Engineering Design Guide, 2nd Edition, University of Canterbury, Christchurch, New Zealand (2001).
- CIBSE Guide E, Fire Engineering, Chartered Institute of Building Services Engineers, UK (February 1997).
- International Organisation for Standardization, Fire Safety Engineering ISO/TR 13387: 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

- Fire Safety Engineering in Buildings – Code of Practice, British Standard BS7974 (2001).
- The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers, Bethesda, MD. USA (2000).

0.1.2 Scope

These Guidelines have been developed for use in the fire engineering design and approval of buildings. However, the concepts and principles may also be of assistance in the fire engineering design and approval of other structures such as ships and tunnels which comprise of enclosed spaces.

This document provides guidance to the fire engineering fraternity in their work to design fire safety systems to achieve acceptable levels of safety. The Guidelines presuppose that the fire engineer has a level of competence and experience that would enable accreditation by an appropriate body.

In particular, the Guidelines provide guidance for the design of Alternative Solutions for the Building Code of Australia (BCA).

Fire engineers need to interpret the guidance given in these Guidelines with flexibility and use it as a tool for responsible fire engineering. The role played by fire engineering in building fire safety and the term 'fire engineer' are discussed in Chapters 0.3 and 0.4 respectively.

These Guidelines will also be of use to other people and organisations, such as the AHJ and fire services, in carrying out their roles of assessing and/or approving Alternative Solutions for the BCA. They may form the basis of checklists commonly used as an aid for such activities but such lists should allow for the flexibility that these Guidelines allow. They may also assist AHJ's and others in assessing the adequacy of fire safety in existing buildings and if necessary, devising an upgrade strategy.

Fire engineering is developing with a large degree of international cooperation. Parts 1, 2 and 3 of these Guidelines are written to have global applicability, whereas Part 0 only applies in Australia.

0.1.3 Limitations

These Guidelines are not intended to:

- apply to those situations where a person is involved, either accidentally or intentionally, with the fire ignition or early stages of development of a fire, where building fire safety systems are not generally designed to protect such persons;
- encompass situations that involve fire hazards outside the range normally encountered in buildings, such as storage of flammable liquids, processing of industrial chemicals or handling of explosive materials;
- be a form of 'recipe book' to enable inexperienced or unqualified people to undertake work that should be done by fire engineers; or
- replace available textbooks, examples of which are given in Section 0.5.3.

The tools and information available to the fire engineer on the fire performance of dangerous goods and hazardous materials is limited. Therefore fire engineers generally do not have the specialised knowledge and competencies to practise in this area. For these situations applicable State and Territory legislation (including State appendices to the BCA) for the storage and handling of hazardous and dangerous goods and appropriate specialist practitioners should be consulted.

The goal of 'absolute' or '100%' safety is not attainable and there will always be a finite risk of injury, death or property damage. Some of the guidance in these Guidelines relates to the evaluation of such risks and the qualitative and quantitative methodologies available.

Furthermore, fire and its consequent effects on people and property are both complex and variable. Thus, a fire safety system may not effectively cope with all possible scenarios and this needs to be understood by the designers, owners, occupiers, contractors, AHJs and others in their assessment of fire engineered solutions.

Chapter 0.2

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, such building codes have been prescriptive, however, such codes cannot cover emerging technologies and every combination of circumstances. Thus, prescriptive regulations have provided constraints to design that are not always appropriate to the specific building being considered.

In order to free designers from such constraints, increase innovation and facilitate trade, building codes have become performance-based. The Building Code of Australia (BCA) is a performance-based code.

0.2.1 The regulatory framework

The Australian regulatory system adopts the following generalised framework:

- **A law** that sets the administrative framework for the control system, and gives the government the authority to issue detailed regulations.
- **Regulations** that set out detailed requirements and procedural matters for assessments, approvals, inspections, certification, appeals, penalties and accrediting bodies and permit the government to include conditions on building developments. The regulations or the law give authority for the use of the building code.
- **A building code** that sets detailed technical requirements including referenced Standards.
- **Other** regulatory documents and publications.

This framework is realised as follows:

- **The Australian Constitution** enables the States and Territory Governments to legislate for building developments.
- **Development/Building Acts** administered by the State or Territory Governments, to control building development.
- **Building regulations,** given status by the development/building Acts, regulate building work.
- **The Building Code of Australia** provides the technical content for the building regulations.
- **Other legislation** which may include other acts, regulations, and standards.

0.2.2 The Building Code of Australia

One of the goals of the BCA is the achievement and maintenance of acceptable standards of safety from fire for the benefit of the community. This goal extends no further than is necessary in the public interest, is considered to be cost effective and not needlessly onerous in its application.

The BCA has multiple levels within its hierarchy, as shown in Figure 0.2.2.

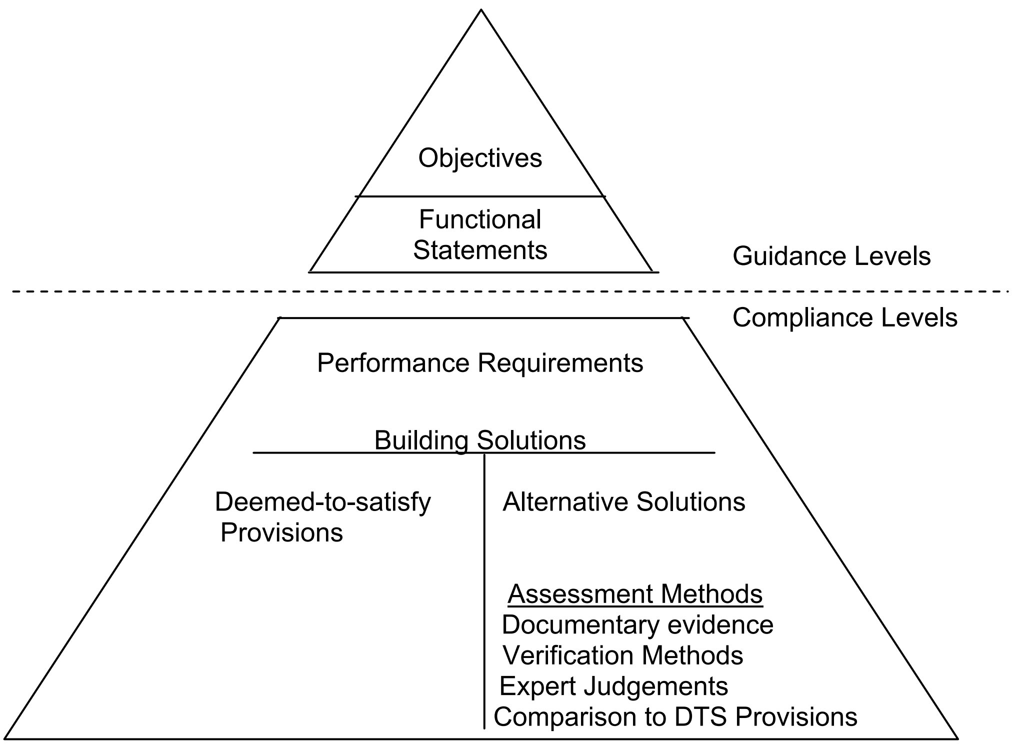


Figure 0.2.2 The BCA hierarchy

The BCA **Objectives** set out in general terms what the community expects from a building. These are often expressed in a 'community aspiration' style that cannot be quantified. **Functional Statements** set out, in general terms, how a building could be expected to satisfy the relevant objectives. Objectives and functional statements are provided as guidance on how to interpret the content and intent of the Performance Requirements and the Deemed-to-Satisfy Provisions (DTS).

In order to receive regulatory approval, a design has to meet all the relevant **Performance Requirements**. Performance Requirements are more specific than Objectives, but are not quantified.
A design that complies with the Performance Requirements is referred to as a Building Solution. A Building Solution complies with the Performance Requirements and may be:

- a design that complies with the **Deemed-to-Satisfy Provisions**
- an **Alternative Solution**
- a combination of both.

Where a design complies with all the relevant Deemed-to-Satisfy Provisions, the design is deemed to satisfy the corresponding Performance Requirements.

An Alternative Solution is a design that is not a prescribed Deemed-to-Satisfy Provision but when analysed can be shown to comply with the relevant Performance Requirements. When varying a Deemed-to-Satisfy provision, relevant Performance Requirements must be considered. Part A0.10 of the BCA provides direction on this matter.

The assessment of an Alternative Solution can be undertaken by one of the following **Assessment Methods** contained within Part A0.9 of the BCA or a combination of these methods:

- acceptable documentary evidence: see Clause A2.2 of BCA
- verification in accordance with a method given in the BCA or as appropriate
- comparison to the Deemed-to-Satisfy Provisions
- expert judgement.

Where fire safety matters are being considered, fire engineering techniques are generally used as part of such assessments.

0.2.3 Performance Requirements

0.2.3.1 Non-quantification of risk

As discussed above, the fire related Performance Requirements of the BCA set out to 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 and the benchmark risk needs to take into account what the community expects and the cost to the community, which may be determined by a cost benefit analysis. Such cost benefit analyses may be necessary for new requirements that might be introduced into the BCA.

The level of safety provided by the BCA is not explicitly stated and this leads to difficulties in the interpretation of the Performance Requirements (which are not 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. This variation can be minimised by the involvement of all stakeholders in the setting of the acceptance criteria that will also form an important part of the fire engineering brief described in Part 1.

The BCA Performance Requirements provide the means by which fires in buildings may be managed to an acceptable degree but the BCA does not quantify the fires which are assumed to occur, although these implicitly vary according to the class of building occupancy and building characteristics. 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 quantification 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 if the process detailed in these Guidelines in Section 1.2.11 is used and there is involvement of other stakeholders as described in the fire engineering brief process (Chapter 1.2). The BCA is silent on the matter of fires set with malicious intent (arson and terrorist activities). The process described in Section 1.2.11 to develop design fires on the basis of a consideration of all potential fire scenarios encompasses such fires. Practice Note 2 of the Engineers Australia Society of Fire Safety Code of Practice provides guidance on this matter (www.sfs.au.com).

In addition to the Performance Requirements not being quantified, they use terminology such as "to the degree necessary" and "appropriate to". The example given in Section 0.2.3.2 below reproduces the Performance Requirements CP2, CP8, DP5 and EP2.2 and show the many factors for which these terms are used in defining a Performance Requirement. The interpretation of the terms "to the degree necessary" and "appropriate to" for any one factor will vary according to the project being designed and subsequently analysed. This adds to the difficulty of setting the acceptance criteria. It is suggested that this issue can be addressed in a similar way to that described above using the fire engineering brief process.

Because of the uncertainties arising from this lack of quantification of Performance Requirements and the deficiencies in the methods and data available to determine whether the acceptance criteria have been met, it is recommended that redundancies be included in a building fire safety system (see discussion of Trial Designs in Part 1). Such redundancies can be used to compensate for these uncertainties and deficiencies and these Guidelines recommend that redundancy be examined in the context of sensitivity studies (see Section 1.2.9.5).

0.2.3.2 Relationship with DTS

Where a building does not meet particular Deemed-to-Satisfy (DTS) Provisions and an Alternative Solution is to be considered, the relevant Performance Requirement(s) need to be determined (see Section 1.2.8). Reference to A0.10 of the BCA is recommended.

In the design of an Alternative Solution, designers must carefully consider the relationship between the Deemed-to-Satisfy Provision and Performance Requirements. This will often require input from other stakeholders, such as the AHJ and others conversant with the practical application of the BCA. This input is greatly facilitated by the fire engineering brief process and it is therefore recommended that particular attention be paid to this area.

Two issues are discussed below:

- interrelationship of Performance Requirements
- DTS Provisions which do not meet the corresponding Performance Requirements.

Just as the DTS Provisions of the BCA 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 two or more Performance Requirements needing to be addressed. An Alternative Solution or design which deviates from the DTS may relate to more than one section of the BCA. However, the analysis strategy for the fire engineering design would need to satisfy both Performance Requirements. An example is discussed in the shaded box below.

Example: Relationship between a design feature, DTS Provisions and Performance Requirements.

If a window is included in the wall of an apartment abutting an internal stairway serving as an egress route in a multi storey residential building of Type A construction, DTS Specification C1.1, Table 3 and Clause D1.3 will not be complied with as the wall will not have the required fire rating.

To determine if the proposal satisfies the relevant Performance Requirements, the relevant Performance Requirements must firstly be identified. For the example, the relevant Performance Requirements could include the following:

"CP2 (a) A building must have elements which will, to the degree necessary, avoid the spread of fire-
(i) to *exits*; and
(ii) to *sole-occupancy units* and *public corridors*; and
(iii) between buildings; and
(iv) in a building
(b) Avoidance of the spread of fire referred to in (a) must be appropriate to-
(i) the function or use of the building; and
(ii) the *fire load*; and
(iii) the potential *fire intensity*; and
(iv) the *fire hazard*; and
(v) the number of *storeys* in the building; and
(vi) its proximity to *other property;* and
(vii) any active *fire safety systems* installed in the building; and
(viii) the size of any *fire compartment*; and
(ix) *fire brigade* intervention; and
(x) other elements they support; and
(xi) the *evacuation time*."

"CP8 Any building element provided to resist the spread of fire must be protected to the degree necessary, so that an adequate level of performance is maintained-
(a) where openings, construction joints and the like occur; and
(b) where penetrations occur for building services."

"DP5 To protect evacuating occupants from a fire in the building *exits* must be fire isolated, to the degree necessary, appropriate to-
(a) the number of *storeys* connected by the *exits*; and
(b) the *fire safety system* installed in the building; and
(c) the function or use of the building; and
(d) the number of storeys passed through by the *exits*; and
(e) *fire brigade* intervention."

"EP2.2 (a) In the event of a fire in a building the conditions in any evacuation route must be maintained for the period of time occupants take to evacuate the part of the building so that-
(i) the temperature will not endanger human life; and
(ii) the level of visibility will enable the evacuation route to be determined; and
(iii) the level of toxicity will not endanger human life.
(b) The period of time occupants take to evacuate referred to in (a) must be appropriate to-
(i) the number, mobility and other characteristics of the occupants; and
(ii) the function or use of the building; and
(iii) the travel distance and other characteristics of the building; and
(iv) the fire load; and
(v) the potential fire intensity; and
(vi) the fire hazard; and
(vii) any active fire safety systems installed in the building; and
(viii) fire brigade intervention."

The example focuses on the fire requirements. Other areas such as sound transmission/insulation would also need to be addressed in the process.

0.2.4 The approval process

The approval process and the documentation required for Alternative Solutions vary from jurisdiction to jurisdiction in Australia. This is because the BCA is given legal effect by regulatory legislation in each State and Territory (see Section 0.2.1 above). **Therefore, only general guidance is given in these Guidelines. The requirements of each State and Territory should be consulted.**

The BCA section on "Documentation of Decisions" in the introductory material says that "Decisions made under the BCA should be fully documented and that copies of all relevant documentation should be retained". In this context, an Alternative Solution and / or fire engineering report prepared according to these Guidelines (see Chapter 1.11) would be appropriate.

The roles and responsibilities of the AHJ and the fire engineer in the approval process may vary for each State and Territory. The following discussion gives general guidance on their roles from the point of view of the fire engineering design and approval of Alternative Solutions in order to facilitate appropriate and consistent outcomes.

The AHJ would generally:

- be responsible for the approval of designs (utilising the appropriate assessment method (see 0.2.2)
- identify the deviations from the DTS Provisions
- confirm the Performance Requirements applicable to the Alternative Solution
- provide regulatory advice during the fire engineering brief process (see comments below with reference to independence)
- carry out the appropriate regulatory functions
- nominate the elements of the design that will be subject to ongoing maintenance and the standards or performance to which they should be maintained; they may rely on information from the fire engineer to fulfil these functions
- if necessary (see Section 0.3.4), seek appropriate third party review of Alternative Solutions
- ensure the retention of all relevant documentation for Alternative Solutions.

In carrying out the above, it is essential for the AHJ to remain independent of the design process to ensure that the AHJ acts in the public interest first and foremost. Some State and Territory legislation may require that the AHJ has no involvement in the design process or development of evidence of compliance.

The fire engineer would generally:

- coordinate consultation with stakeholders during the FEB process
- undertake design of the Alternative Solutions
- provide guidance on and technical justification for proposals made during the fire engineering brief process on matters such as acceptance criteria, design fires, design occupant groups and analysis strategy
- nominate Performance Requirements applicable to the deviations from the DTS Provisions
- provide design advice as part of the design team
- prepare the fire engineering design report, based upon the IFEG guidance and using the format provided in Chapter 1.11 Preparing the Report, for approval by the AHJ
- identify any special commissioning, management in use and maintenance requirements for the Alternative Solution. This will include identification of: the elements of the design that are critical to its ongoing effectiveness; the level of performance required of each element; and the boundary conditions or any limitations that may must be applied for the design to be effective.

In some jurisdictions, the fire engineer who carried out the design of a fire engineering Alternative Solution may not be entitled to issue a certification that the design complies with the BCA, i.e. self certification. In these circumstances the design may have to be analysed for compliance and approval by an independent practitioner before an approval is granted

Chapter 0.3

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 BCA 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 safety engineering or fire engineering as it is referred to in this Guideline is a rapidly developing discipline. In comparison to the traditional, established engineering disciplines, it does not have well-codified methods of approaching and solving problems. These Guidelines have been written to help overcome these deficiencies. Fire engineering has only become a possibility as a result of developments in fire science increasing the understanding of the many aspects of building fires, such as:

- 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 recent developments, such as:

- the computerisation of fire models, particularly the complex models requiring extended computations
- increases in computer capability and capacity
- the introduction of performance-based codes with specific provision for the acceptance of fire engineered solutions.

0.3.1 Benefits

Fire engineering can be used for objectives other than those within the scope of the BCA and thus has wider applicability and potential benefits beyond just evaluating Alternative Solutions.

The general objectives of the BCA are taken as being to:

- protect building occupants which includes emergency services personnel
- facilitate the activities of emergency services personnel
- 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 BCA. Examples of such objectives are:

- 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.

All these objectives, together with the mandatory requirements, should be taken into account for an integrated, cost-effective fire safety system. The fire engineer has a duty of care to draw the client's attention to those objectives which may relate 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 Alternative Solutions
- a basis for selection of appropriate fire safety systems
- monetary savings through the use of Alternative 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 building code requirements
- solutions for upgrading existing buildings when required by regulatory authorities.

These benefits, amongst others, are referred to in the discussion in the following sections.

0.3.2 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 0.3.2. 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. Architects have to work with many disciplines and fire engineering is one of the recent additions. Fire engineering relates closely to the building professions such as 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.

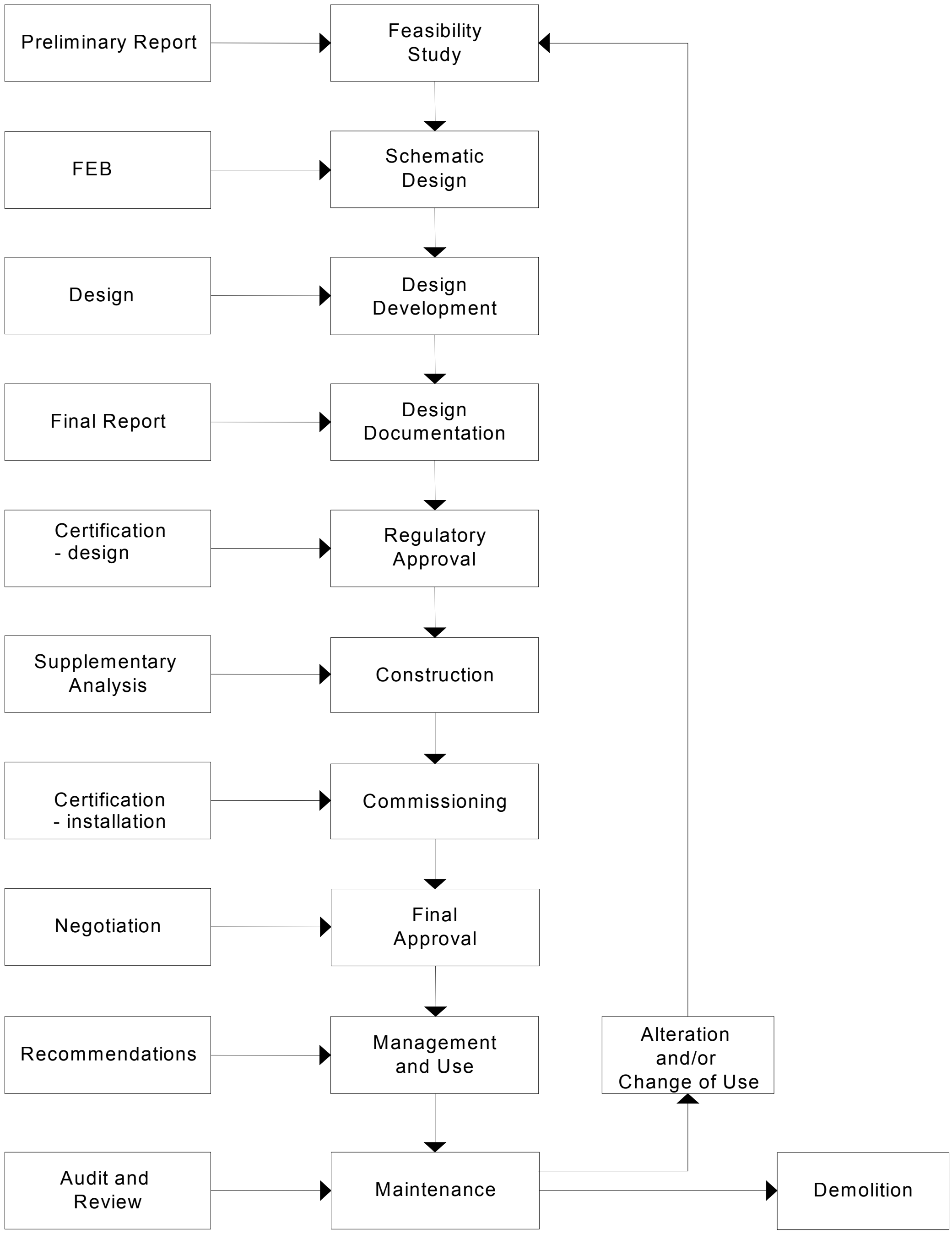
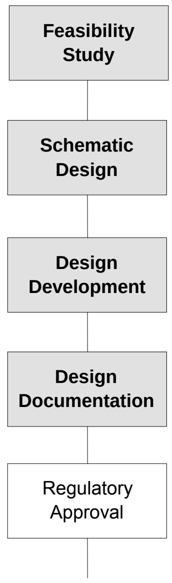


Figure 0.3.2. Fire engineering involvement at the various stages in the life-cycle of a building

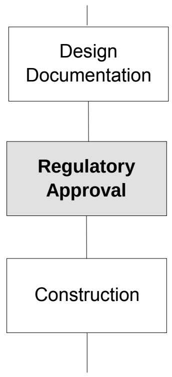
0.3.2.1 Design

The benefits of using fire engineering are greatest if this discipline is involved early in the design process. Indeed, fire engineering can contribute to each stage of the design process as indicated in Figure 0.3.2.



- A preliminary report on potential fire safety systems can be of benefit to a **feasibility study** for a project by providing flexibility in terms of the use of fire safety systems that do not conform to the prescriptive Deemed-to-Satisfy Code Provisions and, in many cases, consequent cost savings. Such a report may form a useful basis for discussions with the AHJ at this stage of the design process.
- The Fire Engineering Brief (FEB), which is discussed in detail in Chapter 1.2, provides a consensus on the fire safety components of the **schematic designs** being considered and the design options that need to be considered. The use of Alternative Solutions (to the code requirements) may lead to designs that are both more functional and economical.
- Analysis of the trial design(s) identified in the FEB may guide the **design development** by indicating which design(s) meet the Performance Requirements set by the code or other stakeholders and which components of the fire safety system need special attention. Conversely, design development may lead to other trial designs needing analysis.
- The fire engineering final report will provide not only the justification for the fire safety system utilised, but also the detailed requirements to ensure that the **design documentation** includes the necessary construction, commissioning, operation and maintenance requirements.

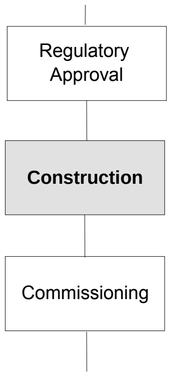
0.3.2.2 Regulatory approval



When the design requirements are considered to have been achieved, it is then the role of the AHJ to assess that design and documentation, and take one of several courses of action:

- approve the design and documentation
- ask for further information to clarify the design intention and/or demonstrate compliance with the BCA
- approve the design and documentation subject to certain conditions
- refuse approval, usually giving reasons.

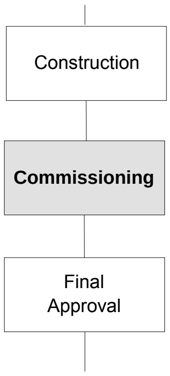
The fire engineer, having carried out an evaluation of the fire safety system for any design, is central to any negotiations necessary to gain approval.



0.3.2.3 Construction

The fire engineer responsible for the design should be involved in the construction stage to:

- facilitate the realisation of the intent of the design
- identify those aspects that are crucial to the attainment of fire safety
- carry out supplementary analysis on the changes to the design that are required (or that inadvertently occur)
- ensure fire safety levels are maintained during refit and refurbishment activities
- determine that the necessary fire safety system components are installed as specified.

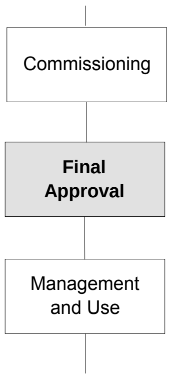


0.3.2.4 Commissioning

Proper commissioning is essential if the fire safety of the design is to be realised and a sound foundation set for subsequent maintenance. Commissioning may be a requirement of Building Law, and reference should be made to the relevant legislation. For an alternative design, the involvement of the fire engineer is advantageous. The fire engineer can:

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

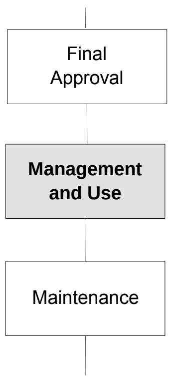
For example, testing with heated artificial smoke ('hot smoke' tests) is often carried out as part of the commissioning process to ensure the correct operation of equipment installed for smoke hazard management.



0.3.2.5 Final approval

The contribution of fire engineering to this stage, which involves the issue of occupancy certificates and the like, is similar to the previous approval stage (Section 0.3.2.2). In particular, the fire engineer may be required to verify that:

- the conditions of the regulatory approval have been met
- construction and commissioning meet the approved design
- fitouts (shops, malls, offices, etc.) do not compromise the fire safety and the fire safety evaluation carried out
- appropriate management and maintenance regimes are in place.



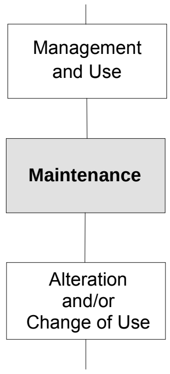
0.3.2.6 Management and use

The day-to-day commitment to safety by a building's management team 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. Fire engineering should play a role in ensuring management and use provisions, appropriate to the fire engineered design are in place, by:

- contributing to the development of emergency evacuation procedures and associated training; the procedures need to be consistent with the fire engineering design, particularly regarding the method of warning occupants and the evacuation strategy (staged, horizontal, etc.)
- listing any limitation on fuel loadings, use of evacuation routes, etc
- providing guidelines for housekeeping and other aspects of management for fire safety (including maintenance discussed in Section 0.3.2.7 below).

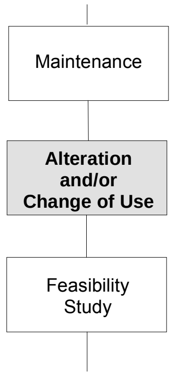
The management and use issues should have been addressed in the design stage (Section 0.3.2.1), refined during commissioning (Section 0.3.2.4) and be subject to final approval (Section 0.3.2.5).

0.3.2.7 Maintenance



The fire safety of a building depends on the ongoing functioning and efficacy of its fire safety system. Fire engineering should be involved in defining the maintenance programs that are necessary to ensure the design performance is maintained, taking into account relevant State or Territory legislation, the BCA and any relevant Standard.

0.3.2.8 Alteration and/or change of use



It is usual for alterations, additions and / or change of use / classification to occur to a building during its life. Fire engineering has potential in these circumstances because the alterations or additions may not meet the current Deemed-to-Satisfy Provisions of the day, or may compromise the original fire engineering design. Thus, fire engineering should:

- contribute to the process undertaken to obtain 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 FEB for the client(s) attention.

0.3.3 Uniqueness of application

Fire engineering is building, occupant and site specific in its application and 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 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 exists when changes occur to the building, occupants and site may require a re-evaluation of the fire safety system . This may not be necessary if the broader approach using a Deemed-to-Satisfy Provision had been adopted.

Many buildings appear to have similar or identical design features. However, detailed examination generally reveals variations (some of which may be quite minor) which can have a major influence on the fire safety of the buildings. Thus, from the fire engineering point of view, every building, however similar it might be superficially, has subtle differences from every other building and these differences may affect fire safety. Thus, using one building or features of that building as a precedent for approval for another is not appropriate except in exceptional circumstances. Such circumstances may exist where a detailed comparison of the buildings and the implications for a fire engineering design has been carried out and documented in order to demonstrate that, for the purposes of a fire engineering design, the buildings are identical.

0.3.4 Third party review

Third party review is taken as encompassing both peer and specialist reviews. (see Definitions – Section 0.5.1.) 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 considered as a constructive process to assist the AHJ in approving a design which is supported by a fire engineering report. It may also assist the fire engineer in ensuring that all matters, especially the justification of expert 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 fire engineer 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. 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 AHJ, it is preferable that the third party reviewer be either recognised as an appropriate expert by the AHJ or selected and appointed by the AHJ. It is also essential that the reviewer be independent of the project and participants in the project in question (refer Definitions Section 0.5.1). The AHJ needs to determine whether a peer or specialist review is required.

Generally a fire engineer would not initiate a peer review but might seek a specialist review of some aspects of the evaluation (see Section 1.10.2 Step 2a). 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 AHJ, the reviewer should:

- use the guidance of the IFEG as the benchmark for the review
- ensure the decisions made in the FEB process have been followed in the analysis and conclusions
- carry out check calculations as appropriate to determine the quality of the analysis
- ensure that the report conforms to the requirements of the IFEG and includes the appropriate items from Chapter 1.11.

In general terms a review process may have a number of outcomes.

- The report adequately documents the evaluation of the design and supports any Alternative 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 fire engineer to satisfy the requirements of the reviewer.
- The design has fundamental flaws or the wrong analysis strategy has been adopted. In such cases, the FEB and the analysis needs to be repeated in whole or part before the acceptability of the trial design can be determined.
- The fire engineering brief process has not been adequately carried out and therefore the design is unsound or not sufficiently justified. The whole fire engineering design including the FEB 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 of the deficiencies in the design and fire engineering report can be remedied expeditiously. In particular:

- assertions and assumptions need to be substantiated and referenced in the manner that these guidelines suggest for the fire engineering report itself
- check calculations should be sufficiently detailed to enable comprehension and evaluation
- the suggested remedial actions need to be clearly identified.

Chapter 0.4

Fire Engineers

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

- 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, spread within and outside of buildings/structures
- understand how fires can be detected, controlled and/or extinguished
- be able to anticipate the behaviour of materials, structures, machines, apparatus, and processes as 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
- be skilled in using and supporting engineering judgement
- understand and participate in the design process for buildings and other facilities
- 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 a building code that may be appropriate for a given project and the fire engineer 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 0.3.1 and 1.2.5 of these Guidelines.

Fire engineering is an evolving discipline. It has few of the well-proven and well-understood tools and data that other engineering disciplines enjoy. Thus, engineering judgement plays a greater role in the discipline of fire engineering than in most other engineering disciplines.

The International Organisation for Standardisation (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 a quantitative analysis."*

This definition indicates that a quantitative analysis method is only a tool for use by the fire engineer, who may choose to what extent the results are used, based on an appreciation of the validity of the tool.

When engineering judgement is used, its use should be justified and the logic used in applying it explained (see Chapters 1.10 and 1.11).

0.4.1 Related disciplines

There are several forms of specialisations amongst engineers working with fire related issues. The nomenclature used for these specialisations is not necessarily consistent and may well vary from state to state and country to country.

In addition to fire engineers, there are other related specialists, such as:

- A **building services engineer** may be skilled in many different engineering services within a building and may well 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 an hydraulic engineer may be skilled at designing fire water supplies.
- A **fire services or fire systems engineer** may be skilled in the design, installation and maintenance of fire detection, warning, suppression and communication equipment.
- A **structural engineer** may be skilled in structural fire engineering design.

0.4.2 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.

In Australia, there are a number of accreditation schemes in operation. The Institution of Engineers, Australia has set criteria for fire safety engineering as an area of practice of its National Professional Engineers Register (NPER).

In addition various State and Territory legislation provides for accreditation or registration of fire engineers within their jurisdiction. In some cases the legislation recognises a number of accreditation bodies both national and local for the administration of the accreditation or registration process.

Reference should be made to the appropriate building legislation for definition of competent persons and acceptable accrediting bodies and criteria for accreditation or registration as a fire engineer.

Chapter 0.5

Definitions, Abbreviations and Information Sources

0.5.1 Definitions

Alternative Solution	A building solution that complies with the Performance Requirements of a code other than by reason of satisfying the Deemed-to-Satisfy Provisions.
Approval	The granting of a statutory approval, licence, permit or other form of consent or certification by an Authority Having Jurisdiction (AHJ). Approval may incorporate assessment of Alternative Solutions.
Assessment	The process carried out by the AHJ which may involve the assessing, verifying, reviewing, and / or comparing a fire engineering solution and /or alternative building solution for compliance with the BCA and adequacy of documentation to demonstrate compliance with the applicable legislation for the purpose of granting an approval.
Authority Having Jurisdiction	A regulatory authority that is responsible for administering building controls including the statutory, administrative, technical and enforcement provisions of State or Territory legislation.
Available Safe Evacuation 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 an Alternative Solution, a solution that complies with the deemed-to-satisfy provisions, or a combination of both.
Certification	The process of certifying compliance of a particular design, design component, 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 appropriately qualified practitioners.
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 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 or DTS (Provisions)	The prescribed provisions of a code that are Deemed-to-Satisfy the Performance Requirements of that code.
Design	This process is carried out by the fire engineer and may involve analysis, evaluation and engineering, with the aim of meeting the objective of the particular building or facility.
Design fire	A representation of a fire that is characterised by the variation of heat output with time and is used as a basis for assessing fire safety systems.
Design fire scenario	A fire scenario that is used as the basis for a design fire.
Deterministic method	A methodology based on physical relationships derived from scientific theories and empirical results that for a given

	set of conditions 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 a quantitative 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, internal or external, to their building.
Evaluation	For the purposes of this document, the process by which a fire engineer reviews and verifies whether an Alternative Solution meets the appropriate Performance Requirements.
Field model	A model that divides a building enclosure into small control volumes and simulates the emission phenomena, the movement of smoke and the concentrations of toxic species in various enclosures so that the times of critical events such as detection of fire and the development of untenable conditions can be estimated.
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.
Fire engineer	A person suitably qualified and experienced in fire engineering (previously known as fire safety engineer in Australia).
Fire engineering	See Section 0.2
Fire Engineering Brief (FEB)	A documented process that defines the scope of work for the fire engineering analysis and the basis for analysis as agreed by stakeholders.
Fire safety system	One or any combination of the methods used in a building to: (a) warn people of an emergency (b) provide for safe evacuation (c) restrict the spread of fire (d) control or extinguish a fire. It includes both active and passive systems.
Fire service intervention	All fire service activities from the time of notification up to the completion of fire attack with consideration of management of re-ignition 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 surfaces within a room or compartment.
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 fire engineer or a person with the equivalent competencies and experience.
Place of safety	A place within a building or within the vicinity of a building, from which people may safely disperse after escaping the effects of fire. It may be an open space (such as an open court) or a public space (such as a foyer or a roadway).
Prescriptive (provisions)	Provisions which are expressed explicitly in quantitative form.
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 Evacuation 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 and consequence of an event occurring.
Schematic design fire	A qualitative representation of a design fire, normally presented in the form of a graph.
Sensitivity analysis	A guide to the level of accuracy and/or criticality of 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.
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	A part of a fire safety system that comprises fire safety measures to protect against a particular hazard (e.g. smoke spread). Note: This Guideline defines six sub-systems (see Chapter 1.3).

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.

0.5.2 Abbreviations

ABCB	Australian Building Codes Board
AHJ	Authority Having Jurisdiction
AS	Australian Standard
ASET	Available Safe Evacuation Time
BCA	Building Code of Australia
DTS	Deemed-to-Satisfy
FCRC	Fire Code Reform Centre Ltd
FE	Fire Engineer
FEB	Fire Engineering Brief
IE Aust	Institute of Engineers Australia
IFE	Institute of Fire Engineers, UK
ISO	International Standards Organization
NFPA	National Fire Protection Association, USA
HRR	Heat Release Rate
RSET	Required Safe Evacuation Time
SFPE	Society of Fire Protection Engineers, USA
SS	Sub-System

0.5.3 Information sources

There are various sources that fire engineering professionals may refer to for specific knowledge and information that may be utilised in fire engineering assessments. The lists provided in the following sections are not comprehensive and only aim to serve as a guide.

0.5.3.1 Reference works

The following publications provide guidance in the general area of fire safety engineering:

Australasian Fire Authorities Council (1997). ‘Fire Brigade Intervention Model — Version 2.1 November 1997’, Box Hill, Victoria, Australia

BSI (2001). *Application of fire safety engineering principles to the design of buildings – Code of practice*, BS7974, British Standards Institution, London, UK.

Buchanan AH (ed). (2001). *Fire Engineering Design Guide*, 2nd Edition, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

CIBSE (The Chartered Institution of Building Services Engineers) (1997) *Guide to Fire Engineering*, CIBSE, London, UK.

Cote AE (ed) (1997). *Fire Protection Handbook*, 18th Edition. National Fire Protection Association, Quincy, MA, USA.

Custer, RLP & Meacham, BJ (1997). *Introduction to Performance Based Fire Safety*, National Fire Protection Association, Quincy, MA, USA.

DiNenno PJ (ed.) (2002) *The SFPE Handbook of Fire Protection Engineering*, 3rd Edition, National Fire Protection Association, Quincy, MA, USA.

Drysdale D. (1999). *An Introduction to Fire Dynamics*, 2nd Edition, , John Wiley & Sons, Chichester, UK.

European Convention for Constructional Steelwork (1985). *Design Manual on the European Recommendations for the Fire Safety of Steel Structures*, Technical Note No. 35.

Karlsson B and Quintiere J (1990). *Enclosure Fire Dynamics*, CRC Press, Boca Raton, FL, USA.

Klote JH and Milke JA (1992) *Design of Smoke Management Systems*, American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), Atlanta, GA, USA.

0.5.3.2 Journals

The following journals may provide a useful resource for fire engineering professionals.

- *Combustion and Flame*, Elsevier, Netherlands
- *Combustion Science and Technology*, Gordon Breach, USA
- *Combustion Theory and Modelling*, Institute of Physics, UK
- *Fire and Materials*, Elsevier, Netherlands
- *Fire Safety Engineer (FSE),* Miller Breeman, UK
- *Fire Safety Journal*, Elsevier, Netherlands
- *Fire Technology*, NFPA, USA
- *International Journal on Performance Based Fire Codes*, Hong Kong Polytechnic Institute, Hong Kong
- *Journal of Applied Fire Science*, JASSA, USA
- *Journal of Fire Protection Engineering*, SFPE, USA
- *Journal of Fire Sciences*, USA
- *NFPA Journal*, NFPA, USA
- *SFPE Journal*, SFPE, USA

0.5.3.3 Conference proceedings

The conferences listed below are held on a continuing basis. There are separate volumes of proceedings for each conference held.

- Asiaflam Fire Science and Engineering Conferences
- Engineers Australia Society of Fire Safety
- Fire Australia Conferences
- IAFSS Symposia
- Interflam Fire Science and Engineering Conferences
- International Conferences on Fire Research and Engineering
- International Conferences on Performance Based Design and Fire Safety Design Methods
- International Symposia on Human Behaviour in Fires
- Pacific Rim Conferences

0.5.3.4 Tertiary institutions

The following is a sample of tertiary institutions that provide courses or conduct research in fire engineering.

- Carleton University, Canada
- Lund University, Sweden

- Oklahoma State University, USA
- Queensland University of Technology, Australia
- Science University of Tokyo, Japan
- South Bank University, UK
- University of Canterbury, New Zealand
- University of Edinburgh, UK
- University of Greenwich, UK
- University of Leeds, UK
- University of Maryland, USA
- University of New Brunswick, Canada
- University of New Haven, USA
- University of Science and Technology of China, Peoples Republic of China
- University of Technology, Sydney, Australia
- University of Ulster, UK
- University of Western Sydney, Australia
- Victoria University of Technology, Australia
- Worcester Polytechnic Institute, USA

0.5.3.5 Fire research institutes

The following private or government research institutes publish and disseminate fire engineering-related knowledge and information.

- Building and Fire Research Laboratory, National Institute of Science and Technology (NIST), USA
- Building Research Association of New Zealand (BRANZ), New Zealand
- Centre for Environmental Safety and Risk Engineering (CESARE), Victoria University of Technology, Australia
- CSIRO Fire Science and Technology Laboratory, Australia
- Duisburg Gerhard-Mercator University Fire Detection Laboratory, Germany
- Factory Mutual, USA
- Fire and Risk Sciences, Building Research Establishment, UK
- Fire Science Centre, University of New Brunswick, USA
- Fire Science Laboratory, Worcester Polytechnic Institute, USA
- FireSERT, Fire Safety Engineering Research and Technology Centre, University of Ulster, UK
- National Fire Data Centre, USA
- National Research Council, Canada
- Scientific Services Laboratory — AGAL, Australia
- SINTEF, Norway
- Swedish National Testing and Research Institute, Sweden
- Technical Research Centre of Finland (VTT), Finland
- The Loss Prevention Council, UK
- Western Fire Centre, Inc. in Kelso, USA

0.5.3.6 Associations and organisations

The following private or government organisations publish and provide fire engineering-related knowledge and information.

- ANSI, American National Standards Institute, USA

- ASTM, American Society for Testing and Material
- CIB, International Council for Building Research Studies and Documentation, Committee W14 Fire, Netherlands
- Engineers Australia Society of Fire Safety
- FAA, Federal Aviation Authority, USA
- FEMA, Federal Emergency Management Agency, USA
- Fire and Risk Sciences, Building Research Establishment, UK
- FPAA, The Fire Protection Association of Australia, Australia
- IAFSS, International Association for Fire Safety Science, UK
- Institution of Fire Engineers, Engineering Council Division, UK
- ISO, The International Standards Organization, Switzerland
- IOSH, Institution of Occupational Safety and Health, USA
- NFPA, National Fire Protection Association, USA
- NIST, National Institute for Science and Technology, Building and Fire Research Laboratory, USA
- NRCC, National Research Council Canada, Canada
- SAA, Standards Australia, Australia
- SFPE, Society of Fire Protection Engineers
- The Combustion Institute, USA

0.5.3.7 Web sites

The following web sites provide on-line information that may be utilised in fire safety engineering assessments.

- Engineers Australia Society of Fire Safety — *www.sfs.au.com*
- IAFSS (USA) — *www.iafss.org/*
- Lund University (Sweden) — *www.brand.lth.se*
- NIST BFRL (USA) — *www.bfrl.nist.gov*
- National Data Centre — *www.usfa.fema.gov*

Part 0 - Canada
Introduction

International
Fire Engineering
Guidelines

Table of Contents

These Guidelines comprise four parts, each of which is a separate entity. For a detailed table of contents, refer to the beginning of each part and each chapter.

Preface

The publication of the International Fire Engineering Guidelines (IFEG) has been supported by the Institute for Research in Construction (IRC) of the National Research Council Canada. The IRC also produces the National Model Codes, including the National Building Code and the National Fire Code, as well as a number of User Guides to the National Model Codes. The IFEG is not one of the suite of documents directly associated with the National Model Codes or the supporting User Guides. The IFEG is a document that may be helpful in the task of meeting the fire safety requirements of the building or fire codes, but it has not been vetted by the Canadian Commission on Building and Fire Codes and is not intended to be a part of the Canadian building regulatory system.

The IFEG address the process and the tasks of fire safety design and other activities aiming at fire safety in buildings, and do not necessarily address the question of who should be involved in these tasks or activities. The qualifications of professionals involved in building design and engineering are regulated by separate legislations and regulations, enacted at the provincial and territorial levels. These legislations and regulations vary across the country and are outside of the scope of the IFEG. Persons engaging in fire engineering should consult the relevant professional regulations in the jurisdiction where the activity is taking place.

Chapter 0.1

Introducing these Guidelines

These Guidelines have four parts, each with its own table of contents. It has been designed for ease of use and cross-referencing with graphics as outlined below:

- **graphic identification** of sub-systems, as explained in Part 1;
- **shaded boxes** containing examples or commentary; and
- **abbreviated flow charts** in the margins, with the relevant boxes shaded.

This Part 0 provides background information and guidance that is integral to an understanding of the entire Guidelines within a Canadian context.

Part 1 describes the process by which performance-based fire safety design is typically undertaken.

Part 2 describes a selection of methodologies that may be used in undertaking the performance-based fire safety design process.

Part 3 provides a selection of data that may be used in applying the methodologies of Part 2 or other chosen methodologies.

The Guidelines are paginated on a chapter basis in order to facilitate revision by replacement of individual chapters. It is envisaged that Part 0 and Part 1 will require less frequent revision than Part 2 and Part 3.

0.1.1 Evolution

The International Fire Engineering Guidelines (IFEG) are based on two editions of the Australian guidelines published in 1996 and 2001 respectively.

The objectives of the guidelines are to:

- provide a link between the regulatory system and performance-based fire safety design (Part 0)
- provide guidance for the process of fire engineering (Part 1)
- provide guidance for fire safety designers on the available methodologies (Part 2) and data (Part 3).

This current document has been written in the form of guidelines rather than in a mandatory or code format to reflect the current state of the art of performance-based fire safety design. The use of a mandatory format was discussed at length before the development of these guidelines. It was concluded that performance-based fire safety design lacks the necessary array of validated tools and data necessary to produce such a mandatory document.

Fire safety design evaluations are complex and generally require the extensive use of expert judgement. In addition, those required to assess the output of performance-based fire safety design need an understanding of the fire safety design process and what constitutes an acceptable fire safety design evaluation. Therefore, guidance is required both to improve the standard of fire safety design by practitioners and to improve the ability of the authorities having jurisdiction (AHJ) to carry out their assessment.

These Guidelines embrace worldwide best practise and draw upon previous work and parallel work from many groups around the world. The documents used include:

- Fire Safety Engineering Guidelines (FSEG), Edition 2001, November 2001, Australian Building Codes Board, Canberra, Australia.
- Fire Engineering Guidelines (FEG), first edition, March 1996. Fire Code Reform Centre Ltd Australia (March 1996).
- Building Code of Australia — Volume 1', Class 2 to Class 9 Buildings, Australian Building Codes Board, Canberra, Australia 2005.
- Fire Engineering Design Guide, 2nd Edition, University of Canterbury, Christchurch New Zealand (2001).
- CIBSE Guide E, Fire engineering, Chartered Institute of Building Services Engineers, UK (February 1997).
- International Organisation for Standardization, Fire Safety Engineering ISO/TR 13387: 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
- Fire Safety Engineering in Buildings – Code of practice, British Standard BS7974 (2001).
- The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers, Bethesda, MD. USA (2000).

0.1.2 Scope

These Guidelines have been developed for use in the performance-based fire safety design and evaluation of buildings. However, the concepts and principles may also be of assistance in a fire safety evaluation of other structures such as ships and tunnels which comprise enclosed spaces.

This document provides guidance for the performance-based design and evaluation of fire safety systems to achieve acceptable levels of safety and other objectives related to fire risks.

In particular, the Guidelines provide guidance for the design and evaluation of performance-based alternative solutions for the National Building Code of Canada (NBC) and the National Fire Code of Canada (NFC).

Designers and authorities need to interpret the guidance given in these Guidelines flexibly and use it as a tool for responsible fire safety design.

These Guidelines will also be of use to other people, such as Authorities Having Jurisdiction (AHJ), in assessing performance-based alternative solutions . They may form the basis of checklists commonly used as an aid for such activities but such lists should allow for the flexibility that these Guidelines allow.

Performance-based fire safety design is developing with a large degree of international cooperation and Parts 1, 2 and 3 of these Guidelines are written to have global applicability, whereas this Part 0 applies to the Canadian situation.

0.1.3 Limitations

These Guidelines are not intended to:

- apply to those situations where a person is involved, either accidentally or intentionally, with the fire ignition or early stages of development of a fire; building fire safety systems are not generally designed to protect such persons
- encompass situations that involve fire hazards outside the range normally encountered in buildings, such as storage of large quantities of flammable liquids, processing of industrial chemicals or handling of explosive materials
- be a form of 'recipe book' to enable inexperienced or unqualified people to undertake work that should be done by qualified practitioners
- replace available textbooks, examples of which are given in Section 0.4.3.

The goal of 'absolute' or '100%' safety is not attainable and there will always be a finite risk of injury, death or property damage. Some of the guidance in these Guidelines relates to the evaluation of such risks and the qualitative and quantitative methodologies available.

Furthermore, fire and its consequent effects on people and property are both complex and variable. Thus, a fire safety system may not effectively cope with all possible scenarios and this needs to be understood by the AHJ and others in their assessment of performance-based fire safety design solutions.

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Chapter 0.2

The Canadian Regulatory System

The intent of regulations related to health and safety in buildings is to mitigate risks to a level accepted by the community.

Building codes have been developed to provide the technical basis for such regulations. Traditionally, such building codes have been prescriptive. However, such codes cannot cover all emerging technologies and every combination of circumstances. Thus, it is felt that prescriptive regulations have not always been appropriate to the specific building being considered.

In order to free designers from such constraints and facilitate innovation, building codes of some countries have become performance-based. The NBC is not a performance-based code, but in its new, objective-based format, additional information is provided to facilitate development and evaluation of alternative solutions.

0.2.1 The regulatory framework

The provincial and territorial governments have the authority to enact legislation that regulates building design and construction within their jurisdiction. This legislation may include the adoption of the National Building Code without change or with modifications to suit local needs, and the enactment of other laws and regulations regarding building design and construction, including the requirements for professional involvement.

The Canadian Commission on Building and Fire Codes (CCBFC) oversees production of the model National Building Code of Canada (NBC) and National Fire Code of Canada (NFC), plus other guidance documents. The model building code is a set of minimum requirements addressing a limited range of safety, health, accessibility and building protection issues. It deals with new construction, including additions and major alterations. The model fire code deals with fire safety during the operation of facilities and buildings. The model national codes have received wide use as the basis for provincial and territorial building and fire codes, and for municipal bylaws.

0.2.2 The National Building Code of Canada

The 2005 edition of the NBC is the first edition to be published in objective-based format. An objective-based code is one which has explicitly stated objectives and in which every provision clearly exists to serve at least one of those objectives.
The objective-based NBC has three divisions – Divisions A, B and C.

Division A contains conformance provisions, Objectives and Functional Statements

Division B contains provisions that are essentially the same as those found in the 1995 edition of the NBC (with technical changes that have occurred through the normal updating process). These are however called "acceptable solutions".

Division C contains Administrative Provisions.

One important difference of the new format is that each of the provisions in Division B is linked to a large amount of additional information. It is linked to –

- one or more of the objectives of the code (such as Fire Safety) that it helps to address
- one or more functions of the building or facility that it helps to achieve
- a detailed statement of the specific intent of the particular code provision (electronic version of Code only)
- a detailed statement of what the provision applies to (electronic version of Code only).

Objectives

The objectives of a Code describe the overall goals that the Code's provisions are intended to achieve. These are described in very broad terms – so broad that they cannot possibly be used on their own in the design and approvals process and they are not intended to be used in this way. They do, however, serve to define boundaries around the areas that the Code addresses.
The objectives of the Code are given in Division A, Section 2.2. There are two levels of sub-objectives below most of the main objectives.

The objectives describe undesirable situations and their consequences that we don't want to happen in the building or facility. They use the wording "limit the probability." This wording acknowledges that codes cannot totally prevent these undesirable things from happening.

A related aspect of the wording is the reference to "unacceptable risk." This wording suggests that there is such a thing as "acceptable risk" and this is indeed the case. The "acceptable risk" is the risk remaining after the Code is complied with.

Functional Statements

The objectives describe undesirable situations and their consequences that the Code seeks to avoid. Functional statements describe conditions in the building that help to avoid those situations. Functional statements are more detailed than the objectives.

The functional statements of this Code are found in Division A, Section 3.2.

There may be several functional statements related to any one provision and a given functional statement may describe a function that serves to achieve more than one objective.

Like the objectives, the functional statements are entirely qualitative. Also like the objectives, the functional statements are not intended to be used on their own in the design and approvals process.

Intent Statements

The most basic and most detailed level of additional information provided by objective-based codes is the detailed intent statement for each specific Code provision. The intent statement explains the basic thinking behind the code requirement.

Because of the sheer volume of these intent statements, they are only available in electronic form.

Application Statements

The application of most code provisions is stated within the provisions themselves or nearby within the same subsection. However, that application may be modified by exceptions and by cross-references elsewhere in the Code. All this information is brought together in new application statements that summarize exactly what each code provision applies to and what it does not apply to.

Like the intent statements, because of the sheer volume of these application statements, they are only available in electronic form.

Divisions of the NBC

Division A, Compliance, Objectives and Functional Statements

The prime function of Division A is to state the objectives the Code addresses and the functions the building or facility may perform to help satisfy those objectives. It serves as a very precise definition of the Code's scope.

Division A can not be used on its own as a basis for designing and constructing a building or facility or for evaluating the compliance of a building or facility.

Division A includes the provisions describing the only two ways of compliance with the code:

"1.2.1.1 Compliance with this Code

1) Compliance with this Code shall be achieved by
a) complying with the applicable acceptable solutions in Division B (see Appendix A), or
b) using alternative solutions that will achieve at least the minimum level of performance required by Division B in the areas defined by the objectives and functional statements attributed to the applicable acceptable solutions (see Appendix A)."

Clause (a) makes it clear that the acceptable solutions in Division B are automatically deemed to satisfy the objectives and functional statements of Division A.

Clause (b) introduces the term "alternative solutions." Whenever a solution is different from Division B acceptable solutions, it is considered an "alternative solution." This is what used to be referred to as an "equivalent" in the 1995 Code.

Division B, Acceptable Solutions

Division B is essentially the 1995 Code (with technical changes).

What used to be called "requirements" in the 1995 code are now called "acceptable solutions."

Each of these acceptable solutions is linked to the Division A objective(s) and functional statement(s) that it helps to satisfy.

Division C, Administrative Provisions

Division C includes administrative provisions formerly found in Parts 1 and 2 of the 1995 National Building Code as well as some new administrative provisions with respect to documentation for alternative solutions. Many provinces and territories establish their own administrative provisions upon adopting or adapting the NBC; therefore having all the administrative provisions in one division facilitates their revision to suit jurisdictional needs.

0.2.3 The acceptance process

The acceptance processes and the documentation required by these processes for alternative solutions vary from jurisdiction to jurisdiction in Canada. This is because the NBC is given legal effect by regulatory legislation in each province and territory (see Section 0.2.1 above). Therefore, only general guidance is given in these Guidelines. The requirements of each Province and Territory should be consulted for detailed information.

The NBC Division C Administrative Provisions says that ”Sufficient information shall be provided to show that the proposed work will conform to this Code ...”. In this context, a report prepared according to these guidelines (see Chapter 1.11) would mitigate concerns regarding differences in the format and content of documentation in support of alternative solutions.

The acceptance of an alternative solution may result from an independent assessment by the authority having jurisdiction, or by acceptance by provincial or territorial boards, commissions and councils.

Chapter 0.3

Fire Engineering

The International Standards Organization (ISO) defines fire 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."*

Fire engineering is a rapidly developing discipline. In comparison to the traditional, established engineering disciplines, it does not have well-codified methods of approaching and solving problems. These Guidelines have been written to help overcome these difficulties.

Fire engineering has only become a possibility as a result of developments in fire science that have provided an increased understanding of the many aspects of building fires, such as:

- 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 recent developments, such as:

- the computerisation of fire models, particularly the complex models requiring extended computations
- increases in computer capability and capacity
- progress in risk assessment methods
- the evolution of building codes with specific provisions for the acceptance of fire engineered solutions.

0.3.1 Benefits

Fire engineering can be used for objectives other than those of the NBC and thus has wider applicability and potential benefits beyond just evaluating alternative solutions.

The general objectives of the NBC with respect to fire can be paraphrased as:

- protect persons in or adjacent to the building
- protect the building and adjacent 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 NBC. Examples of such objectives are:

- 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 a country's 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.

All these objectives, together with the mandatory requirements, should be taken into account for an integrated, cost-effective fire safety system. The fire engineer has a duty of care to draw the client's attention to those objectives, which may relate 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 alternative design solutions
- a basis for selection of appropriate fire protection systems
- monetary savings through the use of alternative 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 building code requirements
- solutions for upgrading existing buildings when required by regulatory authorities.

These benefits, amongst others, are referred to in the discussion in the following sections.

0.3.2 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 that fire safety is achieved for the life of the building. Figure 0.3.2. shows the various stages that represent the life cycle of a building and the role that fire engineering can play in each of these stages.

In general, fire engineering is used when a design does not meet the Acceptable Solutions provisions of the NBC. Such use does not recognize the full potential of fire engineering and its role as a partner with other professional disciplines.

In the design of a building, fire engineering can be integrated with the other professional disciplines. Architects have to work with many disciplines and fire engineering is one of the recent additions. Fire engineering relates closely to the building professions such as architecture, building services engineering, structural engineering and project management.

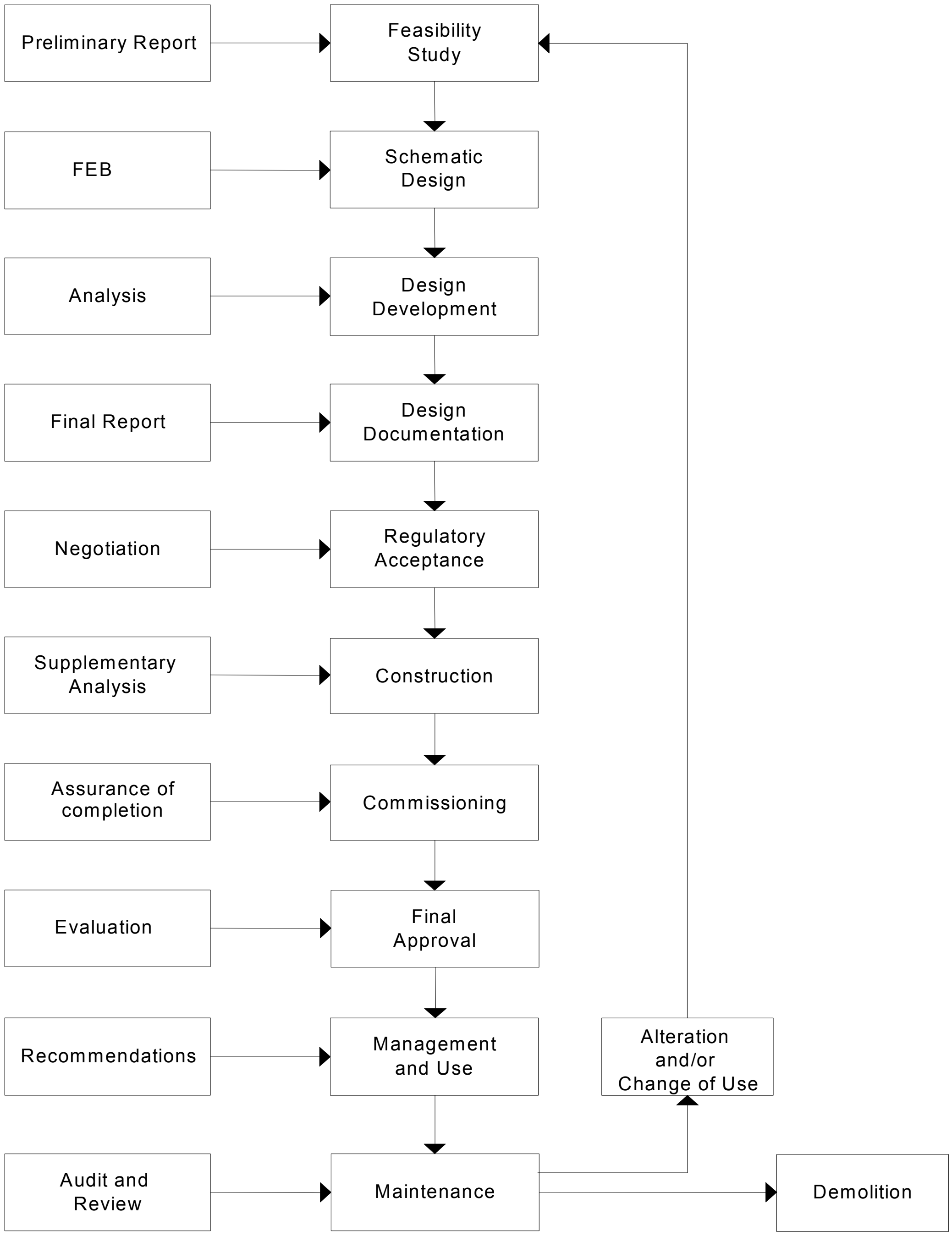
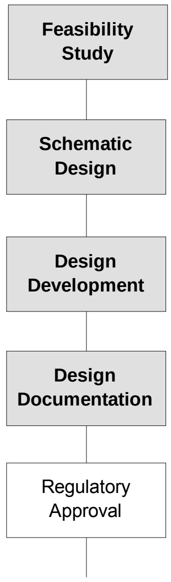


Figure 0.3.2. Fire engineering involvement in the various stages in the life cycle of a building.

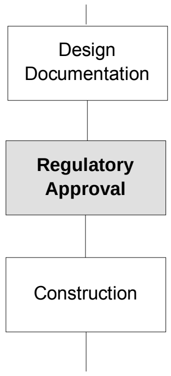
0.3.2.1 Design

The benefits of using fire engineering are greatest if this discipline is involved early in the design process. Indeed, fire engineering can contribute to each stage of the design process as indicated in Figure 0.3.2.



- A preliminary report on potential fire safety systems benefits a **feasibility study** by providing flexibility in terms of the use of fire safety systems that do not conform to the prescriptive deemed-to-satisfy code provisions and, in many cases, consequent cost savings. Such a report may form a useful basis for discussions with approval authorities at this stage of the design process.
- The fire engineering brief (FEB), which is discussed in detail in Chapter 1.2, provides a consensus on the fire safety components of the **schematic designs** being considered and the design options that need evaluation. The use of alternative fire safety solutions (to the code requirements) may lead to designs that are both more functional and economical.
- Analysis of the trial design(s) identified in the FEB may guide the **design development** by indicating which design(s) meet the performance requirements set by the code or other stakeholders and which components of the fire safety system need special attention. Conversely, design development may lead to other trial designs needing analysis.
- The fire engineering final report will provide, not only the justification for the fire safety system used, but also the detailed requirements to ensure that the **design documentation** includes the necessary construction, commissioning, operation and maintenance requirements.

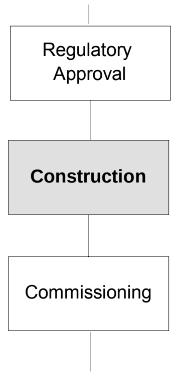
0.3.2.2 Regulatory acceptance



When the design requirements have been achieved, it is then the role of the AHJ to assess that design and take one of several courses of action:

- accept the design;
- ask for further information to clarify the design intention;
- accept the design subject to certain conditions; or
- refuse acceptance, giving reasons.

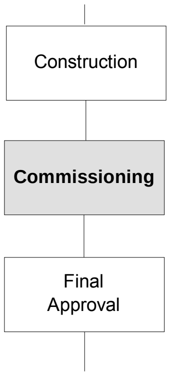
The fire engineer, having carried out an analysis of the fire safety system for any alternative solution, is central to any negotiations necessary to gain acceptance.



0.3.2.3 Construction

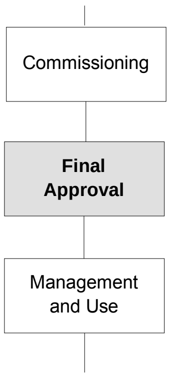
The fire engineer responsible for an alternative solution should be involved in the construction stage to:

- facilitate the realisation of the intent of the alternative design
- identify those aspects that are crucial to the attainment of fire safety
- carry out supplementary analysis on the changes to the design that are required (or that inadvertently occur)
- ensure fire safety levels are maintained during refit and refurbishment activities
- determine that the necessary fire safety system components are installed as specified.



0.3.2.4 Commissioning

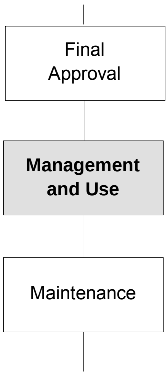
Proper commissioning is essential if the fire safety of the design is to be realised and a sound foundation set for subsequent maintenance. For an alternative solution, the involvement of the fire engineer is advantageous. An example, where such involvement is of evident benefit, is testing with heated artificial smoke ('hot smoke' tests). This is often carried out as part of the commissioning process to ensure the correct operation of equipment installed for smoke hazard management.



0.3.2.5 Final acceptance

The contribution of fire engineering to this stage, which involves the issue of occupancy permits and the like, is similar to the previous acceptance stage (Section 0.3.2.2). In particular, the fire engineer may be required to verify that:

- the conditions of the regulatory acceptance have been met
- construction and commissioning meet the accepted design
- fitouts (shops, malls, offices, etc.) do not compromise the fire safety and the fire safety evaluation carried out
- appropriate management and maintenance regimes are in place.



0.3.2.6 Management and use

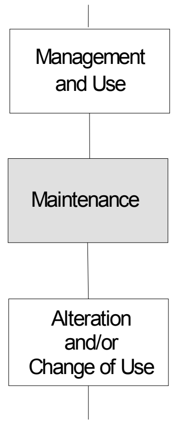
The day-to-day commitment to safety by a building's management team will significantly affect the fire safety of a building. Fire engineering should play a role in ensuring management and use provisions, that are appropriate to the fire safety design, are in place, by:

- providing any specialized information used in project design, such as fire safety design criteria, fuel loading, building and occupants' characteristics required for the development of fire safety plan as required by the relevant Fire Code (Provincial, Territorial or National).
- providing a record of the accepted alternative solution to be retained for the life of the building or until altered. Preferably, the record should be kept by the owner, together with the fire safety plan. As this is an administrative matter, it should be consulted with the authorities.

The management and use issues should have been addressed in the design stage (Section 0.3.2.1), refined during commissioning (Section 0.3.2.4) and be subject to final approval (Section 0.3.2.5).

0.3.2.7 Maintenance

The fire safety of a building depends on the ongoing functioning and efficacy of its fire safety system. Fire engineering should be involved in providing information for maintenance programs for fire safety systems, where those systems form part of the project fire safety design.

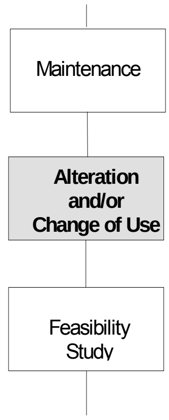


0.3.2.8 Alteration and / or change of use

Often alterations or additions are made to a building during its life and its use changed. Fire engineering has potential in these circumstances because the alterations or additions may not conform to the Acceptable Solutions provisions or may compromise the original fire engineering design. Thus, fire engineering can:

- contribute to the process undertaken to obtain the necessary approvals for the altered building; or
- examine a fire engineering evaluation carried out on the existing building to determine if it still applies.

The alteration of a building or addition to it often triggers a requirement to upgrade all or a portion of the existing building, even parts that are not subject to physical alteration. The original design may no longer comply with the current codes and the building may require re-evaluation and making appropriate changes.



0.3.3 Uniqueness of application

Fire engineering is building, occupant and site specific in its application and this has both advantages and disadvantages. The advantages are in allowing detailed consideration of the fire safety system components most appropriate for the building characteristics, occupants and site. This enables the benefits of the performance based approach to be realised in the most cost effective and practical way. The disadvantages follow from the fact that changes to the building, occupants and site are most likely to occur during the lifetime of the building, which may require a re-evaluation of the fire safety system.

Many buildings appear to have similar or identical design features. However, detailed examination generally reveals variations (some of which may be quite minor) which can have a major influence on the fire safety of the buildings. Thus, from the fire engineering point of view, every building, however similar it might be superficially, has subtle differences from every other building and these differences may affect the fire safety. Thus, using one building or features of that building as a precedent for approval for another is not appropriate except in exceptional circumstances. Such circumstances may exist where a detailed comparison of the buildings and the implications for a fire safety evaluation has been carried out and documented in order to demonstrate that, for the purposes of a fire engineering evaluation, the buildings are identical.

The uniqueness of the fire design for a particular building should be documented as it may be important at times of changing building characteristics or its occupancy. The issue of retaining this kind of documentation has not been resolved nationally, but its importance has been recognized and it would be prudent on part of the designer to retain the documentation. One possible place for the documentation, or at least the key elements of it, could be the fire safety plan.

0.3.4 Third party review

Third party review is taken as encompassing both peer and specialist reviews. See Definitions – Section 0.4-1.

Generally a fire engineer would not initiate a peer review but might seek a specialist review of some aspects of the evaluation (see Section 1.10.2 Step 2a of these guidelines). On the other hand, the owner or project manager may commission a third party review of a fire engineering evaluation in order to substantiate the conclusions.

Where the AHJ has appropriate competence and experience, they may undertake the assessment and approval of the alternative solution. Where they do not have the competence and experience, they may refer the assessment of the fire engineering report to a third party reviewer.

Where a third party review is required by an AHJ, it is preferable that the third party reviewer be selected and appointed by the AHJ and essential that the reviewer be independent of the project and participants in the project in question (refer Definitions Section 0.5.1). The AHJ needs to determine whether a peer or specialist review is required.

A third party review may be undertaken as a constructive process to assist the AHJ in assessing and approving a design involving an alternative solution which is supported by a fire engineering report. It should also assist the fire engineer in ensuring that all matters, especially the justification of expert judgement, are adequately addressed. A third party review should facilitate 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 that a fire engineering evaluation may vary according to the preferences of the fire engineer and a number of different approaches may be used in undertaking a fire engineering evaluation. Professional detachment, flexibility and an open mind are essential characteristics of a good third party reviewer. 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.

The issue of payment for the third party review should be resolved early in the process. The practical options here include a direct payment by the proponent, or costs being recouped as a part of the permit fee.

Subject to the requirements of the AHJ, the IFEG may be used by the reviewer:

- as the benchmark for the review
- to ensure the decisions made in the FEB process have been followed in the analysis and conclusions
- to carry out check calculations as appropriate to determine the quality of the analysis
- to ensure that the report conforms to the requirements of the IFEG and includes the appropriate items from Chapter 1.11.

In general terms a review process may have a number of outcomes.

- The report adequately documents the evaluation of and supports the alternative 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 fire engineer to satisfy the requirements of the reviewer.
- The analysis has fundamental flaws or the wrong analysis strategy has been adopted. In such cases, the analysis needs to be repeated in whole or part before the acceptability of the trial design can be determined.

- The fire engineering brief process has not been adequately carried out and therefore the evaluation is unsound. The whole fire engineering evaluation including the FEB 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 of the deficiencies in the evaluation and fire engineering report can be remedied expeditiously. In particular:

- assertions and assumptions need to be substantiated and referenced in the manner that these guidelines suggest for the fire engineering report itself
- check calculations should be sufficiently detailed to enable comprehension and evaluation
- the suggested remedial actions need to be clearly identified.

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Chapter 0.4

Definitions, Abbreviations and Information Sources

0.4.1 Definitions

The following definitions are for use in the context of these guidelines. Other documents may assign different meaning to the terms defined below.

Acceptable solutions (also DTS – Deem to Satisfy solutions)	The provisions of a code that are deemed to satisfy the objectives and functional statements of the code.
Alternative solution	A proposed building solution that does not satisfy the acceptable solutions of the code (deemed-to-satisfy provisions).
Acceptance	The granting of a licence, permit or other form of consent or certification by an Authority Having Jurisdiction (AHJ).
Assessment	For the purposes of this document, whether a fire engineering report adequately supports an alternative solution. This process is carried out by the AHJ.
Authority Having Jurisdiction	A regulatory authority that is responsible for administering building and fire codes.
Available safe evacuation 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.
Cue	A cue is usually in the form of a stimulus that may or may not elicit a response by a building occupant depending on a number of factors 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.
Design fire	A mathematical representation of a fire that is characterised by the variation of heat output with time and is used as a basis for assessing fire safety systems.
Design fire scenario	A fire scenario that is used as the basis for a design fire.
Deterministic method	A methodology based on physical relationships derived from scientific theories and empirical results that for a given set of conditions 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 a quantitative 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, internal or external, to their building.

Evaluation	For the purposes of this document, the process by which a fire engineer determines whether an alternative solution meets the appropriate performance requirements.
Field model	A model that divides a building enclosure into small control volumes and simulates the emission phenomena, the movement of smoke and the concentrations of toxic species in various enclosures so that the times of critical events such as detection of fire and the development of untenable conditions can be estimated.
Fire	The process of unwanted combustion.
Fire model	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.
Fire engineering	See Chapter 0.3
Fire engineering brief (FEB)	A documented process that defines the scope of work for the fire engineering analysis and the basis for analysis as agreed by stakeholders.
Fire safety system	One or any combination of the methods used in a building to: (a) minimize the risk of accidental ignition (b) to detect and warn people of an emergency (c) provide for safe evacuation (d) restrict the spread of fire (e) extinguish a fire. It includes both active and passive systems.
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 surfaces within a room or compartment.
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 with the equivalent competencies and experience.

Place of safety	A place within a building or within the vicinity of a building, from which people may safely disperse after escaping the effects of fire. It may be an open space (such as an open court) or a public space (such as a foyer or a roadway).
Prescriptive (provisions)	Provisions that are expressed explicitly in quantitative form.
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 evacuation time (RSET)	The time required for safe evacuation of occupants to a place of safety prior to the onset of untenable conditions.
Risk	Product of likelihood of a hazardous event occurring and its consequences.
Schematic design fire	A qualitative representation of a design fire, normally presented in the form of a graph.
Sensitivity analysis	A guide to the level of accuracy and/or criticality of 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.
Smouldering fire	The solid phase combustion of a material without flames and 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	A part of a fire safety system that comprises fire safety measures to protect against a particular hazard (e.g. smoke spread). Note: This Guideline defines six sub-systems (see Chapter 1.3).
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.

0.4.2 Abbreviations

ASET	Available safe evacuation time
AHJ	Authority Having Jurisdiction
DTS	Deemed-to-satisfy
FEB	Fire engineering brief
IFEG	International Fire Engineering Guidelines
ISO	International Standards Organization
NFPA	National Fire Protection Association, USA
HRR	Heat release rate
RSET	Required safe evacuation time
SFPE	Society of Fire Protection Engineers, USA
SS	Sub-system

0.4.3 Information sources

There are various sources that fire engineering professionals may refer to for specific knowledge and information that may be utilised in fire engineering assessments. The lists provided in the following sections are not comprehensive and only aim to serve as a guide.

0.4.3.1 Reference works

The following publications provide guidance in the general area of fire engineering:

Australasian Fire Authorities Council (1997). 'Fire Brigade Intervention Model — Version 2.1 November 1997', Box Hill, Victoria, Australia

BSI (2001). *Application of fire safety engineering principles to the design of buildings – Code of practice*, BS7974, British Standards Institution, London, UK.

Buchanan AH (ed). (2001). *Fire Engineering Design Guide*, 2nd Edition, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

CIBSE (The Chartered Institution of Building Services Engineers) (1997) *Guide E Fire Engineering*, CIBSE, London, UK.

Cote AE (ed) (1997). *Fire Protection Handbook*, 18th Edition. National Fire Protection Association, Quincy, MA, USA.

Custer, RLP & Meacham, BJ (1997). *Introduction to Performance Based Fire Safety*, National Fire Protection Association, Quincy, MA, USA.

DiNenno PJ (ed.) (2002) *The SFPE Handbook of Fire Protection Engineering*, 3rd Edition, National Fire Protection Association, Quincy, MA, USA.

Drysdale D. (1999). *An Introduction to Fire Dynamics*, 2nd Edition, John Wiley & Sons, Chichester, UK.

European Convention for Constructional Steelwork (1985). *Design Manual on the European Recommendations for the Fire Safety of Steel Structures*, Technical Note No. 35.

Karlsson B and Quintiere J (1990). *Enclosure Fire Dynamics*, CRC Press, Boca Raton, FL, USA.

Klote JH and Milke JA (1992) *Design of Smoke Management Systems*, American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), Atlanta, GA, USA.

T.Z. Harmathy *Fire safety design and concrete*, Harlow, Essex, England : Longman Scientific & Technical ; New York, NY, USA : Wiley, 1993

0.4.3.2 FCRC publications

A number of projects have been funded by the Fire Code Reform Centre (FCRC) in Australia, from which the following reports (designated PR) and technical report (TR) have been published by FCRC and are available on the Australian Building Codes Board website www.abcb.gov.au .

FCRC PR 96-02
Final Report on the Restructure of the BCA-90 Fire Provisions, Blackmore, J., FCRC Project 1, CSIRO Division of Building, Construction and Engineering, April, 1996.

FCRC PR 98-01
Fire Safety in Shopping Centres, Bennetts, I.D. *et al.* FCRC Report, Project 6, July 1998.

FCRC PR 98-02
Fire Performance of Wall and Ceiling Materials, final report with supplement, Dowling, V. & Blackmore, J., FCRC Report, Project 2, Stage A, July and September 1998.

FCRC PR 99-01
Room and Furnace Tests of Fire Rated Construction, Blackmore, J. *et al.* FCRC Project 3 Report, CSIRO Division of Building, Construction and Engineering, North Ryde, NSW, Australia, July 1999.

FCRC PR 99-02
Fire Performance of Floors and Floor Coverings, Blackmore, J.M. & Delichatsios, M.A. Final report, FCRC Project 2B-1, Fire Science and Technology Laboratory, CSIRO, North Ryde, NSW, Australia, December 1999.

FCRC PR 00-02
Fire Safety in Shopping Centres Part II: The Effect of Combustible Construction on Fire Safety in Shopping Centres, McMillan, J. & Buchanan, A., Report of FCRC Project 6-A, Fire Engineering Program, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, February 2000.

FCRC PR 00-03
Fire Performance of Exterior Claddings, Wade, C. A. & Clampett, J. C. Report of FCRC Project 2B-2, BRANZ, April 2000.

FCRC PR 01-02
Evaluation of Fire Resistance Levels: Techniques, Data and Results, Beaver, P., Blackmore, J. & Thomas, I. Final Report on FCRC Project 3 Part 2, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, June 2001.

FCRC TR 96-01
Smouldering and Flaming Fires — an Experimental Program, Moore, I. & Beck, V. FCRC Project 4, CESARE Report Number 96-001, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, February 1996.

FCRC TR 96-02
Building Fire Scenarios — An Analysis of Fire Incident Statistics, Dowling, V. P. & Ramsay, G.C. FCRC Project 2 Research Paper 3, CSIRO Division of Building, Construction and Engineering, March 1996.

FCRC TR 96-06

BCA Fire Safety Requirements for Shopping Centres, Bennetts, I. R., Poh, K. W. & Lee, A. C. FCRC Project 6, BHPR/SM/R/045, Broken Hill Proprietary Company, Ltd, Melbourne, Australia, June 1996.

FCRC TR 96-07
Flashover Fires — an Experimental Program, FCRC Project 4, Alam, T. & Beever, P. CESARE Report Number 96-002, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, October 1996.

FCRC TR 96-08
Case Studies of Fires in Retail Buildings, Bennetts, I. D. *et al.* FCRC Project 6, BHPR/SM/R/056, Broken Hill Proprietary Company, Ltd, Melbourne, Australia, October 1996.

FCRC TR 96-11
A Stochastic Model for CO Toxicity in Building Fires, Hasofer, A. M. & Zhao, L. CESARE Technical Report for FCRC Project 4, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, December 1996.

FCRC 96-12
Large Scale Experiments to Provide Data for Validation of Building Fire Performance Parameters, Dowling, V. P., McArthur, N. A & Webb, A. K. FCRC Project 2 Research Paper 5, CSIRO Division of Building, Construction and Engineering, June 1996.

FCRC TR 97-02
Analysis of USA Retail Fires, Thomas, I. R. FCRC Project 6, BHPR/SM/R/G/061, Broken Hill Proprietary Company, Ltd, Melbourne, Australia, February 1997.

FCRC TR 97-05
Review of Fire Safety in Shopping Centres: The Key Issues, Beever, P. F. *et al.* FCRC Project 6, BHPR/SM/R/G/060, Broken Hill Proprietary Company, Ltd, Melbourne, Australia, February 1997.

FCRC TR 97-06
Simulated Shopping Centre Fire Tests, Bennetts, I. D. *et al.* FCRC Project 6, BHPR/SM/R/G/062, Broken Hill Proprietary Company, Ltd, Melbourne, Australia, March 1997.

FCRC TR 97-10
Determination of Interface Height from Measured Parameter Profiles in Enclosure Fire Experiments, He, Y. CESARE Technical Report for FCRC Project 4, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, November 1997.

FCRC TR 97-11
Selected Literature Reviews on Human Behaviour in Fire, Brennan, P. CESARE Technical Report for FCRC Project 4, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, February 1997.

FCRC TR 97-12
Response in Fires Database, Brennan, P. & Doughty, B., CESARE Technical Report for FCRC Project 4, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, February 1997.

FCRC TR 97-13
Effects of Sleep Inertia on Decision Making Performance, Pisani, D. L. & Bruck, D. Technical Report for FCRC Project 4, Victoria University, Melbourne, Australia, March 1997.

FCRC TR 97-15
The Probability of Death in the Room of Fire Origin: An Engineering Formula, Hasofer, A. M. Technical Report for FCRC Project 4, Centre for Environmental Safety and Risk Engineering, Victoria University, Melbourne, Australia, December 1997.

FCRC TR 98-03
Response of Occupants Close to Fire, Brennan, P. CESARE Technical Report for FCRC Project 4, Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia, March 1998.

FCRC TR 98-04
Arousal from Sleep with a Smoke Detector Alarm in Children and Adults, Bruck, D. Technical Report for FCRC Project 4, Victoria University, Melbourne, Australia, March 1998.

FCRC TR 98-05
Reliability of Stairway Pressurisation and Zone Smoke Control Systems, Zhao, L. Technical Report for FCRC Project 4, Victoria University, Melbourne, Australia, August 1998.

FCRC TR 99-01
*Data from Large-Scale and Small-Scale Experiments on Wall and Ceiling Lining*s, Webb, A. K., Dowling, V. P. & McArthur, N.A. FCRC Project 2 Research Paper 7, CSIRO Division of Building, Construction and Engineering, November 1999.

0.4.3.3 Journals

The following journals may provide a useful resource for fire engineering professionals.

- *Combustion and Flame*, Elsevier, Netherlands
- *Combustion Science and Technology*, Gordon Breach, USA
- *Combustion Theory and Modelling*, Institute of Physics, UK
- *Fire and Materials*, Elsevier, Netherlands
- *Fire Safety Engineer (FSE),* Miller Breeman, UK
- *Fire Safety Journal*, Elsevier, Netherlands
- *Fire Technology*, NFPA, USA
- *International Journal on Performance Based Fire Codes*, Hong Kong Polytechnic Institute, Hong Kong
- *Journal of Applied Fire Science*, JASSA, USA
- *Journal of Fire Protection Engineering*, SFPE, USA
- *Journal of Fire Sciences*, USA
- *NFPA Journal*, NFPA, USA
- *SFPE Journal*, SFPE, USA

0.4.3.4 Conference proceedings

The conferences listed below are held on a continuing basis. There are separate volumes of proceedings for each conference held.

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

0.4.3.5 Tertiary institutions

The following tertiary institutions are some of those that provide courses or conduct research in fire engineering.

- Carleton University, Ottawa, Canada
- University of New Brunswick, Canada
- Oklahoma State University, USA
- University of Maryland, USA
- Worcester Polytechnic Institute, USA
- University of Ulster, UK
- University of Edinburgh, UK
- Victoria University of Technology, Australia
- Lund University, Sweden
- Science University of Tokyo, Japan
- Queensland University of Technology, Australia
- University of Canterbury, New Zealand
- University of Greenwich, UK
- University of Leeds, UK
- University of New Haven, USA

- University of Science and Technology of China, Peoples Republic of China

0.4.3.6 Fire research institutes

The following private or government research institutes publish and disseminate fire engineering-related knowledge and information.

- National Research Council, Canada
- Building and Fire Research Laboratory, National Institute of Science and Technology (NIST), USA
- Factory Mutual, USA
- Fire and Risk Sciences, Building Research Establishment, UK
- Fire Science Centre, University of New Brunswick, Canada
- Fire Science Laboratory, Worcester Polytechnic Institute, USA
- Technical Research Centre of Finland (VTT), Finland
- Centre for Environmental Safety and Risk Engineering (CESARE), Victoria University of Technology, Australia
- CSIRO Fire Science and Technology Laboratory, Australia
- Building Research Association of New Zealand (BRANZ), NZ
- Duisburg Gerhard-Mercator University Fire Detection Laboratory, Germany
- FireSERT, Fire Safety Engineering Research and Technology Centre, University of Ulster, UK
- National Fire Data Centre, USA
- SINTEF, Norway
- Swedish National Testing and Research Institute, Sweden
- The Loss Prevention Council, UK
- Western Fire Centre, Inc., Kelso, USA

0.4.3.7 Associations and organisations

The following private or government organisations publish and provide fire engineering-related knowledge and information.

- ANSI, American National Standards Institute, USA
- ASTM, American Society for Testing and Material
- CIB, International Council for Building Research Studies and Documentation, Committee W14 Fire, Netherlands
- FAA, Federal Aviation Authority, USA
- FEMA, Federal Emergency Management Agency, USA
- Fire and Risk Sciences, Building Research Establishment, UK
- IAFSS, International Association for Fire Safety Science, UK
- Institution of Fire Engineers, Engineering Council Division, UK
- ISO, The International Standards Organization, Switzerland
- IOSH, Institution of Occupational Safety and Health, USA
- NFPA, National Fire Protection Association, USA
- NIST, National Institute for Science and Technology, Building and Fire Research Laboratory, USA
- NRCC, National Research Council Canada, Canada
- SFPE, Society of Fire Protection Engineers
- The Combustion Institute, USA

0.4.3.8 Web sites

The following web sites provide on-line information that may be utilised in fire safety assessments.

- IAFSS (USA) — www.iafss.org/
- Lund University (Sweden) — www.brand.lth.se
- NIST BFRL (USA) — www.fire.nist.gov, www.bfrl.nist.gov
- National Data Centre — www.usfa.fema.gov
- NFPA - www.nfpa.org
- SFPE - www.sfpe.org

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Part 0-United States of America Introduction

International
Fire Engineering
Guidelines

The contents of this document have been derived from various sources believed to be the best correct information available internationally. This information provided is of an advisory nature and is not to be an exhaustive treatment of the subject matter.

Table of Contents

These guidelines comprise four parts, each of which is a separate entity. For a detailed table of contents, refer to the beginning of each part and chapter.

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Chapter 0.1

Introducing the Guidelines

These guidelines have four parts, each with its own table of contents. This publication has been designed for ease of use, including cross-referencing, with graphics as outlined below:

- **graphic identification** of sub-systems, as explained in Part 1
- **shaded boxes** containing examples or commentary
- **abbreviated flow charts** in the margins, with the relevant boxes shaded

Part 0 provides background information and guidance integral to an understanding of the entire guidelines in an American context. The term "fire protection engineer" is common in the U.S. and is used periodically within Part 0. The term "fire engineer" was felt to better describe on an international level the type of engineer who would undertake design methods described in these guidelines. Therefore, the primary term used in Parts 1, 2 and 3, and to a lesser extent in Part 0 is "fire engineer."

Another term used typically in the U.S. that tends to vary internationally is the use of the term "performance criteria" versus "acceptance criteria." These terms mean the same thing and may be used interchangeably. Such criteria are used to determine when a design for a particular building or element of a building would be acceptable.

Part 1 describes the fire engineering process.

Part 2 describes a selection of methodologies that may be used in the fire engineering process.

Part 3 provides data that may be used in applying the methodologies of Part 2 or other chosen methodologies for fire engineering.

The guidelines are paginated on a chapter basis in order to facilitate revision by replacement of individual chapters. It is envisaged that Part 1 will likely require less frequent revision than Parts 2 and 3.

0.1.1 Evolution

The International Fire Engineering Guidelines (IFEG) represents the third edition of guidelines published in Australia (1996 and 2001). The first two guideline documents were specifically written for Australia by Australians. This edition is specifically more international.

The objectives of the guidelines are to:

- provide a link between the regulatory system and fire engineering for Australia, Canada, New Zealand and the United States (Part 0)
- provide guidance for the process of fire engineering (Part 1)
- provide guidance for fire engineers on the available methodologies (Part 2) and data (Part 3)

This document has been written in the form of guidelines rather than in a mandatory or code format to reflect the current state of fire engineering. The use of a mandatory format was discussed at length before the development of both the first and second editions (see below) of these guidelines. It was concluded that fire engineering lacks the necessary array of validated tools and data necessary to produce such a mandatory document.

Fire engineering evaluations are complex and require engineering judgment. In addition, those required to assess the output of fire engineering evaluations need an understanding of the fire engineering process and what constitutes an acceptable fire engineering evaluation. Therefore, guidance is required both to improve the standard of application of fire engineering by practitioners and to improve the ability of the authority having jurisdiction (AHJ) to carry out their function of safeguarding the community. Adherence to these guidelines by practitioners is therefore a necessary prerequisite to improving the quality of fire engineering and its acceptance as an engineering discipline.

The ***Canon of Ethics for Fire Protection Engineers*** developed by the Society of Fire Protection Engineers (SFPE) deals with professional issues outside the scope of these guidelines and should be consulted as appropriate. Excerpts from the Canon of Ethics are found in Chapter 0.4. The SFPE also conducts periodic surveys of the industry to understand what roles fire protection engineers play. Additional information relating to fire engineering can be obtained from their website, at www.sfpe.org.

These guidelines embrace the best fire engineering practices throughout the world, and draw on previous work and parallel work from many groups. Documents used include:

- Fire Safety Engineering Guidelines (FSEG), Edition 2001. November 2001, Australian Building Codes Board, Canberra, Australia.
- Fire Engineering Guidelines (FEG), First Edition. March 1996. Fire Code Reform Centre Ltd., Sydney, Australia (March 1996).
- Building Code of Australia (ABCB) — Volume 1, Class 2 to Class 9 Buildings. Australian Building Codes Board, Canberra, Australia, 2005.
- Fire Engineering Design Guide, 2nd Edition. University of Canterbury, New Zealand (2001).
- CIBSE Guide E, Fire Engineering. Chartered Institute of Building Services Engineers, U.K. (February 1997).
- International Organization for Standardization, Fire Safety Engineering ISO/TR 13387: 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 behavior, location and condition

- Fire Safety Engineering in Buildings 2001 – Code of Practice, British Standard BS7974.
- The 2000 SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers, Bethesda MD, USA.
- 2001 and 2003 International Code Council (ICC) Performance Code for Buildings and Facilities, ICC, Falls Church, VA, USA.
- Code Officials Guide to Performance-Based Design. SPFE/ICC, 2004, ICC, Falls Church, VA, USA.

0.1.2 Scope

These guidelines have been developed for use in fire engineering design and evaluation of buildings. However, the concepts and principles may also be of assistance in a fire engineering evaluation of other structures such as ships and tunnels that are comprised of enclosed spaces.

This document provides guidance for fire engineers to design and evaluate fire safety systems to achieve acceptable levels of safety. The guidelines assume the fire engineer has a level of competence and experience that would enable licensing by the respective state.

In particular, the guidelines provide guidance for the design and evaluation of alternative solutions (equivalencies) and general performance design.

Fire engineers need to interpret the guidance provided in these guidelines with flexibility and use the guidelines as a tool for responsible fire engineering. The role played by fire engineering in building fire safety and the term “fire engineer” are discussed in Chapters 0.3 and 0.4, respectively.

These guidelines will also be of use to other people, such as code officials (fire, building, plumbing and mechanical), in carrying out their roles of assessing and approving building design and construction in accordance with appropriate regulations. They may form the basis of checklists commonly used as an aid for such activities but such lists should provide for flexibility these guidelines allow. In addition, the *Code Officials Guide to Performance Design Review* (ICC/SFPE 2004) plays an important role in this regard. Many explanations and resources are offered from the perspective of a code official (building or fire officials).

Fire engineering is developing with a large degree of international cooperation. Parts 1, 2 and 3 of these guidelines are written to be universally applicable, whereas Part 0 applies to fire engineering in the United States.

0.1.3 Limitations

These guidelines are not intended to:

- apply to situations where a person is involved, either accidentally or intentionally, with the fire ignition or early stages of development of a fire; building fire safety systems are not generally designed to protect such persons
- encompass situations that involve fire hazards outside the range normally encountered in buildings, such as storage of flammable liquids, processing of industrial chemicals or handling of explosive materials (hazmat)
- enable inexperienced or unqualified people to undertake work that should be done by licensed and properly experienced fire engineers
- replace available textbooks, examples of which are given in Section 0.5.3.

Hazardous materials are not specifically addressed by these guidelines, though the concepts are generally the same. There are references available (Zalosh, 2003 – Industrial Fire Protection Engineering) which address industrial fire protection. The *International Fire Code* and the *ICC Performance Code for Buildings and Facilities (ICCPC)* specifically address hazardous materials as they relate to the immediate threats to occupants and emergency responders. Federal environmental and transportation laws address additional concerns. For these situations, applicable federal and state regulations for storage and handling of hazardous and dangerous goods and appropriate special experts should be consulted. Provisions found in the ICCPC were crafted based on performance language found in the federal regulations.

The goal of “absolute” or “100-percent” safety is not attainable, and there will always be a finite risk of injury, death or property damage. Some of the guidance in these guidelines relates to the evaluation of such risks and the qualitative and quantitative methodologies available. The ICCPC reflects this by stating “no person not directly adjacent to or involved in the ignition of a fire shall suffer serious injury or death” (602.2 and 1701.2).

Furthermore, fire and its consequent effects on people and property are both complex and variable. Thus, a fire engineering strategy may not effectively cope with all possible scenarios. This needs to be understood by the code official and others in their assessment of fire engineered solutions.

Chapter 0.2

The Regulatory System

In the United States, building regulations are addressed by state and local governments. These local government entities have a choice of several codes they may use for building regulations. They can:

- Write their own regulations
- Adopt a model building code

A model building code is one that is developed through not-for-profit membership organizations. The primary choice for developing regulations is to use a model code. The codes are adopted with varying levels of amendments.

Currently, both performance and prescriptive building codes are available. These include:

Prescriptive

- *International Building Code* (2000, 2003)
- *NFPA 5000* (2003) (contains a performance option)
- *National Building Code* (1999) – Predecessor of IBC
- *Standard Building Code* (1997) – Predecessor of IBC
- *Uniform Building Code* (1997) – Predecessor of IBC

Performance

- *ICC Performance Code for Buildings and Facilities* (2001, 2003)
- Performance Option of *NFPA 5000* (2003)

Most jurisdictions use a prescriptive building code. The IBC is the predominant code being adopted in the United States, and is therefore the focus of this document.

The International Code Council Performance Code (ICCPC) was developed as a performance code and was considered to be the next phase in building code evolution. As knowledge of fire engineering progressed, the need for a new objective-oriented code became apparent. This code is intended to use the prescriptive building code and related codes as a means of compliance, but ultimately jurisdictions decide how the code will be adopted and applied.

To better understand the role of these codes, the intent statements of the IBC and the overall content of the ICCPC will be reviewed. The intent of the *International Building Code* is as follows:

> *To safeguard the public health, safety and general welfare through structural strength, means of egress facilities, stability, sanitation, adequate light and ventilation, energy conservation, and safety to life and property from fire and other hazards and to provide safety to fire fighters and emergency responders during emergency operations.*

The basic intent of the *ICC Performance Code for Buildings and Facilities* is split into building and fire as these subjects relate to the scope of traditional building and fire codes in the U.S. as follows:

101.2 Intent.

101.2.1 Building.

To provide an acceptable level of health, safety and welfare and to limit damage to property from events that are expected to impact buildings and structures"

1. *An environment free of unreasonable risk of death and injury from fires*
2. *A structure that will withstand loads associated with normal use and of the severity associated with the location in which the structure is constructed*
3. *Means of egress and access for normal and emergency circumstances*
4. *Limited spread of fire both within the building and to adjacent properties*
5. *Ventilation and sanitation facilities to maintain the health of occupants*
6. *Natural light, heating, cooking and other amenities necessary for the well being of the occupants*
7. *Efficient use of energy*
8. *Safety to fire fighters and emergency responders during emergency operations*

101.2.2 Fire.

Part III of this code establishes requirements necessary to provide an acceptable level of life safety and property protection from the hazards of fire, explosion or dangerous conditions in all facilities, equipment and processes.

0.2.1 The Regulatory Framework

The United States' regulatory system delegates police powers to the states from the federal level. This includes the power to adopt building regulations. Although states govern in different ways, building regulations are a duty of state and local governments. In some states, all buildings must comply with a state level building code. In other cases, only certain buildings such as schools or hospitals must comply with the state building code. Sometimes, state power is delegated directly to the local government. There are a few federal regulations such as for hospitals that require compliance with additional documents, such as *NFPA 101®* or the *International Building Code,* beyond those required by the state.

- **A law** (ordinance) that sets the administrative framework for the control system, and gives the state and/or communities the police power to adopt codes (regulations).
- **Codes** (regulations) provide technical requirements for buildings and facilities and describe detailed procedural matters, assessments, approvals, inspections,

certifications, appeals, penalties, accrediting bodies and permit the government to include conditions on building construction.

- **Standards** are referenced by the codes and provide detailed guidance on how regulations are to be applied. When standards are referenced in the building regulations, they are legally binding.

This framework is realized as follows:

- **The U.S. Constitution** enables states to regulate building construction; because police powers are a role the states are designated.
- **Building legislation,** administered by the states, controls building construction and may delegate authority to local level (county, town, city, township, etc).
- **Building codes** (regulations), given status by the development/building legislation, regulate building construction.
- **Model building and associated codes and standards** provide the technical content for the building regulations.

With the occasional exception for state and federal buildings, building codes are usually enforced at the local level. There is usually some level of interaction with the local building and fire department during design and construction. This is essential as the fire department, for example, responds to emergencies throughout the jurisdiction. It should be noted that fire departments in the U.S. tend to be more involved during the design and construction process than in most other parts of the world.

Privatization of building departments and fire departments is not typical in the United States, though some departments seek outside assistance with plan review services and inspections. The ICCPC encourages the use of peer review and contract review services when a jurisdiction feels they do not have the qualifications to review a particular design. This is, of course, the decision of the jurisdiction as to how they approach such situations. Peer review, contract review and third party review are discussed further in Section 0.3.4. Special inspection requirements may also necessitate the use of third party inspection agencies, especially since the required expertise may be specialized.

0.2.2 Building Codes

0.2.2.1 Equivalency

As discussed in Section 0.2, in the United States, building codes are developed by not-for- profit public benefit organizations. These codes are developed through the participation of members (Code officials, design professionals, product producers, trade organization and laborers) of these organizations and are made available as models for state and local governments to adopt as their building regulations. The codes used primarily in the United States are prescriptive codes, and are not performance codes, but do have elements that would be considered as performance. A clause in these codes allows the use of equivalent designs to work outside the prescriptive codes. Additionally, NFPA has not developed an independent performance code, but instead includes a performance option within its building code. Prior to that option, equivalencies were the main mechanism for performance design. Now both the equivalency clause and the performance option are available. As noted in Section 0.2, performance codes are available, but are not currently in wide use and are used primarily as an alternative process for equivalencies in several jurisdictions. For example Pennsylvania has adopted the ICC Performance Code as an alternative compliance option.

The intent of the *International Building Code* is addressed in Section 0.2 of this document. It is very similar to that of the ICC Performance Code, but the code itself provides a prescriptive approach for designers. The equivalency clause, which allows performance design within the IBC, is as follows:

.

> ***104.11 Alternative materials, design and methods of construction and equipment.*** *The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.*

This section is supported by two subsections addressing necessary research reports and tests. The subsections read as follows:

> ***104.11.1 Research reports.*** *Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, shall consist of valid research reports from approved sources.*

> ***104.11.2 Tests.*** *Whenever there is insufficient evidence of compliance with the provisions of this code, or evidence that a material or method does not conform to the requirements of this code, or in order to substantiate claims for alternative materials or methods, the building official shall have the authority to require tests as evidence of compliance to be made at no expense to the jurisdiction. Test methods shall be as specified in this code or by other recognized test standards. In the absence of recognized and accepted test methods, the building official shall approve the testing procedures. Tests shall be performed by an approved agency. Reports of such tests shall be retained by the building official for the period required for retention of public records.*

If the ICCPC is adopted by a state or local jurisdiction, it is generally intended to provide a framework that encompasses the prescriptive building, fire, mechanical and associated codes as compliance options. Those documents would likely be deemed to comply with the performance objectives, functional statements and performance requirements found in the ICCPC.

As noted, most jurisdictions will have adopted a prescriptive building code for their building regulations. In this case, all designs would need to demonstrate equivalency with the prescriptive requirements. Some states have adopted the prescriptive codes, but allow the use of the ICCPC as an alternative to those codes.

0.2.2.2 Performance Code

The ICC has published a performance code titled the *ICC Performance Code for Buildings and Facilities*. As discussed above, NFPA does not publish a performance code, but instead has provided a performance option within their building code (*NFPA 5000*®). This section will provide an overview of the ICCPC.

The ICCPC has four main parts, listed as follows:

- Part I – Administrative (Chapters 1—4)
- Part II – Building Provisions (Chapters 5—15)
- Part III – Fire Provisions (Chapters 16—22)
- Part IV– Appendices (A—E)

Part I—Administrative

Part I of the document contains four chapters. These chapters are those which common approaches were found for both building and fire code related topics. Chapter 1 includes administrative provisions such as intent, scope and requirements related to qualifications, documentation, review, maintenance and change of use or occupancy. This section could be used as a framework for jurisdictions even when the ICCPC is not adopted. Provisions for approving acceptable methods are also provided in Chapter 1. Chapter 2 provides definitions specific to this ICCPC.

Chapter 3, entitled "Design Performance Levels," provides the framework for determining the appropriate performance desired from a building or facility, based on a particular event such as wind, earthquake or fire. Specifically, the user of the code may easily determine the expected performance level of a building during an earthquake. In the current prescriptive code, the required performance is simply prescribed without a method to determine or quantify the level of the building or facility's performance. In other words, all the requirements such as heights and areas, sprinklers and structural specifications are indirectly attempting to address the hazards buildings are subjected to and the losses society is able to tolerate. Since these issues are dealt with indirectly, it is difficult to measure the level of safety provided. Therefore, when applying the alternate materials and methods approach for the prescriptive code, it is difficult to determine what is meant by "equivalent.". The designer frequently ends up trying to determine what is considered to be equivalent. The problem with the designer determining the intended performance level is that such decisions are not technical in nature. Such decisions are value judgments, which should ultimately be made by policy makers. This chapter can serve as the link between the policy makers and the designers by providing measurable guidance as to desired performance.

Finally, Chapter 4 addresses topics of reliability and durability and how these issues interact with the overall performance of a building or facility over the life of the building or facility. This is an issue that has always been relevant to codes and standards but becomes more obvious when a performance code requires a designer to consider buildings as a system. Also, there is often a concern that when performance designs are implemented, necessary redundancies may be removed. For example, greater dependence may be placed on the use of a single active fire protection system rather than relying on a combination of passive compartmentation and active fire protection systems. It is hoped that a specific focus on the issues of reliability and durability within the code document will help to address this concern in the future. Reliability includes redundancy, maintenance, durability, quality of installation, integrity of the design and, generally, the qualifications of those involved with this process.

Parts II and III–Building and Fire

Parts II and III provide topic-specific qualitative statements of intent that relate to current prescriptive code requirements. As noted, Parts II and III are building and fire components, respectively. The reason the building and fire components were not fully integrated was due to the concerns relating to how such a document might be used. For instance, a fire department may want to use the document for existing buildings or facilities, but would not be able to adopt chapters dealing with issues such as structural stability or moisture. Therefore, the code is designed so a fire department could adopt only Parts I and III. When Part II is adopted the entire document should be adopted, Part III should always be included in the adoption of the performance code.

The topic-specific qualitative statements are the basic elements missing from the prescriptive codes. The statements, found in Parts II and III, follow a hierarchy, as described below.

Objective. The objectives state what is expected in terms of societal goals. In other words, the objectives outline what society "demands" from buildings and facilities. Objectives are topic-specific and deal with aspects of performance required in a building, such as safeguarding people during escape and rescue.

Functional Statement. The functional statement explains the function a building must provide to meet the objective. For example, a building must be constructed to provide people with adequate time to reach a place of safety without exposure to untenable conditions.

Performance Requirements. Performance requirements are detailed statements that break down the functional statements into measurable terms. This is where the link is made to acceptable methods such as the *International Building Code*.

Societal goals are difficult to determine, but need to be reflected in the code, since they are the reason regulations for buildings and facilities exist. Society expects a certain performance from buildings and facilities, and demands local codes and their enforcement to provide that protection. Such goals need to match what policy makers expect. These goals will vary among communities because of specific needs and concerns, such as the preservation of an historic part of a community, or perhaps a business that employs a majority of the town's work force. The model codes have been relied on by policy makers to reflect these goals, but the model codes have focused on protecting life and property of individual buildings to minimize life loss and property protection to "acceptable levels." Desired goals are not always achieved by the adoption of model codes. Variations in community social objectives are reflected by local amendments. In the performance-based code, objectives, functional statements and performance requirements are general in nature and use terms such as "reasonable," "adequate" or "acceptable." In the current prescriptive code, there is only one value deemed "reasonable;" thus, communities must amend the code to reflect their local needs. Justifying amendments is often difficult in a prescriptive code environment since there is a single solution versus understanding outcomes tolerated by society in events such as earthquakes. Much of the structural provisions in the prescriptive building code are somewhat performance-oriented and easily accommodate a variety of design approaches and unique building features. In the performance code, an environment is being created where "reasonable" is qualified by what level of damage is tolerable to a community, based on the type of events expected, and use and importance of the building impacted. It is hoped this code will create a framework policy makers can use to clearly reflect what society expects in the built environment.

Part IV-Appendices

Part IV simply contains the appendices to the code document. Each of the appendices relate back to specific provisions of this code and are discussed in more detail within the User's Guide of the ICCPC in terms of how they are intended to apply.

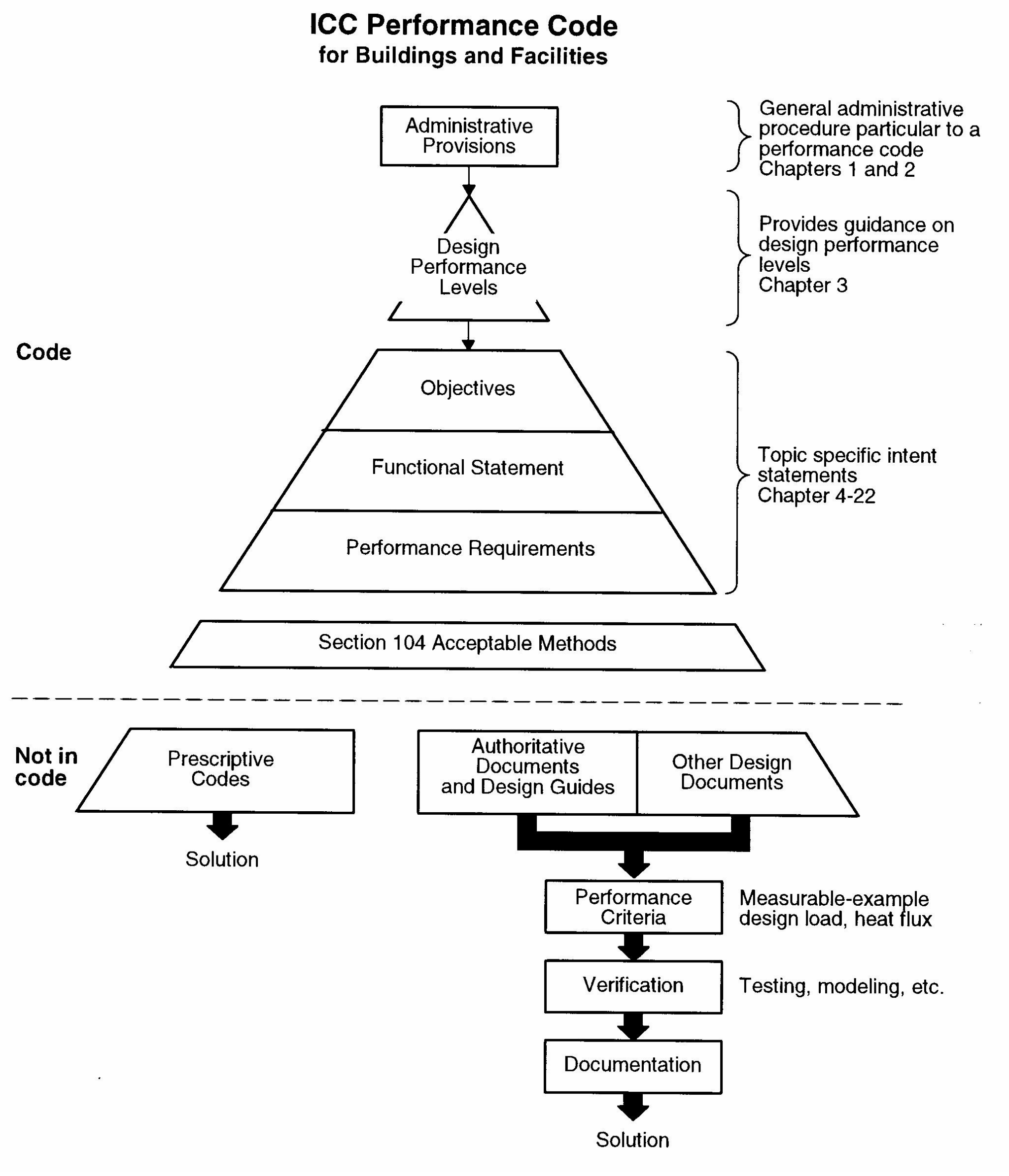

Figure 0.2.2 The ICCPC Hierarchy

0.2.2.3 Non-Quantification of Risk

The fire-related requirements of the ICCPC aim to provide a benchmark for the risk of fatality, injury and loss of property to the building and adjacent structures through fire. This benchmark is not intended to guarantee "absolute safety" or "zero risk" because these concepts are not possible. The benchmark risk must take into account what a community expects, and what the cost to the community will be—as determined by a cost-benefit analysis. This is also true of the prescriptive codes.

The level of safety outlined in the ICCPC is contained qualitatively in the levels of performance determined in Chapter 3 and, in many cases, as defined by the prescriptive codes. The performance requirements are the closest link to the prescriptive code and include the most detail to designers. The relationship between the acceptance criteria used to verify a design and the relevant performance requirements is often a matter of engineering judgment, whether or not the prescriptive code is used as a benchmark. Therefore, the level of safety provided can vary between individual practitioners and from project to project. This variation can be minimized by involving stakeholders in setting acceptance criteria, and compiling the Fire Engineering Brief described in Part 1 encourages such involvement.

The ICCPC requirements provide means by which fires in buildings may be managed to an acceptable degree. The ICCPC does not quantify the fires assumed to occur, although these implicitly vary according to the class of building and building characteristics. When a fire engineering evaluation is carried out, “design fires” have to be developed in order to evaluate the fire safety system under consideration. The quantification of design fires relies, to some extent, on the application of engineering judgment and can therefore vary between individual practitioners and from project to project. This variation can be minimized if the process described in Section 1.2.11 of these guidelines is used, and, as discussed in the fire engineering brief process (Chapter 1.2), stakeholders are involved. Also, Section 1701.3.15, Magnitude of Fire Event, found within the ICCPC provides a framework to determine fire sizes that should be addressed when using that code. It has been discussed that a standard or guide procedure will be developed to facilitate a consistent methodology for determining design fires. The SFPE is currently involved with activities in this area.

The I-Codes do not address intentional acts such as arson or terrorism. The ICCPC could be adapted to deal with such events. Essentially, these occurrences would simply be considered as another type of event that impacts a building.

In addition to the performance requirements not being quantified, such requirements use terminology such as “acceptable” and “adequate.” The interpretation of the terms “to the degree necessary” and “appropriate to” for any one factor will vary according to the project being evaluated. This adds to the difficulty in setting the acceptance criteria. This issue can be addressed in a similar way to the approach involving stakeholders described previously relating to the compilation of the Fire Engineering Brief. Most performance designs tend to address the equivalency process from the prescriptive codes.

Redundancies are important in many performance designs due to uncertainties arising from the lack of quantification of performance requirements and deficiencies in methods and data available (see discussion of Trial Designs in Part 1 of these guidelines). Such redundancies can be used to compensate for uncertainties and deficiencies, and these guidelines recommend redundancy be examined in the context of sensitivity studies (see Section 1.2.9.5).

0.2.2.4 Performance Design

In the U.S., prescriptive building codes are commonly used. Performance codes are available, but have not been fully integrated into the building regulatory framework. If the performance codes are adopted, they are adopted to be used as an alternative to the prescriptive building code, rather than as the overriding document specifying the intent of the regulations. Therefore, the primary method of use will be through an equivalency design approach as it relates to the performance code. Otherwise, performance designs are simply undertaken through the traditional equivalency process.

When a building does not meet code requirements and an alternative (equivalency) solution is considered, the relevant performance requirement(s) need to be determined (See Section 1.2.8) when using the performance code. Another solution is to determine the intent of the prescriptive code through agreement and discussions with the authority having jurisdiction. In either situation, the AHJ should be involved in the process as early as possible. The SFPE Engineering Guide to Performance-Based Fire Protection (SFPE 2000) and *the SFPE Code Officials Guide to Performance-Based Design Review* (SFPE/ ICC 2004) are good resources to determine goals and objectives. Both these documents acknowledge that a performance code may not be adopted and that goals and objectives need to be derived for a particular project.

Example: Relationship between Prescriptive Provisions and Performance Requirements

Performance requirements are the closest link to the prescriptive code requirements.

IBC Requirement

803.5 Interior finish requirements based on group. *Interior wall and ceiling finish shall have a flame spread index not greater than that specified in Table 803.5 for the group and location designated. Interior wall and ceiling finish materials, other than textiles, tested in accordance with NFPA 286 and meeting the acceptance criteria of section 803.2.1 shall be permitted to be used where a class A classification in accordance with ASTM E 84 is required.*

The associated performance requirement from the ICCPC is as follows:

1701.3.1 Interior surface finishes. *Interior surface finishes on walls, floors, ceilings and suspended building elements shall resist the spread of fire and limit the generation of unacceptable levels of toxic gases, smoke and heat appropriate to the design performance level and associated hazards, risks, and fire safety systems or features installed.*

If a material that does not meet the requirements of either ASTM E84 or NFPA 286 is introduced, the analysis must focus on the performance requirements of Section 1701.3.1 of the ICCPC. This section describes the intent of the requirements in Section 803.5 of the IBC. Application of this section of the ICCPC would require the determination of acceptance criteria and the use of some type of verification methods to demonstrate compliance. Verification methods may involve computer model analysis and, in some cases, full-scale testing. A full review of the ICCPC provisions within Chapter 3 for performance levels and Sections 1701.2 and 1701.3 would be necessary to get the entire context of the requirements. The functional statement found in Section 1701.2 limits the spread of fire so that no person not directly adjacent to or involved in the ignition of a fire shall suffer serious injury or death.

Regardless of the process used to determine relevant performance requirements or code intent, input from other stakeholders is essential to obtaining buy-in. This input is greatly facilitated by the fire engineering brief process and it is therefore recommended that particular attention be paid to this area.

0.2.2.5 Multiple Objectives – Beyond Fire

In many cases, prescriptive code requirements satisfy several intents. This can also be true when applying the performance code. These guidelines focus on fire but, it is possible a change made in the fire safety strategy will affect other aspects of the building, such as sound-related objectives or structural integrity. It is important to keep the possibility that multiple objectives may be involved when undertaking a design. This is especially critical when doing an equivalency strictly based on the prescriptive requirements. Ideally, the entire performance code should be reviewed to ensure all aspects of building performance relevant to building codes are addressed.

0.2.2.6 Beyond the Regulations

In addition to looking beyond fire-related code objectives, there is often a need to look beyond the building codes themselves. Part 0 focuses on the regulatory environment from the standpoint of building codes, but there may be other relative stakeholders or regulatory requirements that would necessitate coordination of the fire engineering strategy for a building or facility. Some examples may include, but not be limited to the following:

- Regulations from other government sectors
    - Environmental Protection Agency

    - Occupational Safety Health Administration
    - Others
- Insurance policy requirements where applicable
- Building owner needs
    - Historic preservation
    - Business continuity
    - Design flexibility
    - Cost effectiveness

These issues are discussed in Chapter 0.3 and 0.4 of these guidelines.

0.2.3 The Approval Process

The approval processes and the documentation for alternative solutions required vary from jurisdiction to jurisdiction in the United States. This is because the police power has been delegated by the federal government to the states. The states are then allowed to further delegate such police powers as they desire. Each state varies in addressing qualifications of design professionals and contractors, and the procedures for demonstrating compliance with building codes. Jurisdictions may be hesitant to consider equivalencies. Therefore, only general guidance is given in these guidelines. The requirements of each state and appropriate local jurisdiction should be consulted for detailed information.

One of the keys to the approval process with equivalencies and performance design is documentation. The prescriptive code does not provide guidance on such documentation, whereas the performance code has extensive guidance on documentation within Section 103 of the ICCPC. Section 103 also focuses extensively on responsibilities and qualifications. Section 103 of the ICCPC may serve as a framework for the administrative aspects of the design, construction and maintenance process.

The roles and responsibilities of the AHJ and fire engineer in the approval process may vary for each state and local jurisdiction. In most situations, fire engineers are not part of the main design team. The following discussion provides general guidance on their roles from the point of view of the fire engineering and approvals process by the AHJ to facilitate appropriate and consistent outcomes.

The AHJ would generally:

- be responsible for assessing and approving equivalencies and performance designs
- identify areas of non-compliance
- confirm the performance requirements and/or intent applicable to the areas of non-compliance
- participate in the fire engineering brief process
- if necessary (see Section 0.3.4), seek appropriate third party review of alternative solutions or peer reviews
- ensure appropriate inspections and testing are undertaken and documented to verify the building functions as designed
- ensure the retention of all relevant documentation
- ensure future use and maintenance conform with the conditions of approval

In carrying out the directives listed above, it is essential for the AHJ to remain independent of the design process while still providing input for the project.

The fire engineer would generally:

- undertake evaluation of equivalencies or performance designs
- provide guidance on and technical justification for decisions made during the fire safety protection engineering design brief process on matters such as acceptance criteria, design fires, design occupant groups and analysis strategy

- in the case of the performance code application, determine, with approval from the AHJ, which performance requirements are applicable to the focus of the design
- provide design advice as part of the building team
- prepare the fire engineering evaluation report, based on the IFEG guidance, and using the format provided in Chapter 1.11 Preparing the Report, for assessment by the AHJ
- identify any special commissioning, management in use and maintenance requirements of design

Currently, it is not customary for the design engineer to participate in the construction, approval process. Requirements for special inspections may determine the need for a fire engineer to follow through with specific issues during construction such as smoke control and spray-applied fire resistance. Ultimately, it is the jurisdiction that will determine the need for special inspections on unique designs and must approve the person or persons undertaking the inspections and testing. It is possible the jurisdiction will take on the responsibility. Chapter 17 of the IBC has specific requirements for special inspections. The ICCPC administrative provisions will determine any specific needs for special inspections and approvals for a given design.

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Chapter 0.3

Fire Engineering

The International Standards Organization (ISO) defines fire engineering as:

> *"The application of engineering principles, rules and expert judgment based on a scientific appreciation of the fire phenomena, of the effects of fire, and the reaction and behavior 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 Society of Fire Protection Engineers describes fire protection engineering as the following:

> *"Fire protection engineering is the application of science and engineering principles to protect people and their environment from destructive fire and includes: analysis of fire hazards; mitigation of fire damage by proper design, construction, arrangement, and use of buildings, materials, structures, industrial processes, and transportation systems; the design,*

installation and maintenance of fire detection and suppression and communication systems; and post/fire investigation and analysis.

A fire protection engineer (FPE) by education, training, and experience: (1) is familiar with the nature and characteristics of fire and the associated products of combustion; (2) understands how fires originate, spread within and outside of buildings/structures, and can be detected, controlled, and/or extinguished; and (3) is able to anticipate the behavior of materials, structures, machines, apparatus, and processes as related to the protection of life and property from fire."

Fire engineering is a rapidly developing discipline. In comparison to established engineering disciplines, it does not have widely accepted methods of approaching and solving problems. These guidelines have been written to help overcome these deficiencies, along with other resources that currently exist.

Fire engineering has only become a possibility as a result of developments in fire science that have provided an increased understanding of many aspects of building fires, such as:

- 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 behavior and effects modeling
- human behavior and toxic effects modeling

The practice of fire engineering has been facilitated by recent developments, such as:

- the computerization of fire models, particularly the complex models requiring extended computations
- increases in computer capability and capacity
- the introduction of performance-based codes with specific provisions for the acceptance of fire-engineered solutions

0.3.1 Benefits

Fire engineering can be used for objectives other than those of building and fire regulations, and thus has wider applicability and potential benefits beyond evaluating alternative solutions for building codes.

Some of these objectives are:

- 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 a country's heritage in older or significant buildings
- limiting the release of hazardous materials into the environment (beyond the limits required by fire codes)
- safeguarding community interests and infrastructure beyond that which is normally required of the building code

In addition, the client may have various non-fire related objectives for the building design that impact 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

All these objectives, together with the mandatory requirements, should be taken into account for an integrated, cost-effective fire protection strategy. The fire engineer has a duty of care to draw the client's attention to objectives that may adversely affect the client or the community.

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

- a disciplined approach to fire design
- a better appreciation of the interaction of the components that make up a building's fire protection systems
- a method of comparing the fire safety inherent in design solutions
- a basis for selection of appropriate fire protection systems
- monetary savings through the use of alternative methods and materials
- 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 building code requirements
- solutions for upgrading existing buildings when required by regulatory authorities
- solid technical ability to challenge some of the prescriptive requirements in today's model codes

0.3.2 Life Cycle Fire Engineering

Building design is only one element of the process to ensure fire safety is achieved for the life of a building. Figure 0.3.2. shows the various stages that represent the life cycle of a building, and the role that fire engineering can play in each of these stages.

In general, fire engineering is used when a design does not meet the prescriptive building code requirements. Such use does not recognize the potential of fire engineering and its role as a partner with other professional disciplines.

In building design, fire engineering can be integrated with other professional disciplines. Architects work with many disciplines, and fire engineering is a recent addition. Fire engineering closely relates to building professions such as architecture, electrical engineering, structural engineering, mechanical engineering and project management.

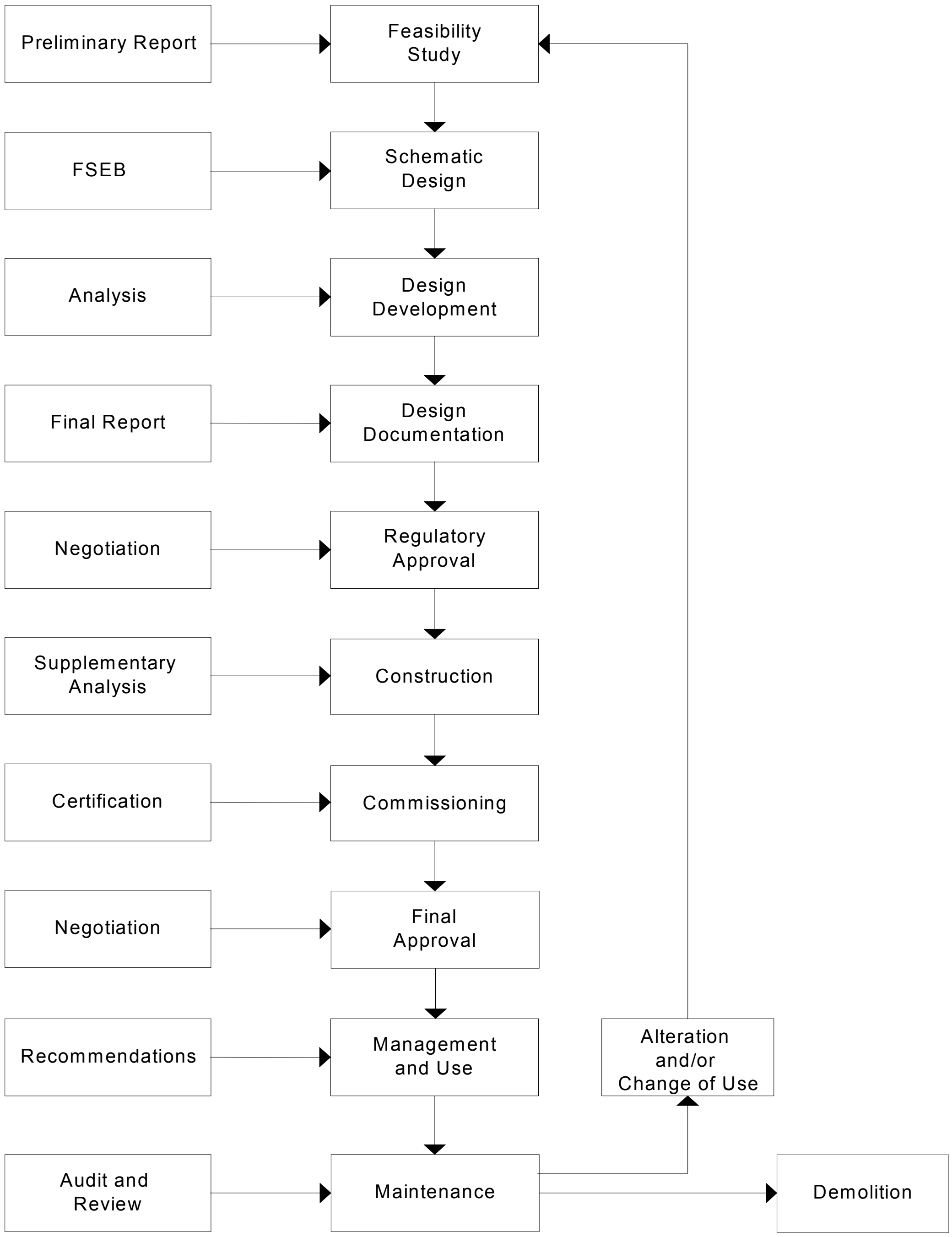
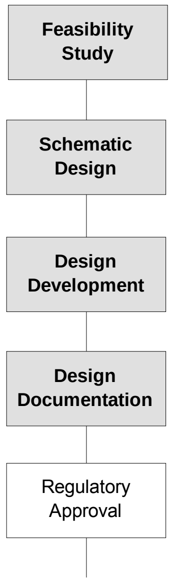


Figure 0.3.2.
Fire engineering involvement in the various stages in the life cycle of a building.

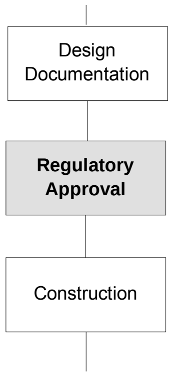
0.3.2.1 Design

Benefits of fire engineering are greatest if involved early in the design process. Indeed, fire engineering can contribute to each stage of the design process indicated in Figure 0.3.2.



- A conceptual design can assist in understanding the benefits during the **feasibility study** phase by providing flexibility in terms of the use of fire safety systems that do not conform to the prescriptive code provisions and, in many cases, consequent cost savings. A feasibility report incorporating this information may form a useful basis for discussions with building and fire officials at this stage of the design process.
- The fire engineering brief (FEB), which is discussed in detail in Chapter 1.2, provides a consensus on the fire safety components of the **schematic designs** being considered and the design options that need evaluation. The use of alternative fire safety solutions (to the code requirements) may lead to designs that are both more functional and economical.
- Analysis of the trial design(s) identified in the FEB may guide the **design development** by indicating which design(s) meet the performance criteria derived from the prescriptive building code, performance requirements from a performance code and goals of other stakeholders. This may also demonstrate which components of the fire safety system need special attention; in other words which variables were more sensitive to change. Design development may also lead to additional trial designs needing analysis.
- The fire engineering final report will provide not only the justification for the fire safety system utilized, but also the detailed requirements to ensure that the **design documentation** includes the necessary construction, commissioning, operation and maintenance requirements. All of this documentation should be agreed upon and approved by the stakeholders early in the process to ensure a consistent approach.

0.3.2.2 Regulatory Approval



When the design requirements have been achieved, it is then the role of the authority having jurisdiction (AHJ) to assess that design and take one of several courses of action:

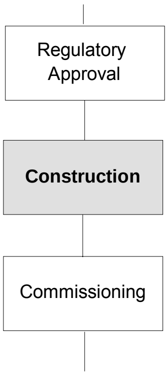
- approve the design
- ask for further information to clarify the design intention
- approve the design subject to certain conditions
- refuse approval, usually citing reasons for so doing

To undertake this process, the AHJ may choose to involve a third party with more expertise to assist in this process. Additionally, the AHJ may seek a peer review to ensure the overall philosophical approach and associated technical decisions are appropriate.

The regulator should be involved as early in the process as possible. This phase of approval will go more smoothly if the regulators are aware of the overall conceptual approach and have participated in the process of agreeing on acceptance criteria. The same is true of both third party reviewers and peer reviewers.

The fire engineer, having carried out an analysis of the fire safety system for any equivalency or performance design, is central to negotiations necessary to gain approval.

0.3.2.3 Construction/Installation

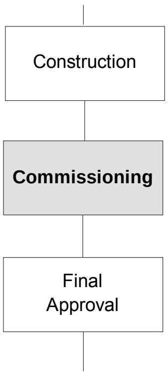


The fire engineer responsible for an alternative solution may be involved in the construction/installation stage to:

- facilitate the realization of the intent of the alternative design
- identify aspects crucial to the attainment of fire safety
- carry out supplementary analysis of changes to the design required (or that inadvertently occur)
- ensure fire safety levels are maintained during refit and refurbishment activities
- determine whether necessary fire safety system components are installed as specified (for example: sprinklers and smoke detectors)

It has not been common practice for fire engineers to be consulted during the construction phase of a project. Design approval can be affected by the fire engineer, which in turn affects the commissioning process. The building or fire official may require special inspections for elements of the design. For example, special inspections may be required for spray-applied fire proofing and smoke control systems.

0.3.2.4 Commissioning

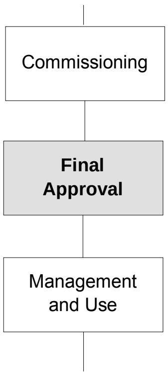


To realize fire safety of the design and to set a sound foundation for subsequent maintenance, proper commissioning is essential. For an alternative solution, it is advantageous to involve the fire engineer. The fire engineer can:

- set system performance criteria for the fire safety system
- certify the commissioning has complied with the fire engineered alternative solution

Commissioning occurs during and after the construction phase, and in many cases, may require a special inspection by a third party other than the fire engineer who undertook the design. The building code has specific areas where special inspections are required, (Chapter 17 of the *International Building Code*) and the unique features of a design may necessitate further special inspections to verify compliance.

0.3.2.5 Final Approval

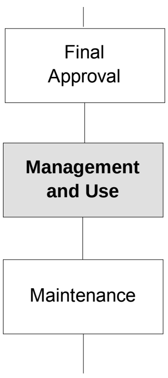


The final approval stage involves the issue of occupancy certificates and related issues. This stage is similar to the previous approval stage (Section 0.3.2.2 of these guidelines). In particular, the fire engineer may be required to verify that:

- the conditions of the regulatory approval have been met
- construction and commissioning meet the approved design
- fit outs (shops, malls, offices, etc.) do not compromise the fire safety and the fire safety evaluation carried out
- appropriate management and maintenance procedures are in place

Much of this information will be included in a design report.

0.3.2.6 Management and Use



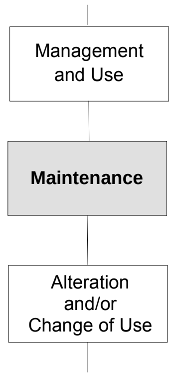
The day-to-day safety commitment by a building's management team will significantly affect the fire safety of a building. Fire engineering should ensure management and use provisions appropriate to the fire engineered design are in place. This may be accomplished by:

- contributing to the development of emergency evacuation procedures and associated training; [the procedures need to be consistent with the fire engineering evaluation, particularly regarding the method of warning occupants and the evacuation strategy (staged, horizontal, etc)

- listing any limitation on fuel loadings, use of evacuation routes, etc.
- providing guidelines for housekeeping and other aspects of management for fire safety (including maintenance discussed in the Section 0.3.2.7, below)

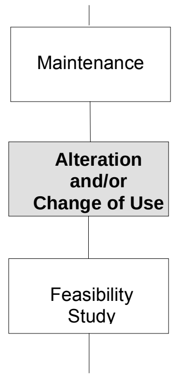
These guidelines often include non-technical descriptions and checklists to ensure requirements are able to be met by both building owners and fire inspectors. They are a unique fire prevention/maintenance code for a particular building or facility. Management and use issues should have been addressed in the design stage (Section 0.3.2.1), refined during commissioning (Section 0.3.2.4) and be subjected to final approval (Section 0.3.2.5).

0.3.2.7 Maintenance



The fire safety of a building depends on the ongoing functioning and efficacy of its fire safety system. The fire engineering process should be involved, where possible, in defining necessary periodic testing and maintenance programs, taking into account relevant codes, standards and related state and local requirements.

0.3.2.8 Alteration and/or Change of Use



Alterations or additions are frequently made to a building during its life, and it is not unusual for the use of a building to change. Fire engineering has potential in these circumstances because the alterations or additions may not conform to the prescriptive provisions or may compromise the original fire engineering design. Thus, fire engineering can:

- contribute to the process undertaken to obtain the necessary approvals for the altered building
- examine a fire engineering evaluation of the existing building to determine whether it still applies

In existing situations, fire engineering has the potential to develop realistic and effective solutions. This can be a beneficial tool to help meet the concerns of the code official (building and/or fire) and the building owner and designer.

0.3.3 Uniqueness of Application

Fire engineering is building-, occupant- and site-specific in its application; this can be both a strength and a weakness. Its strength is that it allows detailed consideration of the fire safety system most appropriate for the building characteristics, occupants and site. This enables the performance based approach to be realized in the most cost effective and practical way. A weakness may be that changes to the building, occupants and site may require a re-evaluation of the fire safety system to be carried out. This may not be necessary if a prescriptive approach was adopted. Steps can be taken to make the design more rigorous by examining reliabilities and taking a risk approach that may encompass a wider range of variables.

Many buildings appear to have similar or identical design features. However, detailed examination often reveals variations (some of which may be minor) that can have a significant influence on the fire safety of the buildings. Thus, from the fire engineering point of view, every building has subtle differences from other buildings. These differences may affect the fire safety. Thus, using one building or feature of a building as a precedent for approval for another is not appropriate, except in exceptional circumstances. Such circumstances may exist when a detailed comparison of the buildings and the implications for a fire engineering evaluation have been carried out and documented to demonstrate that, for the purposes of a fire engineering evaluation, the buildings are identical.

0.3.4 Third Party and Peer Review

Third party review and peer review are essential mechanisms in performance design and equivalency. Third party review is sometimes referred to as contract review because such a review can be substituted for the review by the code official, though ultimately the code official still needs to approve the design. Peer review is in addition to the typical review by the jurisdiction and focuses on the concepts and criteria chosen for design. (See Definitions – Section 0.5.1.)

A third party review should be undertaken as a constructive process to assist the authority having jurisdiction (AHJ) in assessing and approving a design involving an alternative solution supported by a fire engineering report. It should also assist the fire engineer in ensuring that all matters, especially the justification of expert judgment, are adequately addressed. A third party review should facilitate rather than hinder the approval of a given project. If this is not done, the process may be unduly protracted and jeopardize the worth of the third party review.

Those undertaking a third party review should understand that a fire engineering evaluation may vary according to preferences of the fire engineer and a number of different approaches may be used in undertaking a fire engineering evaluation. Professional detachment, flexibility and an open mind are essential characteristics of a good third party reviewer. 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.

When the AHJ has appropriate competence and experience, they may undertake assessment and approval of the alternative solution. When they do not have appropriate competence and experience, they may refer the assessment of the fire engineering report to a third party reviewer.

Generally, a fire engineer would not initiate a peer review, but might seek a third party review of some aspects of the evaluation (see Section 1.10.2, Step 2a of these guidelines). The owner or project manager may commission a third party review of a fire engineering evaluation in order to substantiate the conclusions. When the AHJ desires a third party review, it is best that such a review be contracted and paid for by the owner of the building, but be approved by the AHJ.

When a third party review is required by an AHJ, it is essential the reviewer be independent of the project and participants in the project in question (refer to Definitions, Section 0.5.1). The AHJ needs to determine whether a peer review is required. A peer review is likely going to be commissioned when methods being used are new or the building is high profile and very unique. A peer review is a more intense first principles review of a design. The focus is on the overall approach taken by the designer, rather than on the calculations. The qualifications of the peer reviewer should be at least the same, if not higher than, those of the designer.

Confidentiality issues are of concern during peer review, as they are with a third party review.

Subject to requirements of the AHJ, the reviewer should:

- use the guidance of the IFEG and other relevant resources, such as the Chapter 1 of the *ICC Performance Code for Buildings and Facilities*, the *SFPE*

Engineering Guide to Performance–Based Fire Protection, Analysis and Design of Buildings (SFPE 2000) and *The SFPE Code Officials Guide to Performance Based Design Review* (ICC/SFPE 2004) as the benchmark for the review
- ensure the decisions made in the FEB process have been followed in the analysis and conclusions
- carry out check calculations as appropriate to determine the quality of the analysis
- ensure that the report conforms to the requirements of the IFEG and relevant regulatory requirements and includes the appropriate items from Chapter 1.11

A review process may have a number of outcomes:
- The report adequately documents the evaluation of and supports the equivalency or performance design.
- Although the trial design appears to be acceptable, it is not adequately supported by the evaluation. In this case, it should be relatively simple for the fire engineer to satisfy the requirements of the reviewer.
- The analysis has fundamental flaws or the wrong analysis strategy has been adopted. In such cases, the analysis needs to be repeated in whole or in part before the acceptability of the trial design can be determined.
- The fire engineering brief (FEB) process has not been adequately carried out and the evaluation is unsound. The whole fire engineering evaluation, including the FEB and analysis may need to be revisited.

The conclusions of a third party review and peer review, if undertaken, should be documented. The report from the reviewer must be explicit and constructive in its approach so deficiencies in the evaluation and fire engineering report may be remedied. In particular:
- assertions and assumptions need to be substantiated and referenced in the manner these guidelines suggest for the fire engineering report itself
- check calculations should be sufficiently detailed to enable comprehension and evaluation
- the suggested remedial actions need to be clearly identified

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Chapter 0.4

Fire Engineers

0.4.1 About Fire Engineering

A fire engineer should have appropriate education, training and experience to:

- 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, spread within and outside of buildings/structures
- understand how fires can be detected, controlled and/or extinguished
- anticipate the behavior of materials, structures, machines, apparatus, and processes as 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
- be skilled in using and supporting engineering judgment
- understand and participate in the design process for buildings and other facilities
- understand building regulatory legislation and associated issues
- balance obligations to the client and the community
- negotiate with the client instructions that are appropriate to the work to be undertaken and to decline where the clients objectives are unacceptable

Objectives other than those of a building code may be appropriate for a given project, and the fire engineer should bring these to the attention of the client and explain the benefits. Such objectives, which may include limiting building damage, maintaining building operation and limiting environmental damage, are discussed in Sections 0.3.1 and 1.2.5 of these guidelines.

Fire engineering is an evolving discipline. It has few of the well-proven and well-understood tools and data other engineering disciplines enjoy. Thus, engineering judgment plays a greater role in fire engineering than in most other engineering disciplines.

The International Organization for Standardization (ISO) defines engineering judgment as:

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

This definition indicates a quantitative analysis method is only a tool for use by the fire engineer, who may choose what results are used, based on an appreciation of validity of the tool.

When engineering judgment is used, its use should be justified and the logic used in applying it explained (see Chapters 1.10 and 1.11).

Excerpts from the Society of Fire Protection Engineers Canon of Ethics are as follows:

Canon of Ethics for Fire Protection Engineers

Preamble

Fire protection engineering is an important learned profession. The members of the profession recognize that their work has a direct and vital impact on the quality of life for all people. Accordingly, the services provided by fire protection engineers require honesty, impartiality, fairness and equity, and must be dedicated to the protection and enhancement of the public safety, health and welfare. In the practice of their profession, fire protection engineers must maintain and constantly improve their competence and perform under a standard of professional behavior which requires adherence to the highest principles of ethical conduct with balanced regard for the interests of the public, clients, employers, colleagues, and the profession. Fire protection engineers are expected to act in accordance with this Code and all applicable laws and actively encourage others to do so.

Fundamental Principles

Fire protection engineers uphold and advance the honor and integrity of their profession by:

I. Using their knowledge and skill for the enhancement of human welfare.

II. Being honest and impartial, and serving with fidelity the public, their employers, and clients;

III. Striving to increase the competence and prestige of the fire protection engineering profession.

0.4.2 Licensing and Registration

Professional registration 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.

In the United States, professional registrations, similar to building regulations, are under the purview of each state. To obtain a Professional Engineering License as a fire protection engineer in the U.S., experience and education are the essential requirements. There are a variety of ways that experience and knowledge are recognized. On-the-job experience is extremely important, but taking the Fundamentals of Engineering (FE) test reduces the years of on-the-job experience required. This test can be taken as early as the 4^{th} year of an Accreditation Board for Engineering and Technology (ABET) accredited engineering program or when a non-ABET accredited engineering degree is completed. This depends on the requirements of each state. This test is general in nature and is not particular to fire protection engineering.

Once the qualifications are obtained, the fire engineering exam can be taken. The test provided is the same throughout the United States, but qualifications required to take the test vary by state. In addition, the level of responsibility granted by the professional registration varies depending on the state of issue. A license is strictly issued by an individual state. Obtaining a fire protection engineering license in one state does not entitle an engineer to automatically be recognized in another state. To obtain further state licenses, comity must be granted by each particular state, which usually requires demonstration of experience through documentation.

In terms of building design, it is important to understand what levels of responsibility the regulations in each state allow. In some states, for instance, having a professional engineering license in fire protection simply means one has the right to use the title, but is not allowed or required to stamp engineering designs.

When undertaking performance designs and equivalencies, people feel professional registration is not enough to demonstrate qualifications for such projects. In addition to professional registration, experience in certain types of projects is warranted to demonstrate abilities. This is related to the fact that there is a variety of people with varying areas of specialization who take the test. Such variation means that people who take and pass the exam may not have the expertise to undertake performance design. The variation in experience and expertise is a heavily debated issue amongst those in the design and construction industry. This is related to the thought that individuals should work within their area of expertise and be aware of their abilities and limitations. It is often difficult for jurisdictions to ask for additional qualifications as they do not have the authority to require further qualifications. Additionally, it could be argued market pressures would drive the appropriate experience and background for certain projects, which is outside the influence of the AHJ.

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Chapter 0.5

Definitions, Abbreviations and Information Sources

0.5.1 Definitions

Alternative solution	A building solution that complies with the performance requirements of a code other than by reason of satisfying the prescriptive code.
Approval	The granting of an approval, license, permit or other form of consent or certification by an authority having jurisdiction (AHJ).
Architect/engineer	The individual architect or engineer registered or licensed to practice his or her respective design profession, as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed.
Assessment	For the purposes of this document, whether a fire engineering report adequately supports an alternative solution. This process is carried out by the AHJ.
Authoritative document	A document containing a body of knowledge commonly used by practicing architects or engineers. It represents the state-of-the-art, including accepted engineering practices, test methods, criteria, loads, safety factors, reliability factors and similar technical matters. The document portrays the standard of care normally observed with a particular discipline. The content is promulgated through an open consensus process or a review by professional peers conducted by recognized authoritative professional societies, codes or standards organizations, or governmental bodies.
Authority having jurisdiction (AHJ)	A regulatory authority responsible for administering building controls. (Building and/or fire official.)
Available safe evacuation time (ASET)	The time between ignition of a fire and the onset of untenable conditions in a specific part of a building or facility.
Boundary conditions	A set of constraints for mathematical models.
Building solution	A solution that complies with the performance requirements of a code and is an alternative solution; a solution that complies with the deemed-to-satisfy provisions; or a combination of the two.
Code official	The code enforcement officer or other designated authority charged by the applicable governing body with duties of administration and enforcement of a code, including duly authorized representative. Often referred to as either building or fire code official. Considered the AHJ.
Commissioning	The process of verifying whether a system meets design, technical standards and code expectations via inspection, testing and operational functionality.
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 associated with the respondent, event type, clarity of information and situation. In a fire situation, the cues may be automatic, related to the combustion products of the fire,

	or given by other people.
Design documents	Design drawings, computations, geotechnical and other reports, specifications and related documentation submitted to governmental agencies for approval and for the purpose of constructing buildings and structures.
Design guide	A document containing a body of knowledge or information used by practicing architects and engineers, not required to meet an open consensus requirement. It represents accepted architectural/engineering principles and practices, tests and test data, criteria, loads, safety factors, reliability factors and similar technical data.
Design professional	An individual registered or licensed to practice his or her respective design profession, as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed.
Design fire	A mathematical representation of a fire that is characterized by the variation of heat output with time and is used as a basis for assessing fire safety systems.
Design fire scenario	A fire scenario used as the basis for a design fire.
Deterministic method	A methodology based on physical relationships derived from scientific theories and empirical results that will always produce the same outcome for a given set of conditions.
Engineering judgment	Process exercised by a professional qualified because of training, experience and recognized skills, to complement, supplement, accept or reject elements of a quantitative analysis.
Evacuation	The process in which: occupants become aware of a fire-related emergency; go through a number of behavioral stages before and/or while they travel to reach a place of safety, internal or external, away from the fire-related emergency.
Evaluation	For the purposes of this document, the process by which a fire engineer determines whether an alternative solution meets appropriate performance requirements or requirements of the prescriptive building code.
Field model	A model that divides a building enclosure into small control volumes and simulates the emission phenomena; the movement of smoke; and the concentrations of toxic species in various enclosures so times of critical events, such as detection of fire and the development of untenable conditions, can be estimated.
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.
Fire engineer	A person suitably qualified and experienced in fire engineering. In the U.S., this person is usually referred to

	as a fire protection engineer.
Fire engineering	See Section 0.2.
Fire engineering brief (FEB)	A documented process that defines the scope of work for the fire engineering analysis and the basis for analysis, as agreed by stakeholders.
Fire safety system	One or any combination of the methods used in a building to: (a) warn people of an emergency (b) provide for safe evacuation (c) restrict the spread of fire (d) extinguish a fire A fire safety system includes both active and passive systems.
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 localized fire to the combustion of all exposed surfaces within a room or compartment.
Functional statement	A requirement of the fire, building, system or occupants that must be obtained to achieve an objective. Functional statements are stated in more specific terms than objectives. Functional statements define a series of actions necessary to make the achievement of an objective more likely and are sometimes termed "objectives."
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 with the potential to give rise to unwanted consequences.
Heat release rate (HRR)	The rate at which heat is released by a fire.
Objective	Desired overall safety outcome, expressed in qualitative terms. Sometimes referred to as a "goal."
Operations and maintenance manual	Documentation that describes requirements and procedures necessary to keep a performance-based design within conditions of approval. In the ICCPC, conditions of approval are termed "bounding conditions."
Peer review	An independent, objective technical review of the design of a building or structure, to examine proposed conceptual and analytical concepts, objectives and criteria of the design and construction. It shall be conducted by an architect or engineer who has a level of experience in the design of projects similar to the one being reviewed, at least comparable to that of the architect or engineer responsible for the project.

Performance-based design	An engineering approach to design elements of a building, based on: agreed on performance goals and objectives; engineering analysis; quantitative assessment of alternatives to design goals and objectives, using accepted engineering tools, methodologies and performance criteria.
Performance requirement	Criteria, stated in engineering terms, by which the adequacy of any developed trial designs will be judged. Sometimes termed "performance criteria."
Place of safety	A place in a building or in the vicinity of a building, from which people may safely disperse after escaping effects of fire. It may be an open space (such as an open court) or a public space (such as a foyer or a roadway).
Prescriptive codes.	Codes that provide specific (design, construction and maintenance) requirements for building, energy conservation, fire prevention, mechanical, plumbing and so forth.
Principal Design Professional.	An architect or engineer responsible to the building owner, who has contractual responsibility and authority over all professional design disciplines to prepare and coordinate a complete, comprehensive set of design documents for a project.
Qualitative analysis	Analysis that involves a non-numerical and conceptual evaluation of identified processes.
Quality Assurance.	Inspection by code officials; special inspection and testing by qualified persons; and observation by architects/engineers, where applicable, of the construction of a building or structure, to verify general conformance with the construction documents, and applicable performance and prescriptive code requirements.
Quantitative analysis	Analysis that involves numerical evaluation of an identified processes.
Required safe evacuation time (RSET)	The time required for occupants to safely evacuate to a place of safety, prior to the onset of untenable conditions.
Risk	The likelihood of a hazardous event occurring.
Schematic design fire	A qualitative representation of a design fire, normally presented in the form of a graph.
Sensitivity analysis	A guide to the accuracy and/or criticality of 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 that evolve when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.
Smoldering fire	The solid phase combustion of a material, without flames but with smoke and heat production.
Special expert	An individual who has demonstrated qualifications in a specific area, outside the practice of architecture or

	engineering, by education, training and experience.
Special inspector	A qualified individual or entity performing intermittent or continuous observations of work or testing of materials, fabrication, erection, or placement of materials or components, acceptance testing of systems and related functions on behalf of the code official.
Sub-system	A part of a fire safety system that comprises fire safety measures to protect against a particular hazard (e.g., smoke spread). Note: These guidelines defines six sub-systems (see Chapter 1.3).
Third party review	A term associated with quality assurance and independence from another party whose work product is reviewed. Third party review does not apply to the peer review process. A third party is often used to review performance based designs for a jurisdiction.
Trial design	A fire safety system assessed using fire engineering techniques.
Untenable conditions	Environmental conditions associated with a fire in which human life is not sustainable.

0.5.2 Abbreviations

AHJ	Authority having jurisdiction
ASET	Available safe evacuation time
DTS	Deemed-to-satisfy
FCRC	Fire Code Reform Centre Ltd.
FE	Fire engineer
FEB	Fire engineering brief
IBC	2003 International Building Code
ICC	International Code Council Inc., U.S.A.
ICCPC	ICC Performance Code for Buildings and Facilities
ISO	International Standards Organization
NFPA	National Fire Protection Association, U.S.A.
HRR	Heat release rate
RSET	Required safe evacuation time
SFPE	Society of Fire Protection Engineers, U.S.A.
SS	Sub-system

0.5.3 Information Sources

Fire engineering professionals may refer to various sources for specific knowledge and information used in fire engineering assessments. The lists provided in the following sections are not comprehensive and only aim to serve as a guide to relevant resources.

0.5.3.1 Reference Works

The following publications provide guidance in the area of fire engineering:

Australasian Fire Authorities Council (1997). Fire Brigade Intervention Model — Version 2.1 November 1997, Box Hill, Victoria, Australia.

BSI (2001). *Application of Fire Protection Engineering Principles to the Design of Buildings – Code of Practice*, BS7974, British Standards Institution, London, U.K.

Buchanan, AH (Ed.) (2001). *Fire Engineering Design Guide*, 2nd Edition, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

CIBSE (The Chartered Institution of Building Services Engineers) (2003) *Guide Fire Engineering*, CIBSE, London, U.K.

Cote, A.E. (Ed.) (2003). *Fire Protection Handbook*, 2003 Edition. National Fire Protection Association, Quincy, MA, U.S.A.

Custer, R.L.P. & Meacham, B.J. (1997). *Introduction to Performance Based Fire Safety*, National Fire Protection Association, Quincy, MA, U.S.A.

DiNenno, P.J. (Ed.) (2002). *The SFPE Handbook of Fire Protection Engineering*, 3rd Edition, National Fire Protection Association, Quincy, MA, U.S.A.

Drysdale, D. (1999). *An Introduction to Fire Dynamics*, 2nd Edition, , John Wiley & Sons, Chichester, U.K.

European Convention for Constructional Steelwork (1985). *Design Manual on the European Recommendations for the Fire Safety of Steel Structures*, Technical Note No. 35.

Fitzgerald, R. (2004), *Building Fire Performance Analysis,* John Wiley and Sons, Chichester, UK.

ICC/SFPE (2004), *The SFPE Code Officials Guide to Performance Based Design Review*.

Karlsson, B. and Quintiere, J. (1990). *Enclosure Fire Dynamics*, CRC Press, Boca Raton, FL, U.S.A.

Klote, J.H. and Milke, J.A. (2002). *Design of Smoke Management Systems*, American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), Atlanta, GA, U.S.A.

Meacham, B.J. (2004). *Performance Based Building Design Concepts: A Companion Document to the ICC Performance Code*, ICC 2004.

0.5.3.2 Journals

The following journals may be useful for fire engineering professionals.

- *Combustion and Flame*, Elsevier, Netherlands
- *Combustion Science and Technology*, Gordon Breach, U.S.A.
- *Combustion Theory and Modeling*, Institute of Physics, U.K.
- *Fire and Materials*, Elsevier, Netherlands
- *Fire Safety Engineer (FSE),* Miller Breeman, U.K.
- *Fire Safety Journal*, Elsevier, Netherlands
- *Fire Science and Technology*, Center for Fire Science and Technology, Tokyo University of Science
- *Fire Technology*, NFPA, U.S.A.
- *International Journal on Performance Based Fire Codes*, Hong Kong Polytechnic Institute, Hong Kong, China
- *Journal of Applied Fire Science*, JASSA, U.S.A.
- *Journal of Fire Protection Engineering*, SFPE, U.S.A.
- *Journal of Fire Sciences*, U.S.A.
- *NFPA Journal*, NFPA, U.S.A.
- *SFPE Journal*, SFPE, U.S.A.

0.5.3.3 Conference Proceedings

The conferences listed below are held on an ongoing basis. There are separate volumes of proceedings for each conference held.

- Asiaflam Fire Science and Engineering Conferences
- Fire Australia Conferences
- IAFSS Symposia
- Interflam Fire Science and Engineering Conferences
- International Conferences on Fire Research and Engineering
- International Conferences on Performance Based Design and Fire Safety Design Methods
- International Symposia on Human Behaviour in Fires
- Pacific Rim Conferences

0.5.3.4 Tertiary Institutions

The following tertiary institutions are some of those that provide courses or conduct research in fire engineering.

- Carleton University, Canada
- Lund University, Sweden
- Oklahoma State University
- Queensland University of Technology, Australia
- Science University of Tokyo, Japan
- South Bank University, U.K.
- University of Canterbury, New Zealand
- University of Edinburgh, U.K.
- University of Greenwich, U.K.
- University of Leeds, U.K.
- University of Maryland, U.S.A.

- University of New Brunswick, Canada
- University of New Haven, U.S.A.
- University of Science and Technology of China, People's Republic of China
- University of Technology, Sydney, Australia
- University of Ulster, U.K.
- University of Western Sydney, Australia
- Victoria University of Technology, Australia
- Worcester Polytechnic Institute, U.S.A.

0.5.3.5 Fire Research Institutes

The following private or government research institutes publish and disseminate fire engineering-related knowledge and information.

- Building and Fire Research Laboratory, National Institute of Science and Technology (NIST), U.S.A.
- Building Research Association of New Zealand (BRANZ), New Zealand
- Centre for Environmental Safety and Risk Engineering (CESARE), Victoria University of Technology, Australia
- CSIRO Fire Science and Technology Laboratory, Australia
- Duisburg Gerhard-Mercator University Fire Detection Laboratory, Germany
- Factory Mutual, U.S.A.
- Fire and Risk Sciences, Building Research Establishment, U.K.
- Fire Science Centre, University of New Brunswick, U.S.A.
- Fire Science Laboratory, Worcester Polytechnic Institute, U.S.A.
- FireSERT, Fire Safety Engineering Research and Technology Centre, University of Ulster, U.K.
- National Fire Data Centre, U.S.A.
- National Research Council, Canada
- Scientific Services Laboratory — AGAL, Australia
- SINTEF, Norway
- Swedish National Testing and Research Institute, Sweden
- Technical Research Centre of Finland (VTT), Finland
- The Loss Prevention Council, U.K.
- Western Fire Centre, Inc., Kelso, Washington, U.S.A.

0.5.3.6 Associations and Organizations

The following private or government organizations publish and provide fire engineering-related knowledge and information.

- ANSI, American National Standards Institute, U.S.A.
- ASTM, American Society for Testing and Material
- CIB, International Council for Building Research Studies and Documentation, Committee W14 Fire, Netherlands
- FAA, Federal Aviation Authority, U.S.A.
- FEMA, Federal Emergency Management Agency, U.S.A.
- Fire and Risk Sciences, Building Research Establishment, U.K.
- FPAA, The Fire Protection Association of Australia, Australia
- IAFSS, International Association for Fire Safety Science, U.K.
- Institution of Fire Engineers, Engineering Council Division, U.K.

- ISO, The International Standards Organization, Switzerland
- IOSH, Institution of Occupational Safety and Health, U.S.A.
- NFPA, National Fire Protection Association, U.S.A.
- NIST, National Institute for Science and Technology, Building and Fire Research Laboratory, U.S.A.
- NRCC, National Research Council Canada, Canada
- SAA, Standards Australia, Australia
- SFPE, Society of Fire Protection Engineers
- The Combustion Institute, U.S.A.

0.5.3.7 Web Sites

The following web sites provide on-line information that may be used in fire engineering assessments.

- IAFSS, International Association for Fire Safety Science (U.S.A.) — *www.iafss.org*
- Lund University (Sweden) — *www.brand.lth.se*
- NIST, BFRL, Building and Fire Research Laboratory (U.S.A.) — *www.bfrl.nist.gov*
- National Data Centre — *www.usfa.fema.gov*

Part 0 - New Zealand Introduction

International
Fire Engineering
Guidelines

The contents of this document have been derived from various sources that are believed to be correct and to be the best information available internationally. However, the information provided is of an advisory nature and is not claimed to be an exhaustive treatment of the subject matter.

This Document (Part 0- New Zealand) is Country specific and the contents are to be read in order to use the guidelines within New Zealand.

Alternative introductions to the International Fire Engineering Guidelines (IFEG) are available for other Countries and are specific to each individual country in isolation.

Table of Contents

These Guidelines comprise four parts, each of which is a separate entity. For a detailed table of contents, refer to the beginning of each part and each chapter.

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Chapter 0.1

Introducing these Guidelines

Comment

These Guidelines have four parts, each with its own table of contents. It has been designed for ease of use and cross-referencing with graphics as outlined below:

- **Graphic identification** of sub-systems, as explained in Part 1
- **Shaded boxes** containing examples or commentary
- **Abbreviated flow charts** in the margins, with the relevant boxes shaded.

Part 0 provides background information and guidance that is integral to an understanding of the entire Guidelines within a New Zealand context.

Part 1 describes the process by which fire engineering is typically undertaken.

Part 2 describes a selection of methodologies that may be used in undertaking the fire engineering process.

Part 3 provides a selection of data that may be used in applying the methodologies of Part 2 or other chosen methodologies.

The Guidelines are paginated on a chapter basis in order to facilitate revision by replacement of individual chapters. It is envisaged that Part 0 and Part 1 will require less frequent revision than Part 2 and Part 3.

0.1.1 Evolution

The International Fire Engineering Guidelines (IFEG) have evolved from guidelines produced for the Australian domestic context and supersedes both the Fire Engineering Guides 1996 and the Fire Safety Engineering Guides 2001 published in Australia. These documents are therefore no longer current and should not be used or referred to.

The objectives of the guidelines are to:

- provide a link between the regulatory system and fire engineering (Part 0)
- provide guidance for the process of fire engineering (Part 1
- provide guidance for fire engineers on the available methodologies (Part 2) and data (Part 3).

The IFEG is published by the Chief Executive of the Department of Building and Housing as Guidance information under section 175 of the Building Act 2004.

This current document has been written in the form of guidelines rather than in a mandatory or code format to reflect the current state of fire engineering. The use of a mandatory format was discussed at length before the development of both the first and second editions (see below) of these guidelines. It was concluded that fire engineering lacks the necessary array of validated tools and data necessary to produce such a mandatory document.

Fire engineering evaluations are complex and generally require the extensive use of engineering judgments. In addition, those required to assess the output of fire engineering evaluations need an understanding of the fire engineering process and what constitutes an acceptable fire engineering evaluation. Therefore, guidance is required both to improve the standard of and application of fire engineering by practitioners and to improve the ability of Territorial Authorities (TAs) and Building Consent Authorities (BCAs), to carry out their functions under the Building Act 2004. Adherence to these guidelines by practitioners is therefore necessary to improve the quality of fire engineering and it's acceptance as an engineering discipline.

These Guidelines embrace worldwide best practice and draw upon previous work and parallel work from many groups around the world. The documents used include:

- Fire Safety Engineering Guidelines (FSEG), Edition 2001, November 2001, Australian Building Codes Board, Canberra, Australia.
- Fire Engineering Guidelines ('FEG'), first edition, March 1996. Fire Code Reform Centre Ltd, Sydney, Australia (March 1996).
- Building Code of Australia — Volume 1', Class 2 to Class 9 Buildings, Australian Building Codes Board, Canberra, Australia, 2005.
- Fire Engineering Design Guide, 2nd Edition, University of Canterbury, Christchurch, New Zealand (2001).
- CIBSE Guide E, Fire engineering, Chartered Institute of Building Services Engineers, UK (February 1997).
- International Organization for Standardization, Fire engineering ISO/TR 13387: 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

- Fire engineering in Buildings – Code of practice, British Standard BS7974 (2001).
- The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers, Bethesda, MD. USA (2000).
- The New Zealand Building Act 2004.

0.1.2 Scope

These Guidelines have been developed for use in the fire engineering design, evaluation and approval of buildings. However, the concepts and principles may also be of assistance in the fire engineering design and approval of other structures such as ships and tunnels, which may comprise enclosed spaces. In particular, the Guidelines provide guidance for the design of Alternative Solutions in order to meet the requirements of the New Zealand Building Code.

This document provides guidance to the fire engineering fraternity in their work to design and evaluate fire safety systems to achieve acceptable levels of safety. The Guidelines assume that the fire engineer has a level of competence and experience that would enable accreditation by an appropriate body should such accreditation be available.

Fire engineers need to interpret the guidance given in these Guidelines using professional judgment and use it as a tool for responsible fire engineering. The role of fire engineering in building fire safety and the term 'fire engineer' are discussed in Chapters 0.3 and 0.4 respectively.

The Guidelines will be useful for training and educating purposes. They will also be of use to other people and organisations, such as the Building Consent Authority, BCA, and the New Zealand Fire Service, in carrying out their roles of assessing and/or approving alternative solutions. The Guidelines may form the basis of checklists to be used as an aid for such activities, but such lists should allow for the flexibility that these Guidelines allow. They may also assist BCAs and others in assessing the adequacy of fire safety in existing buildings and, if necessary, devising an upgrade strategy.

Fire engineering is developing with a large degree of international cooperation. Parts 1, 2 and 3 of these Guidelines are written to have global applicability, whereas Part 0 only applies in New Zealand.

0.1.3 Limitations

These Guidelines are not intended to:

- apply to those situations where a person is, either accidentally or intentionally, intimate with the fire ignition or early stages of development of a fire; building fire safety systems are not generally able to protect such persons
- encompass situations that involve fire hazards outside the range expected to be encountered in buildings, such as bulk storage of flammable liquids, processing of industrial chemicals or handling of explosive materials. In this instance legislation other than the Building Act will apply
- be a form of 'recipe book' to enable inexperienced or unqualified people to undertake work that should be done by qualified fire engineers
- replace available textbooks, examples of which are given in Section 0.5.3.

Tools and information available to the fire engineer on the fire performance of dangerous goods and hazardous materials are available. However not all fire engineers have the specialized knowledge and competencies to practice in this area. For these situations applicable legislation for the safe storage and handling of hazardous and dangerous goods and appropriate specialist practitioners may need to be consulted.

It is given that 'absolute' or 'total' safety is not physically attainable within buildings and there will always be a risk of injury, death or property damage should a fire occur. Some of the guidance in these Guidelines relates to the evaluation of such risks and the qualitative and quantitative methodologies available.

Fire, its dynamics and the consequential effects on people and property are complex issues and variable in nature. Thus, a fire safety system may not effectively cope with all possible scenarios and this needs to be understood by the Building Consent Authorities, New Zealand Fire Service and others in their assessment of fire engineered solutions.

0.1.3.1 Other legislation

This guidance is not intended to describe how the designer can achieve the requirements of any other regulatory requirements required for the building other than achieving the performance requirements of the New Zealand Building Code.

Chapter 0.2

The Regulatory System

Comment

The intent of regulations related to health, safety and amenity in buildings is to mitigate risks to a level accepted by the user of the building and the wider community.

Building codes have been developed to provide the technical basis for such regulations. Traditionally, such building codes have been prescriptive. However, such codes cannot cover emerging technologies and every combination of circumstances. Thus, prescriptive regulations have provided constraints to design that are not always appropriate to the specific building being considered.

In order to free design from such constraints, increase innovation and facilitate trade, building codes have become performance-based. The New Zealand Building Code (the first schedule of the Building Regulations 1992) is a performance-based code.

0.2.1 The regulatory framework

The New Zealand regulatory system adopts the following framework:

The Building Act 2004

- is legally binding.
- provides the framework for the entire building control system, and allows for the issue of detailed regulations.
- regulates buildings as physical entities.
- does not cover planning or the activities of people.
- authorizes regulations establishing a national uniform performance based building code.
- is mainly concerned with new building work, the construction and alteration of buildings, and also requires existing buildings to be kept safe.

The Building Regulations 1992

- are legally binding.
- contains the New Zealand Building Code.

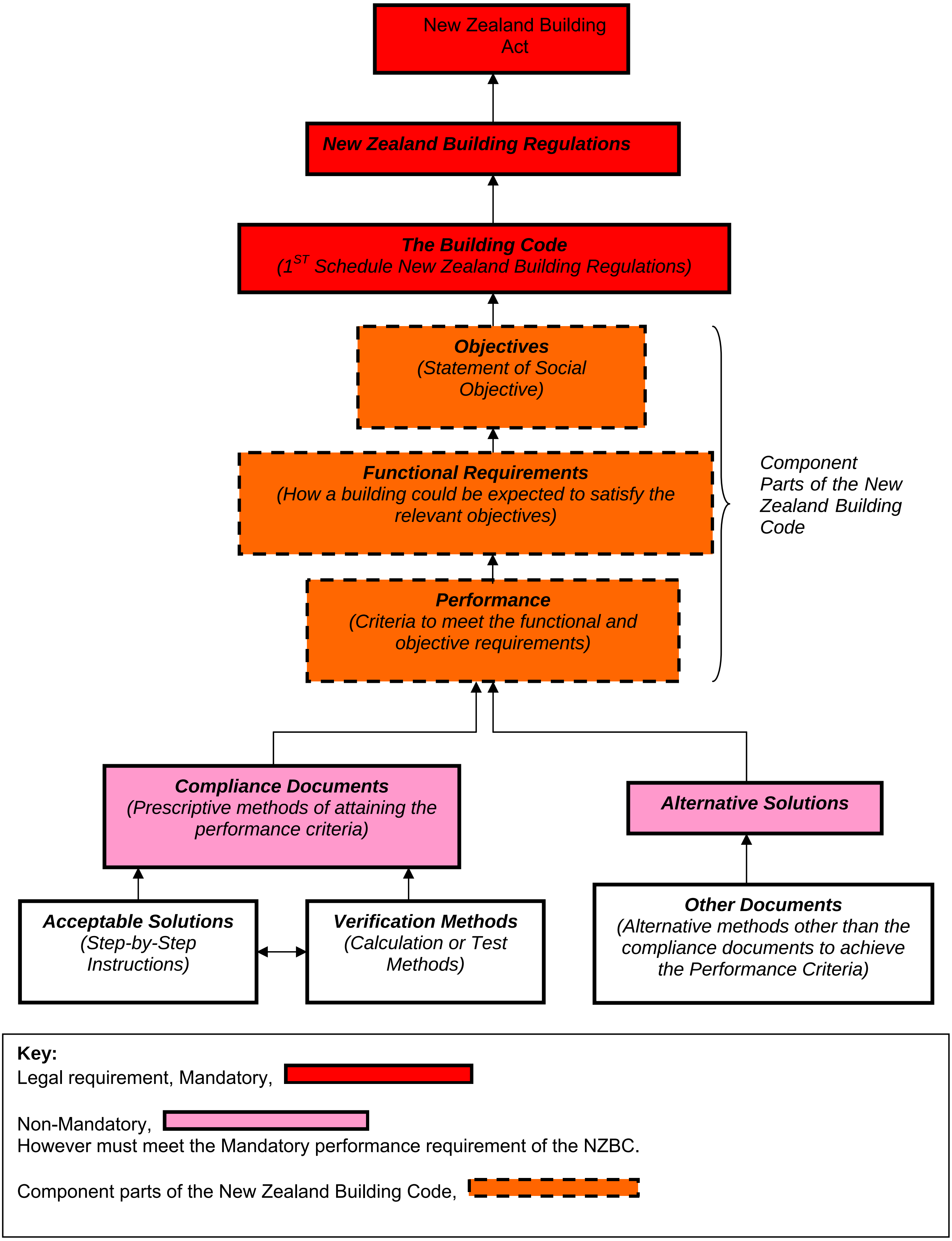
The New Zealand Building Code

- is legally binding
- consists of two preliminary clauses and 35 technical clauses.
- sets the minimum legal requirement for building works in New Zealand.
- states the performance criteria for a building, but does not contain prescriptive requirements

The New Zealand Building Code Handbook and Compliance Documents

- describe ways of complying with the Building Code.
- are not mandatory.
- are generally prescriptive and contain acceptable solutions and verification methods.

Alternative solutions have to be assessed against the performance criteria of the NZBC. The BCAs will accept alternative solutions (solutions other than those given in the Compliance Documents) if they are satisfied on reasonable grounds that the alternative solutions meets the performance criteria of the NZBC.


New Zealand Building Act
New Zealand Building Regulations
The Building Code
(1ST Schedule New Zealand Building Regulations)
Objectives
(Statement of Social Objective)
Functional Requirements
(How a building could be expected to satisfy the relevant objectives)
Performance
(Criteria to meet the functional and objective requirements)
Component Parts of the New Zealand Building Code
Compliance Documents
(Prescriptive methods of attaining the performance criteria)
Alternative Solutions
Acceptable Solutions
(Step-by-Step Instructions)
Verification Methods
(Calculation or Test Methods)
Other Documents
(Alternative methods other than the compliance documents to achieve the Performance Criteria)
Key:
Legal requirement, Mandatory,
Non-Mandatory,
However must meet the Mandatory performance requirement of the NZBC.
Component parts of the New Zealand Building Code,

0.2.2 The New Zealand Building Code

The NZBC is written to achieve and maintain acceptable standards of safety from fire for the benefit of the community. This goal extends no further than is necessary in the public interest, is considered to be cost effective and not needlessly onerous in its application.

The NZBC has multiple levels within its hierarchy, as shown in Figure 0.2.2.

Objectives set out, in general terms, the social objectives in terms of health, safety, amenity and sustainability.

Functional Requirements set out, in general terms, how a building could be expected to satisfy the relevant objectives.

Performance Requirements are given as the qualitative or quantitative criteria necessary for a building to achieve compliance with the NZBC

Objectives and functional requirements may assist to interpret the content and intent of the performance criteria.

In order to receive regulatory approval, a design must meet all the relevant Performance Requirements.

Where a design complies with all the relevant acceptable solution requirements, the Building Consent Authority must accept the design.

For any building solution to comply with the performance criteria of the NZBC three possible routes exist. These are:

1. A design that complies with the Acceptable Solution contained within the Compliance Document.

2. The verification method, contained within the Compliance Document has been applied to the design using calculation methodology or results from test procedures to give the Building Consent Authorities the confidence that the performance criteria has been met.

3. Alternative Solution where a solution is presented to the BCA which gives details of a method, or combination of methods, used to achieve the performance criteria. An alternative solution is a design that does not comply with one or more of the Acceptable Solutions but can be shown to comply with the relevant performance criteria of the NZBC.

   These methods may be from one or more of the following: -

   - Results, for example, from research or tests performed on elements of building structure, human movement modeling, and fire research.

   - Fire Engineered solutions, based upon engineering judgments from suitably qualified fire engineers employing quantified analysis.

Where the design team is considering fire safety matters, in conjunction with other performance criteria of the NZBC as part of the building design, fire engineering techniques may be used as part of such assessments. Any submission would comprise a fire engineering evaluation calculations, drawings, specifications (if any) and report. The fire-engineered solution must not compromise any other performance criteria of the NZBC. The fire engineering strategy for the building is therefore a part of the holistic building design.

0.2.2.1 Other relevant legislation

Due regard should be given to the requirements of other relevant legislation that is applicable to the building and its local environment

The legislation may include, but is not limited to, the Fire Service Act 1975, The Fire Safety and Evacuation of Buildings Regulations 1992. The Hazardous Substances and New Organisms Act 1996.

0.2.3 Performance Requirements

0.2.3.1 Non-quantification of risk

The fire related performance criteria of the NZBC sets out to provide a level of safety with respect to the risk of fatality, injury and loss of adjacent structures through fire. It is not intended that this should be "absolute safety" or "zero risk" because these concepts are not achievable. The risk needs to take into account what the community expects and the cost to the community as might be determined by a cost benefit analysis. Regulatory Impact Statements and cost benefit analyses are required to be completed for all new requirements before they can be introduced into the NZBC.

The level of safety provided by the NZBC is not always explicitly stated and this may lead to difficulties in the interpretation of the performance requirements.

When a fire engineering evaluation is carried out, "design fires" have to be developed in order to evaluate the fire safety system under consideration. The quantification of design fires relies, to some extent, on the application of engineering judgment. Such judgments may therefore vary. This variation can be minimized if the process detailed in these guidelines in Section 1.2.11 is used and there is involvement of other stakeholders as described in the fire engineering brief process (Chapter 1.2). The process described in Section 1.2.11 to develop design fires on the basis of a consideration of all potential fire scenarios encompasses such fires as far as is reasonably practicable.

Any evaluation to achieve the performance criteria may require the involvement of stakeholders. These stakeholders will have input into the fire-engineering brief, which forms the basis of the fire engineering strategy to meet the performance criteria for acceptance. The fire engineering brief described in Part 1 facilitates such involvement.

Throughout the Fire Engineering Brief (FEB) all relevant criteria stipulated under the performance criteria as laid down by the NZBC must be taken into consideration. The relevance of the requirements in the FEB needs to be addressed specifically to the building in question.

Uncertainties may arise from a lack of quantification of performance requirements and deficiencies in the methods and data available to determine whether the acceptance criteria have been met. Therefore, it is recommended that margins of safety or redundancies be included in a building fire safety system (see discussion of Trial Designs in Part 1.2.7). Such redundancies can be used to compensate for these uncertainties and deficiencies and these Guidelines recommend that redundancy be examined in the context of sensitivity studies (see Section 1.2.9.5).

0.2.3.2 Input from other stakeholders

The fire engineer must carefully consider the performance requirements of the NZBC. This will often require input from other stakeholders, such as the Building Consent Authority and others, conversant with the practical application of the NZBC. This input is greatly facilitated by the fire engineering brief process and it is therefore recommended that particular attention be paid to this forum.

0.2.4 The approval process

In New Zealand a national approach is adopted to building control that should not have major differences between the Building Consent Authorities across New Zealand. Any solution accepted in one part of the country should be acceptable in other parts of New Zealand as long as the performance criteria of the Building Code have been met. The uniqueness of each individual building must be considered, as no two buildings can be identical (see 0.3.3)

In New Zealand the following outline demonstrates the typical route to approval

	Steps	Who is Involved
Planning Stage	Ideas/prepare sketch plans	Owner/ Designer Territorial Authority
	Obtain Project Information Memorandum	Owner/ Territorial Authority
	Prepare detailed plans and Specifications	Owner/ Fire Service
	Decide who shall do checks and inspections	Owner/BCA
	Submit Plans and Specifications	Owner/Agent
	Check Plans and Specifications	BCA
	Issue Building Consent	BCA
Construction	Supervise Construction	Consultant/Main Contractor/Other
	Inspect Construction	BCA/Designers
	Notify project Completion	Owner
Completion	Issue Code Compliance Certificate	BCA
	Issue Compliance schedule and building compliance schedule statement for Buildings with certain systems	Council
	Maintain, Inspect and report on compliance schedule items	Owner & Licensed Building Practitioner
	Prepare and display building warrant of fitness	Owner

With regard to documentation for alternative solutions in New Zealand:

The New Zealand Building Act (s216) (2)(a) states,

"The information to be kept by a Territorial Authority under subsection (1) includes-
(a) All plans and specifications submitted to the territorial authority in relation to an application for a building consent"

The New Zealand Building Act (s216) (3)(a) states,

"A territorial authority must keep the information referred to in-
(a) Subsections (1) and (2)(a) to (d) and (g), at least for the life of the building to which the information relates"

In this context, a fire engineering report prepared according to these guidelines (see Chapter 1.11) shall be retained. Any decisions taken towards forming the fire engineering strategy should be fully documented and the Building Consent Authority should have retained copies of all relevant documentation. This should mitigate concerns regarding differences in the format and content of documentation in support of alternative solutions and should therefore lead to a uniform level of documentation being produced, submitted and retained by the Building Consent Authority.

The roles and responsibilities of the Building Consent Authorities. The NZFS and fire engineer in the approval process within New Zealand should be uniform and should not vary excessively between individual Building Consent Authorities. The following gives general guidance on their roles from the point of view of the fire engineering process and alternative solutions in order to facilitate appropriate and consistent outcomes.

The Building Consent Authorities should generally:

- Provide regulatory advice during the fire engineering brief process (see comments below with reference to independence)
- Assess and approve of alternative solutions
- Seek appropriate third party review of alternative solutions if necessary, (see Section 0.3.4)
- Retain all relevant documentation.
- Carry out all other appropriate regulatory functions.

In carrying out the above, it is essential for the Building Consent Authorities to remain independent of the design process to ensure that the BCA acts in the public interest first and foremost whilst providing input to the project.

The fire engineer should generally:

- Facilitate the Fire Engineering Brief process
- Develop and undertake evaluation of the alternative solution;
- Provide guidance on and technical justification for decisions made during the FEB process on matters such as acceptance criteria, design fires, design occupant groups and analysis strategy including the selection use and design parameters of any Computer based design tools;
- Provide design advice as part of the building team;
- Prepare the fire engineering report, based upon the IFEG guidance and using the format provided in Chapter 1.11 Preparing the Report, for assessment by the Building Consent Authorities.
- Identify any special commissioning, management in use and maintenance requirements of the alternative solution.
- Present recommendations for inspection, maintenance and reporting in respect to the compliance schedule.

The fire engineer who carried out the fire engineering evaluation is not entitled to issue certification for third party review that the design complies with the NZBC. Any fire engineering design may be subject to an independent check for compliance.

It is essential to establish with the BCA at the FEB stage whether or not they will be requiring a third party review, and if so, who the BCA will be engaging. Ideally the third party reviewer should review the fire engineering brief as soon as it has been completed. Engaging a third party reviewer at an early stage will prevent undue delays in the development and acceptance of the alternative design. It will also enable the evolving design to be reviewed at stages throughout its development.

To maintain the integrity of the review process the third party reviewer must be independent of the design process itself.

0.2.4.1 Involvement of the New Zealand Fire Service

The New Zealand Building Act 2004 S. 46 provides for the involvement of the New Zealand Fire Service (NZFS) in the consent process. Copies of the fire report will be sent from the BCA to the NZFS “Design Review Unit” for comment. The NZFS may within 10 working days pass comment by way of a memorandum back to the BCA on:

- The provisions for means of escape from fire:
- The needs of persons who are authorised by law to enter the building to undertake fire-fighting.

The NZFS are not entitled to ask for any performance criteria in excess of that already laid down in the NZBC.

If the NZFS does not comment within ten working days then the BCA may proceed to determine the application without the memorandum from the NZFS.

Chapter 0.3

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."*

Fire engineering is a rapidly developing discipline. In comparison to the traditional, established engineering disciplines, it does not have well-codified methods of approaching and solving problems. These Guidelines have been written to help overcome these deficiencies.

Fire engineering has become a possibility as a result of developments in fire science and an increased understanding of the many aspects of building fires, such as:

- pyrolysis of fuel sources
- fire physics and chemistry
- how various materials ignite
- the manner in which fire develops
- the manner in which the products of combustion (smoke), including toxic products spread
- how structures react to fire
- how people respond to the threat of fire, alarms and products of combustion.
- the interaction of building services

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 recent developments, such as:

- The introduction of performance-based codes with specific provision for the acceptance of fire engineered solutions.
- The computerization of fire models, particularly the complex models requiring extended computations
- Increases in computer capability and capacity

0.3.1 Benefits

Fire engineering may also be used for objectives other than those of the NZBC and thus has wider applicability and potential benefits beyond just developing alternative solutions for NZBC compliance.

0.3.1.1 General objectives of the NZBC

The general objectives of the NZBC are taken as being:

- People who use buildings can do so safely and without endangering their health
- Buildings have attributes that contribute appropriately to the health, physical independence, and wellbeing of the people who use them
- People who use buildings can escape from the building if it is on fire
- Buildings are designed, constructed, and able to be used in ways that promote sustainable development.

0.3.1.2 Additional fire safety objectives

For some projects, the client or other stakeholders may have fire safety objectives in addition to those of the NZBC.

Examples of such objectives may be to:

- Mitigate structural and fabric damage;
- Mitigate building contents and equipment damage;
- Maintain continuity of business operations and financial viability;
- Protect corporate and public image;
- Protect the national heritage in older or significant buildings;
- Safeguard community interests and infrastructure.

0.3.1.3 Additional non fire related objectives

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;
- Flexibility for future uses
- Aesthetically pleasing design
- Aesthetically fitting design, suitable to the surrounding environment.

All these objectives, together with the mandatory requirements, may be taken into account for an integrated, cost-effective fire safety system. The fire engineer has a responsibility to ensure that the non-fire related objectives, if fulfilled, do not impact on the design to meet the fire related performance requirements of the NZBC.

0.3.1.4 Additional fire engineering benefits

Fire engineering has many other benefits. For example, it provides:

- a disciplined approach to fire safety design

- a better appreciation of the interaction of the components that make up a building's overall fire safety system
- a method of assessing the fire safety inherent in alternative design solutions
- a basis for selection of appropriate fire protection systems
- potential economic savings through the use of alternative 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 building code requirements
- solutions for upgrading existing buildings when required by building legislation
- an analysis that can go beyond the minimum code requirements for life safety and identify for the owner property protection, business interruption protection and consequential loss protection associated with different alternative solutions.

These benefits, amongst others, are referred to in the discussion in the following sections.

0.3.2 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 that fire safety is achieved for the life of the building. Figure 0.3.2 shows the various stages that represent 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 needs to be successfully integrated with other professional disciplines such as architecture, building services engineering, structural engineering and project management. Architects have to work with many disciplines and fire engineering is one of the recent additions.

The following flow chart indicates the involvement of a fire engineer during the life of a building.

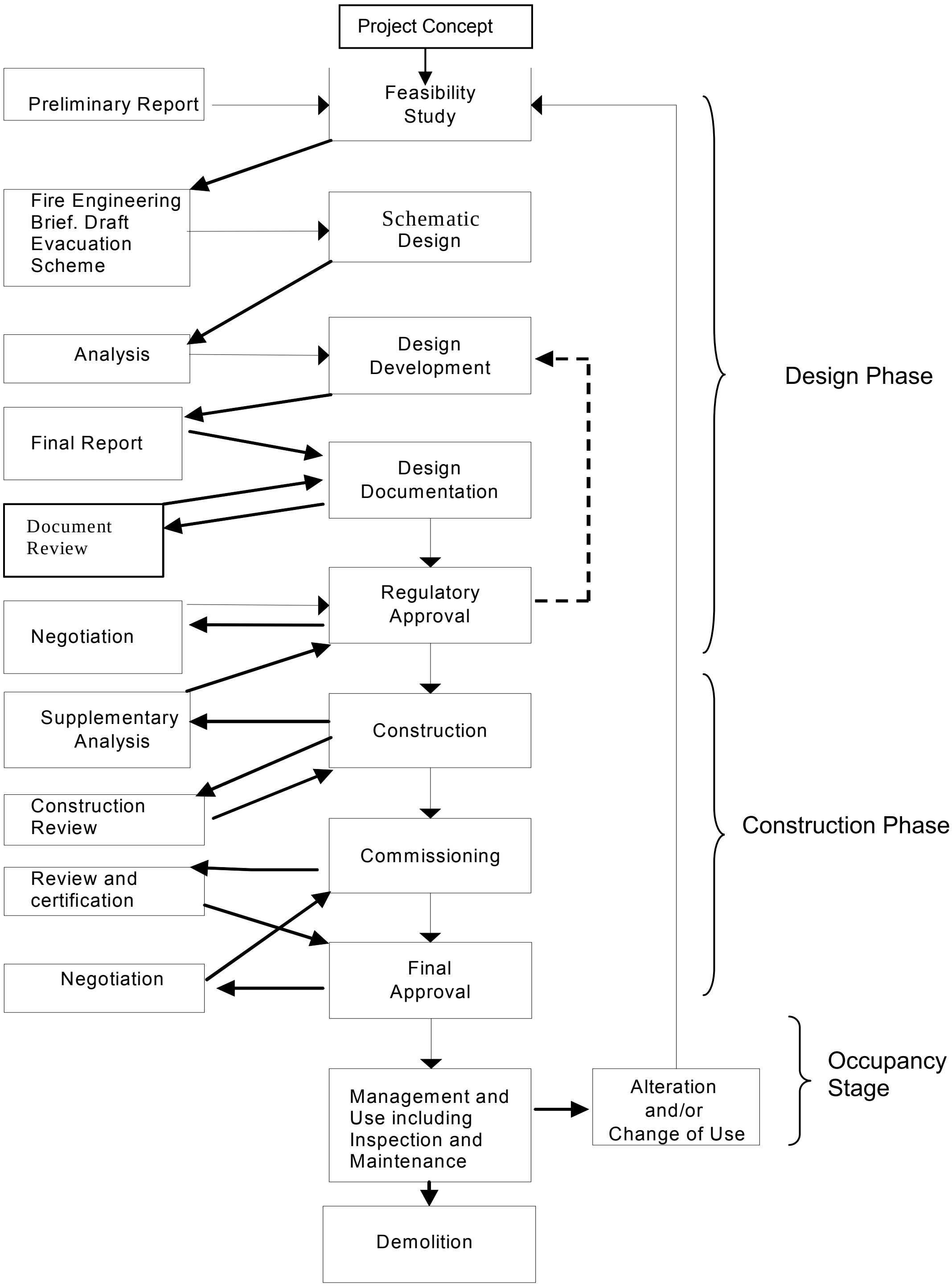
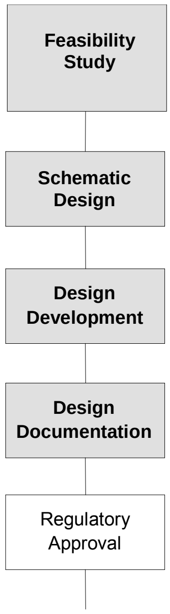


Figure 0.3.2.1 Flow chart showing the potential involvement of a fire engineer in the various stages in the life cycle of a building

Other guidelines demonstrate the actions of the fire engineer in other ways, such as The NZ Construction Industry Council Design Document Guidelines for Fire Engineering. It is not the intention to reproduce those within this document. The above is only an indication of where a fire engineer might be involved, and is not a definitive statement.

0.3.2.1 Design

The benefits of using fire engineering are greatest if this discipline is involved early in the design process. Indeed, fire engineering can contribute to each stage of the design process indicated in Figure 0.3.2.



- A preliminary report on potential fire safety systems is beneficial at the **feasibility study** phase. It identifies potential design flexibility provided through alternative solutions, and, in many cases, consequent cost savings. Such a report may form a useful basis for discussions with approval authorities at this stage of the design process.
- The fire engineering brief (FEB), which is discussed in detail in Chapter 1.2, provides a consensus on the fire safety components of the **schematic designs** being considered and the design options that need evaluation. The use of fire-engineered solutions (as an alternative to the Acceptable Solutions) may lead to designs that are both more functional and economical.
- Analysis of the trial design(s) identified in the FEB may guide the **design development** by indicating which design(s) meet the performance criteria of the NZBC and which components of the fire safety system need special attention. Conversely, design development may lead to other trial designs needing analysis.
- The fire engineering report will provide, not only the justification for the fire safety system utilized, but also the detailed requirements necessary for inclusion in the **design documentation** (e.g. for construction, commissioning, operation, inspection and maintenance).

Other stakeholders involved in the process may suggest design criteria, but the Building Act 2004 Section 18 states that: -

"(1) A person who carries out any building work is not required by this Act to-

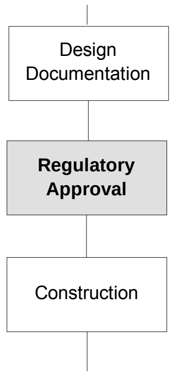
(a) achieve performance criteria that are additional to, or more restrictive than, the performance criteria prescribed in the building code in relation to that building work"

(b) take any action in respect of that building work if it complies with the building code.

(2) Subsection (1) is subject to any express provision to the contrary in any Act."

It is therefore the choice of the property owner whether or not to exceed the requirements of the NZBC.

0.3.2.2 Regulatory approval

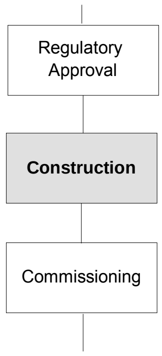


When the design requirements have been achieved, it is then the role of the Building Consent Authorities to assess that design and take one of several courses of action:

- Approve the design.
- Ask for further information to clarify the design.
- Approve the design subject to certain conditions.
- Refuse approval, providing reasons.

The fire engineer, having prepared the fire engineering evaluation, is central to any negotiations between stakeholders necessary to gain approval.

0.3.2.3 Construction



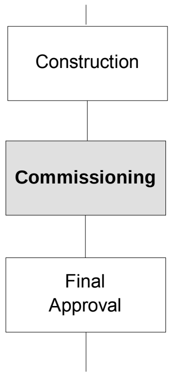
A fire engineer must be involved in the construction stage; it is recommended that this is the fire engineer responsible for preparing the fire engineering report. This involvement is to:

- determine that the necessary fire safety system components are installed as specified.
- identify those features that are required to attain a satisfactory level fire safety.
- facilitate the realization of the alternative solution design;
- carry out supplementary analysis on the changes to the design that are required (or that inadvertently occur).
- advise on what fire safety levels and precautions should be maintained during construction .

NOTE

Fire safety during construction is normally the responsibility of the contractor, not the design fire engineer.

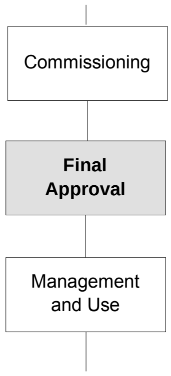
0.3.2.4 Commissioning



Proper commissioning is essential if the fire safety of the design is to be realized and a sound foundation set for subsequent maintenance. For an alternative solution, the involvement of the fire engineer is recommended. The fire engineer is expected to:

- evaluate the performance of the fire safety system.
- verify and advise that the commissioning has proved compliance with the fire engineered alternative solution.

0.3.2.5 Final approval

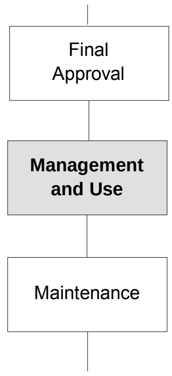


The contribution of fire engineering to this stage, which involves the issue of code compliance certificates and the like, is similar to the previous approval stage (Section 0.3.2.2). In particular, a fire engineer may be required to advise that:

- the fire safety conditions of the regulatory approval have been met
- construction and commissioning meet the approved design.

The BCA has the option to perform audits of the fire engineer to ensure consistency and accuracy.

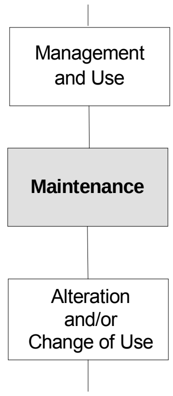
0.3.2.6 Management and use



The day-to-day commitment to safety by a building's management team will significantly affect the fire safety of a building. Fire engineering plays a role in ensuring management and use provisions that are appropriate to the fire engineered design are in place, by:

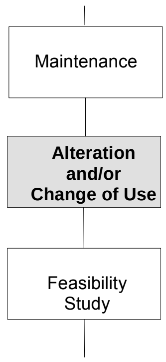
- contributing to the development of emergency evacuation strategies and associated training; the procedures need to be consistent with the fire safety evaluation, particularly regarding the method of warning occupants and the evacuation strategy
- listing any limitation on fuel loadings, use of evacuation routes, etc
- compliance schedules and Warrants of Fitness

0.3.2.7 Inspection, testing, maintenance and reporting



The fire safety of a building depends on the ongoing functioning and efficacy of its fire safety system. The fire engineer should be involved in defining the inspection, testing and maintenance programs that are necessary with due regard to standards and legislation applicable to New Zealand.

0.3.2.8 Alteration and/or change of use



Alterations or additions may be made to a building during its life and it is not unusual for the use of a building to be changed. Any alterations or changes in use of the building must result in the building complying with the Building Act. Fire engineering may be required in circumstances where the alterations or additions do not conform to the acceptable solution or may compromise the original fire engineering design. Thus, fire engineering can:

- contribute to the process undertaken to obtain the necessary approvals for the altered building; or
- examine a fire engineering evaluation carried out on the existing building to determine if it still applies.

0.3.3 Uniqueness of application

Fire engineering design is building, occupant and site specific. Detailed consideration of various features and systems contributing to fire safety that are the most appropriate for the stakeholders, building characteristics, occupants and site can be included in the design. This enables the benefits of the performance based approach to be realized in the most cost effective and practical way. However, as more of these specific features are included in the design and relied on for fire safety, changes to any of these features may require a re-evaluation of the fire design.

Many buildings may appear to have similar or identical design features. However even minor variations can have a major influence on the fire safety of the buildings. Thus, from the fire-engineering point of view, every building, however similar it might be superficially, has subtle differences from every other building and these differences may affect the fire safety. Using solutions developed for one building, or features of that building, as a precedent for approval for another is not appropriate except in exceptional circumstances.

Such circumstances may exist where a detailed comparison of the buildings and the implications for a fire engineering design has been carried out and documented in order to demonstrate that the solution achieves the required performance objectives.

0.3.4 Third party review

Third party review is taken as encompassing both peer and specialist reviews. See Definitions – Section 0.5.1.

A third party review should be undertaken as a constructive process to assist the Building Consent Authorities to assess and approve a design involving an alternative solution which is supported by a fire engineering report. It should also assist the fire engineer in ensuring that all matters, especially the justification of engineering judgment, are adequately addressed. A third party review should facilitate rather than hinder the approval of a given project. If this is not done correctly, the process may be unduly protracted and jeopardize the worth of the third party review.

Those undertaking a third party review should understand that a fire engineering evaluation may vary according to the preferences of the fire engineer and a number of different approaches may be used in undertaking a fire engineering evaluation. Professional detachment, flexibility and an open mind are essential characteristics of a good third party reviewer, who should be a competent and qualified fire engineer. 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. The reviewing engineer may inform the initial design engineer that they are reviewing a design. (IPENZ Code of Ethics). The third party reviewer have a responsibility to ensure that they are familiar with the FEB, and are aware of any particular requirement made known to the design engineer, relating to the design.

Where the Building Consent Authorities have appropriate competence and experience, they may undertake the assessment and approval of the alternative solution. Where they do not have the competence and experience, they should refer the assessment of the fire engineering report to a third party reviewer.

A building owner or project manager may commission a third party review of a fire engineering report in order to substantiate the conclusions.

Where a third party review is required by a Building Consent Authority, the Authority is responsible for the selection of the third party reviewer. It is essential that the reviewer be independent of the project and participants in the project in question (refer Definitions Section 0.5.1).

Subject to the requirements of the Building Consent Authority, the reviewer should:

- use the guidance of the IFEG as the benchmark for the review
- verify that the decisions made in the FEB process have been followed in the analysis and conclusions;
- carry out a check of assumptions and calculations to determine the appropriateness of the techniques used and the accuracy of the analysis
- check that the report conforms to the requirements of the IFEG and includes the appropriate items from Chapter 1.11.
- check that all consent drawings/ plans comply with the requirements of the approved fire report

In general terms a review process may have a number of outcomes.

- The report adequately documents the evaluation of and supports the alternative solution.

- Although the design appears to be acceptable, it is not adequately supported by the evaluation. In this case it should be relatively straightforward for the fire engineer to satisfy the requirements of the reviewer.

- The analysis has fundamental flaws or the wrong analysis strategy has been adopted. In such cases, the analysis needs to be repeated in whole or part before the acceptability of the design can be determined.

- The fire engineering brief process has not been adequately carried out and as a result the evaluation is unsound. The whole fire engineering evaluation including the FEB and analysis may need to be redone. This may be avoided if the reviewing engineer reviews the FEB prior to futher design work or may be limited of the reviewing engineer is involved at an early stage.

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

- Assertions and assumptions need to be substantiated and referenced in the manner that these guidelines suggest for the fire engineering report itself

- It must be clear why and to what extent the proposed design does not appear to comply. General statements are to be avoided as the basis for non acceptance

- Check calculations should be sufficiently detailed to enable comprehension and evaluation.

- The suggested remedial actions need to be clearly identified

- Correspondence and alterations as discussed and agreed between the reviewer and engineer should be included in the documentation.

Chapter 0.4

Fire Engineers

Comment

A person practising as a fire engineer should have appropriate education, qualifications, training and experience to enable them to:

- 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, spread within and outside of buildings/structures;
- Understand how fires can be detected, controlled and/or extinguished;
- Be able to predict the behaviour of materials, structures, machines, apparatus, and processes as 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;
- Be skilled in using and supporting engineering judgment;
- Understand and participate in the design process for buildings and other facilities;
- Understand building regulations and associated compliance issues;
- Be able to objectively balance obligations to the client and the community in the manner expected of a professional engineer;
- Be able to negotiate with the client 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 the building code that may be appropriate for a given project and the fire engineer has a responsibility to draw these to the attention of the client and explain the impact of adopting or not adopting these objectives. Such objectives, which may include limiting building damage, maintaining building operation and limiting environmental damage, are discussed in Sections 0.3.1 and 1.2.5 of these Guidelines.

Fire engineering is an evolving discipline. It has few of the well-proven and well-understood tools and data available to other engineering disciplines. Thus, engineering judgment plays a greater role in fire engineering than in most other engineering disciplines.

The International Organization for Standardization (ISO) defines engineering judgment as:

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

This definition indicates that a quantitative analysis method is only a tool for use by the fire engineer, who may choose to what extent the results are used, based on an appreciation of the validity of the tool.

When engineering judgment is used, its use should be justified and the logic used in applying it explained (see Chapters 1.10 and 1.11).

0.4.1 Related disciplines

There are several forms of specializations amongst engineers working with fire related issues. The nomenclature used for these specializations is not necessarily consistent and may well vary.

In addition to fire engineers, there are other related specialists.

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

0.4.2 Accreditation

New Zealand currently has no formal registration specifically detailed for fire engineers. There are institutions that will register fire engineers, such as the Institute of Professional Engineers New Zealand (IPENZ) within a practice college area. Whilst there is no formal scheme within New Zealand some comfort may be gained by the employer of the fire engineer if an appropriate professional body recognizes that engineer, although at this time this does not provide a bar to any practicing fire engineer.

Members of IPENZ are obliged by their code of practice not to practice outside their field of core competency. Fire engineers may also be approved for full membership of bodies such as the Society of Fire Protection Engineers (USA) on confirmation of achieving appropriate qualifications and experience. However memberships of institutions may not necessarily be taken as proving competence of the individual.

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Chapter 0.5

Definitions, Abbreviations and Information Sources

0.5.1 Definitions

Acceptable Solution	A non-mandatory prescriptive solution deemed to comply with the NZBC, and which if followed must be accepted by the Building Consent Authority.
Alternative solution	A building solution other than the acceptable solutions.
Approval	The granting of a building consent, license, permit or other form of consent or certification by a Building Consent Authority.
Assessment	For the purposes of this document, whether a fire engineering report adequately supports an alternative solution. This process is carried out by the BCA.
Authority Having Jurisdiction	A regulatory authority that is responsible for administering building controls. In a New Zealand context this refers to the Building Consent Authority.
Available safe evacuation time (ASET)	The time available between the start of established burning of a fire and the onset of untenable conditions in a specific part of a building.
Building Consent Authority (BCA)	An authority responsible for administering building controls.
Boundary conditions	A set of constraints for mathematical models.
Building solution	A solution that complies with the performance requirements of a code.
Certification	The process of approval by independent appropriately qualified practitioners that the submitted design and design documentation meet the requirements of the NZBC and relevant legislation.
Construction Review	A review of the physical building and comparison to the approved design to check design implementation
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 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 or DTS (provisions)	In a New Zealand context read as the Acceptable Solutions.
Design fire	A mathematical representation of a fire that is characterized by the variation of heat output with time and is used as a basis for assessing fire safety systems.
Design fire scenario	A fire scenario that is used as the basis for a design fire.
Deterministic method	A methodology based on physical relationships derived from scientific theories and empirical results that for a given set of conditions will always produce the same outcome.

Engineering judgment	Process exercised by a professional who is qualified because of training, experience and recognized skills to complement, supplement, accept or reject elements of a quantitative 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, **internal or external**, to their building.
Evaluation	For the purposes of this document, the process by which a fire-engineer determines whether an alternative solution meets the appropriate performance requirements of the NZBC.
Field model	A model that divides a building enclosure into small control volumes and simulates the emission phenomena, the movement of smoke and the concentrations of toxic species in various enclosures so that the times of critical events such as detection of fire and the development of untenable conditions can be estimated.
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 parameters such as temperature, fire severity, the time dependent the movement of smoke and the concentrations of toxic species.
Fire engineer	A person suitably qualified and experienced in fire engineering.
Fire engineering	See Section 0.3
Fire engineering brief (FEB)	A documented process that defines the scope of work for the fire engineering analysis and the basis for analysis as agreed by stakeholders.
Fire Engineering Report	A full building specific fire engineering report prepared by a fire engineer. In a NZ context this may be a full Fire Engineering Design..
Fire Hazard	A physical situation which if a fire occurs has the potential for injuring humans, damaging property, damaging the environment, or some combination of these.
Fire safety system	One or any combination of the methods used in a building to: (a) warn people of an emergency, (b) provide for safe evacuation, or (c) restrict the spread of fire, or (d) extinguish a fire. It includes both active and passive systems.
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 localized fire to the combustion of all exposed surfaces within an enclosure.
Fuel load	The quantity of combustible material within a room or firecell 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 energy is released by a fire.
New Zealand Building Code (NZBC)	The National building code for New Zealand. Containing the performance criteria that must be satisfied for a design to be accepted.
New Zealand Fire Service (NZFS)	The National fire service for New Zealand.
Peer review	A third party review undertaken by an independent or a person with the equivalent competencies and experience.
Place of safety	*A place within a building or within the vicinity of a building, from which people may safely disperse after escaping the effects of fire. It may be an open space (such as an open court) or a public space (such as a foyer or a roadway).*
Prescriptive (provisions)	Provisions that are expressed as explicit solutions, often in quantitative form.
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 evacuation time (RSET)	The time required for safe evacuation of occupants to a place of safety prior to the onset of untenable conditions.
Risk	The likelihood of a hazardous event occurring.
Safety Factor	Adjustment made to compensate for uncertainty in the methods, calculations and assumptions employed in developing engineering designs.
Schematic design fire	A qualitative representation of a design fire, normally presented in the form of a graph.
Sensitivity analysis	A guide to the level of variation hence criticality of 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.
Smouldering fire	The solid phase combustion of a material without flames and with smoke and heat production.

Specialist review	See Third Party Review.
Sub-system	A part of a fire safety system that comprises fire safety measures to protect against a particular hazard (e.g. smoke spread). Note: This Guideline defines six sub-systems (see Chapter 1.3).
Third Party Review	A review of fire engineering reports, documents and supporting information carried out by a fire engineer or a person with equivalent competencies and experience, who is independent of the organization preparing the report and is independent of those assessing and approving the report.
Trial design	A trial fire safety design that is to be assessed using fire engineering techniques.
Untenable conditions	Environmental conditions associated with a fire in which human life is not sustainable.

0.5.2 Abbreviations

ABCB	Australian Building Codes Board
AS	Australian Standard
ASET	Available safe evacuation time
BCAs	Building Consent Authorities
BSAP	Building Surveyors and Allied Professions
FEB	Fire engineering brief
HRR	Heat release rate
IFE	Institution of Fire Engineers, UK
IFEG	International Fire Engineering Guidelines
IPENZ	Institution of Professional Engineers NZ
ISO	International Standards Organization
NFPA	National Fire Protection Association, USA
NZBC	New Zealand Building Code
NZFS	New Zealand Fire Service
RSET	Required safe evacuation time
SFPE	Society of Fire Protection Engineers, USA
SS	Sub-system
TA	Territorial Authority

0.5.3 Information sources

There are various sources that fire engineering professionals may refer to for specific knowledge and information that may be utilized in fire engineering assessments. The lists provided in the following sections are not comprehensive and only aim to serve as a guide.

0.5.3.1 Reference works

The following publications provide guidance in the general area of fire engineering:

Australasian Fire Authorities Council (1997). ‘Fire Brigade Intervention Model — Version 2.1 November 1997’, Box Hill, Victoria, Australia

BSI (2001). *Application of fire engineering principles to the design of buildings – Code of practice*, BS7974, British Standards Institution, London, UK.

Buchanan AH (ed). (2001). *Fire Engineering Design Guide*, 2nd Edition, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

CIBSE (The Chartered Institution of Building Services Engineers) (1997) *Guide E Fire Engineering*, CIBSE, London, UK.

Cote AE (ed) (1997). *Fire Protection Handbook*, 18th Edition. National Fire Protection Association, Quincy, MA, USA.

Custer, RLP & Meacham, BJ (1997). *Introduction to Performance Based Fire Safety*, National Fire Protection Association, Quincy, MA, USA.

DiNenno PJ (ed.) (2002) *The SFPE Handbook of Fire Protection Engineering*, 3rd Edition, National Fire Protection Association, Quincy, MA, USA.

Drysdale D. (1999). *An Introduction to Fire Dynamics*, 2nd Edition, John Wiley & Sons, Chichester, UK.

European Convention for Constructional Steelwork (1985). *Design Manual on the European Recommendations for the Fire Safety of Steel Structures*, Technical Note No. 35.

Karlsson B and Quintiere J (1990). *Enclosure Fire Dynamics*, CRC Press, Boca Raton, FL, USA.

Klote JH and Milke JA (1992) *Design of Smoke Management Systems*, American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), Atlanta, GA, USA.

0.5.3.2 Journals

The following journals may provide a useful resource for fire engineering professionals.

- *Combustion and Flame*, Elsevier, Netherlands
- *Combustion Science and Technology*, Gordon Breach, USA
- *Combustion Theory and Modelling*, Institute of Physics, UK
- *Fire and Materials*, Elsevier, Netherlands
- *Fire Safety Engineer (FSE),* Miller Breeman, UK
- *Fire Safety Journal*, Elsevier, Netherlands
- *Fire Technology*, NFPA, USA
- *International Journal on Performance Based Fire Codes*, Hong Kong Polytechnic Institute, Hong Kong
- *Journal of Applied Fire Science*, JASSA, USA
- *Journal of Fire Protection Engineering*, SFPE, USA
- *Journal of Fire Sciences*, USA
- *NFPA Journal*, NFPA, USA
- *SFPE Journal*, SFPE, USA

0.5.3.3 Conference proceedings

The conferences listed below are held on a continuing basis. There are separate volumes of proceedings for each conference held.

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

- Pacific Rim Conferences

0.5.3.4 Tertiary institutions

The following tertiary institutions are some of those that provide courses or conduct research in fire engineering.

- Carleton University, Canada
- Lund University, Sweden
- Oklahoma State University, USA
- Queensland University of Technology, Australia
- Science University of Tokyo, Japan
- South Bank University, UK
- University of Central Lancashire, UK
- University of Canterbury, New Zealand
- University of Edinburgh, UK
- University of Greenwich, UK
- University of Leeds, UK
- University of Maryland, USA
- University of New Brunswick, Canada
- University of New Haven, USA
- University of Science and Technology of China, Peoples Republic of China
- University of Technology, Sydney, Australia
- University of Ulster, UK
- University of Western Sydney, Australia
- Victoria University of Technology, Australia
- Worcester Polytechnic Institute, USA

0.5.3.5 Fire research institutes

The following private or government research institutes publish and disseminate fire engineering-related knowledge and information.

- Building and Fire Research Laboratory, National Institute of Science and Technology (NIST), USA
- Building Research Association of New Zealand (BRANZ), New Zealand
- Centre for Environmental Safety and Risk Engineering (CESARE), Victoria University of Technology, Australia
- CSIRO Fire Science and Technology Laboratory, Australia
- Duisburg Gerhard-Mercator University Fire Detection Laboratory, Germany
- Factory Mutual, USA
- Fire and Risk Sciences, Building Research Establishment, UK
- Fire Science Centre, University of New Brunswick, USA
- Fire Science Laboratory, Worcester Polytechnic Institute, USA
- FireSERT, Fire Safety Engineering Research and Technology Centre, University of Ulster, UK
- National Fire Data Centre, USA
- National Research Council, Canada
- Scientific Services Laboratory — AGAL, Australia
- SINTEF, Norway
- Swedish National Testing and Research Institute, Sweden

- Technical Research Centre of Finland (VTT), Finland
- The Loss Prevention Council, UK
- Western Fire Centre, Inc. in Kelso, USA

0.5.3.6 Fire research institutes

The following private or government research institutes publish and disseminate fire engineering-related knowledge and information.

- Building and Fire Research Laboratory, National Institute of Science and Technology (NIST), USA
- Building Research Association of New Zealand (BRANZ), NZ
- Centre for Environmental Safety and Risk Engineering (CESARE), Victoria University of Technology, Australia
- CSIRO Fire Science and Technology Laboratory, Australia
- Duisburg Gerhard-Mercator University Fire Detection Laboratory, Germany
- Factory Mutual, USA
- Fire and Risk Sciences, Building Research Establishment, UK
- Fire Science Centre, University of New Brunswick, USA
- Fire Science Laboratory, Worcester Polytechnic Institute, USA
- FireSERT, Fire engineering Research and Technology Centre, University of Ulster, UK
- National Fire Data Centre, USA
- National Research Council, Canada
- Scientific Services Laboratory — AGAL, Australia
- SINTEF, Norway
- Swedish National Testing and Research Institute, Sweden
- Technical Research Centre of Finland (VTT), Finland
- The Loss Prevention Council, UK
- Western Fire Centre, Inc. in Kelso, USA

0.5.3.7 Associations and organisations

The following private or government organizations publish and provide fire engineering-related knowledge and information.

- ANSI, American National Standards Institute, USA
- ASTM, American Society for Testing and Material
- CIB, International Council for Building Research Studies and Documentation, Committee W14 Fire, Netherlands
- FAA, Federal Aviation Authority, USA
- FEMA, Federal Emergency Management Agency, USA
- Fire and Risk Sciences, Building Research Establishment, UK
- FPAA, The Fire Protection Association of Australia, Australia
- IAFSS, International Association for Fire Safety Science, UK
- Institution of Fire Engineers, Engineering Council Division, UK
- ISO, The International Standards Organization, Switzerland
- IOSH, Institution of Occupational Safety and Health, USA
- NFPA, National Fire Protection Association, USA
- NIST, National Institute for Science and Technology, Building and Fire Research Laboratory, USA
- NRC, National Research Programme, Canada

- SAA, Standards Australia, Australia
- SFPE, Society of Fire Protection Engineers
- The Combustion Institute, USA

0.5.3.8 Web sites

The following web sites provide on-line information that may be utilized in fire engineering assessments.

- IAFSS (USA) — www.iafss.org/
- Lund University (Sweden) — www.brand.lth.se
- NIST BFRL (USA) — www.bfrl.nist.gov
- National Data Centre — www.usfa.fema.gov

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Part 1
Process

International
Fire Engineering
Guidelines

Table of Contents

These Guidelines have four parts, each of which is a separate entity. For a detailed table of contents, refer to the beginning of each part and each chapter.

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Chapter 1.1

Overview

The International Fire Engineering Guidelines have been prepared to assist fire engineers and other practitioners who are involved in building design and approval and the matter of fire safety in particular.

These guidelines comprise of four parts, each with its own table of contents. It has been designed for ease of use and cross-referencing, with graphics as outlined below:

- **graphic identification** of sub-systems, as explained below
- **shaded boxes** containing examples or commentary
- **abbreviated flow charts** in the margins, with the relevant boxes shaded.

Part 0 provides background information and guidance that is integral to an understanding of the entire Guidelines.

This Part 1 describes the process by which fire engineering is typically undertaken.

Part 2 describes a selection of methodologies that may be used in undertaking the fire engineering process.

Part 3 provides a selection of data that may be used in applying the methodologies of Part 2 or other chosen methodologies.

1.1.1 The fire engineering process

The typical fire engineering process normally goes through five stages, as shown in Figure 1.1.2.

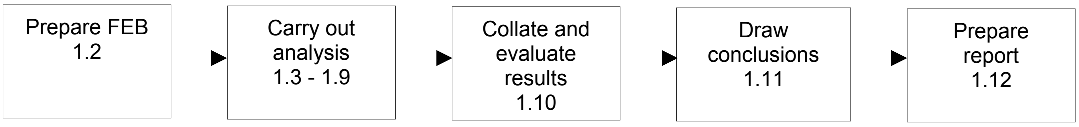
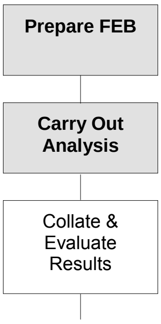


Figure 1.1.2 Typical fire engineering process



First, a fire engineering brief (FEB) should be prepared, as discussed in Chapter 1.2. This task is of fundamental importance and forms the basis of the fire engineering process.

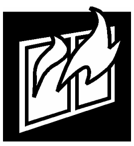
Chapters 1.3 to 1.9 discuss how the analysis, as determined by the FEB, can be undertaken. In any building, there are many features that combine to create an overall fire safety system for the building. To assist in the analysis of the fire safety system, it is convenient to consider it as comprising six sub-systems, each of which is shown below (further discussion may be found in Chapter 1.3.).

Sub-system A
SS-A
Fire Initiation & Development & Control
Chapter 1.4

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.

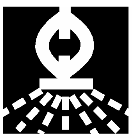
Sub-system B
SS-B
Smoke Development & Spread & Control
Chapter 1.5

Sub-system B (SS-B) is used to analyze 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
Chapter 1.6

Sub-system C (SS-C) is used to analyze 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
Chapter 1.7

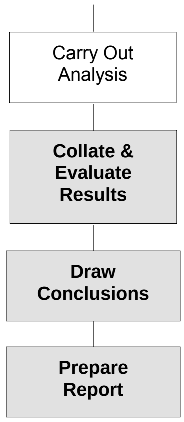
Sub-system D (SS-D) is used to analyze detection, warning and suppression for fires. This process enables estimates to be made of the effectiveness of suppression.

Sub-system E
SS-E
Occupant Evacuation & Control
Chapter 1.8

Sub-system E (SS-E) is used to analyze 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
Chapter 1.9

Sub-system F (SS-F) is used to analyze the effects of the intervention activities of fire services on a fire including the effectiveness of suppression activities.



Careful collation and evaluation of the results from the analysis is vital and this is discussed in Chapter 1.10. Drawing conclusions requires engineering judgement, as discussed in Chapter 1.10. 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 work of preparing a FEB, carrying out the requisite analysis, collating the results, and drawing conclusions is of little use unless it is reported in a transparent manner that is responsible, accurate and aimed at helping the ultimate decision maker. This essential process is discussed in Chapter 1.11.

1.1.2 Application of the process

The fire engineering process may be considered to be used in two different ways, namely in the design of a fire safety system and components or in the evaluation of a given fire safety system. In the early stages of a project, where the building design is evolving, the fire engineering process may contribute to the development of the design and the evaluation of the various design options. The primary use of fire engineering in this instance would be in the design sense. In the latter project stages, when the design has become essentially fixed, a fire engineering evaluation will be carried out in order to demonstrate that the building solution meets the relevant objectives or performance requirements of the relevant building code and other client/stakeholder requirements.

Thus, a distinction can be drawn between the use of the fire engineering process as a means of designing, or a means of evaluating a given design for a building’s fire safety system. From this latter process, a fire engineering report is generated which forms the basis of the documentary evidence required in support of an alternative solution that may be needed for building approval.

In actual fact, the majority of fire engineering studies will be a mixture of design and evaluation. To that end, the fire engineer 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 being reduced and costs are being refined continually. Once the fire engineer has completed the evaluation of the fire safety strategy and design solution, the other designers still have to complete the design of the components such as sprinklers, detection and smoke control systems. It is critical therefore that any evaluation is completed before the design or cost estimate of the project is complete.

The fire engineering process outlined above may be carried out in many different ways and, as discussed in the next chapter on analysis, the knowledge and skills of a fire engineer is needed to determine, based upon the guidance in this document, the most effective way of devising an analysis strategy and carrying out the evaluation. These guidelines provide comprehensive choices for the fire engineer who is required to select those aspects that are appropriate to the project in hand.

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Chapter 1.2

Preparing a Fire Engineering Brief (FEB)

For each project, the fire engineer should prepare a Fire Engineering Brief (FEB). This Section provides guidance on what issues should be addressed in the FEB. A FEB is a process that defines the scope of work for the fire engineering analysis. Its purpose is to set down the basis, as agreed by the relevant stakeholders, on which the fire safety analysis will be undertaken. It is not the contract agreed between the fire engineer and the owner or nominated representative, although the contract may include aspects of the FEB.

The FEB is an essential part of the fire engineering process. Where appropriate it allows the broader community aspirations to be taken into account during the development and evaluation of alternative solutions, whilst at the same time ensuring that levels of safety accepted by the community are maintained.

In the case of a fire engineering analysis that considers a simple departure from a deemed-to-satisfy or prescriptive provision of the relevant building code, the FEB might be a short document, however for large and / or complex projects the FEB could be a major document.

Ideally, the FEB 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 1.2.2.

The flow chart in Figure 1.2 illustrates a formalized process by which the FEB is conducted and refers to the relevant sections of these Guidelines. However, the process will vary for any particular project and steps may be re-ordered, omitted or an iterative process introduced. The fire engineer should ensure that the process actually followed is appropriate for the design or evaluation being undertaken.

In principle, the objectives, proposed trial designs, analysis methods and acceptance criteria are all 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, by analysis, to be unacceptable (it does not meet the objectives or performance requirements) the FEB process is revisited and a further trial design developed.

Sometimes, as the analysis of a design proceeds or as a project develops, it may be appropriate to revise the FEB, adopting the same consultative approach as with the original. The 'final' FEB will be incorporated into the overall report (Chapter 1.11).

Each step in the flow chart (Figure 1.2) is discussed in the relevant Sections 1.2.1 to 1.2.14.

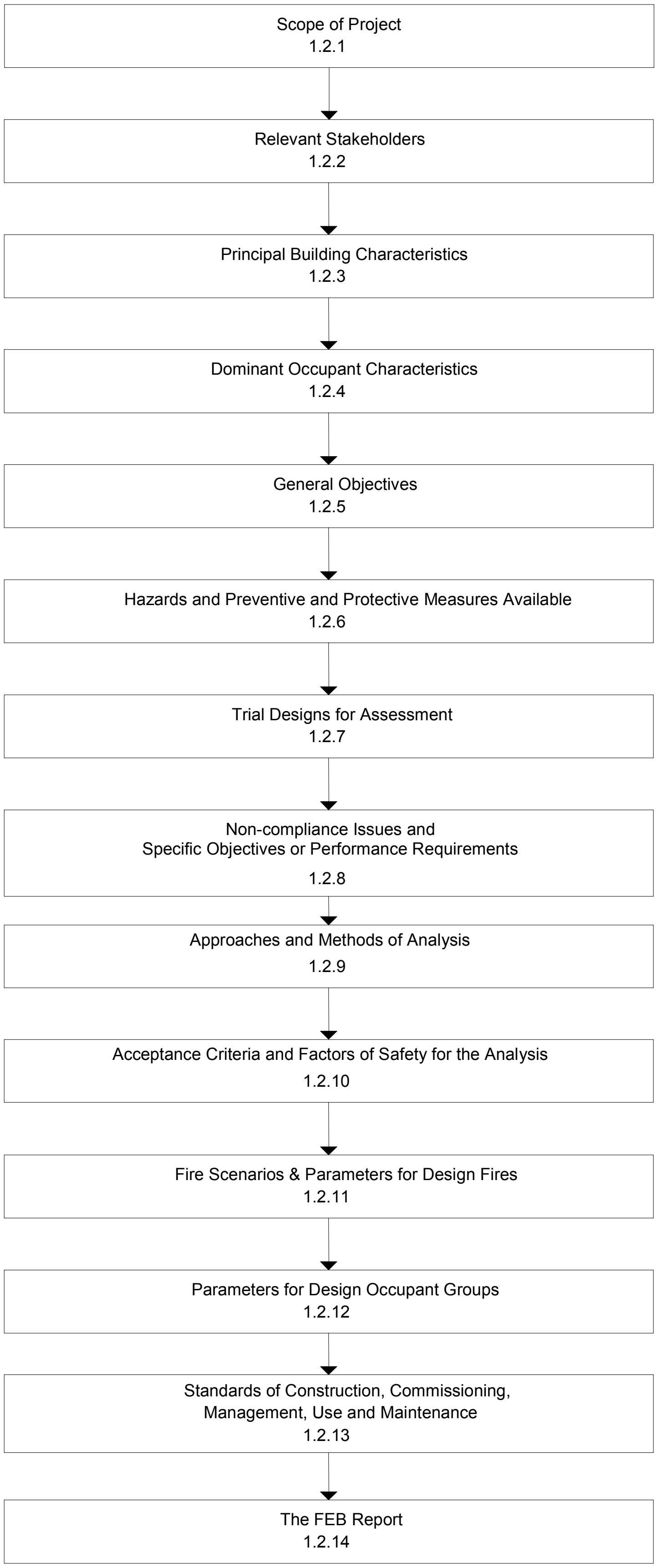
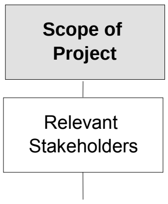


Figure 1.2 A process for developing a FEB

1.2.1 Scope of the project



In order to contribute effectively to the FEB process, each stakeholder should understand the scope and intent of the project. The relevant topics are discussed below.

1.2.1.1 Contractual context

All design is carried out in a contractual context unique to each individual project. Understanding the contractual context is often a key to achieving agreement on many issues. It would be useful to know, for example, whether the project is:

- a conventional design and separate construction process
- design-and-build
- one where the owner's design team will be transferred over to join the contractor's team to complete the design, or
- one where a project manager is appointed by the owner to exercise control over the total process.

1.2.1.2 Regulatory framework

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

- Are there any relevant legislative requirements relating to the building project?
- Is the relevant building regulatory system generally prescriptive or performance-based?
- What is the process of accepting a performance-based solution as an alternative to a prescriptive design?
- Who are the authorities having jurisdiction for the building permits?
- Which other bodies should be consulted?
- What timescales can be expected for the various regulatory approval options that may be available?

In some cases, there may be no regulatory framework, such as the voluntary upgrade of all or part of an existing building by an owner or tenant to meet their own risk management requirements. Nevertheless, in this situation they should give due regard to the regulatory environment to ensure there is not regulatory impact.

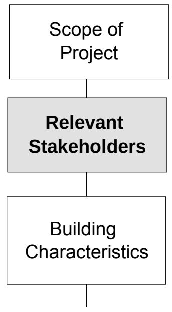
1.2.1.3 Project schedule

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 carry out a professional fire engineering analysis; a standard deemed-to-satisfy or prescriptive design may have to be adopted, even though potential cost savings, flexibility and design innovation may be foregone, or
- 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. Usually, inherent in this is an understanding of the extent to which the various stakeholders and the FEB team members are to be consulted and asked to review draft reports.

1.2.2 Relevant stakeholders

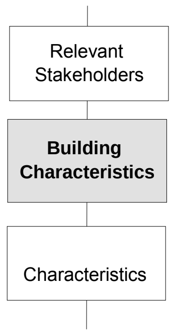


Ideally, the FEB should be developed collaboratively by the relevant stakeholders in the particular project. For example, the following parties may be involved:

- client or client's representative (such as a project manager)
- fire engineer
- architect or designer
- regulations consultant
- various specialist consultants
- fire service (both public and private)
- authority having jurisdiction (AHJ)
- representative of owner's insurance company
- tenants
- building operations management.

However, not all stakeholders will be able to contribute equally or be available to contribute. The reality of many projects means that often a draft FEB is prepared by the fire engineer, submitted for comment to the other stakeholders, then refined and approved by all the stakeholders. The circumstances of each project and the method by which it will receive its regulatory approval will generally dictate the precise process to be used and how many meetings (face-to-face, telephone, teleconferencing, etc.) are held.

1.2.3 Principal building characteristics

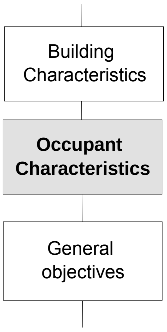


In order to evaluate or design a building's fire safety system, it is important to understand the building's characteristics and its normal mode of functioning. The principal characteristics should be identified early in the FEB process in order to facilitate the decisions that need to be made and issues to be resolved (see Figure 1.2 and the following Sections). The information available will vary according to the stage in the design process but the following list of characteristics, together with examples, is indicative of those characteristics that might be appropriate:

Characteristics	**Examples**
Occupancy	Building classification Usage, particularly unusual uses
Location	Proximity to other buildings and boundaries Proximity to building of high importance (e.g. building used for post disaster recovery) Proximity to other hazards Proximity to fire station(s) Fire services access
Size & 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 1.2.6.1
Fire preventive and protective measures	See Section 1.2.6.2
Management and use	Regular inspections of preventive and protective measures Training of occupants
Maintenance	Frequency and adequacy of maintenance regimes Availability of repair personnel / parts
Environmental conditions	Ventilation and prevailing internal air currents Prevailing patterns of wind and snow
Value	Capital Community Infrastructure Heritage
Other	Environmental impact of a fire Fire fighting concerns

1.2.4 Dominant occupant characteristics



Understanding the likely nature of the building's occupants is an important element in an FEB. As with the building, there are many characteristics that can be identified making complete characterization a complex and difficult task. However, for a given fire engineering evaluation only a limited number of 'dominant occupant characteristics' may affect the outcome. Here are some examples of dominant occupant characteristics that are likely to be relevant:

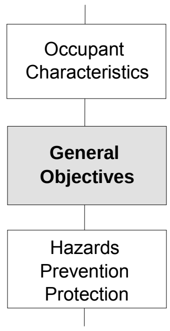
Characteristics	**Examples**
Distribution	Number Gender Age Location
State	Awake or asleep Intoxicated or sober Unconscious or fully conscious
Physical attributes	Mobility Speed of travel Hearing ability Visual ability
Mental attributes	Level of understanding Potential emergency behaviour Ability to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

All of these characteristics should be considered in identifying the design occupant groups for the building. The concept of design occupant groups is explained in Section 1.2.12 of these Guidelines.

It may be prudent to consider potential future building occupancies as well as those planned for the immediate future, because the occupant characteristics used for the analysis may impose limitations on the different future uses of the building.

1.2.5 General objectives



The FEB should define the agreed fire safety objectives for the project. In order to define the objectives, it is useful to first identify the objectives of each stakeholder (which may be different). The project objectives can be divided into three broad categories, building regulatory objectives, other regulatory objectives and non-regulatory objectives.

1.2.5.1 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 in question
- preventing the spread of fire between buildings.

1.2.5.2 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 be limited to:

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

1.2.5.3 Non-regulatory objectives

However, there may be other objectives set by the client or other stakeholders (for example 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 a country's heritage in older or significant buildings
- limiting the release of hazardous materials into the environment.

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:

- increased security
- extensive natural lighting
- an open plan layout
- the use of new materials
- measures to improve energy efficiency and sustainability
- flexibility for future uses
- low life-cycle costs.

1.2.6 Hazards and preventive and protective measures available

General Objectives

Hazards Prevention Protection

Trial Designs for Evaluation

A systematic review should be conducted to establish potential fire hazards (both normal and special) of the building. The information gathered in determining the principal building characteristics in Section 1.2.3 forms the basis for this review. Section 1.2.6.1 provides examples of potential fire hazards.

The various preventive and protective measures that already exist, are planned or could be used to address the hazards should then be identified. Examples of such measures are listed below in Section 1.2.6.2.

1.2.6.1 Hazards

In determining the likely hazards, the following factors should be considered:

Factors	**Examples**
General layout	Dead end corridors Unusual egress provisions Location of hazardous materials / processes Exposures to external radiant sources
Activities	Repair and maintenance Process and construction Disregarding safety procedures
Ignition sources	Smoking materials Electrical equipment Heating appliances Unusual ignition sources
Fuel sources	Amount of combustible materials Location of combustible materials Fire behaviour properties Dangerous goods and explosives

1.2.6.2 Preventative and protective measures

Examples of preventative and protective measures are set out below for each of the fire safety sub-systems used in these Guidelines.

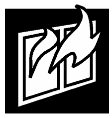
Sub-system A
Fire Initiation and Development and Control

- 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)

Sub-system B
Smoke Development and Spread and Control

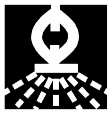
- Smoke barriers
- Natural smoke venting
- Mechanical smoke management

Sub-system C
Fire Spread and 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

Sub-system D
Fire Detection, Warning and Suppression

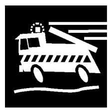


- Automatic and manual detection equipment
- Automatic and manual warning equipment
- Surveillance equipment
- Automatic suppression equipment
- Manual suppression equipment

Sub-system E
Occupant Evacuation and Control

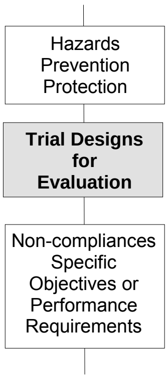
- Evacuation plans
- Occupant training
- Emergency communications
- Egress signage
- Egress routes (including fire isolated elements)

Sub-system F
Fire Services Intervention



- Type of fire services available (full-time/permanent or volunteer).
- Characteristics of fire services capability and resources
- Fire service access to the site and to the building
- Water supplies and infrastructure

1.2.7 Trial designs for evaluation



A fire safety system should be developed bearing in mind many other factors, such as aesthetics, cost, ease of everyday use, speed of construction, and the importance of maintenance.

As the architectural and engineering drawings develop, the design team (including the fire engineer) should incorporate measures which are expected to achieve an acceptable level of fire safety. The FEB team should select one or more trial designs for detailed evaluation as described in Chapter 1.3.

The trial designs may incorporate measures which are not required by the relevant deemed-to-satisfy or prescriptive provisions in order to compensate for non-complying design features.

In addition, trial designs should incorporate redundancies to compensate for potential failures of components of the fire safety system of the trial design. Quantification of these redundancies should be carried out by using the sensitivity studies selected in Section 1.2.9.5.

Further trial designs will need to be developed in the event of the trial designs selected not meeting the required performance criteria.

Each trial design being considered should be clearly identified and all its features, including those relating to fire safety, should be described. Sections 1.2.3 'Identify Principal Building Characteristics' and 1.2.6.2 'Preventative and Protective Measures' should provide the necessary information for a description. This description needs to be sufficiently detailed so that the essential features of the design are readily identifiable for the purposes of the analysis and future reference.

1.2.8 Non-compliance issues and specific objectives or performance requirements

Having defined the general objectives (Section 1.2.5), the specific objectives or performance requirements used for the evaluation of the trial designs need to be determined. In order to determine the specific objectives or performance requirements it is necessary to determine where the trial designs do not comply with the relevant deemed-to-satisfy or prescriptive provisions. This process will identify the issues that need to be addressed in the analysis of the trial design (see Chapter 1.3).

In cases where there are no deemed-to-satisfy or prescriptive provisions, the relevant objectives or performance requirements need to be identified directly (see 1.2.8.2) and the determination of non-compliance issues (Section 1.2.8.1) omitted. This situation may occur where the relevant codes comprise objectives or performance requirements only or when general objectives, other than those covered by recognised codes, have been agreed to during the FEB process (see Section 1.2.5).

Some building codes require fire engineered trial designs to demonstrate equivalence only, and other building codes allow equivalence or direct demonstration of compliance with the objective / performance requirements. In every case it is important that the fire engineer identify clearly whether the trial design is being evaluated in terms of equivalence to the deemed-to-satisfy provisions or not (see 1.2.9.1).

1.2.8.1 Non-compliance issues

Each of the trial designs selected for analysis will comply, to a greater or lesser extent, with deemed-to-satisfy provisions (of an objective or performance based code) or prescriptive provisions (of a prescriptive code). Each of the non-compliance issues need to be identified, quantified and documented by comparing the detail of the trial designs with the relevant provisions.

A design may consist of a mixture of complying and non-complying features. As the degree of compliance with the deemed-to-satisfy or prescriptive provisions of the relevant code increases, the scope of the fire engineering evaluation will generally decrease. This is because the analysis is limited to addressing the non-compliance issues.

1.2.8.2 Specific objectives or performance requirements

The determination of the relevant specific objectives or performance requirements is based upon the non-compliance issues identified above and the general non-regulatory objectives (see Section 1.2.5) that are required to be met. This determination of specific objectives or performance requirements is not necessary where a comparative approach based upon deemed-to-satisfy or prescriptive provisions is used in the analysis (see Section 1.2.9).

It needs to be recognized that a single non-compliance issue may relate to more than one objective or performance requirement. In addition, the non-compliance and all the relevant objectives or performance requirements may not be in the same section of a code.

In cases where there are no applicable deemed-to-satisfy or prescriptive requirements, all the specific objectives or performance requirements may need to be addressed in the analysis. In cases where there are no applicable objectives or performance requirements these will need to be developed during the FEB.

Example: Selection of relevant Performance Requirements

An alternative solution proposes an open stair connecting 4 floors in a sprinkler-protected office building that discharges into a ground level foyer.

Australia

CP2 (a) A building must have elements which will, to the degree necessary, avoid the spread of fire-

(i) to *exits*; and
(ii) to *sole-occupancy units* and *public corridors*; and
(iii) between buildings; and
(iv) in a building, appropriate to-

(b) Avoidance of the spread of fire referred to in (a) must be appropriate to-

(i) the function or use of the building; and
(ii) the *fire load*; and
(iii) the potential *fire intensity*; and
(iv) the *fire hazard*; and
(v) the number of *storeys* in the building; and
(vi) its proximity to *other property;* and
(vii) any active *fire safety systems* installed in the building; and
(viii) the size of any *fire compartment*; and
(ix) *fire brigade* intervention; and
(x) other elements they support; and
(xi) the *evacuation time*."

To provide occupants with a safe egress path, Clause D1.3 of the Deemed-to-Satisfy Provisions of BCA 2005 requires the stair to be located in a fire-isolated shaft and discharge directly to outside the building.

The corresponding performance requirement in Section D is **DP5**, which states:

> To protect evacuating occupants from a fire in the building *exits* must be fire isolated, to the degree necessary, appropriate to-
>
> (a) the number of *storeys* connected by the *exits*; and
>
> (b) the *fire safety system* installed in the building; and
>
> (c) the function or use of the building; and
>
> (d) the number of storeys passed through by the *exits*; and
>
> (e) *fire brigade* intervention.

(Example continued)

However, as the tenability levels of the exit routes would also need to be considered, it would be necessary to address Performance Requirement **EP2.2**, which states:

(a) *In the event of a fire in a building the conditions in any evacuation route must be maintained for the period of time occupants take to evacuate the part of the building so that-*

- *(i)* *the temperature will not endanger human life; and*
- *(ii)* *the level of visibility will enable the evacuation route to be determined; and*
- *(iii)* *the level of toxicity will not endanger human life.*

(b) *The period of time occupants take to evacuate referred to in (a) must be appropriate to-*

- *(i)* *the number, mobility and other characteristics of the occupants; and*
- *(ii)* *the function or use of the building; and*
- *(iii)* *the travel distance and other characteristics of the building; and*
- *(iv)* *the fire load; and*
- *(v)* *the potential fire intensity; and*
- *(vi)* *the fire hazard; and*
- *(vii)* *any active fire safety systems installed in the building; and*
- *(viii)* *fire brigade intervention.*

(Example continued)

USA

Section 707 of the *2003 International Building Code* would require the stairway to be enclosed by 2 hour fire barriers with 1 ½ hour rated opening protection.

The performance code requirements would be as follows:

Chapter 3 Design Performance Levels

Building would classify as Performance Group II therefore the maximum damage levels would be as follows:

Performance Group II Damage Level limits	
Event Size	**Damage Level**
Very Large	Severe
Large	High
Medium	Moderate
Small	Mild

Fire Impact Management

Section 602

602.1 Objective. *To provide an acceptable level of safety performance when facilities are subjected to fires that could occur in the fire loads that may be present in the facility during construction or alteration and throughout the intended life. (Same as 1901.1)*

602.2 Functional Statements. *Buildings shall be designed with safeguards against the spread of fire so that no person not directly adjacent to or involved in the ignition of a fire shall suffer serious injury or death from a fire and so that the magnitude of the property losses are limited as follows:*
Performance Group I – High
Performance Group II – Moderate
Performance Group III – Mild
Performance Group IV – Mild

(essentially the same as 1701.2 and it should be noted that this section is more specific than the damage limits provided in Chapter 3 and does two things

- Provides a single level of performance for life safety and
- Simply places an upper limit for damage for all event sizes

In this particular case the upper limit for damage would be moderate based upon the classification as Performance Group II in Chapter 3)

602.2.1 Building and Adjacent buildings. *Buildings and facilities shall be designed and constructed so that the building and adjacent buildings or facilities and their occupants, contents and amenities are appropriately protected from the impact of fire and smoke.*

602.2.2 Needs of fire fighters*. Buildings and facilities shall be designed and constructed so that fire fighters can appropriately perform rescue operations, protect property, and utilize fire-fighting equipment and controls.*

602.3 Performance requirements – refers you to Chapter 17.

Chapter 17

1701.1 Objective. *To provide an acceptable level of fire safety performance when facilities are subjected to fires that could occur in the fire loads that may be present in the facility during construction or alteration and throughout the intended life.* (Same as 602.1)

1701.2 Functional Statements. *Facilities shall be designed with safeguards against the spread of fire so that no person not directly adjacent to or involved in the ignition of a fire shall suffer serious injury or death from a fire and so that the magnitude of the property loss is limited as follows:*
Performance Group I – High
Performance Group II – Moderate
Performance Group III – Mild
Performance Group IV – Mild
(essentially the same as 602.2)

(Example continued)

1701.2.2 Fire Impact. *Facilities shall be designed, constructed and maintained in a manner that limits the potential for fire.*

1701.2.3 Time for evacuation. *Facilities shall be designed, constructed, maintained and operated with appropriate safeguards in place to limit the spread of fire and products of combustion so that occupants have sufficient time to escape the fire.*

1701.2.4 Limitation on fire spread. *Facilities shall be designed, constructed, maintained and operated in such a manner that the spread of fire through a building is restricted and that fire does not spread to adjacent properties.*

1701.2.6 Emergency Responder needs. *Facilities shall be arranged, constructed, maintained and operated with appropriate safeguards in place to allow fire-fighting personnel to perform rescue operations and to protect property.*

1701.3 Performance Requirements. *Facilities or portions thereof shall be designed constructed and operated to normally prevent any fire from growing to a stage that would cause life loss or serious injury, taking into account all anticipated and permitted fire loads that would affect their performance. Facilities shall be designed to sustain local fire damage, and the facility as a whole will remain intact and not be damaged to an extent disproportionate to the original local damage.*

1701.3.3 Emergency responders. *Where necessary, provide appropriate measures to limit fire and smoke spread and damage to acceptable levels so that fire fighters are not unduly hindered in suppression or rescue operations.*

1701.3.7 Control of smoke. *Smoke control systems, when provided shall limit the unacceptable spread of smoke to non fire areas.*

1701.3.9 Vertical openings. *Vertical openings shall be constructed, arranged, limited or protected to limit fire and smoke spread as appropriate to the fire- and life-safety strategies selected.*

1701.3.10 Wall, floor, roof and ceiling assemblies. *Wall, floor, roof and ceiling assemblies forming compartments including their associated openings shall limit the spread of fire appropriate to the associated hazards, risks and fire safety systems or features installed.*

1701.3.15 Magnitude of fire event. *Design fire events shall realistically reflect the ignition, growth and spread potential of fires and fire effluents that could occur in the fire load that may be present in the facility by its design and operational controls.*

Means of Egress

It should be noted that the primary focus with regard to Means of Egress is providing appropriate paths etc to meet the needs of the occupants and is not specific only to fire. Fire is dealt with more specifically within Section 602 and Chapter 17.

Section 701

701.1 Objective. *To protect people during egress and rescue operations. (Same as 1901.1)*

701.2 Functional statement. *Enable occupants to exit the building, facility and premise or reach a safe place as appropriate to the design performance level determined in chapter 3. (Same as 1901.2)*

701.3 Performance requirements. *– Refers to chapter 19.*

Chapter 19

1901.1 Objective. *To protect people during egress and rescue operations (same as 701.1)*

1901.2 Functional Statement. *Enable occupants to exit the building, facility and premise or reach a safe place as appropriate to the design performance level determined in chapter 3. (Same as 701.2)*

1901.3 Performance requirements.

1901.3.1 General. *The construction, arrangement and number of means of egress, exits and safe places for buildings, shall be appropriate to the travel distance, number of occupants, occupant characteristics, building height, and safety systems and features.*

1901.3.4 Protection from untenable conditions. *Each safe place shall provide adequate protection from untenable conditions, an appropriate communication system and adequate space for the intended occupants.*

(Example continued)

Canada

Compliance with the Objective Based Building Code of Canada "... shall be achieved by

a) complying with the applicable acceptable solutions in Division B ... or
b) using alternative solutions that will achieve at least the minimum level of performance required by Division B in the areas defined by the objectives and functional statements attributed to the applicable acceptable solutions ..."

An open stair, being a single means of egress in a multi-storey building, raises two issues that have to be verified with respect to code compliance:

1. Interconnected floor space created by the stair, and
2. Provision of safe egress

The first one can be verified as complying due to the permission by Division B for interconnected floor space in a sprinklered office building. The second one does not comply with the acceptable solutions in Division B, which requires exit facilities from every floor area. An open stair does not qualify as exit; this would have to be an interior stairway separated by rated assemblies from the rest of the building, a "horizontal exit" (typically found in hospitals, an area on the same level separated from the floor area by a rated assembly) or an exterior exit facility (fire escape, exterior stairway etc.). Moreover, a minimum of two exits is required from each floor area in a building of this size and occupancy.

Provisions of Division B relevant to egress in the subject building are listed below, with references to Objectives and Functional Statements. The list of relevant Objectives and Functional Statements (in an abbreviated version) is provided following the provisions of Division B. Also listed are Intent Statements for each provision. These statements are not part of the National Building Code of Canada; they are published in a separate explanatory document.

3.4.2.1.(1). *... every floor area intended for occupancy shall be served by at least 2 exits*

***Objective**: OS3 **Subobjective**: OS3.7 **Functional Statements**: F10,F05/F12,F06*

Intents

I1. To reduce the probability that persons will not have a choice of an alternative exit in the case of one exit being blocked or obstructed in an emergency situation, which could lead to delays in evacuation or movement to a safe place, which could lead to harm to persons.

I2. To reduce the probability that emergency responders will not have a choice of an alternative exit in the case of one exit being blocked or obstructed in an emergency situation, which could lead to emergency responders being delayed in gaining access to a floor area, which could lead to delays or ineffectiveness in carrying out emergency response operations, which could lead to delays in evacuation or moving to a safe place, which could lead to harm to persons.

***Objective**: OS1 **Subobjective**: OS1.2 **Functional Statements**: F12,F06*

Intent

I1. To reduce the probability that emergency responders will not have a choice of an alternative exit in the case of one exit being blocked or obstructed in a fire situation, which could lead to emergency responders being delayed in gaining access to a floor area, which could lead to delays or ineffectiveness in carrying out emergency response operations, which could lead to spread of fire, which could lead to harm to persons.

***Objective**: OP1 **Subobjective**: OP1.2 **Functional Statements**: F12,F06*

Intent

I1. To reduce the probability that emergency responders will not have a choice of an alternative exit in the case of one exit being blocked or obstructed in a fire situation, which could lead to emergency responders being delayed in gaining access to a floor area, which could lead to delays or ineffectiveness in carrying out emergency response operations, which could lead to spread of fire, which could lead to damage to property.

3.4.4.1.(1). *... every exit shall be separated from the remainder of the building by a fire separation ...*

***Objective**: OS1 **Subobjective**: OS1.5/OS1.5,OS1.2/OS1.2*

***Functional Statements**: F05/F06/F03*

Intents

I1. To reduce the probability that fire will spread into an exit, which could lead to delays in evacuation or moving to a safe place, which could lead to harm to persons.

(Example continued)

I2. To reduce the probability that fire will spread into an exit, which could lead to emergency responders being delayed in gaining access to floor areas, which could lead to fire emergency response operations being delayed or ineffective, which could lead to:

A. delays in evacuation or moving to a safe place, which could lead to harm to persons including emergency responders, and

B. spread of fire to other parts of the building, which could lead to harm to persons.

I3. To reduce the probability that fire will spread from one floor area to another floor area by means of an exit, which could lead to harm to persons in the other floor area.

***Objective**: OP1* ***Subobjective**: OP1.2* ***Functional Statements**: F06,F03*

Intents

I1. To reduce the probability that fire will spread into an exit, which could lead to fire emergency response operations being delayed or ineffective, which could lead to further spread of fire, which could lead to damage to property.

I2. To reduce the probability that fire will spread from one floor area to another floor area by means of an exit, which could lead to damage to property.

If a designer wants to use an external fire escape as a component of an alternative solution, the following provisions apply:

***3.4.7.1.(1)**. Except as permitted by Sentence (2), fire escapes shall not be erected on a building.*

2) If it is impracticable to provide one or more of the exit facilities listed in Article 3.4.1.4., fire escapes conforming to Articles 3.4.7.2. to 3.4.7.7. are permitted to serve floor areas in an existing building provided the floor areas served are not more than

...

b) 5 storeys above ground level ...

***Objective**: OS3* ***Subobjective**: OS3.7* ***Functional Statements**: F10,F12*

Intent

I1. To reduce the probability that an exterior exit facility not fully complying with Subsections 3.4.1. to 3.4.6. will be used, which could lead to:

A. delays in evacuation or moving to a safe place in an emergency situation, which could lead to harm to persons, and

B. delays by emergency responders in gaining access to floor areas in an emergency situation, which could lead to delays in evacuation or moving to a safe place, which could lead to harm to persons.

List of relevant Objectives

OS1 Fire Safety - risk of injury ... caused by:
- *OS1.2 fire or explosion impacting areas beyond its point of origin*
- *OS1.5 persons being delayed in or impeded from moving to a safe place during a fire emergency*

OS3 Safety in Use - risk of injury ... caused by:
- *OS3.7 persons being delayed in or impeded from moving to a safe place during an emergency*

OP1 Fire Protection of the Building - the risks of damage due to fire ... caused by:
- *OP1.2 fire or explosion impacting areas beyond its point of origin*

List of relevant Functional Statements

F03 To retard the effects of fire on areas beyond its point of origin.
F05 To retard failure or collapse due to the effects of fire.
F06 To protect facilities for notification, suppression and emergency response from the effects of fire.
F10 To facilitate the timely movement of persons to a safe place in an emergency.
F12 To facilitate emergency response.

Another piece of information with respect to code compliance is provided by the Appendix Note A-3.4.1.1.(1):

"... the requirements described in Section 3.4. are intended to provide the level of safety to be achieved. If alternative measures are used, they should develop the level of safety implied in these requirements."

(Example continued)

New Zealand

The problem given in the above example lies outside of the acceptable solution found in the New Zealand Building Code (NZBC) Approved Documents and is to be considered as an alternative solution. Compliance with the acceptable solution is one way of achieving building consent. However, compliance to the performance criteria must be met for an alternative solution to be approved by a Building Consent Authority.

The situation presented in the problem would need clarification on several key areas for a full solution to be presented. In the absence of detailed information the performance criteria contained in the NZBC are given below to demonstrate the areas that need to be addressed in order for the solution to be acceptable. All other areas of the NZBC that are applicable to the building will need to be addressed. Other requirements of the NZBC not referenced in this answer will apply to the overall design solution for the premises.

This assumes that the fire design for the building has been correctly engineered, and quantified where possible, to ensure that there is an adequate level of safety.

Assuming that the performance criteria given below are demonstrated to comply to the NZBC then this solution can be accepted by the building consent authority.

The performance criteria state:

[Section C2- Means of Escape]

C2.3.1 The number of open paths available to each person escaping to an exitway or final exit shall be appropriate to

- *(a) The travel distance*
- *(b) The number of occupants*
- *(c) The fire hazard*
- *(d) The fire safety systems installed in a fire cell*

C2.3.2 The number of exitways or final exits available to each person shall be appropriate to

- *(a) The open path travel distance*
- *(b) The building height*
- *(c) The number of occupants*
- *(d) The fire hazard*
- *(e) The fire safety systems installed in the building*

C2.3.3 Escape routes shall be

- *(a) Of adequate size for the number of occupants*
- *(b) Be free of obstruction in the direction of escape*
- *(c) Of a length appropriate to the mobility of the people using them*
- *(d) Resistant to the spread of fire as required by Clause C3- "Spread of Fire"*
- *(e) Easy to find as required by Clause F8- "Signs"*
- *(f) Provided with adequate illumination as required by Clause F6-"Lighting for Emergency"*
- *(g) Easy and safe to use as required by Clause D 1.3.3- "Access Routes"*

[From Clause C3 "Spread of Fire"]

C3.3.1 Interior surface finishes on walls, floors, ceilings and suspended building elements, shall resist the spread of fire and limit the generation of toxic gases, smoke and heat, to a degree appropriate to:

- *(a) The travel distance*
- *(b) The number of occupants*
- *(c) The fire hazard*
- *(d) The active fire safety systems installed in the building*

(Assuming that the stair is open to all floors and that the office comprises one entire firecell the requirement of C3.3.2, C3.3.3 may not apply.)

C3.3.4 Concealed spaces and cavities within buildings shall be sealed and subdivided where necessary to inhibit the unseen spread of fire and smoke.

C3.3.6 Automatic fire suppression systems shall be installed where people would otherwise be

- *(a) Unlikely to reach a safe place in adequate time because of the number of stories in the building*
- *(b) Required to remain within the building without proceeding directly to a final exit, or where the evacuation time is excessive*

(Example continued)

C3.3.9 The fire safety systems installed shall facilitate the specific needs of fire service personnel to:
(a) Carry out rescue operations and
(b) Control the spread of fire

[From Clause F8-Signs]

F8.3.1 Signs shall be clearly visible and readily understandable under all conditions of foreseeable use

F8.3.2 Signs indicating potential hazards shall be provided in sufficient locations to notify people before they encounter the hazard

F8.3.3 Signs to facilitate escape shall:
Be provided in sufficient locations to identify escape routes and guide people to a safe place, and
Remain visible in the event of a power failure of the main lighting supply, for the same duration as required by clause F6 "lighting for Emergency"

F8.3.4 Signs shall be provided in sufficient locations to identify accessible routes and facilities provided for people with disabilities.

[From Clause F6-"Lighting for Emergency"]

F6.3.1 An illuminance of 1 lux minimum shall be maintained at floor level throughout buildings for a period equal to 1.5 times the evacuation time [or 30 minutes, whichever is the greater]

F6.3.2 Signs to indicate escape routes shall be provided as required by clause F8 "Signs"

[From Clause D1.3.3- "Access Routes"]

Access routes shall:
(a) Have adequate activity space,
(b) Be free from dangerous obstructions and from any projections likely to cause an obstruction,
(c) Have a safe cross fall, and safe slope in the direction of travel,
(d) Have adequate slip-resistant walking surfaces under all conditions of normal use,
(e) Include stairs to allow access to upper floors irrespective of whether an escalator or lift has been provided,
(f) Have stair treads, and ladder treads or rungs which:
(i) provide adequate footing, and
(ii) have uniform rise within each flight and for consecutive flights,
(g) Have stair treads with a leading edge that can be easily seen,
(h) Have stair treads which prevent children falling through or becoming held fast between treads, where open risers are used,
(i) Not contain isolated steps,
(j) Have smooth, reachable and graspable handrails to provide support and to assist with movement along a stair or ladder,
(k) Have handrails of adequate strength and rigidity as required by Clause B1 "Structure",
(l) Have landings of appropriate dimensions and at appropriate intervals along a stair or ramp to prevent undue fatigue,
(m) Have landings of appropriate dimensions where a door opens from or onto a stair, ramp or ladder so that the door does not create a hazard, and
(n) Have any automatically controlled doors constructed to avoid the risk of people becoming caught or being struck by moving parts.

(Example continued)

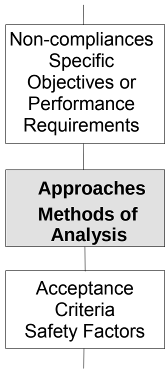
[In Addition to the above ClauseD1.3.4 states]

"An accessible route, in addition to the requirement of Clause D1.3.3, shall:

(a) Be easy to find, as required by Clause F8 "Signs",
(b) Have adequate activity space to enable a person in a wheelchair to negotiate the route while permitting an ambulant person to pass,
(c) Include a lift complying with Clause D2 "Mechanical Installations for Access" to upper floors where:
  - *(i) buildings are four or more storeys high,*
  - *(ii) buildings are three storeys high and have a total design occupancy of 50 or more persons on the two upper floors,*
  - *(iii) buildings are two storeys high and have a total design occupancy of 40 or more persons on the upper floor, or*
  - *(iv) an upper floor, irrespective of design occupancy, is to be used for the purposes of public reception areas of banks, central, regional and local government offices and facilities, hospitals, medical and dental surgeries and medical, paramedical and other primary health care centres,*

(d) Contain no thresholds or upstands forming a barrier to an unaided wheelchair user,
(e) Have means to prevent the wheel of a wheelchair dropping over the side of the accessible route,
(f) Have doors and related hardware which are easily used,
(g) Not include spiral stairs, or stairs having open risers,
(h) Have stair treads with leading edge which is rounded, and
(i) Have handrails on both sides of the accessible route when the slope of the route exceeds 1 in 20. The handrails shall be continuous along both sides of the stair, ramp and landing except where the handrail is interrupted by a doorway.

1.2.9 Approaches and methods of analysis



Having determined the non-compliance issues or the relevant specific objectives or performance requirements, the next step is to select the approaches and the methods of analysis which are to be used to determine whether the trial design meets the acceptance criteria (see Section 1.2.10).

A consideration of the total analysis strategy (Chapter 1.3) may be needed for this process. Non-compliance issues may be grouped for the analysis where the same or similar approaches and methods are involved in their evaluation.

In selecting the approaches to be used to analyse the groups of issues or single issues identified in the analysis strategy, a number of decisions need to be made. 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.

1.2.9.1 Comparative or absolute approach

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

Comparative approach

Typically, the fire safety provided by one element, or a sub-system, or the complete fire safety system, is compared to the level of fire safety that would be achieved in an identical building in which that element, sub-system or system is designed in compliance with the deemed-to-satisfy or prescriptive provisions identified in Section 1.2.8. If the analysis is carried out on such a comparative basis, it will involve the same assumptions, models, calculations and input data for the proposed trial design and the deemed-to-satisfy or prescriptive design.

A comparative approach aims to determine whether the alternative solution is equivalent to (or better than) the deemed-to-satisfy or prescriptive design. The comparative approach is often referred to as an “equivalence” approach.

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 1.2.10), against the objectives or performance requirements without comparison to deemed-to-satisfy or prescriptive or “benchmark” designs.

1.2.9.2 Qualitative or quantitative approach

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

Qualitative approach

In the minority of cases, qualitative analysis may be agreed during the FEB process to be sufficient for the consideration of a single non-compliance issue. The basis (logic) on which this approach is used should be documented with appropriate references.

A “Delphi” approach may also be appropriate in certain circumstances, ie. where a group of suitably expert professionals reach consensus agreement regarding the suitability of a particular solution.

Quantitative approach

In the majority of cases the complexity of the non-compliance issues will require a quantitative approach. This entails the use of one or more of the many analysis methods available (see Section 1.2.9.4 where various forms of quantitative methods of analysis and their desirable attributes are listed). The quantitative methods will often be supported by additional qualitative arguments.

1.2.9.3 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. Characteristically, for a given set of initial boundary conditions, a deterministic methodology will always produce the same outcome. They do not, however, indicate the probability of that outcome being realized.

Deterministic methods are the most commonly used as they are better developed, less complex and less demanding on data and analysis than a probabilistic method. There is also a wide range of such methods to suit various analysis requirements.

An analysis using deterministic methods generally adopts a timeline approach where the time of occurrence of various events is calculated and compared. An example is given in the shaded box below.

Example: ASET - RSET time-line approach

The Available Safe Evacuation Time (ASET), obtained from Sub-system B or C using acceptance criteria for tenability is compared with the Required Safe Evacuation Time (RSET) obtained from Sub-system E.

For an absolute type evaluation, ASET should be greater than RSET by a margin determined during the FEB process (a safety factor), i.e.

$$\text{ASET} > \text{RSET}$$

This is shown in the figure below which depicts the time-line under consideration:

For a comparative type evaluation, this margin for the trial design should be the same or greater than that for the deemed-to-satisfy or prescriptive design.

Probabilistic approach
Probabilistic approaches use a variety of risk based methodologies (see Chapter 2.3). These methods generally assign reliabilities to the performance of the various fire protection measures and assign frequencies of occurrence of events. They may analyze and combine several different scenarios as part of a complete fire engineering evaluation of a building design. This use of multiple scenarios and their combination through probabilistic techniques is the key feature of some of the methods.

Probabilistic methods generally require much statistical data which are not always readily available and because of their complexity, may involve time-consuming calculations. Furthermore, their validity may be more difficult to demonstrate because detailed examination of fire statistics and many experiments may be necessary.

An example of a methodology using multiple design fire scenarios combined using event trees is given in the shaded box below.

Example: Probabilistic event-tree approach

A procedure for such an analysis may comprise the steps set out below:

- 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; and
  - 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:

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

- 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 deemed-to-satisfy or prescriptive provisions (a comparative-type evaluation).

1.2.9.4 Methods of analysis

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

There are many forms of analysis methods:

- formulas, equations and hand calculations
- spread sheet 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 fire engineer
- be well validated
- be suitable for the task
- generate outputs that can be compared with the acceptance criteria agreed for the analysis (see Section 1.2.10)
- have clearly defined limitations and assumptions that are well documented.

The FEB report should record, as appropriate, the above information for each method chosen. Information about some methodologies is given in Part 2.

1.2.9.5 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 evaluation outcomes. Sensitivity studies, redundancy studies and uncertainty studies should be incorporated into the process of quantitative evaluation and are described below. The nature and extent of these studies may be influenced by the approaches and the methods selected.

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

Examples: Sensitivity studies

Typical examples are:

- a design fire with a rate of growth chosen to be the most credible might be modified to have a rate of growth several times greater
- 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.

Redundancy studies
Redundancy studies are similar to sensitivity studies but examine the redundant measures of a trial design that essentially fulfil the same function (see Section 1.2.7). The FEB 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, but designers should look for single points of failure and what systems will be available to provide backup to such a failure.

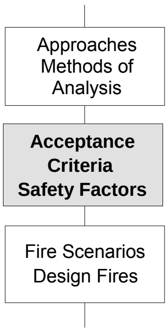
Example: Redundancy study

A trial design for a shopping centre may include provision of sprinklers, smoke control, smoke detectors, fire alarm and public address equipment amongst other measures. In the event of fire, the fire may be detected by the public or staff, smoke detectors or sprinklers. Smoke control equipment may be activated by a signal from the fire detectors or sprinklers or manual activation by staff or the fire brigade. In each case, there are multiple, redundant paths or operation. In the event that one component fails or does not operate to its full capacity, there is back up from the redundant system, and no single point of failure or situation where an equipment failure is not recognised by building managers or fire authorities.

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 by the use of a number of appropriate methods and comparing outputs. The uncertainties may be due to poor conceptualization of the problem being investigated or to inadequate formulation of the conceptual or computational model used. Calculation and documentation errors may also lead to uncertainties. The FEB team should determine whether an uncertainty study is appropriate for the analysis to be carried out.

Example: Uncertainty study

Fire safety equipment, such as smoke exhaust fans, will have uncertainties associated with their stated performance characteristics. An uncertainty study uses such data on uncertainties as input in order to determine the impact on the analysis.



1.2.10 Acceptance criteria and factors of safety for the analysis

In order to determine whether the results of the analysis of a trial design are equivalent to a deemed to satisfy or prescriptive design (comparative approach), meet the specific objectives or performance requirements (absolute approach), acceptance criteria and associated factors of safety need to be set for the analysis (see Chapters 1.3 to 1.9) and the collation and evaluation of results (see Chapter 1.10).

1.2.10.1 Acceptance criteria

The acceptance criteria need to:

- be appropriate to the general and specific objectives, the performance requirements and the analysis methods used (see examples below);
- be numerical in nature (unless the analysis is qualitative), and
- be realistic, for example, zero risk is not an appropriate criterion.

Examples: Typical acceptance criteria parameters for the analysis grouped according to general objectives (see Section 1.2.5)

General Objectives	**Criteria Parameters***
Protect building occupants	Expected risk to life ASET/RSET margin** Smoke layer height Temperature of hot layer Radiant heat from hot layer Smoke optical density Carbon monoxide level
Facilitate fire services intervention	Radiant heat from hot layer Structural failure Water supply Resources at fire scene
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 environmental effects	Toxicity of effluent gases Impoundment of water

Expected risk to flora and fauna

*The actual numerical value may be that obtained by analysis of a deemed-to-satisfy or prescriptive design (for a comparative analysis) or be agreed to in the FEB process (for an absolute analysis).

**The other parameters for protecting building occupants are some of those that can be used as criteria for the determination of ASET which is an output of Chapters 1.5 and 1.6. The determination of RSET is set out in Chapter 1.8.

It is 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 (see examples above).

For a comparative approach, the same criteria should be used for both the deemed-to-satisfy or prescriptive (or benchmark) design and the trial design being evaluated and the performance of the trial design should not be less than that of the deemed-to-satisfy or prescriptive design.

For an absolute approach, the criteria should take into account any uncertainties in the analysis and the factors of safety employed (see Section 1.2.10.2).

For the purposes of sensitivity studies, less rigorous acceptance criteria are appropriate and should be agreed during the FEB process in order to avoid overly conservative outcomes.

1.2.10.2 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 the above may not be quantified until the analysis has been completed, actual numerical values for the factors of safety may not be determined at the FEB stage. In such cases the FEB may give guidance on acceptable values and the fire engineer will need to justify the actual values used in the report.

Factors of safety should only be applied at the end of a calculation sequence, and not throughout the analysis steps because this could lead to over conservative outcomes.
In a comparative evaluation, it should not be necessary to include explicit factors of safety because the same methods and assumptions for the analysis would be used for both the deemed-to-satisfy or prescriptive design and the proposed design.

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

Further guidance on factors of safety is given in Chapter 2.2 of these Guidelines.

Acceptance Criteria Safety Factors
Fire Scenarios Design Fires
Design Occupant Groups

1.2.11 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 and 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 1.2.11.1).
2. From these possibilities, select the design fire scenarios to be used for developing the design fires (see Section 1.2.11.2).
3. For each of these design fire scenarios, specify a schematic design fire (see Section 1.2.11.3).

1.2.11.1 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 potential fire scenarios. This can be done by a variety of techniques, such as:

- reviewing information assembled for the FEB, especially that obtained from the hazard analysis of Section 1.2.6
- examining data in the published literature
- reviewing fire statistics
- drawing on experience and knowledge.

1.2.11.2 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 non-compliance issues being addressed, methods of analysis used and the characteristics of the building itself.

From the potential fire scenarios, the FEB 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 (life, property, etc.) are selected for analysis. Care and judgement should be used to avoid unnecessarily analysing events with a very low probability of occurrence, but 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.

The process undertaken in Section 1.2.11.1 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 some large scale arson attacks and terrorist events may be beyond the scope or capacity of the fire safety system to respond adequately, and other measures to deal with these situations need to be put in place.

1.2.11.3 Schematic design fires

In order to carry out a fire engineering analysis, it is usual to formalize the fire scenarios being considered as 'design fires', and to specify each of them in the form of a relationship between parameters such as heat release rate and time. In particular cases, other fuel properties such as propensity to produce smoke and toxic species maybe use to characterize these aspects of design fires. At the FEB stage, the task is to define and describe (to the extent possible without involving calculation) the design fires which will be quantified during the analysis.

Such a design fire is normally presented as a graph conceived as a shape known as a 'schematic design fire'. It should be remembered that design fires are normally intended to be conservative and they are simplified techniques developed for the purpose of fire engineering evaluation or design.

The **first step** in developing a schematic design fire is the definition of the type of fire, viz, smouldering, non-flashover, flaming and flashover. These types are described below.

A ***smouldering fire*** may or may not develop into a flaming fire. Figure 1.2.11.3a illustrates a notional Heat Release Rate (HRR) – time graph for a schematic design fire representing a smouldering fire that does not undergo the transition to a flaming fire. Typically, the maximum heat release rate is less than 5kW.

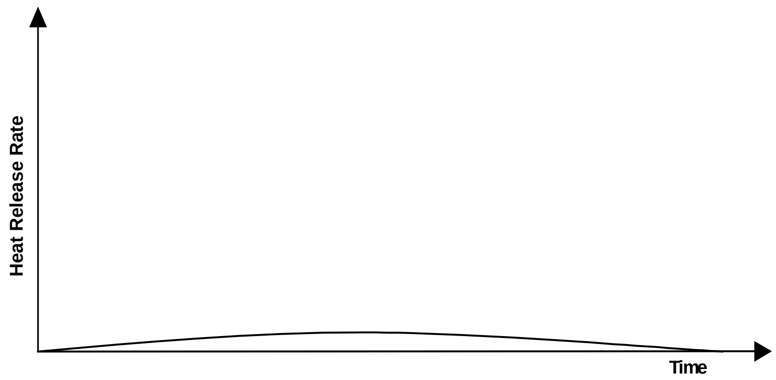


Figure 1.2.11.3a Typical schematic design fire—smouldering

There is a developing phase which is a function of time, a developed phase where the HRR is independent of time and a decay phase where the HRR is again a function of time.

A ***non-flashover flaming fire*** is a flaming fire that does not flashover. Figure 1.2.11.3.b illustrates a notional HRR–time graph for a schematic design fire for such a fire.

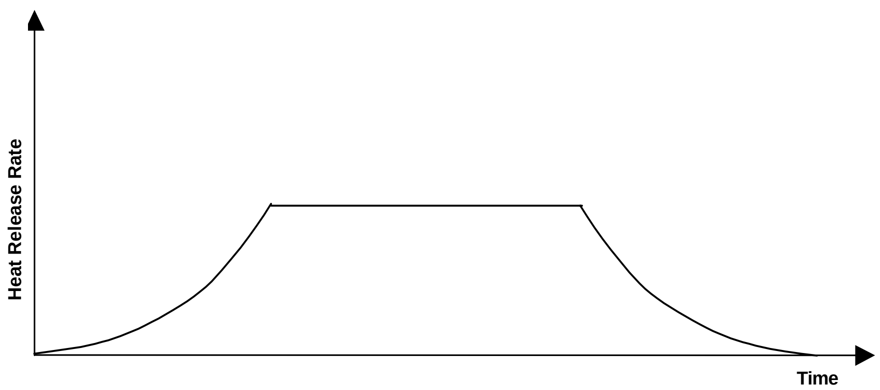


Figure 1.2.11.3.b Typical schematic design fire—non-flashover

It is generally assumed that the heat release rate:

- increases quadratically after ignition as a t^2 fire (the growth phase);
- reaches a steady state HRR determined by either fuel or ventilation controlled burning (the fully developed phase); and
- decreases at a nominated rate when the fuel starts to be depleted (decay phase).

Definition of these parameters in terms of the rate of fire growth, the type of steady state fire and the rate of fire decay, may be done in principle during the FEB discussions or determined quantitatively when Sub-system A, Fire Initiation and Development and Control, is analyzed (Chapter 1.4).

A ***flashover fire*** is the third fire type. Figure 1.2.11.3c illustrates a notional HRR–time graph for a schematic design fire for such a fire.

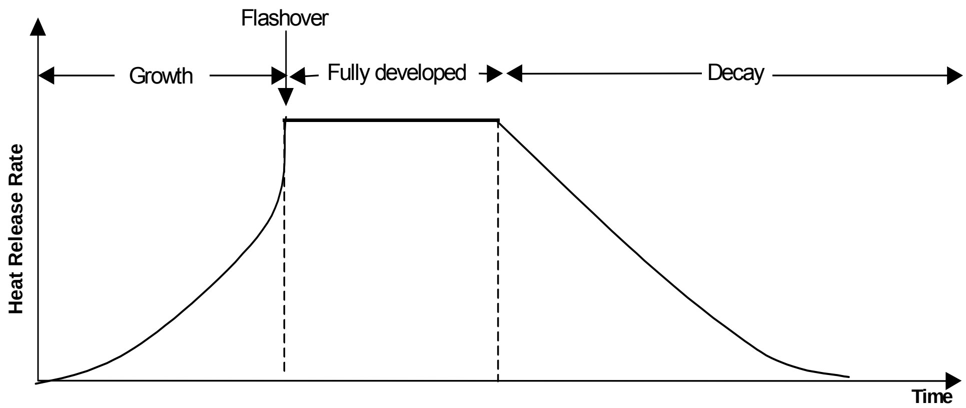


Figure 1.2.11.3c Typical schematic design fire—flashover

In practice, flashover occurs over a short period of time. However, for the purposes of the schematic design fire, flashover is assumed to be instantaneous and the increase in the heat release rate due to flashover is represented by a vertical section of the heat release rate – time graph. The criteria for flashover may be set during the FEB discussions (several criteria are available depending on the method of analysis) or determined (quantitatively) when Sub-system A is analyzed (Chapter 1.4). The figure also shows the other phases that flashover fires have in common with non-flashover flaming fires.

The **second step** is to modify the above notional relationships between HRR and time to take into account the effect of various events that affect a fire burning in a building. Typical events are:

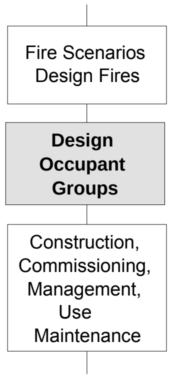
- changes in ventilation conditions due to
  - window glazing breaking (Sub-system B or C)
  - the operation of air handling or smoke management equipment (Sub-systems B)
  - doors or other partitions burning through (Sub-system C)
  - openings created by fire services intervention (Sub-system F)
- the commencement of suppression by
  - automatic equipment (Sub-system D)
  - occupants (Sub-system E)
  - fire services (Sub-system F).

The qualitative effect of these events may be agreed to during the FEB discussions, based on the information and options discussed in the chapters of these Guidelines, which describe the analysis of the relevant sub-systems. Alternatively, the effect may be determined (quantitatively) when Sub-system A is analyzed with input from the relevant sub-systems.

During the analysis, each schematic design fire will be quantified, and will become known as a design fire. This quantification is done using Sub-system A (Fire Initiation and Development and Control), as discussed in Chapter 1.4, with input from other sub-systems.

For the purposes of sensitivity studies, these schematic design fires may be varied, for example, by choosing a rate of growth significantly greater than the schematic design fire.

1.2.12 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. This approach is similar to the selection of design fires for fire and smoke modelling.

Dominant characteristics that may be considered in identifying design occupant groups are listed in Section 1.2.4 of these Guidelines. 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 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.

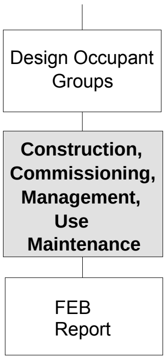
There may be more than one design occupant group for an evaluation and, in some cases, each design occupant group may play a dominant role at a different stage of the evacuation process.

The FEB team should identify the design occupant group or groups 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 (i.e. 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).

1.2.13 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:

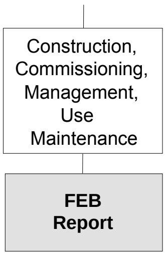
- construction—how the design is transformed into reality
- commissioning—how the building is commissioned to become a working entity
- management and use—how the occupants and the fire hazards are managed and how the building is used
- maintenance—how the building and its fire safety system are maintained.

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

During the preparation of the FEB, all parties should agree as to what standards for these various elements should be assumed and determine how these standards might best be:

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

1.2.14 The FEB Report



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

- summarize 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, and
- be suitable for inclusion in the final report on the fire safety evaluation of the design.

A typical FEB report should include headings such as those enumerated below.

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
Non-compliance issues and specific objectives or 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

Chapter 1.3

Analysis

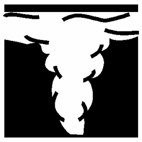
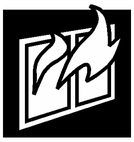
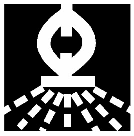
Preparing the Fire Engineering Brief (FEB) is the essential precursor to the actual analysis of the trial design(s). Generally, all the major decisions necessary to allow the analysis to be carried out will have been made during the FEB process and duly recorded. This process will have also provided most of the input data required for the analysis.

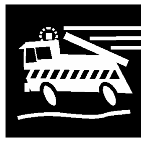
This chapter gives general guidance on the analysis process, but each project needs to be considered individually and the analysis strategy varied accordingly (see Section 1.3.2).

Various codes may require or allow different approaches to demonstrate compliance with the objectives or performance requirements (see Section 1.2.8.2). This needs to be taken into account in developing the analysis strategy.

1.3.1 The fire safety sub-systems

As discussed in Chapter 1.1, in any building there are many features that combine to create an overall fire safety system for the building. To assist in analysing the fire safety system, it is convenient to consider the system as comprising six 'sub-systems', each of which is discussed in a subsequent chapter in these Guidelines:



Sub-system A SS-A	***Sub-system B SS-B***	***Sub-system C SS-C***	***Sub-system D SS-D***	***Sub-system E SS-E***	***Sub-system F SS-F***
Fire Initiation & Development & Control	Smoke Development & Spread & Control	Fire Spread & Impact & Control	Fire Detection, Warning & Suppression	Occupant Evacuation & Control	Fire Services Intervention
Chapter 1.4	**Chapter 1.5**	**Chapter 1.6**	**Chapter 1.7**	**Chapter 1.8**	**Chapter 1.9**

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

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

- the non-compliance issues (see Section 1.2.8.1)
- the specific objectives or performance requirements (see Section 1.2.8.2)
- the inputs and outputs of the sub-systems (see Chapters 1.4 to 1.9)
- the approaches and methods of analysis selected (see Section 1.2.9)

The order of the chapters for each of the six sub-systems broadly follows a typical chronological sequence for an analysis and each chapter includes:

- the **scope** of the sub-system
- the **procedure** for using the sub-system
- the **output** information that the sub-system can be expected to provide and for which other sub-systems this data may be used as input
- the **input** information that is required and where it may be obtained from (generally from the FEB or other sub-systems)
- how the **analysis** can be undertaken
- aspects of **construction, commissioning, management, use and maintenance** that are likely to be particularly important
- a **bibliography** containing references which may be useful.

1.3.2 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 fire engineer to plan the analysis for the particular project, based on the decisions taken during the preparation of the FEB as discussed in Chapter 1.2.

Figure 1.3.2 shows the factors which will influence the analysis strategy and which will have been agreed upon in the FEB 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.

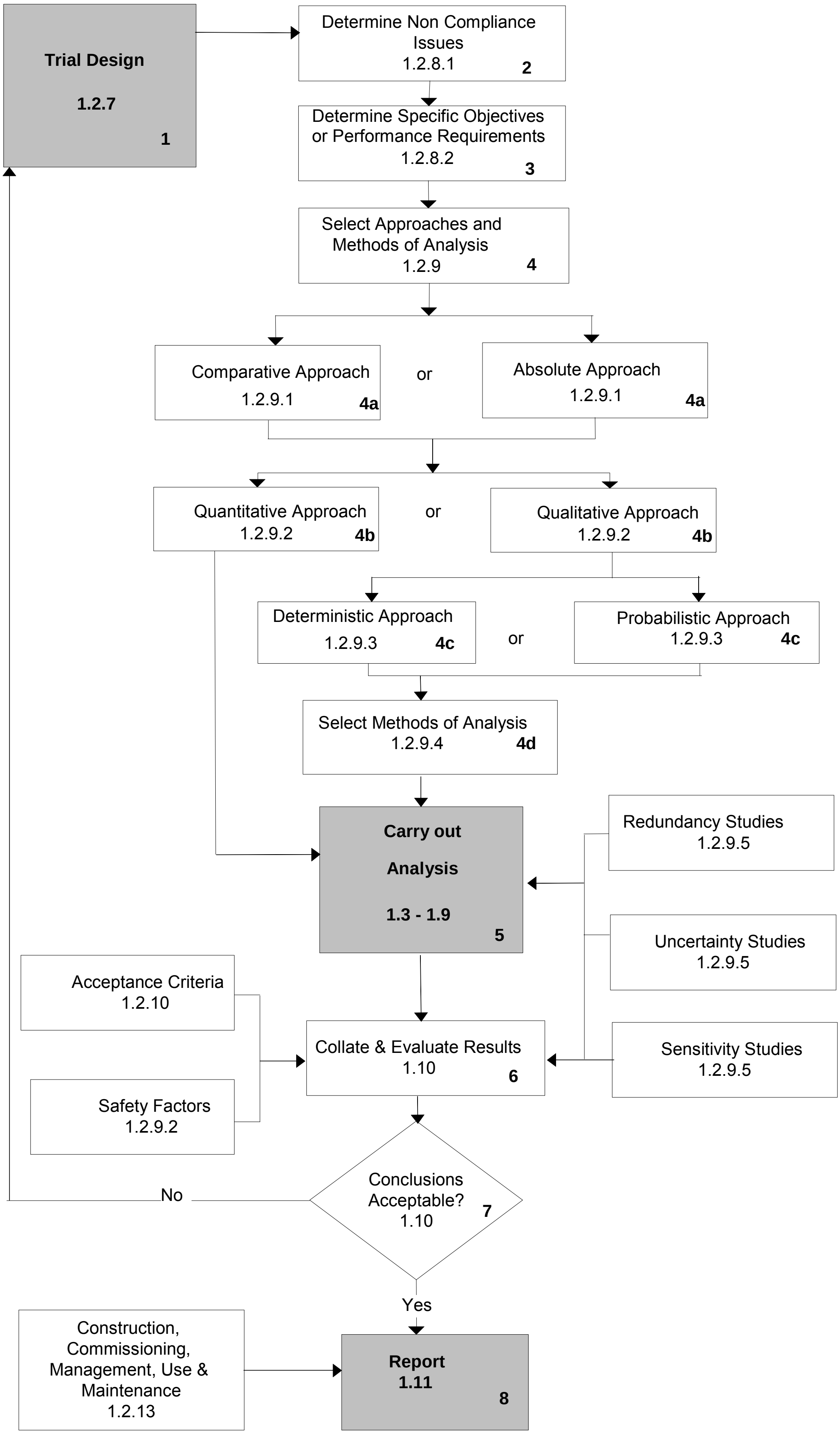
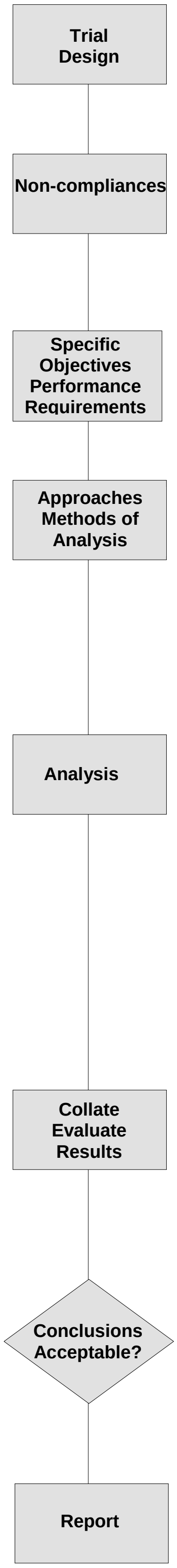


Figure 1.3.2 Analysis of trial designs

In the following paragraphs, each step in Figure 1.3.2 is discussed with reference to the FEB and later chapters in these Guidelines.



STEP 1

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

STEP 2

The **non compliance** issues of the trial design, with respect to the deemed-to-satisfy or prescriptive provisions, need to be established in order to identify the issues to be addressed. (This does not apply to objective or performance–based codes without deemed-to-satisfy provisions)

STEP 3

The **specific objectives or performance requirements** are determined from the non-compliance issues identified in Step 2, or in the case of objective or performance-based codes without deemed-to-satisfy provisions, directly.

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 or quantitative approach
- Step 4c — select deterministic or probabilistic approach
- Step 4d — select analysis methods

STEP 5

The above steps, together with data from the FEB, provide the basis for **carrying out the analysis** (using the sub-systems identified in Section 1.3.1).

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

Other factors from the FEB 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.

STEP 6

After the analysis has been carried out, the **results** need to be **collated and evaluated.** This step is discussed in Chapter 1.10 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 **Chapter 1.10**

STEPS 7 and 8

Alternatively, if the conclusion (Step 7) is that the results indicate that the trial design is acceptable, the results should be **reported** (Step 8**)** as discussed in **Chapter 1.11.**

Chapter 1.4

Fire Initiation and Development and Control
Sub-system A

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. The design fires are normally described in terms of three types (see discussion in Section 1.2.11.3):

- smouldering fire;
- non-flashover flaming fire; and
- flashover fire.

For the purposes of these guidelines, 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 chapter provides guidance on how to:

- consider the initiation of a fire in a fire engineering context
- quantify design fires (developed during the FEB process, Section 1.2.11.3) in terms of
    - heat release rate
    - 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 chapter also discusses the relationships between this sub-system and other sub-systems. Descriptions of selected methods that may be used in connection with this sub-system are given in Chapter 2.4. Selected data for these methods are given in Part 3 of these Guidelines.

Although this chapter provides guidance on the analysis of Sub-system A in the general analysis context discussed in Chapter 1.3, each project needs to be considered individually and the analysis varied accordingly.

1.4.1 Procedure—SS-A

1.4.1.1 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 1.4.1 illustrates how fire development can be analyzed. Discussion of the figure can be found in the following sections:

- Section 1.4.2 Outputs;
- Section 1.4.3 Inputs; and
- Section 1.4.4 Analysis.

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

Where the FEB 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 fire engineer 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.

1.4.1.2 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 1.4.4.2.

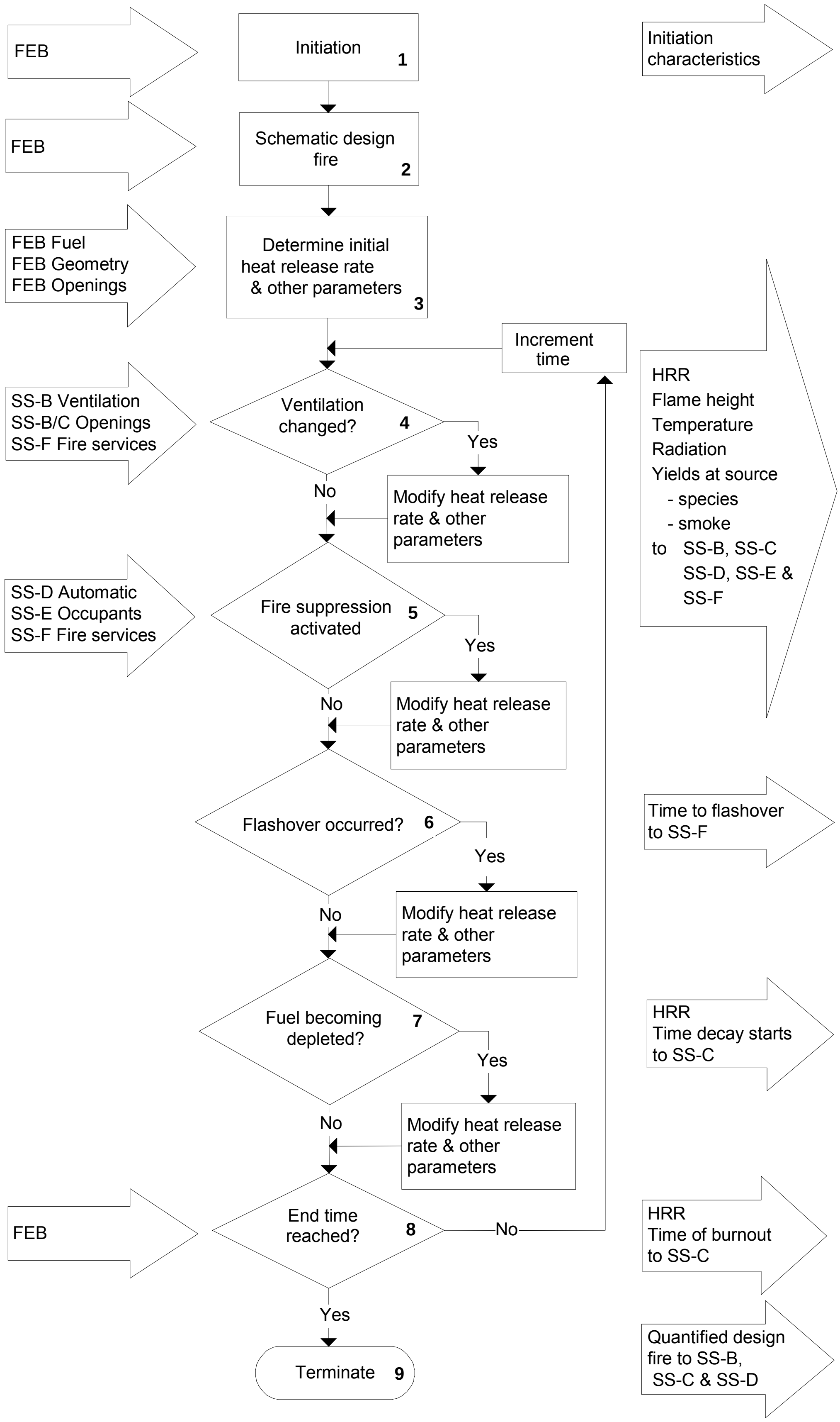


Figure 1.4.1 Flow chart for fire initiation and development analysis

1.4.2 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.

1.4.3 Inputs—SS-A

The following **input data** may be required:

- material and product ignitability data for enclosure linings and contents
- schematic design fires from the FEB
- fuel characteristics from the FEB
- occupancy characteristics from the FEB
- building characteristics from the FEB, 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 envelop (e.g. EPS panel construction)
  - leakage rates through doors and barriers
- activation of smoke management equipment (SS-B)
  - when
  - the effect on hot layer parameters
- activation of suppression (SS-D)
  - when
  - the effect on heat release rate
- fire fighting activities of occupants (SS-E) or fire services (SS-F)
  - when
  - with what effect, e.g. on heat release rate.

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

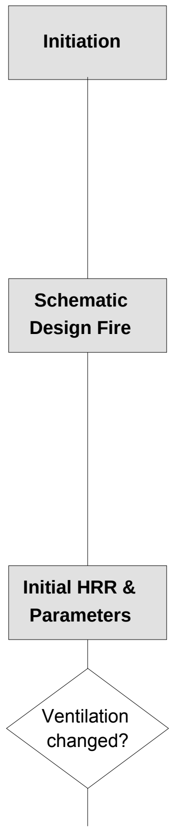
1.4.4 Analysis—SS-A

1.4.4.1 Analysing fire initiation and development

As discussed in Section 1.4.1.1, 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 FEB. The typical process of analysis is shown in Figure 1.4.1 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 1.3.2)
- how a fire may spread into a second (or subsequent) compartment by ignition of material in that compartment.

Step 2
Obtain schematic design fires from the FEB process (see Section 1.2.11.3). The required types (smouldering, non-flashover flaming and flashover) and numbers of design fires will have been decided during that process.

Qualitative decisions may have also been made during the FEB process on the effect of ventilation and suppression on the schematic design fires. The analysis of this Sub-system will quantify such effects.

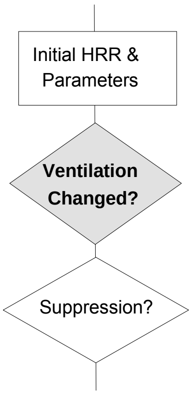
Step 3
For each design fire, an initial heat release rate and the initial yields of specific combustion products need to be established. The basis for choosing these initial characteristics will have been agreed upon during the FEB process, and in some cases, may even have been quantified.

As discussed in the FEB, 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 analyze 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 1.4.1. Their influences need to be determined as discussed in the following steps.



Step 4
One of the most important factors affecting the heat release rate is the ventilation available to the fire. Two possible regimes are generally identified as:

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

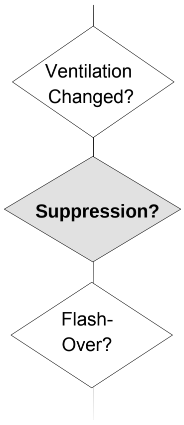
Calculations can be carried out to determine:

- which regime predominates (and is therefore limiting the heat release rate); and
- 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 include:

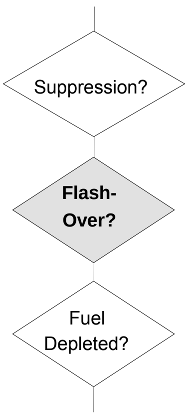
- window glass breaking (SS-A, -B or -C)
- the operation of air handling or smoke extraction systems (SS-B)
- doors or other partitions burning through (SS-C)
- openings created by fire service intervention (SS-F).

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:

- Sub-system D which covers automatic suppression equipment. The qualitative effect on the design fire will have been decided during the FEB process and Sub-system D will quantify that effect.
- Sub-systems D and 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 recognized in the FEB, such action may be taken into account.
- Sub-systems D and F which cover fire service suppression activities (this also includes private industrial fire crews). The qualitative effect of these activities will have been agreed during the FEB process and Sub-system F will quantify that effect.



Step 6
Determine if the conditions are appropriate for flashover to occur.

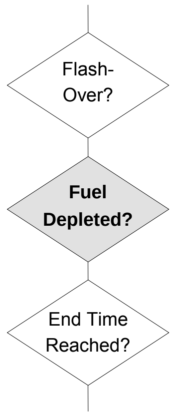
The criteria used for determining the onset of flashover will depend on the method of analysis used, and on the engineering judgement of the fire engineer, and may have been agreed during the FEB process.

To simplify design, the growth period between flashover and the maximum heat release rate is usually ignored and it may be assumed that when flashover occurs, the heat release rate instantaneously increases to the maximum value. This assumption is conservative and is illustrated in Figure 1.2.11.3c.

Once flashover has occurred, the fire is said to be fully developed and is commonly assumed to have a constant heat release rate 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 FEB process or set (and justified) by the fire engineer using engineering judgement.

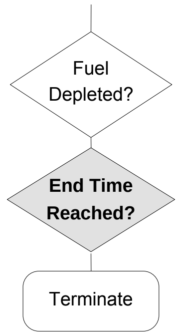
If the decay phase has started, then the heat release rate should be decreased in the manner agreed in the FEB process or determined by the fire engineer.



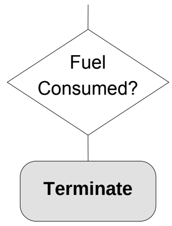
Step 8
Determine if the end time has been reached. This is when:

- all the fuel has been calculated to have been consumed;
- the stage of the design fire agreed to in the FEB process, has been reached; or
- 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 not been reached, the next iteration is undertaken and the analysis continued until the end time has been reached.



Step 9
The analysis of Sub-system A is terminated.



1.4.4.2 Analysing control of fire initiation and development

It may be determined during the analysis, or in drawing conclusions (Chapter 1.10), that it would be beneficial to control fire initiation and development as a means of meeting the objectives or performance requirements. In such cases, other measures noted below (in addition to those shown in Figure 1.4.1) may be considered, subject to the issues discussed in Section 1.4.5:

- Elimination or control of ignition sources.
- Changing the configuration of fuel items (e.g. from rack storage to palletized storage and storing items horizontally rather than vertically).
- Reducing the ignition and fire spread characteristics of the fuel load, which includes the building contents (furnishing etc.), 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 Section 1.2.6).

1.4.5 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; and
- 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.

1.4.6 Bibliography—SS-A

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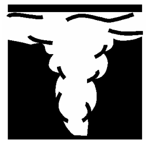
Chapter 1.5

Smoke Development and Spread and Control *Sub-system B*



Sub-system 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 these Guidelines:

- smoke is considered to include both visible and invisible products of combustion or pyrolysis and entrained air
- 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 chapter 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 minimize smoke accumulation and spread
- The Available Safe Evacuation Time (ASET) where appropriate.

This chapter also discusses the relationships between this sub-system and others. Descriptions of selected methods that may be used in connection with this sub-system may be given in Chapter 2.5. Selected data for these methods may be given in Part 3 of these Guidelines.

Although this chapter provides guidance on the analysis of Sub-system B in the general analysis context discussed in Chapter 1.3, each project needs to be considered individually and the analysis varied accordingly.

1.5.1 Procedure—SS-B

1.5.1.1 Smoke development and spread

Figure 1.5.1 illustrates how smoke development and spread within a building can be analyzed. Discussion of the figure can be found in the following sections:

- Section 1.5.2 Outputs
- Section 1.5.3 Inputs
- Section 1.5.4 Analysis.

An analysis needs to be undertaken for each design fire specified by the FEB and quantified using Sub-system A.

Where the FEB 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 fire engineer 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.

1.5.1.2 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 1.5.4.

1.5.2 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 Sub-system E,
  - evaluate the effect of smoke on fire services activities in Sub-system F, and
  - form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (Collating results and evaluating and drawing Conclusions) and may be coupled with smoke temperature, smoke optical density and species concentration to determine ASET.

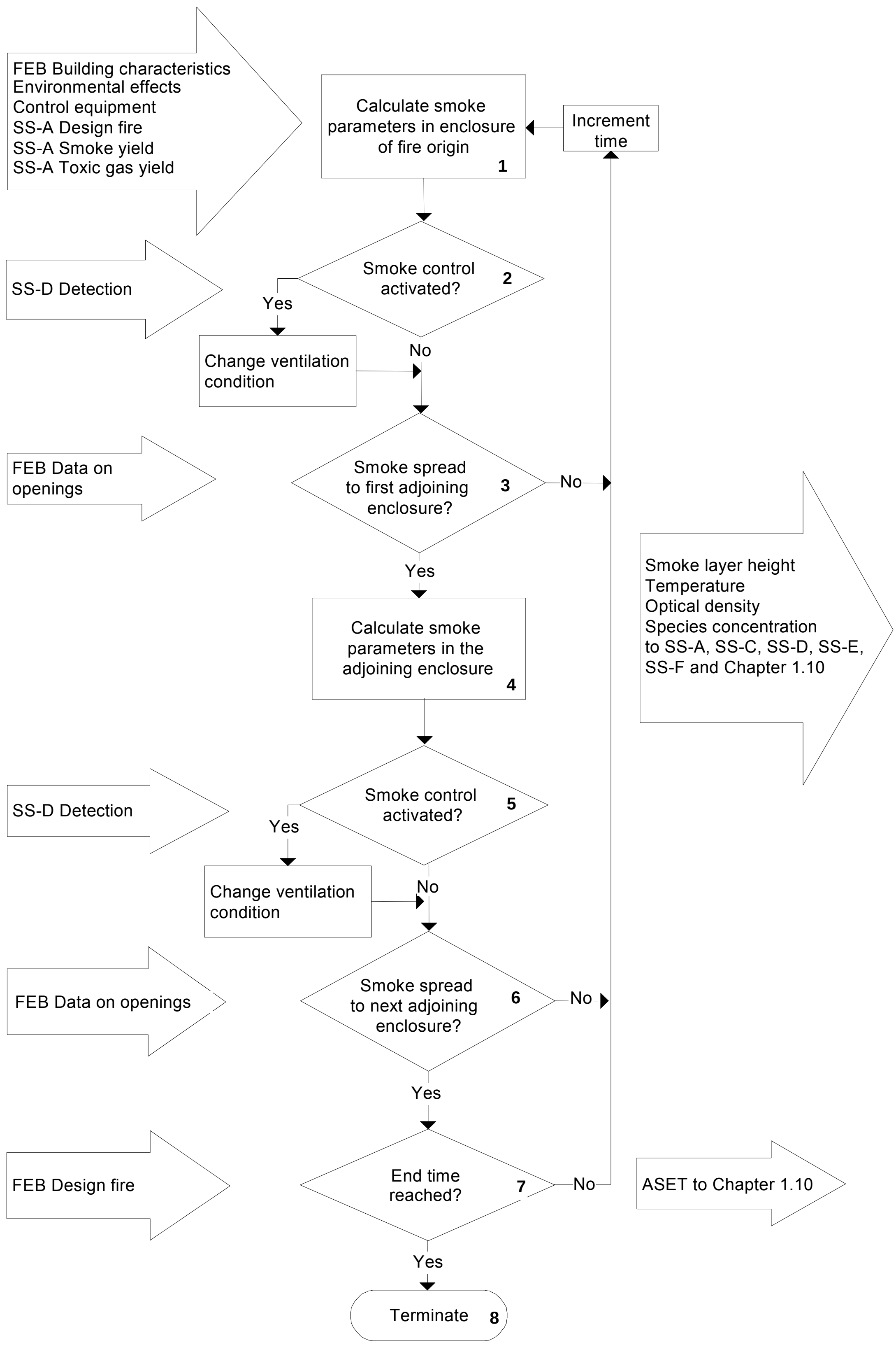


Figure 1.5.1 Flow chart for smoke development and spread analysis

- **Smoke temperature**

  This parameter may be used to:
  - establish the expected times of heat detector and sprinkler activation (Sub-system D)
  - evaluate the effect of smoke on occupant behaviour in Sub-system E
  - evaluate the effect of smoke on fire services activities in Sub-system F
  - form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (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' (Sub-system B)
  - establish the time of failure of smoke management equipment components, e.g. exhaust fan motor (Sub-system B)
  - determine the likelihood of fire spread to unignited fuel items (Sub-system 1) and spread through barriers (Sub-system 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 Sub-system D
  - evaluate the effect of smoke on occupant behaviour in Sub-system E
  - evaluate the effect of smoke on fire service activities in Sub-system F
  - form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (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 Sub-system E
  - evaluate the effect of smoke on fire services activities in Sub-system F
  - form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (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.

- **Available Safe Evacuation Time (ASET)**

  This parameter is used in a timeline analysis and when compared (see Chapter 1.10) with Required Safe Evacuation Time (RSET), obtained from Sub-system E, provides a criterion for acceptability (see Section 1.2.10) of that design.

ASET may be determined using the above outputs on the basis of the acceptance criteria (see Section 1.2.10).

1.5.3 Inputs—SS-B

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

- **Building characteristics**

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

  - 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 (CO), 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 FEB. 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 Sub-system D, and coupled with the delay in activation of the smoke management equipment, gives the time at which smoke management commences

- **Environmental effects**

  The FEB 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.

1.5.4 Analysis—SS-B

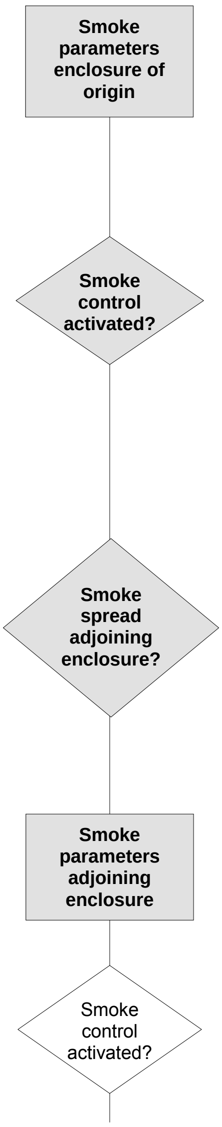
SS-B is generally used in one of two situations.

- 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 (see 1.5.4.1) and to determine ASET (see Chapter 1.10). 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 (see 1.5.4.2.).

1.5.4.1 Analyzing smoke production and spread

Whether smoke management equipment is installed or not, the typical process of analysis is presented in Figure 1.5.1.

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.



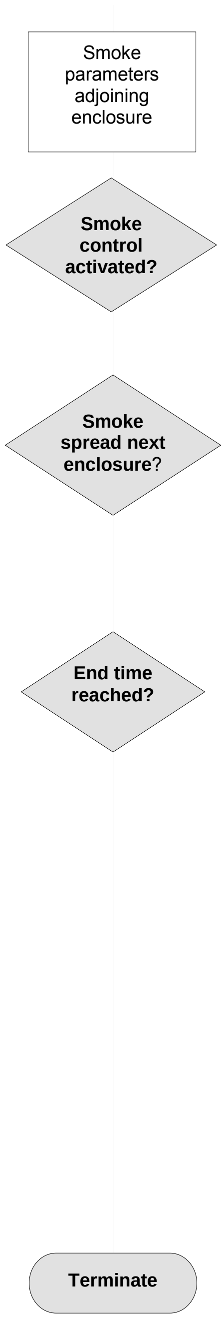
Step 1
Calculate how much smoke (including entrained air) is expected to be generated, and how thick the smoke layer in the upper part of the enclosure of fire origin, is expected to be. At the same time, the expected smoke layer temperature, optical density and the concentrations of various toxic species may be calculated.

Step 2
Where smoke management equipment has been installed, data from Sub-system 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 FEB 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 Available Safe Evacuation Time (ASET) based upon the criteria for ASET set in Section 1.2.10.

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.

1.5.4.2 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 Sub-section 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 1.5.1 as the analysis process described in Section1.5.4.1. It enables the quantification of those characteristics of the smoke management equipment (see Section 1.5.3) that enable the attainment of the relevant acceptance criteria for the analysis (as determined in the FEB process) used in Chapter 1.10 (Collating the results and drawing conclusions).

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

1.5.5 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. Smoke management equipment is often considered to have a relatively low probability of successful operation. To improve the probability of successful operation of smoke management equipment, its incorporation into the necessary occupant comfort systems used on a daily basis (e.g. air-conditioning) will be of benefit.

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 Chapter 1.11). 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 (measurement of airflows, pressure gradients, etc.) 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.

1.5.6 Bibliography—SS-B

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Chapter 1.6

Fire Spread and Impact and Control
Sub-System C

Sub-system C (SS-C) is used to analyze 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 these guidelines:

- spread beyond a fire enclosure is deemed to have occurred when any material outside that enclosure ignites and another fire is initiated; flames projecting from openings therefore do not constitute spread unless they ignite another material, existing or potential, outside the enclosure; and
- 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.

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 chapter together with Chapter 2.6 provides guidance on how to:

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

This chapter discusses the relationships between this sub-system and others. Descriptions of selected methods that may be used in connection with this sub-system may be given in Chapter 2.6. Selected data for these methods may be given in Part 3.

Although this chapter provides guidance on the analysis of Sub-system C in the general analysis context (discussed in Chapter 1.3), each project needs to be considered individually and the analysis varied accordingly.

1.6.1 Procedure—SS-C

1.6.1.1 Fire spread and impact

Figure 1.6.1 illustrates how fire spread between enclosures and its impact on the enclosures can be analyzed. Discussion of the figure can be found in the following sections:

- Section 1.6.2 Outputs;
- Section 1.6.3 Inputs; and
- Section 1.6.4 Analysis.

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

Where the FEB 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 fire engineer 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.

1.6.1.2 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 1.6.4.

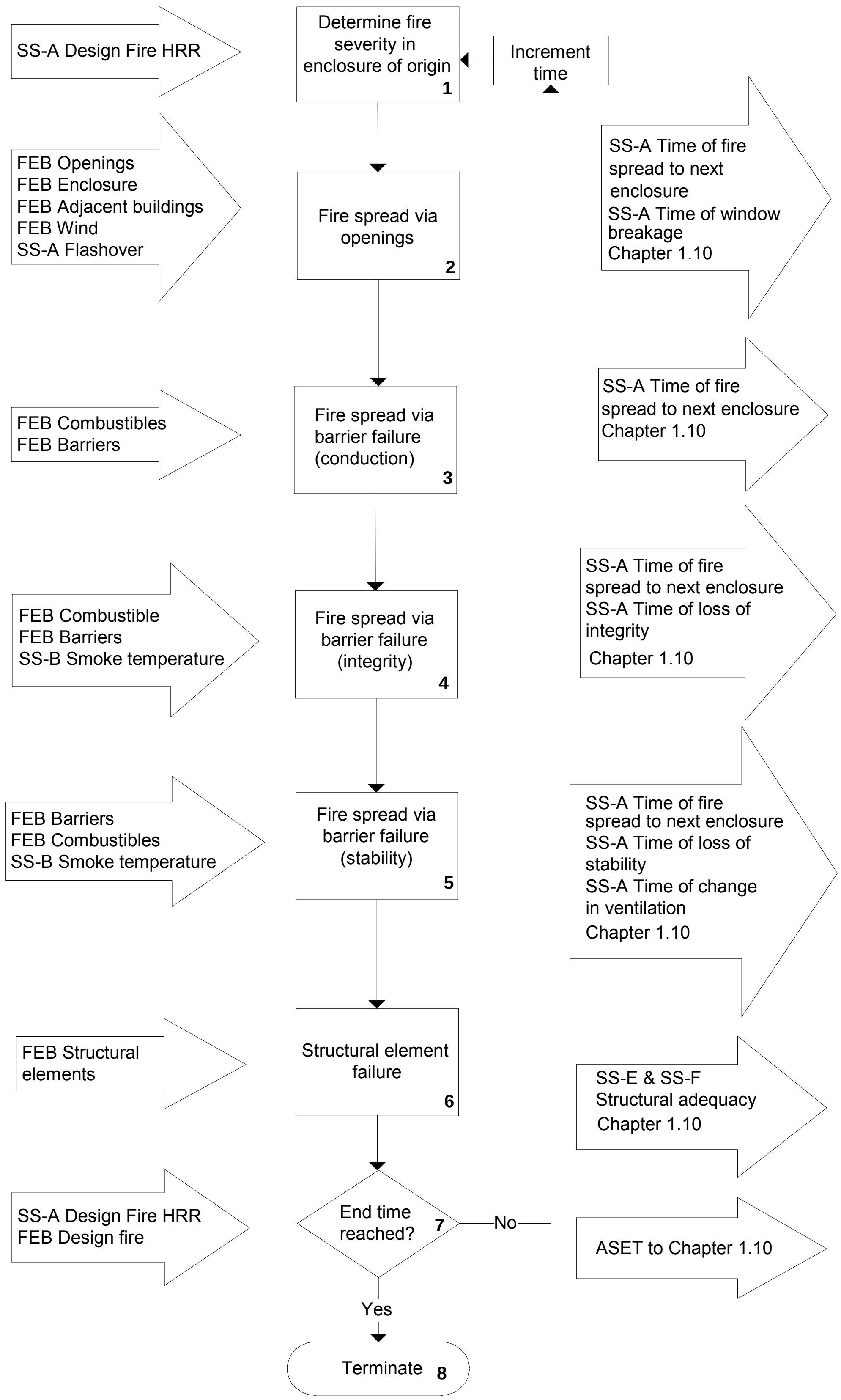


Figure 1.6.1 Flow chart for fire spread and impact analysis

1.6.2 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 Sub-system A to indicate when the design fire for the next enclosure is initiated,
  - in Sub-system E to assess evacuation of occupants,
  - in Sub-system F to assess fire fighting activities, and
  - to form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (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 Sub-system A to assess changes in ventilation,
  - in Sub-system E to assess evacuation of occupants,
  - in Sub-system F to assess fire fighting activities, and
  - to form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (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 Sub-system A to assess changes in ventilation,
  - in Sub-system E to assess evacuation of occupants,
  - in Sub-system F to assess fire fighting activities, and
  - to form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (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 Sub-system E to assess evacuation of occupants,
  - in Sub-system F to assess fire fighting activities, and
  - to form the basis for one of the acceptance criteria for the analysis, as determined in Section 1.2.10 of the FEB; it is used in Chapter 1.10 (Collating and evaluating results and drawing conclusions) and may also be used to determine ASET.
- **Available Safe Evacuation Time (ASET)**
  This parameter is used in a timeline analysis and when compared (see Chapter 1.10) with Required Safe Evacuation Time (RSET), obtained from Sub-system E, provides a criterion for acceptability (see Section 1.2.10) of that design.

  ASET may be determined using the above outputs on the basis of the acceptance criteria (see Section 1.2.10).

1.6.3 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 Sub-system A and may be expressed in terms of heat release rate or heat flux or temperature as a function of time
- **Time of flashover**
  This parameter is obtained from Sub-system A and may be used (see Section 1.6.4.1), in certain circumstances, as the time for fire to spread to an adjacent enclosure
- **Smoke temperature**
  This parameter is obtained from Sub-system 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 FEB
  - 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/wild fires.

1.6.4 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 1.6.4.1) and, in some cases, to determine an ASET (see Chapter 1.10)
- 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 1.6.4.2.).

1.6.4.1 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 should therefore 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 service pipe, cable trays etc
- 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 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.

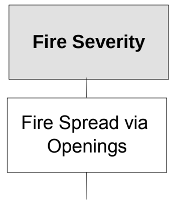
These features are treated as enclosures for the purpose of analysing fire spread and impact.

The features of interest and the potential routes of spread should be defined during the FEB. 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 chapter, 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

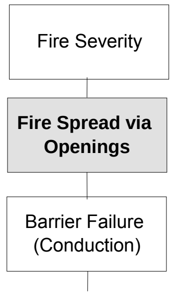


Determine the fire severity in the enclosure of origin. This is generally achieved using input from Sub-system A on the design fire. The characteristic fire profile, expressed as HRR as a function of time, can be used to give fire severity in terms of:

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

The fire severity can also be determined independently of Sub-system A using information from the FEB 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; and
- direct flame contact.

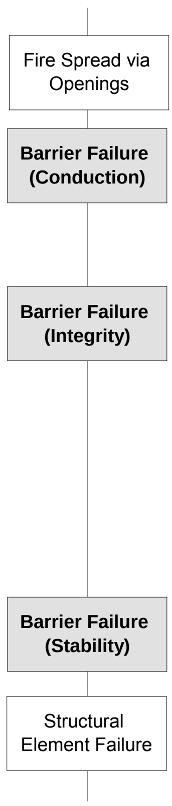
As discussed above, the 'adjacent enclosure' includes vertical shafts and concealed spaces as well as rooms on the floor of fire origin and floors above that of fire origin. In the latter case, the fire may spread by way of flames projecting through windows.

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 Sub-system A. Alternatively, as noted above, the time to flashover from sub-system 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 Sub-system E.

Step 3



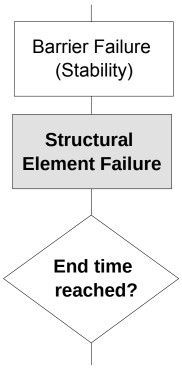
Determine the possibility and time of spread due to conduction through the boundaries ('barriers') of the enclosure of fire origin. Barrier failure due to conduction of sufficient heat through the barrier to meet failure criteria can occur without loss of integrity and stability of the barrier. Whether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

Step 5

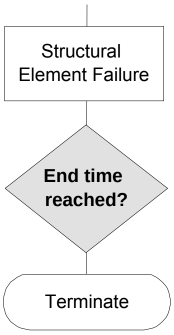
Determine the possibility and time of spread due to the loss of stability of the boundaries ('barriers') of the enclosure of fire origin. Barrier failure due to loss of stability involves the collapse of the barrier that may or may not be a structural element of the building. The ignition of combustibles 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 FEB.

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. 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 FEB. The evaluation of the collapse mechanisms of complex and redundant structures may require input from structural engineers.

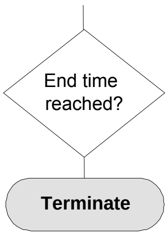
Barriers that are supported by structural elements, or are structural elements themselves supported by other elements, may also fail when the supporting element fails. Thus, the time of failure of the structural element should be evaluated to ensure that the barrier it is supporting does not fail prematurely. 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 FEB process, has been reached; and
- 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 Available Safe Evacuation Time (ASET) based upon the criteria for ASET set in Section 1.2.10. 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 Sub-system C is terminated.

1.6.4.2 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 heat release rate or are difficult to ignite and burn slowly if ignited are used (see Sub-system 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 1.6.1 as the analysis process described in Section 1.6.4.1. 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 FEB process) used in Chapter 1.10 (Collating the results and drawing conclusions).

1.6.5 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; and
- 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.

1.6.6 Bibliography—SS-C

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Chapter 1.7

Fire Detection, Warning and Suppression *Sub-system D*

Sub-system D (SS-D) is used to analyze 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 recognized 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 analyzed in Sub-system F.

This chapter 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 chapter also discusses the relationships between this sub-system and others. Descriptions of selected methods that may be used in connection with this sub-system may be given in Chapter 2.7. Selected data for these methods may be given in Part 3.

Although this chapter provides guidance on the analysis of Sub-system D in the general analysis context discussed in Chapter 1.3, each project needs to be considered individually and the analysis varied accordingly.

1.7.1 Procedure—SS-D

1.7.1.1 Fire detection, warning and suppression

Figure 1.7.1 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 1.7.2 Outputs
- Section 1.7.3 Inputs
- Section 1.7.4 Analysis.

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

Where the FEB decision is an analysis that includes consideration of probabilities of various events and scenarios occurring should be undertaken, the flow chart can assist the fire engineer 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.

1.7.1.2 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 1.7.4.2.

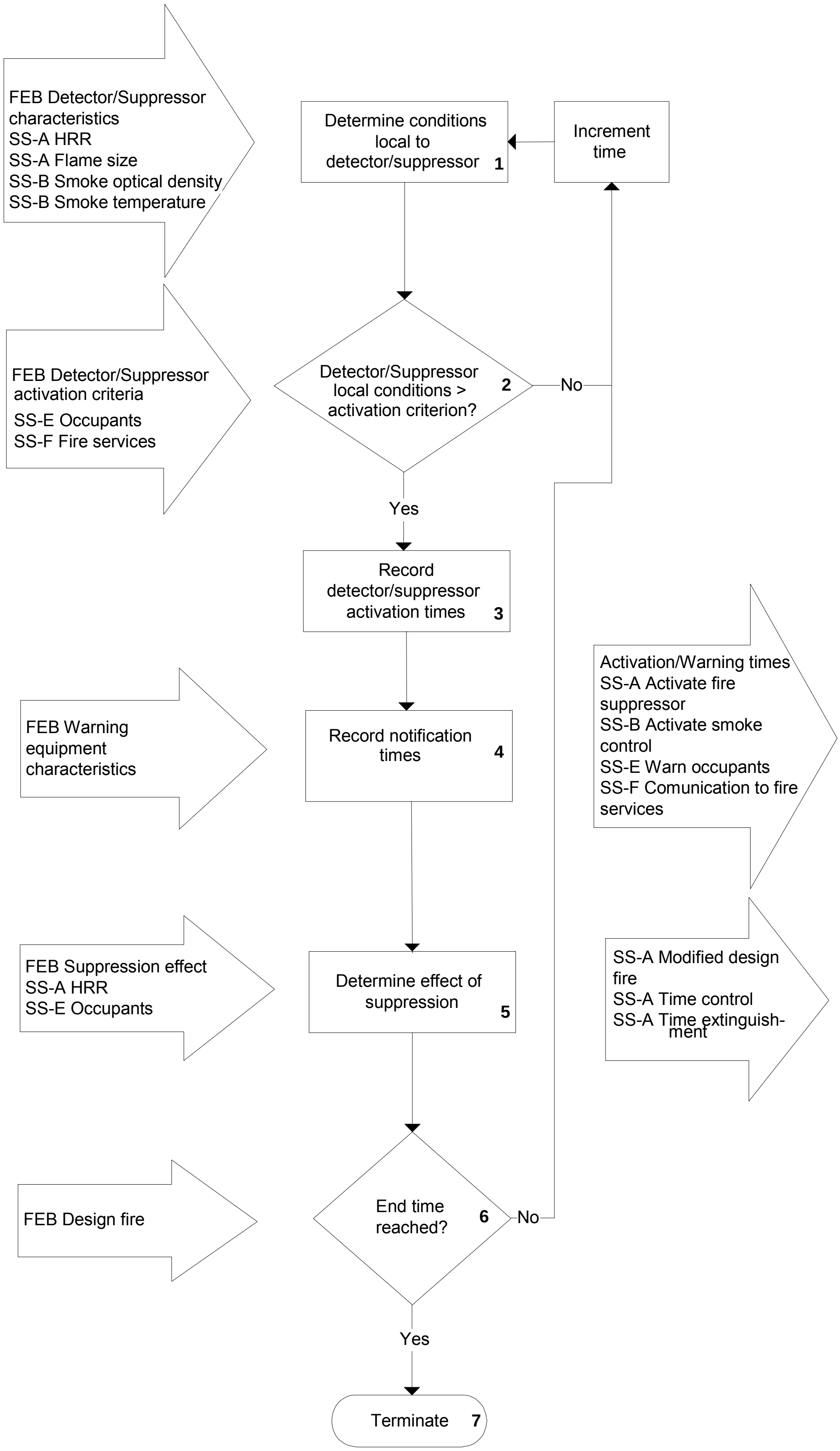


Figure 1.7.1 Flow chart for detection, warning and suppression analysis

1.7.2 Outputs—SS-D

1.7.2.1 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 Sub-system 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 Sub-system E).

- **Time to alert fire services.**
  This includes delay time discussed in Step 4 of the analysis in Section 1.7.4.1. This provides input to Sub-system F.

1.7.2.2 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 Sub-systems A and F.

- **Modified heat release rate versus time**
  This reflects the effect of suppression that is generally categorized as
  - no effect
  - control
  - extinguishment

  This provides input to Sub-systems A and F.

- **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 Sub-systems A and 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 Sub-systems A and F.

1.7.3 Inputs—SS-D

1.7.3.1 Inputs for fire detection and warning

Typical inputs are discussed below:

- **Detector and warning characterization**

Information is required on the location, type and actuation criteria of the detectors and alarms from the FEB. 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 Sub-system E).

- **Fire conditions**

  A number of fire parameters may be used to determine detector activation according to the type of detector

  - heat release rate from Sub-system A
  - flame size and temperature from Sub-system A
  - carbon monoxide concentration from Sub-system A
  - smoke optical density from Sub-system B
  - smoke temperature from Sub-system B.

1.7.3.2 Inputs for fire suppression

Typical inputs are discussed below:

- **Suppressor characterization**

  Information on the location, type, actuation criteria and suppressing agent characteristics of the suppression equipment are obtained from the FEB. 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

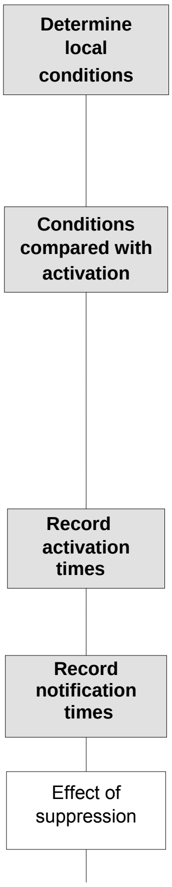
  - heat release rate from Sub-system Asmoke optical density from Sub-system B
  - smoke temperature from Sub-system B
  - nominated suppression effectiveness from the FEB.

1.7.4 Analysis—SS-D

1.7.4.1 Analysing fire detection, warning and suppression

The process of analysis is shown in Figure 1.7.1.

- 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 Sub-system 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, their 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.

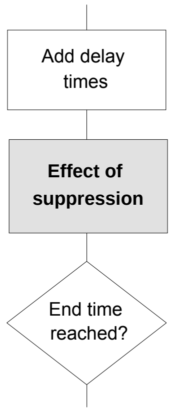
If the criterion has not been exceeded, the time should be incremented and the situation should be re-examined.

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 itself 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, to fire stations by way of automatic equipment, alarm monitoring companies or manual alarms.)
- time for coincident detector operation
- provision of time for occupant evacuation before the release of a suppression agent that would harm them.



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 Sub-system A).

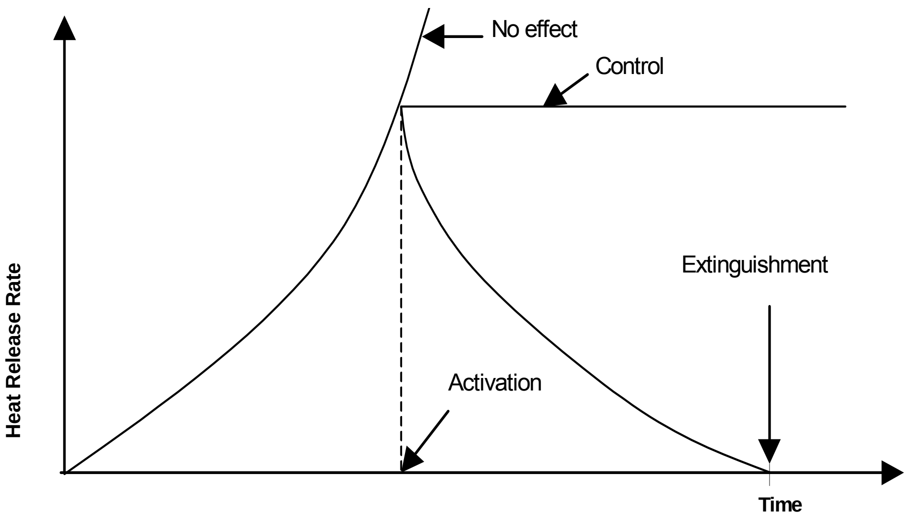


Figure 1.7.4 Possible effects of suppression on a design fire

The effect of the suppressor can be expressed (as illustrated in Figure 1.7.4) as one of three possible outcomes:

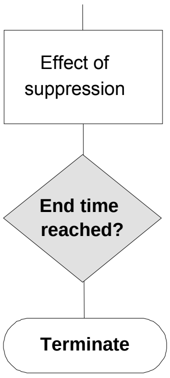
- **No effect**
  Although this is an unlikely outcome, it is sometimes used as a conservative assumption. This is based on those cases where the suppressor may be inoperative or a fire has developed beyond flashover and is thus difficult to extinguish.

- **Control**
  This outcome is represented by a steady heat release rate 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 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.

The outcome or outcomes to be used in the analysis will generally have been decided qualitatively during the FEB process but may require input from Sub-system 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 have been made during the FEB process.

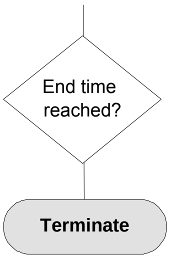
Suppression by fire services is covered by Sub-system F.



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 FEB process has been reached; or
- 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 not been reached, the next iteration is undertaken and the analysis continued until the end time has been reached.



Step 7
The analysis of Sub-system D is terminated.

1.7.4.2 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 1.7.1 as the analysis process described in Section 1.7.4.1. It enables the quantification of those characteristics of the detection and suppression equipment (see Section 1.7.3) that enable the attainment of the relevant acceptance criteria for the analysis (as determined in the FEB process) used in Chapter 1.10 (Collating the results and drawing conclusions).

1.7.5 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, manufacturer's literature and specific maintenance requirements recommended by the fire engineer, it may be possible to ensure that this is done through the essential safety provisions that may apply in some jurisdictions.

1.7.6 Bibliography—SS-D

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Chapter 1.8

Occupant Evacuation and Control
Sub-System E

Sub-system E (SS-E) is used to analyze 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 the Required Safe Evacuation Time (RSET).

RSET comprises a number of components that are shown in the detection and evacuation timeline of Figure 1.8. 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)** is time zero for the analysis of the fire, evacuation and determination of RSET
- **Occurrence of cue (t_c)** is 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)** is the time at which occupants, having received a cue, recognize it as an indication of a fire

- **Initiation of movement (t_d)** is 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)** is the time when occupants reach an (internal or external) safe area.

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 Figure 1.8:

- **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 1.8:

- **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, the evacuation maybe managed by trained personnel, with occupants on floors furthest from the fire placed initially on alert and evacuated progressively only if the fire continues to develop.

In particular types of buildings, the concept of a fire safe refuge, where occupants go to a special fire compartment to await rescue by the fire service rather than evacuate, is sometimes used.

A further and more recent development is the 'protect in place' concept. Occupants are encouraged to remain where they are, rather than try to evacuate through potentially smoke-filled corridors and/or stairs.

While many of these newer occupant management and evacuation concepts are still developing, these Guidelines are restricted to addressing the situation where evacuation of occupants to a place of safety is adopted as the approach in a fire emergency.

In all buildings, consideration should be given to the question of providing safety for persons with disabilities. Use of refuges and use of elevators for evacuation of persons with disabilities, are some of the options that may be considered.

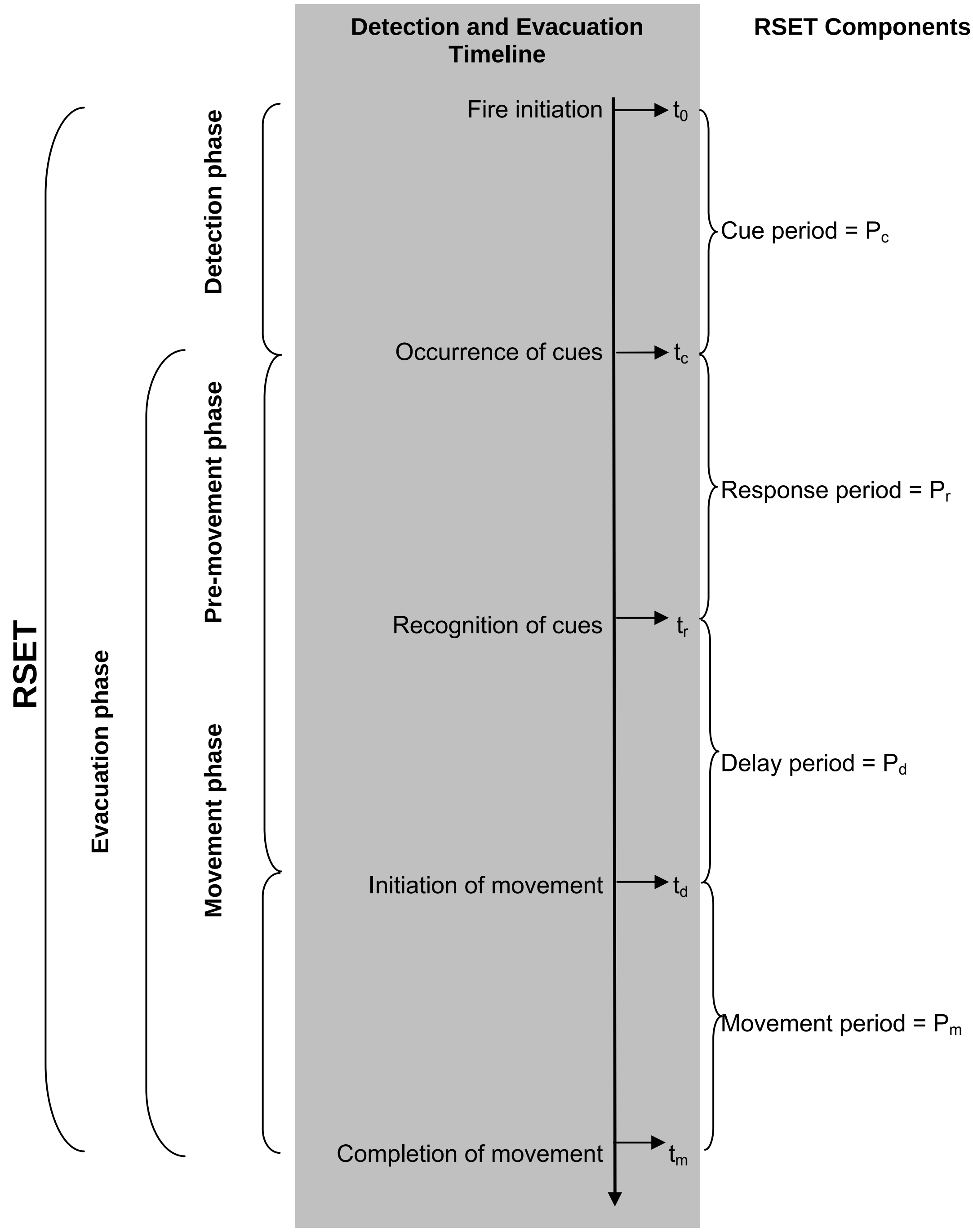


Figure 1.8 Detection and evacuation timeline

This chapter 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 Chapter 1.10 Collating results and drawing conclusions).

This chapter also discusses the relationships between this sub-system and others. Descriptions of selected methods that may be used in connection with this sub-system may be given in Chapter 2.8. Selected data for these methods may be given in Part 3 of these Guidelines.

Although this chapter provides guidance on the analysis of Sub-system E in the general analysis context discussed in Chapter 1.3, each project needs to be considered individually and the analysis varied accordingly.

1.8.1 Procedure—SS-E

1.8.1.1 Occupant evacuation

Figure 1.8.1 illustrates how occupant evacuation can be analyzed. Discussion of the figure can be found in the following sections:

- Section 1.8.2 Outputs
- Section 1.8.3 Inputs
- Section 1.8.4 Analysis

Figure 1.8.1 is supplemented by other flow charts presented in the Analysis Section 1.8.4. An analysis needs to be undertaken for each design occupant group specified by the FEB.

Where the FEB decision is an analysis that includes consideration of probabilities of various events and scenarios occurring should be undertaken, the flow chart can assist the fire engineer 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.

1.8.1.2 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 1.8.4.2.

1.8.2 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 FEB should have set the criteria by which the analysis will determine whether the occupants recognize 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 recognized the fire cues (and become aware of a fire-related emergency), but before they initiate their movement towards an internal or external 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.

- **Required Safe Evacuation Time (RSET)**
  The sum of the cue period, response period, delay period and movement period is known as the Required Safe Evacuation Time. This time is used in the collation of the results and in drawing conclusions as discussed in Chapter 1.10.

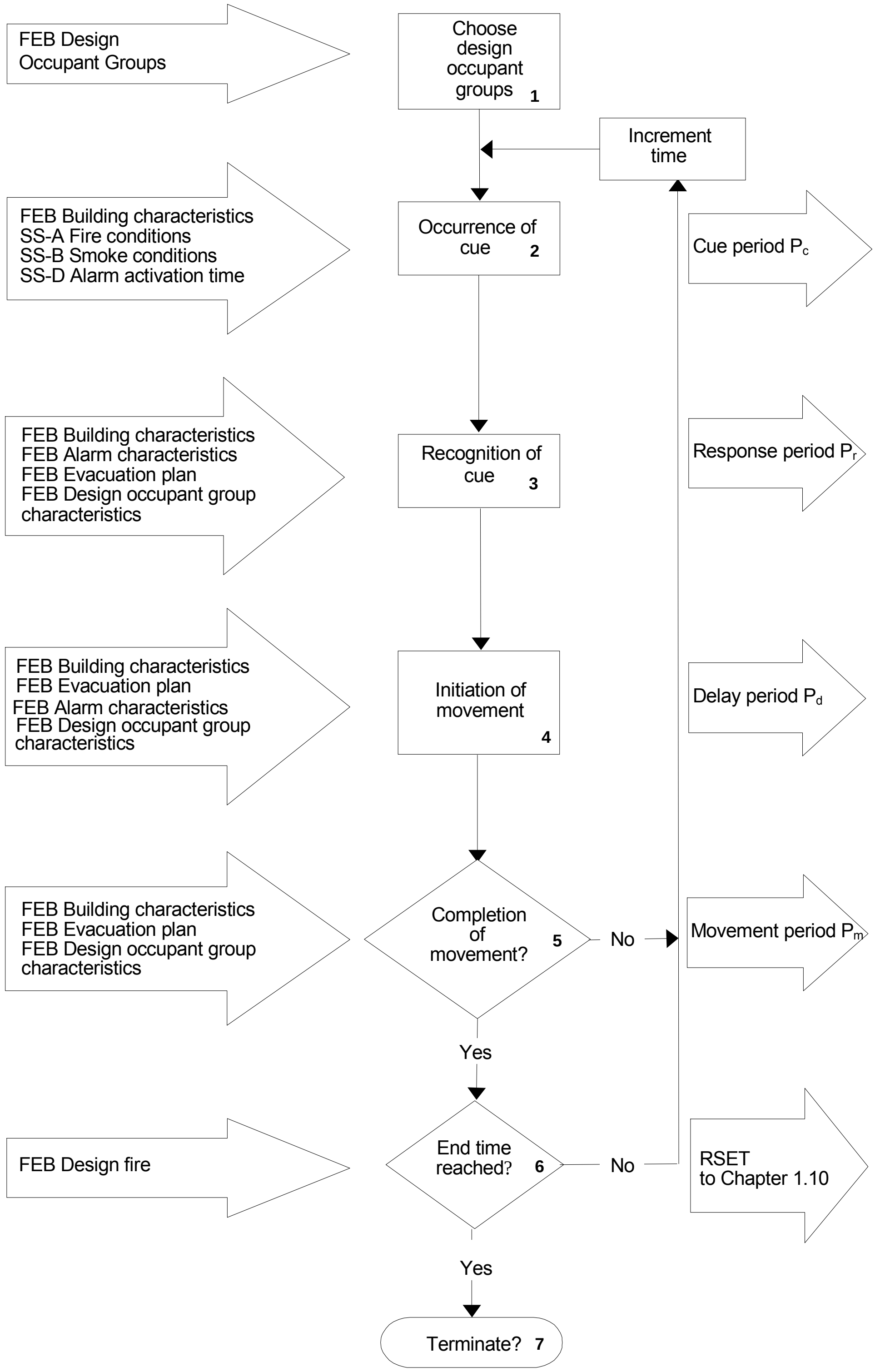


Figure 1.8.1 Flow chart for occupant evacuation analysis

1.8.3 Inputs—SS-E

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

- **Building characteristics**
  The following parameters are usually relevant and should be available from the FEB
  - 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, including
  - whether evacuation is controlled or uncontrolled
  - for controlled evacuations, what the evacuation type is (full, zone or staged).

  Although fire services assistance may be included in the evacuation plan, such assistance may not be used in the analysis in some evaluations.

- **Design occupant groups and characteristics**
  The design occupant groups and their characteristics to be used for the analysis would have been determined during the FEB process (Section 1.2.12). As a number of groups may be analyzed separately or used for different components of RSET, the relevant characteristics for each group are required.

- **Time of occurrence of cues**
  The cues may be
  - the activation of an automatic alarm (audio or visual), obtained from Sub-system D
  - fire related cues (audio, olfactory, visual and tactile), based on information from Sub-systems A and B
  - warnings (in the form of actions or word of mouth) by other people, based on information from the FEB or this sub-system.

1.8.4 Analysis—SS-E

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

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

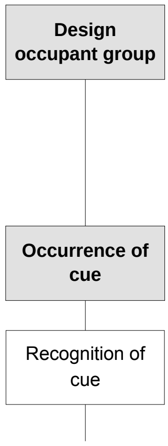
The data needs to be well documented and the engineering judgement well substantiated (as described in Chapter 1.11, Preparing the Report).

1.8.4.1 Analysing occupant evacuation

The process of analysis is shown in Figure 1.8.1, and supplementary flow charts are given in Figures 1.8.4.1a–d. 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 have been identified and described in the FEB. The design occupant group recognized 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 1.8.4.1a 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, UV detectors and IR 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.

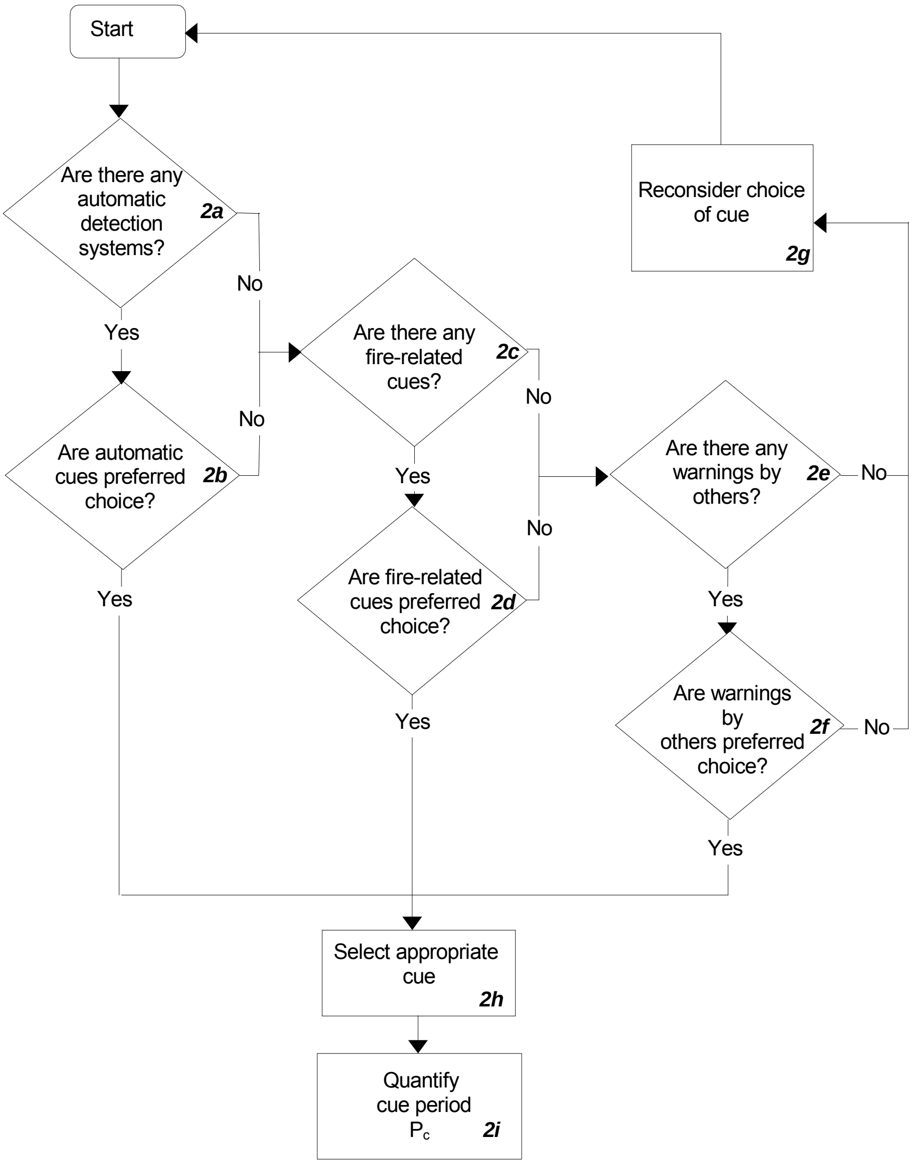


Figure 1.8.4.1a Flow chart for quantifying cue period (P_c)

The following steps comprise the quantification of the Cue Period (Pc) as set out in Figure 1.8.4.1a above:

Steps 2a and 2b
Assess automatic cues. The presence of automatic detection equipment has been established in the FEB. 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 recognized a cue (see **Step 3**). If warning by others is used, proceed to ***Step 2h***.

Step 2g
Re-consider choice of cue. If the fire engineer has not chosen to consider any of the available cues, the analysis cannot progress any further and the fire engineer needs to re-consider the choice of cues by returning to the 'start' of the flow chart.

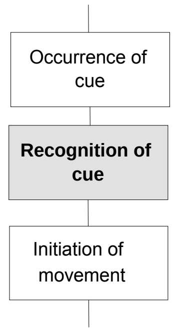
Step 2h
Select appropriate cue. Where the above process has identified more than one possible cue to be used for the analysis, select the most appropriate cue (for example, one of several possible automatic cues). In all cases, the reasons for choosing the cue should be documented.

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, Sub-system D;
- for fire related cues, Sub-systems A and B; or
- for warnings by others, **Step 3.**

Having obtained the information determine the cue time and then the cue period.

Step 3
Determine cue recognition and quantify response period. Figure 1.8.4.1b explains the steps involved in determining cue recognition and quantification of the response period (P_c).



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.

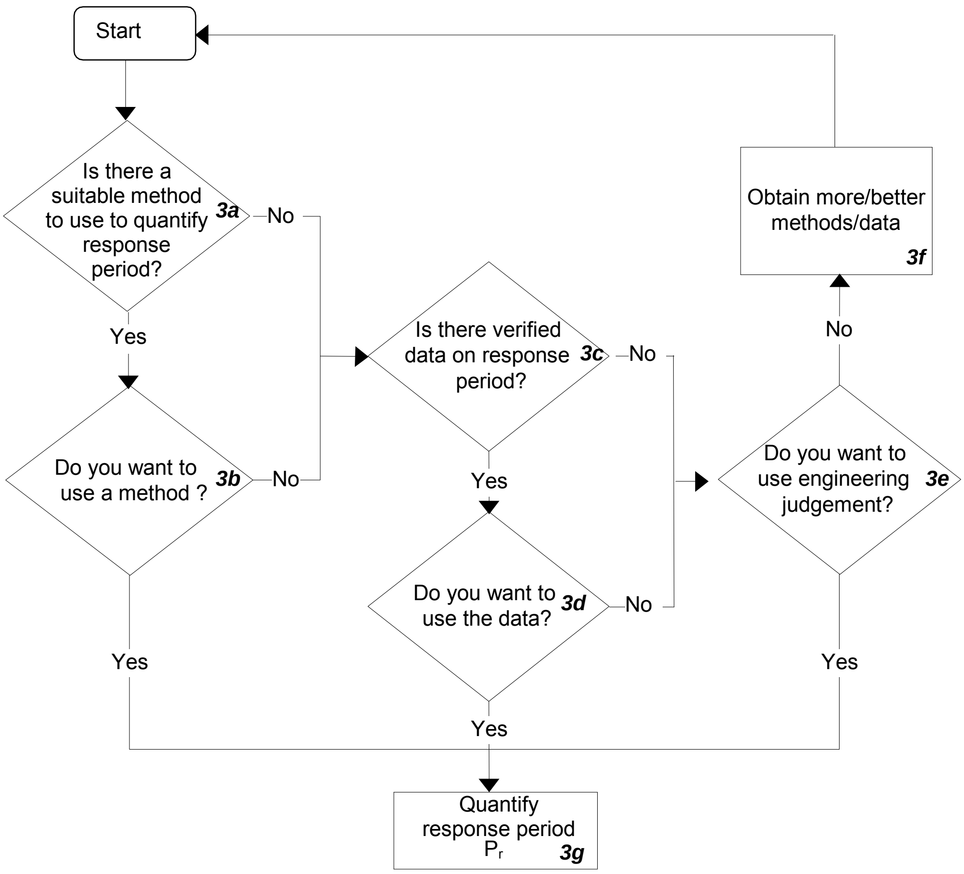


Figure 1.8.4.1b Flow chart for quantifying response period (Pr)

The following steps comprise the quantification of response period as set out in Figure 1.8.4.1b above.

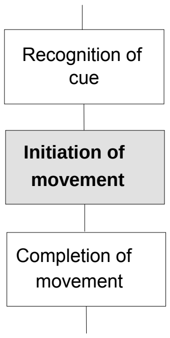
Steps 3a and 3b
Establish the availability of a suitable method and decide whether to use it. The fire engineer needs to establish the availability of a suitable method to quantify the response period. The decision on whether to use the method will depend on the suitability of the method and the availability of input data.

Steps 3c and 3d
Establish the availability of verified data and decide whether to use it or not. The fire engineer 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 Chapter 1.11 Preparing the report).

Step 3f
Obtain other methods or data. Where the methods and data considered are not appropriate and engineering judgement cannot be used, the fire engineer needs to obtain other methods or data in order to quantify the response period.

Step 3g
Quantify response period. By using methods, adopting data or by applying engineering judgement, the response period should be quantified.



Step 4
Determine time of initiation of movement and quantify delay period (P_d). The flow chart in Figure 1.8.4.1c 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 being considered.

The following steps comprise the quantification of response period as set out in Figure 1.8.4.1c below.

Steps 4a and 4b
Establish the availability of a suitable method and decide whether to use it. The fire engineer 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 fire engineer 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 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 Chapter 1.11 Preparing the report).

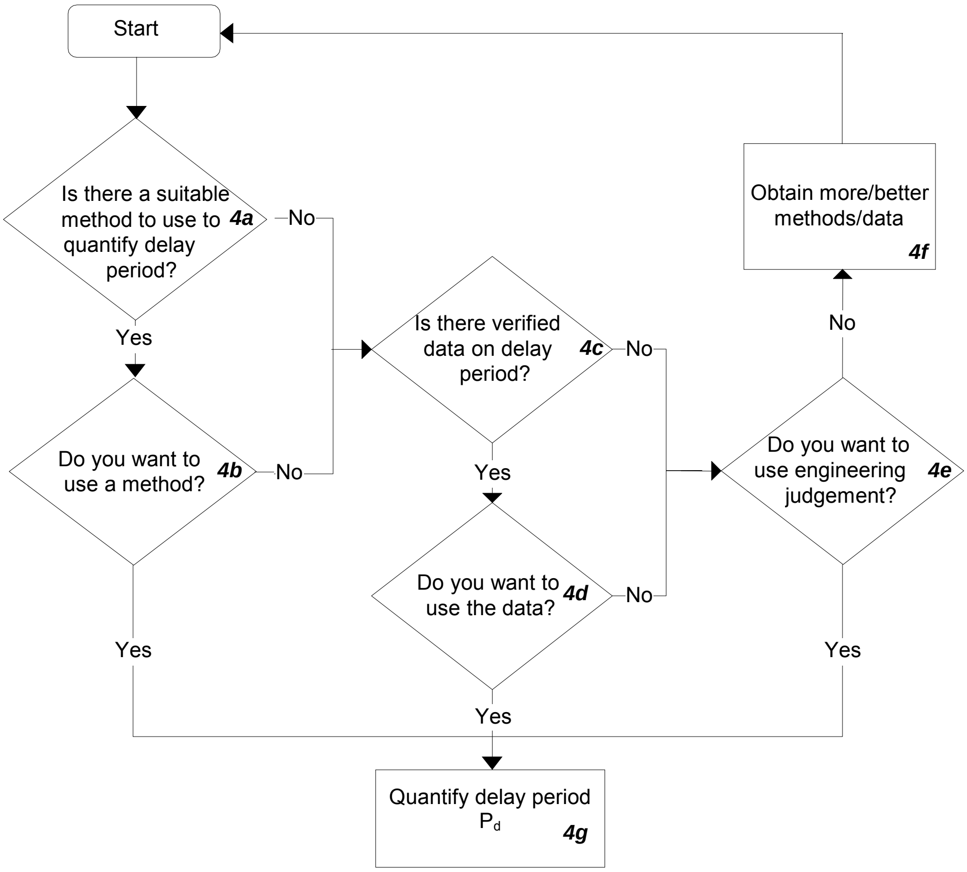
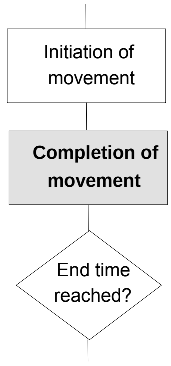


Figure 1.8.4.1c Flow chart for quantifying delay period (P_d)

Step 4f
Obtain other methods or data.
Where the methods and data considered are not appropriate and engineering judgement cannot be used, the fire engineer needs to obtain other methods or data in order to quantify the delay period.

Step 4g
Quantify delay period. By using methods, adopting data or by applying engineering judgement, the delay period should be quantified.



Step 5
Determine completion of movement and quantify movement period (P_m). Figure 1.8.4.1d explains the steps involved in determining completion of movement and quantification of the movement period (Pm).

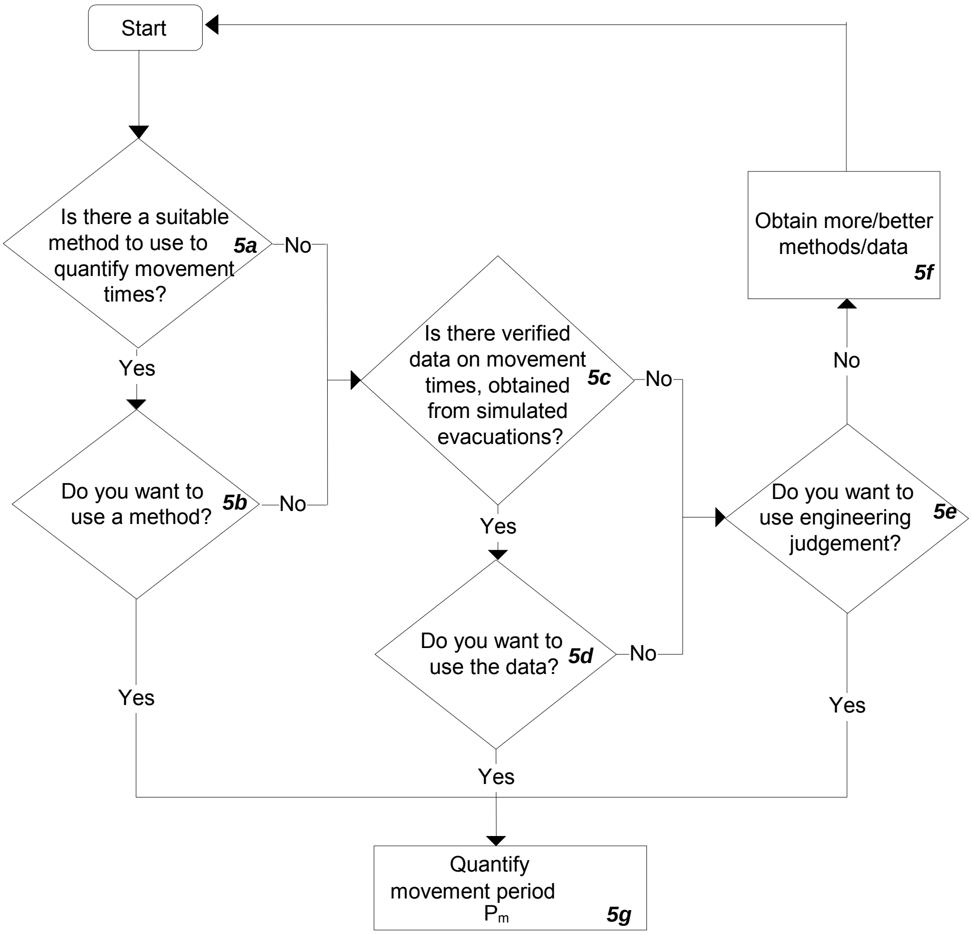


Figure 1.8.4.1d Flow chart for quantifying movement period (P_m)

The following steps comprise the quantification of movement period as set out in Figure 1.8.4.1d above.

Steps 5a and 5b

Establish the availability of a suitable method and decide whether to use it. The fire engineer 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 fire engineer 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

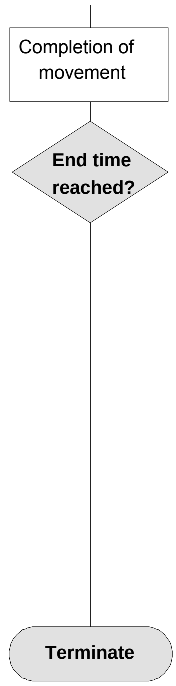
Use of engineering judgement. Where valid methods or simulated evacuation data are not available or not appropriate, engineering judgement may be used. However, all quantification based on engineering judgement needs to be justified in detail (see Chapter 1.11 Preparing the report).

Step 5f

Obtain other methods or data. Where the methods and data considered are not appropriate and engineering judgement cannot be used, the fire engineer 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 FEDB
- all the occupants have reached a place of safety
- all the relevant enclosures have been analyzed
- the stage of the design fire, agreed to in the FEB 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 calculate the Required Safe Evacuation Time (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, the next iteration is undertaken and the analysis continued until the end time has been reached.

Step 7
The analysis of Sub-system E is terminated.

1.8.4.2 Analysing control of occupant evacuation

There are a number of ways of reducing the Required Safe Evacuation Time (RSET) as a means of improving 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 include the following:

- 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 signagemore 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 analyzed by varying one or more of these factors and using the processes described in Section 1.8.4.1 to quantify a modified RSET.

1.8.5 Construction, commissioning, management, use and maintenance—SS-E

The evacuation measures that contribute to a building's fire safety system comprises both physical measures (egress paths, fire corridors and exits, signage, etc.) and an emergency organization and procedures (emergency planning committee, emergency control organization, emergency procedures, evacuation plans, education and training, testing and maintaining).

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 the recommendations of the fire engineering study. Again, this should be carried out by, or with input from, the fire engineer.

Comment: Evacuation procedures

Documented evacuation procedures should include the following:

- 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 organization
- setting up of an emergency control organization, the preparation of emergency plans and procedures
- the role and authority of emergency control organization personnel while executing their duties
- an education and training programme.

The document should take into account fire engineering assumptions and particular recommendations of the fire engineering evaluation.

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

Once a structure and procedures have been adopted, it becomes the responsibility of the building management to establish the emergency planning committee, emergency control organization, appointments, education and training programs, testing procedures, and to review and amend them as necessary.

Maintenance is another building management responsibility which includes the following:

- 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 organization and procedures. The building management should ensure that the organization 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 the above measures are maintained through the essential safety provisions for buildings that may apply in some jurisdictions.

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Chapter 1.9

Fire Services Intervention
Sub-System F

Sub-system F (SS-F) is used to analyze the effects of the intervention activities of fire services on a fire. This process enables estimates to be made 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 and the building fire safety system is evaluated on the basis of the other five sub-systems. In particular, the analysis of evacuation of occupants to a place of safety should not rely on fire services intervention.

This, however, does not mean that the fire engineering evaluation should discount the needs of fire services carrying out their intervention activities.

This chapter 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

This chapter also discusses the relationships between this sub-system and others. Descriptions of selected methods that may be used in connection with this sub-system may be given in Chapter 2.9. Selected data for these methods may be given in Part 3.

Although this chapter provides guidance on the analysis of Sub-system F in the general analysis context discussed in Chapter 1.3, 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 services location, budgets, equipment and changes in traffic density.

1.9.1 Procedure—SS-F

Figure 1.9.1 illustrates how fire service intervention can be analyzed. Discussion of the figure can be found in the following sections:

- Section 1.9.2 Outputs
- Section 1.9.3 Inputs
- Section 1.9.4 Analysis.

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

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

The flow chart provides guidance but does necessarily cover all the factors which may be relevant to a particular fire engineering analysis.

1.9.2 Outputs—SS-F

Outputs from an analysis of fire service 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.

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 Sub-system 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.

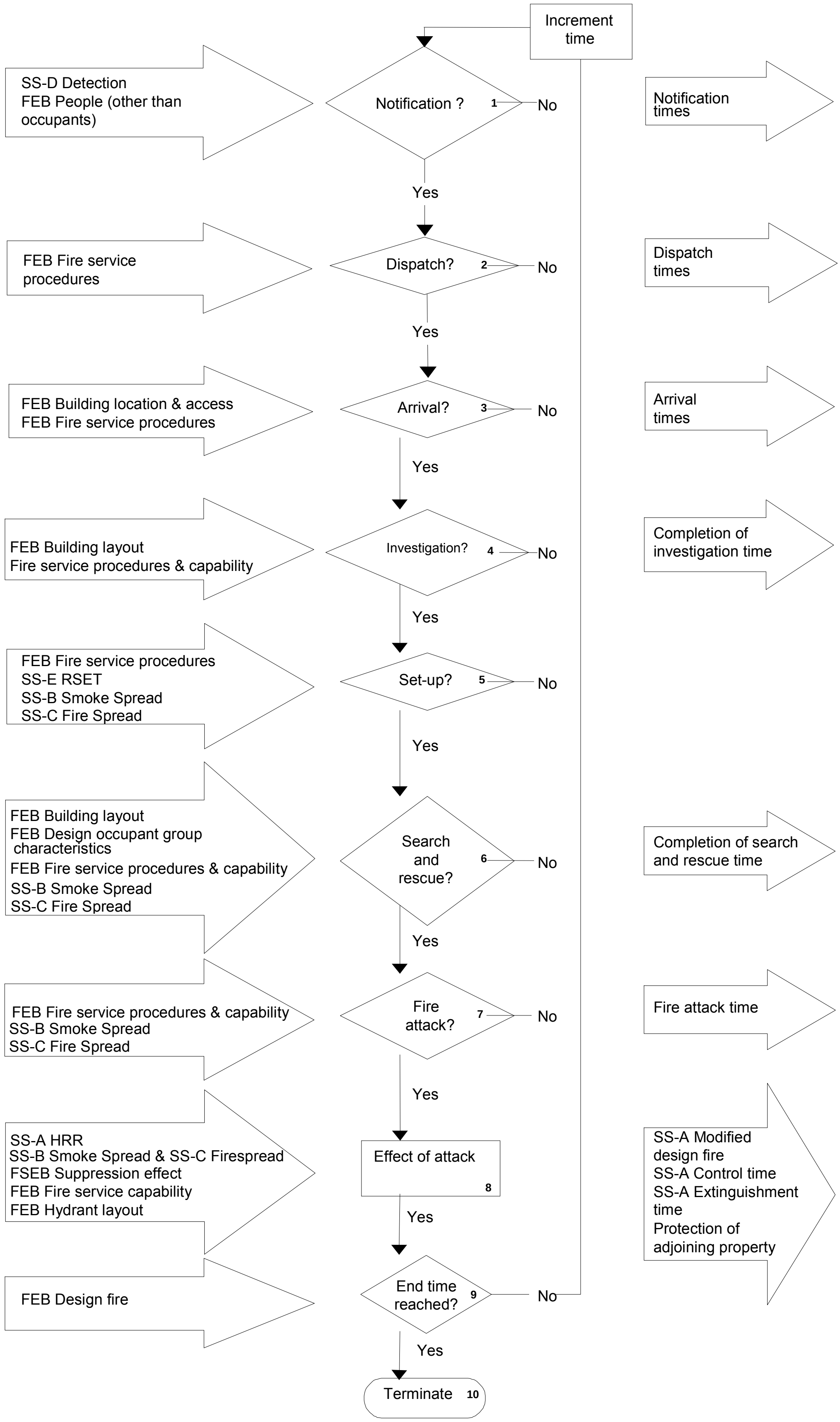


Figure 1.9.1 Flow chart for fire service intervention analysis

- **Time to complete investigations**
  This will include location of the fire using information from installed fire safety equipment, occupants and observations of smoke and flames. Fire fighters may gather and don safety equipment and enter the building before investigations are complete and before set up and search and rescue commences.

- **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 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 Sub-system A.

- **Modified heat release rate versus time**
  This reflects the effect of suppression that provides input to Sub-system A and is generally categorized 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 Sub-system 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 Sub-system 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 Sub-system A.

The outputs modified heat release rate, time to control and time to extinguishment may also be calculated during the analysis of Sub-system D, Fire Detection, Warning and Suppression. Therefore, a choice needs to be made as to which sub-system will include this part of the analysis of fire service intervention.

1.9.3 Inputs—SS-F

The required input parameters to SS-F are determined by the analysis methods being used and may include those listed below:

- **Building characteristics**
  The following parameters are usually relevant and should be available from the FEB
  - 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 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 in the FEB stage that these matters be discussed with the fire service, which should be able to provide the necessary data.

  The principal factors that govern the capability of a fire service are
  - 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 (air temperature, humidity, radiant heat etc.)
  - fire services crew equipment (protective clothing, breathing apparatus etc.).

- **Detection time**
  Account should be taken of 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 Sub-system D.

- **Required Safe Evacuation Time (RSET)**
  The calculations of RSET from Sub-system E may indicate that occupant evacuation is complete before fire services arrival. However, in practice, the fire service may undertake a search for any trapped or injured occupants.

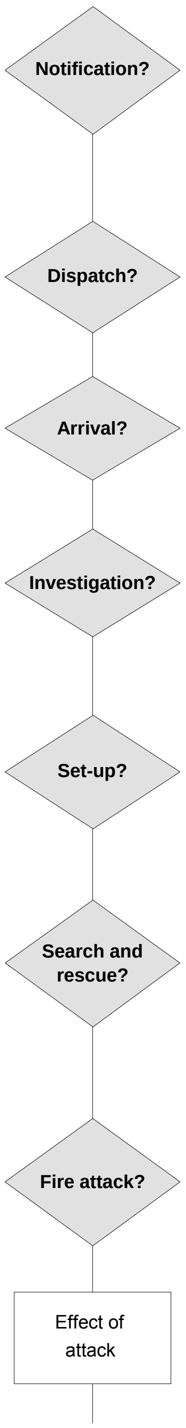
- **Heat release rate (HRR)**
  The effectiveness of fire suppression by the fire service will be dependent on the heat release rate at the time of attack. Data on heat release rate as a function of time is provided by Sub-system A.

- **Effectiveness of attack**
  This will have been decided in the FEB process in one of three forms: no effect, control and extinguishment for the subject building or prevention of spread with respect to an adjoining property.

1.9.4 Analysis—SS-F

Fire service 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 process of analysis is shown in Figure 1.9.1. 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.



Step 1
Determine the time of notification of the fire service. The notification time is based on time of detection obtained from Sub-system D with additional time, where appropriate, for any delays due to call handling, verification of calls etc. If notification is received after the fire had been extinguished, the analysis is terminated.

Step 2
Determine time of dispatch.

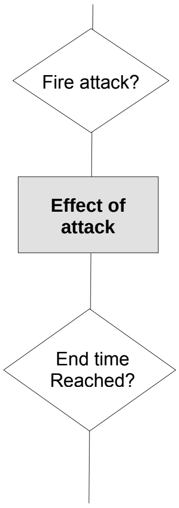
Step 3
Determine the time of arrival.

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. Where all the occupants have evacuated (i.e. the time is ≥ RSET) and been accounted for, this step is omitted.

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 Sub-system A) or in preventing fire spread to adjoining property.

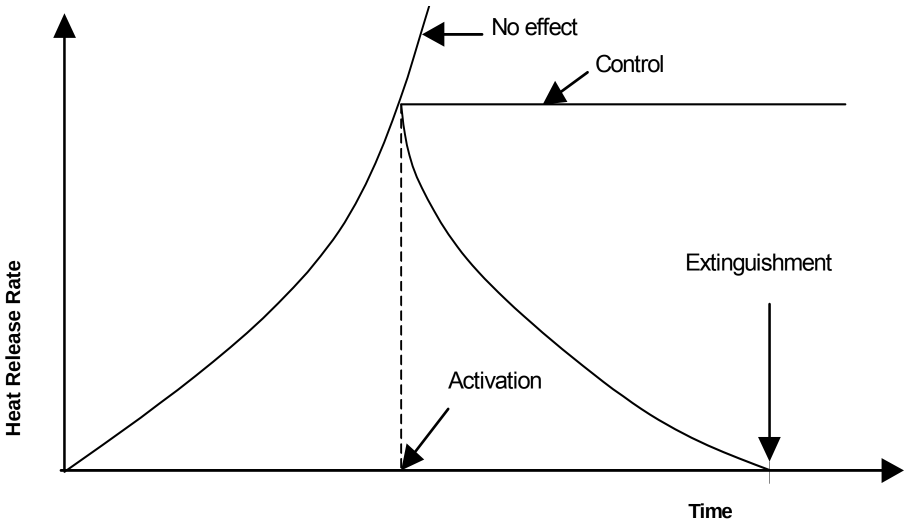


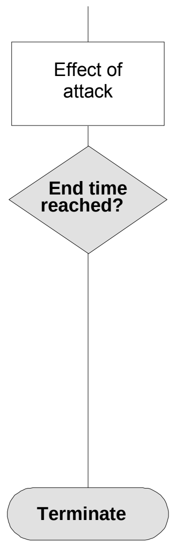
Figure 1.9.4 Possible effects of suppression on a design fire

The effect of the suppression activities can be expressed, as illustrated in Figure 1.9.4, 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 heat release rate 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 occurs 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 FEB 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 not been reached, the next iteration is undertaken and the analysis continued until the end time has been reached.

Step 10
The analysis of Sub-system F is terminated.

1.9.5 Construction, commissioning, management, use and maintenance—SS-F

There are some construction, commissioning, management, use and maintenance requirements directly related to fire service intervention. In particular, the design and maintenance of the following items is needed to facilitate effective fire service 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 would utilize during intervention (for example, hydrants).

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

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Chapter 1.10

Collating and Evaluating the Results and Drawing Conclusions

When one or more trial designs have been analyzed, it is necessary for the fire engineer to collate and evaluate the results and to draw conclusions so that a report of the evaluation can be written.

This chapter provides guidance on these processes but each project needs to be considered individually and the processes varied accordingly.

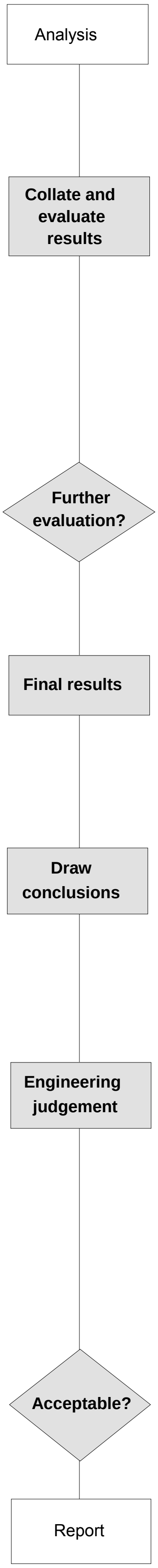
Figure 1.10 illustrates:

- collating and evaluating the results (Section 1.10.1)
- drawing conclusions (Section 1.10.2).

It is of note that the processes generally involve the use of engineering judgement in collating and evaluating the results and in drawing conclusions. Engineering judgement is defined by ISO 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 a quantitative analysis."*

This use of engineering judgement emphasizes the need for evaluations to be conducted by fire engineers with the necessary knowledge and experience.



1.10.1 Collating and evaluating the results

Step 1a

The results obtained from the analysis according to Chapters 1.3 to 1.9 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 1.2.10.1
- the safety factors set according to Section 1.2.10.2, which are to be applied in determining whether the results meet the acceptance criteria
- whether the agreed redundancy (see Section 1.2.7), has been demonstrated by the redundancy studies (see Section 1.2.9.5)
- the results of the uncertainty studies carried out according to Section 1.2.9.5
- the results of the sensitivity studies carried out according to Section 1.2.9.5.

Step 1b

The fire engineer should apply engineering judgement to the collated and evaluated results in order to determine if further evaluation (for example, further sensitivity studies) or adjustments to the results are required in the light of the engineer's knowledge and experience. Such engineering judgement should be adequately justified and the logic used explicitly stated in the report (Chapter 1.11).

Step 1c

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

1.10.2 Drawing conclusions

Step 2a

The conclusions of the evaluation need to be drawn based upon the final results and taking into account the specific objectives or performance requirements for the evaluation as determined during the FEB process (see Section 1.2.8.2). These processes may require consultation with other professionals with building-related expertise, for example, where specialist fire engineering issues or complex fire protection equipment are involved.

Step 2b

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

- the FEB 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 (Chapter 1.11).

Step 2c

If the final conclusions indicate that the trial design is acceptable, the report can be written. But if this is not the case, it may be appropriate to analyze another trial design. Additional trial designs may have been identified already during the FEB process. If this is not the case, further consultations and modification of the FEB 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.

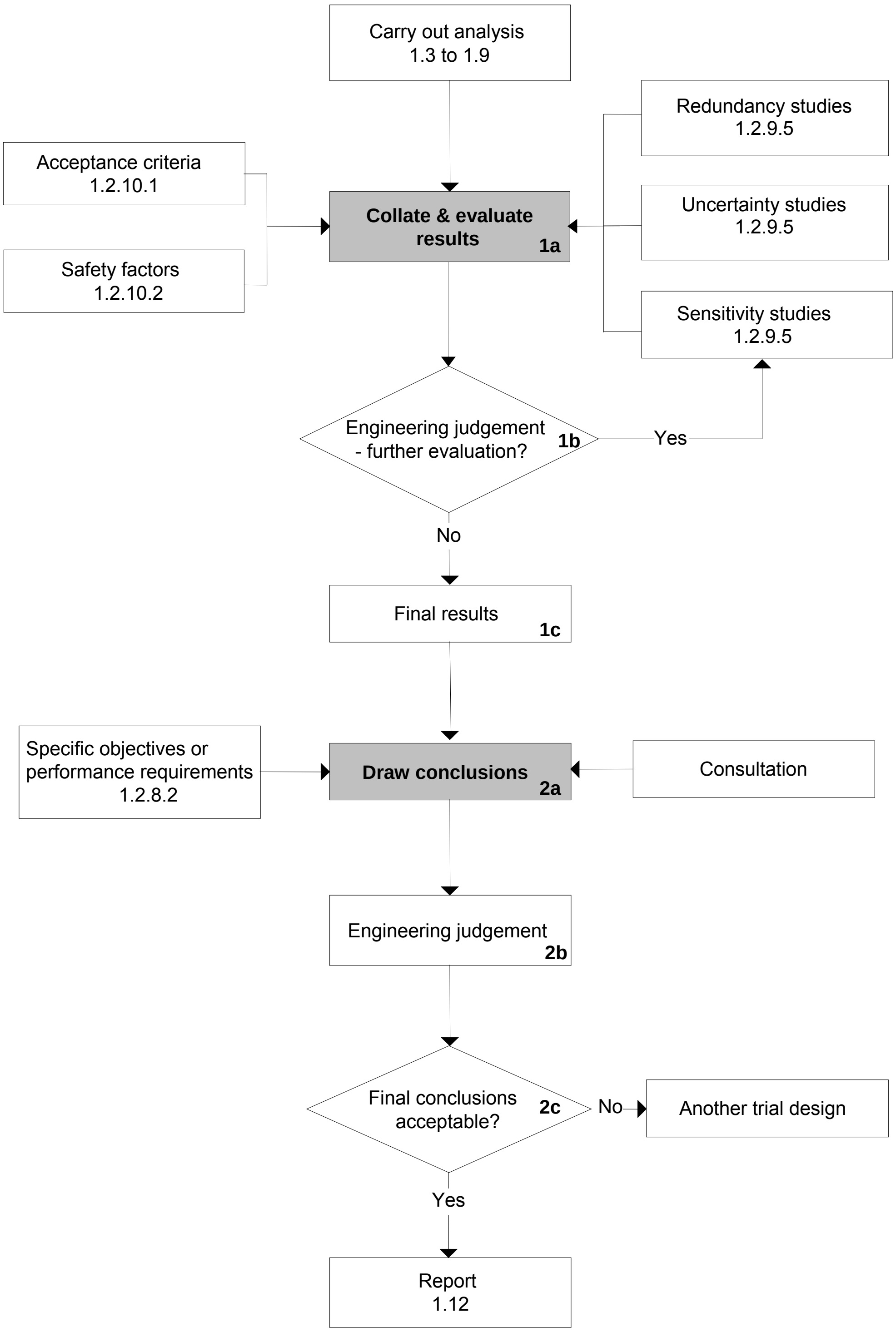


Figure 1.10.1 Flow chart for collating and evaluating the results and drawing conclusions

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Chapter 1.11

Preparing the Report

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

The report should be comprehensible to all the stakeholders and in a form suitable for retention as a source of information on the building in question. This may be either in the form of a bound hard copy or a combined issue of a bound hard copy and a complete electronic version.

The information contained in the final report may find use during construction, commissioning, management, use, maintenance, audits, alteration/extension or change of use of the building.

The report should follow good report writing guidelines, including:

- using jargon only when it is explained
- using graphics wherever it may be helpful to the reader
- explaining the source of the information used with appropriate references
- justifying assumptions and any engineering judgement used.

1.11.1 Report format

There are many possible formats for a report but the framework should follow the fire engineering process described in Section 1.1.1. In the case of electronic reports, a format should be used that inhibits subsequent alteration.

The following headings provide a recommended format:

- Executive Summary
- Introduction
- Fire Engineering Brief
- Analysis
- Collating and Evaluating the Results
- Conclusions
- References
- Appendices

1.11.2 Report contents

The following paragraphs provide guidance for the contents of the report:

Report Identification

- unique identification by name of project
- version or issue number
- date
- numbered pages and a table of contents
- qualifications and accreditations of the author(s) responsible
- the signatures of the authors.

Executive Summary
This should be appropriate to the length and complexity of the report but convey succinctly the essential features and outcomes of the fire engineering study.

Introduction
The introduction may contain general matters such as:

- the client details
- the genesis of the report (including generic project details)
- reference to pertinent documentation.

Fire Engineering Brief (FEB)
The FEB is a separate section of the report and should generally follow the section headings detailed in Chapter 1.2 and set out below:

- Scope of the project
- Relevant stakeholders
- Principal building characteristics
- Dominant occupant characteristics
- General objectives
- Non-compliance issues and specific objectives or performance requirements
- Hazards and preventative and protective measures available
- Trial designs for evaluation
- 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

In smaller projects where a full FEB process was not considered appropriate (see discussion in Chapter 1.2), this section of the report should contain the basic information of an FEB and as far as practicable use the appropriate section headings from the above list.

Analysis
This section of the report should address the following;

- the analysis strategy used (see Chapter 1.3)
- the calculations carried out
- the sensitivity, redundancy and uncertainty studies carried out
- the results obtained.

Collation and Evaluation of Results
This section of the report should address the following:

- the assembling of the results in a form suitable for evaluation
- comparison of results with acceptance criteria and safety factors set during the FEB process
- any further sensitivity studies carried out
- any engineering judgement applied and its justification.

Conclusions
This section of the report should address the following:

- specification of the final trial design shown to be acceptable (this may be by reference to the FEB Section)
- the performance requirements which have been addressed and met
- any assumptions that were made
- any limitations that apply to the acceptability of the final trial design
- any construction requirements that are needed to ensure that the fire safety system is properly realized
- any commissioning requirements
- any procedures or processes that should be adhered to during management and use of the building
- any maintenance requirements, especially where 'non standard' components (those not fully complying with the prescriptive or deemed-to-satisfy requirements) are used in the fire safety system.

References
The study should be supported by references which are:

- listed in a conventional format
- universally accessible
- taken from recognised texts or papers in journals and conference proceedings which have been refereed
- not unpublished materials or confidential or in-house reports.

Drawings and technical data identification
Such material should be:

- uniquely identified
- included in the form of appendices.

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Part 2
Methodologies

International
Fire Engineering
Guidelines

Table of Contents

These Guidelines have four parts, each of which is a separate entity. For a detailed table of contents, refer to the beginning of each part and each chapter.

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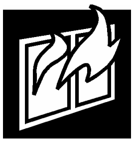
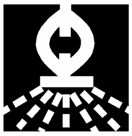
Chapter 2.1

Overview

These Guidelines have four parts, each with its own table of contents. It has been designed for ease of use and cross-referencing with graphics that should be self-explanatory. For example:

- **graphic identification** of sub-systems, as shown below

					
Sub-system A	***Sub-system B***	***Sub-system C***	***Sub-system D***	***Sub-system E***	***Sub-system F***
SS-A	SS-B	SS-C	SS-D	SS-E	SS-F
Fire Initiation & Development & Control	Smoke Development & Spread & Control	Fire Spread & Impact & Control	Fire Detection, Warning & Suppression	Occupant Evacuation & Control	Fire Services Intervention
Chapter 2.4	**Chapter 2.5**	**Chapter 2.6**	**Chapter 2.7**	**Chapter 2.8**	**Chapter 2.9**

- **shaded boxes** containing examples or commentary
- **abbreviated flow charts** in the margins with the relevant boxes shaded.

Part 0 provides background information and guidance that is integral to an understanding of the entire Guidelines.

Part 1 describes the process by which fire engineering is typically undertaken.

This Part 2 describes a selection of methodologies that may be used in undertaking the fire engineering process. This does not preclude the use of other methodologies that might be chosen by the fire engineer and that are acceptable to regulatory authorities or certifiers.

Part 3 provides a selection of data that may be used in applying the methodologies of Part 2 or other chosen methodologies.

This part has been divided into chapters that correspond to those of Part 1. Material of a general nature has been collected in either Chapter 2.2 (if it is used in the FEB process) or Chapter 2.3 (general methodologies encompassing the whole of the fire safety system). Other more specific methodologies have been assigned to one of the sub-systems.

The present compilation is not meant to be comprehensive and reflects the manner in which it was prepared (see below). It is envisaged that further material will be added as it is developed, recognised or made available.

The material selected at the time of writing is mainly that extracted from the Fire Code Reform Centre (FCRC) Fire Engineering Guidelines 96. In addition, some material from the FCRC research projects has been included, as have extended abstracts of relevant USA Society of Fire Protection Engineers (SFPE) publications that support the SFPE Guidelines document.

Chapter 2.2

Preparing a Fire Engineering Brief (FEB)

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

Chapter 1.2 of Part 1 of these Guidelines describes the process by which the fire engineer should prepare an FEB and provides general guidance on the aspects that should be addressed in an FEB.

Part 3 provides a selection of data that may be used in applying the methodologies of Part 2 or other chosen methodologies.

2.2.1 Acceptance criteria for analysis

As indicated in Section 1.2 of Part 1 (Preparing a Fire Engineering Brief), 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 1.2.10.1.

One of the criteria that may be used for analysis is a limiting radiation from the fire that would cause skin burns. A number of methods are available for predicting injury to human skin exposed to radiation from the fire. The general approaches have been described and discussed in an engineering guide developed by the Society of Fire Protection Engineers (SFPE 2000). This guide is intended for use in conjunction with the SFPE guide on flame radiation from pool fires (SFPE 1999) or other methods of predicting thermal radiation. The methods discussed are limited to predicting first and second-degree burns and the onset of pain. In addition to the prediction methods, the skin burn guide presents a brief overview of human skin biology and skin burn morphology, along with a discussion of burn statistics and clinical treatment time. For each method, data requirements and data sources are provided along with any assumptions and a validation analysis. The validation analysis compares the predictive models to experimental data. Factors of safety are discussed and recommended equations and limitations presented.

Simple algorithms are presented for predicting the onset of pain (Beyler 2002) and blistering (Beyler 2002, Stoll & Greene 1959, Conn & Grant 1991) given the level of exposure to radiant flux. The guide includes skin temperature–time models with cooling (Torvi & Klute 1994) and without it (Beyler 2002). Damage integral (Henriques 1947, Diller & Klutke 1993) and 'critical energy' (Beyler 2002) models are also provided. These models require the time–temperature history of the skin that can be determined from the temperature–time models.

2.2.2 Fire scenarios

2.2.2.1 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 FEB enables them to be described in a manner suitable for the quantification process.

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
- building construction and materials

- air handling equipment characteristics.

External environmental conditions may be influenced by:

- the season (summer versus winter)
- wind speed and direction
- a ‘stack effect’.

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 to be considered are listed below:

- Fire Initiation and Development and Control (SS-A)
  - smouldering, non-flashover or flashover fires
- Smoke Development and 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 and Impact and Control (SS-C)
  - doors open or closed
  - barriers, successful or not
  - external spread via windows -, 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 2.2.2.1. From these events it is possible to characterise three fire scenarios, Fire Scenarios I, II and III, which 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, it is possible to quantify the occurrence of the fire scenario by defining the times of occurrence of key events along a time line.

Further information on the systematic development of fire scenarios, based on the use of event trees, is presented in Section 2.2.2.2.

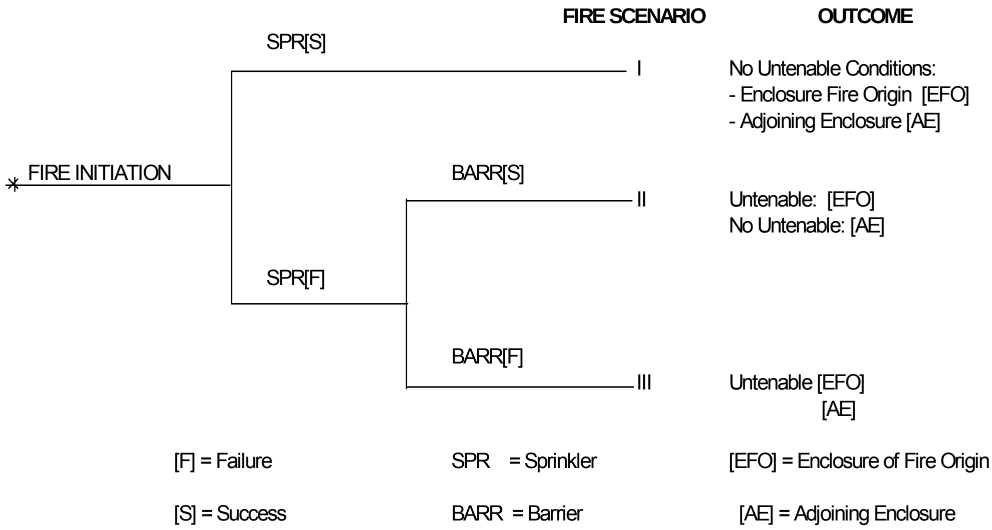


Figure 2.2.2.1. Event Tree representation of the possible events associated with a fire safety system including sprinklers and barriers

2.2.2.2 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. Publications specific to fire engineering include texts such as *SFPE Handbook of Fire Protection Engineering* (DiNenno 2002), *Introduction to Performance Based Design* (SFPE 1997) and *NFPA Fire Protection Handbook* (Cote 1997).

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 2.2.2.2a. These scenarios are based on the event tree approach.

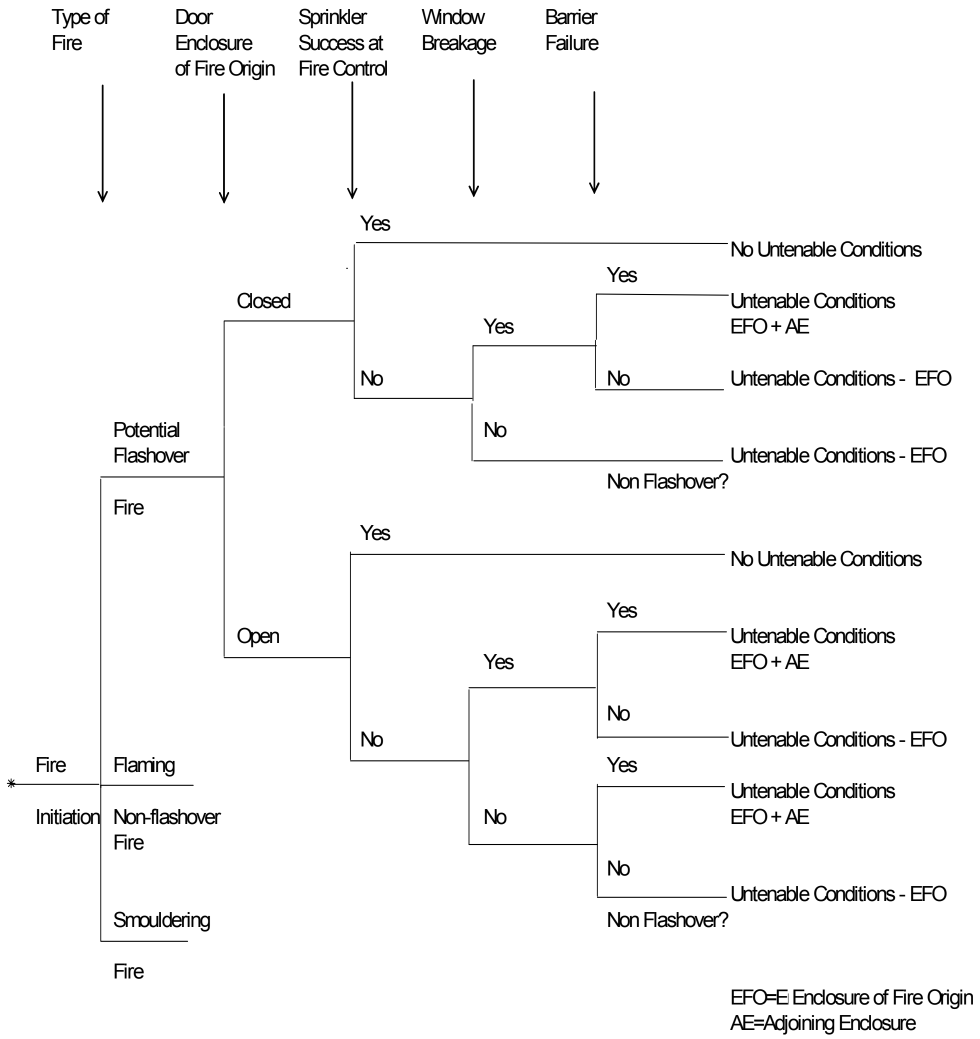


Figure 2.2.2.2a. Fire scenarios using an event tree approach

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 2.2.2.2b shows the four assumed occupant detection responses, together with the associated time line for such responses.

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

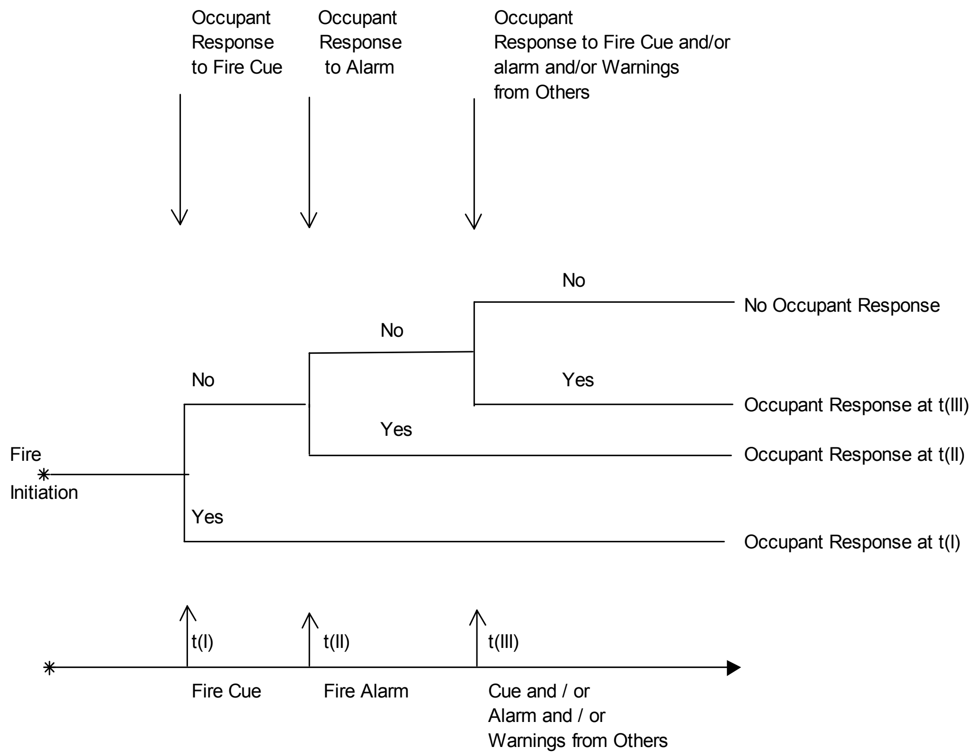


Figure 2.2.2.2b. Occupant responses based on an event tree formulation plus associated timeline

It should further be noted that each of the above four occupant detection response scenarios, as shown in Figure 2.2.2.2b, should be combined separately with each of the fire scenarios identified in Figure 2.2.2.2a. A combined scenario is obtained from the combination of one fire scenario with one occupant detection response scenario.

2.2.3 References

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Chapter 2.3

Analysis

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

Chapter 1.3 of Part 1 of these Guidelines describes the process.

Part 3 provides data that may be used in applying these methodologies.

2.3.1 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 these Guidelines 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.

2.3.2 Probabilistic approaches

There are a number of methodologies (Magnusson *et al*. 1995) 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 relate to life safety or property loss. Other issues could be introduced as the principal parameters if desired.

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

This method of evaluation developed by Beck and Yung (1994) is appropriate where an alternative fire safety system Trial Design is composed of essentially different elements to those in the deemed-to-satisfy 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 (Watts 1997). The quantitative results are then weighted with the probabilities associated with the fire scenarios and combined to obtain the risk parameters.

A path in an event tree is defined by a particular combination of events and may start with the initiating event and finish 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 are shown in Figure 2.3.2.1a. These scenarios are based on the event tree approach.

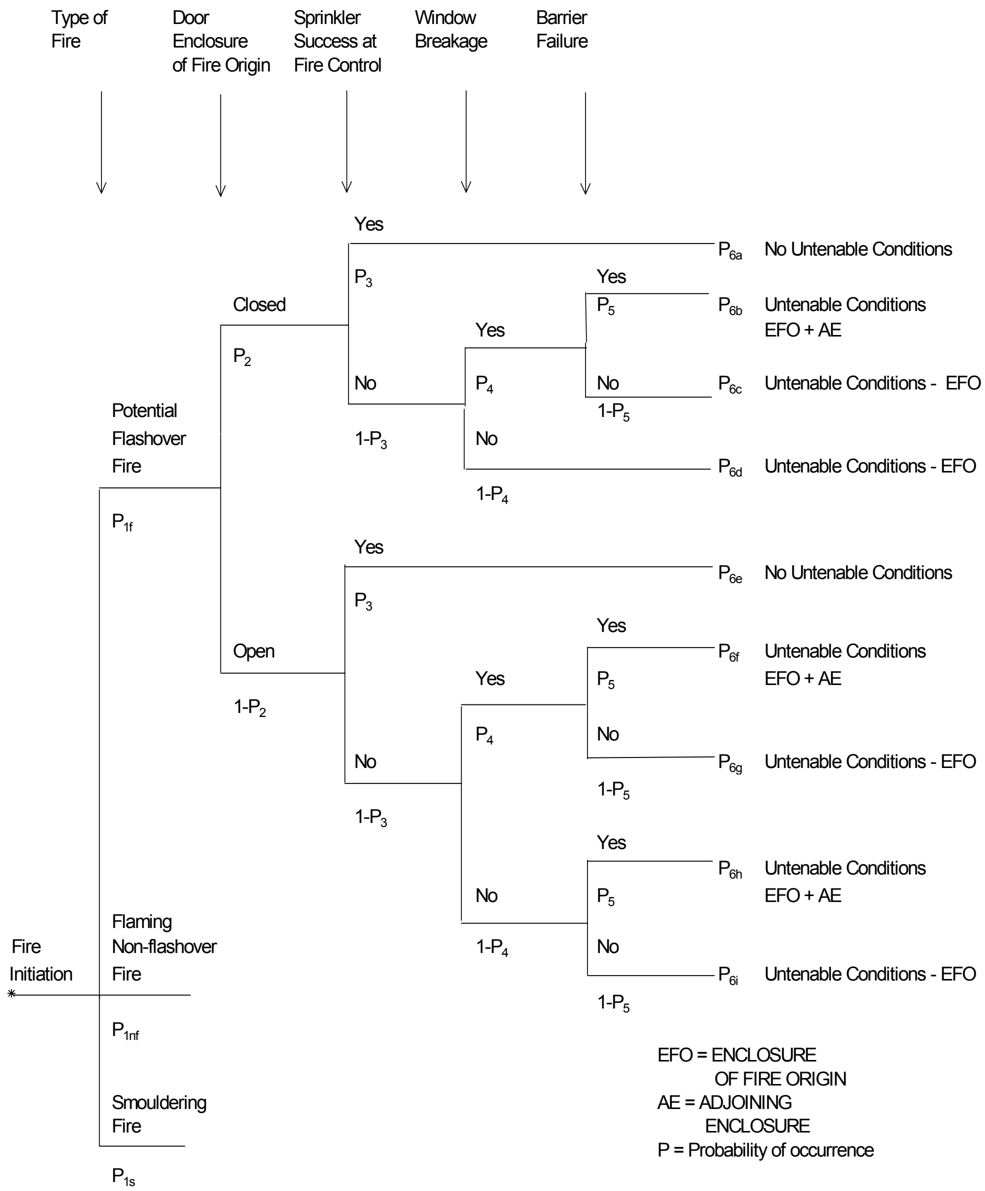

Figure 2.3.2.1a. Indicative fire scenarios based on an event tree formulation

Typical occupant response scenarios are shown in Figure 2.3.2.1b. The occupant detection scenarios are based on the following assumptions:

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

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

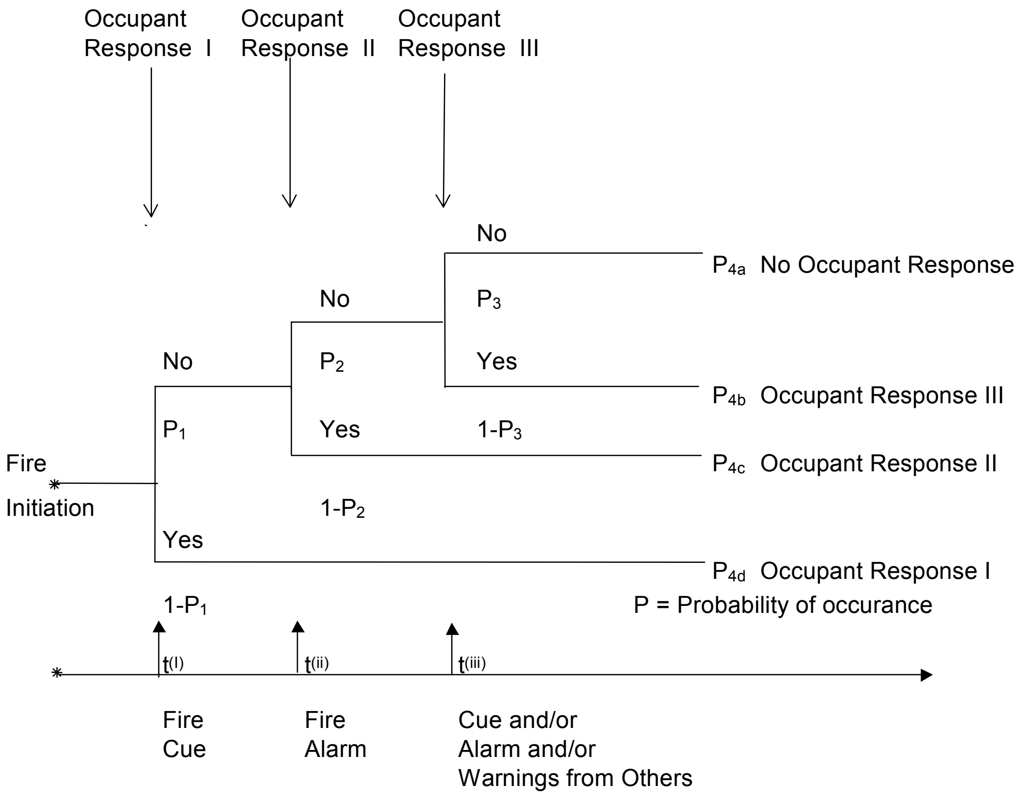

Figure 2.3.2.1b. Occupant responses based on an event tree formulation plus associated timeline

It should be further noted that each of the four occupant detection response scenarios shown in Figure 2.3.2.1b should be combined separately with each of the fire scenarios identified in Figure 2.3.2.1a. A combined scenario is obtained from the combination of one fire scenario with one occupant detection response scenario.

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

- *Occupant safety* is defined as: When no occupants are exposed to the occurrence of untenable conditions for the particular enclosure under investigation.
- *Occupant number of deaths* is defined as: 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; and
- 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 the following equation:

$$END_j = P_j \, x \, N_j$$

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:

$$END = \sum_j END_j = \sum_j P_j N_j$$

The Expected Risk-to-Life Safety Parameter (Beck *et al.* 1989) is defined below:

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

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 FEB team (see Chapter 2.2) is therefore an essential precursor to carrying out a comprehensive Probabilistic Risk Assessment (PRA). 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 part 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 is 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 Fire Cost Expectation (present value), FCE is defined below (Beck *et al*. 1989):

$$FCE = \begin{matrix}\text{Capital cost} \\ \text{associated with} \\ \text{active and passive} \\ \text{fire protection}\end{matrix} + \begin{matrix}\text{Annual costs for} \\ \text{inspection and} \\ \text{maintenance of} \\ \text{fire equipment}\end{matrix} + \begin{matrix}\text{Expected cost of} \\ \text{building and} \\ \text{contents fire losses}\end{matrix}$$

2.3.3 References

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Chapter 2.4

Fire Initiation and Development and Control

Sub-system A

Sub-system A (SS-A) is used to describe the ignition and development stages of fire growth. This process is used to quantify the design fires applicable to given enclosures with fuel loads.

This chapter describes a selection of methodologies that may be used to characterise the fire but does not preclude the use of other methodologies that might be chosen by the fire engineer.

Chapter 1.4 of Part 1 of these Guidelines describe the process by which fire initiation and development are used to define the design fires applicable to an enclosure.

Part 3 provides a selection of data that may be used in applying these, or any other applicable, methodologies.

2.4.1 Fire load densities

The fire load within a room or compartment will influence the duration and severity of a fire. Fire load data are therefore required in order to evaluate the potential for structural failure and fire spread beyond the compartment of origin.

Work has been carried out in various centres to establish the fire load densities in a range of different occupancies. Some of this data is provided in Part 3. Lees (1994) also provides useful information.

The effective fire load density is generally expressed as fuel calorific heat value per unit of floor area but may be expressed in terms of an equivalent weight of wood as a function of floor area. The effective fire load may be utilised in SS-A (see Steps 7 and 8) and Sub-system C (see Chapters 1.6 and 2.6) to establish the duration and severity of a fire.

Several methods may be used to establish the effective fire load in a room or compartment:

- direct measurement or estimate
- statistical survey
- use of characteristic fire load density

2.4.1.1 Direct measurement

Where the fire loading is unlikely to change significantly over the design life of the building, the fire load density may be estimated from knowledge of the weight and calorific value of the contents using the following equation:

$$q_{ki} = \frac{\sum m_{ci} H_{ci}}{A_f}$$

where

q_{ki}	is the fire load density for the compartment	MJ/m^2	Btu/ft2
m_{ci}	is the total weight of combustible material in the compartment	kg	lb
H_{ci}	is the calorific value of combustible material	MJ/kg	Btu/lb
A_f	is the total internal floor area of the compartment	m^2	ft^2

Calorific values for a range of common materials may be obtained from various textbooks. Where wet or damp materials are present the effective calorific value may be modified to take account of the moisture content by use of the equation (Thomas 1986):

$$H_c = H_u(1 - 0.01M) - 0.025M$$

where

H_c	is the effective calorific value of the wet material	MJ/kg	Btu/lb
H_u	is the calorific value of the dry material	MJ/kg	Btu/lb
M	is the moisture content by dry weight	%	%

Combustible materials stored within containers that have a degree of fire resistance (for example, steel filing cabinets) will be protected, to some degree, and will not be fully consumed in a fire. The effective fire load may, therefore, be less than that of the total quantity of combustible materials present. The extent of this reduction in effective fire load will depend upon:

- fire temperature
- fire duration
- container integrity
- the nature of the combustibles.

These effects are often difficult to quantify unless the container has been specifically tested for fire resistance. Some guidance is offered in DIN 18230-1 (1998).

The type of fuel likely to be present in the compartment (thermoplastic vs. thermosetting plastic) can have an impact on fire dynamics and should be noted, Drysdale (1999).

2.4.1.2 Statistical survey

To determine statistically the characteristic fire load density from surveys of similar buildings the following guidance is given:

- a number of buildings should be considered, with the actual number determined by their variability
- buildings investigated should have comparable use and similar size and contents
- the buildings should preferably be located in the same country as the building under study or in countries of similar social and economic conditions

2.4.1.3 Characteristic fire load density

When using published fire-load-density data, care should be taken to ensure that the sampling and evaluation techniques used are appropriate to the particular fire engineering study.

2.4.2 Ignition

Three modes of ignition can be considered.

- **Piloted ignition** takes place when the pyrolysis vapours and gases are ignited by a localised hot object or energy source such as a flame or spark.
- **Non-piloted ignition** takes place when the temperature of the pyrolysis vapours and gases is sufficient to ignite the mixture of oxygen and pyrolysis products.
- **Self-induced ignition** takes place when oxidisation reactions within certain solid materials produces sufficient energy to pyrolyse the material and raise the temperature above the ignition point.

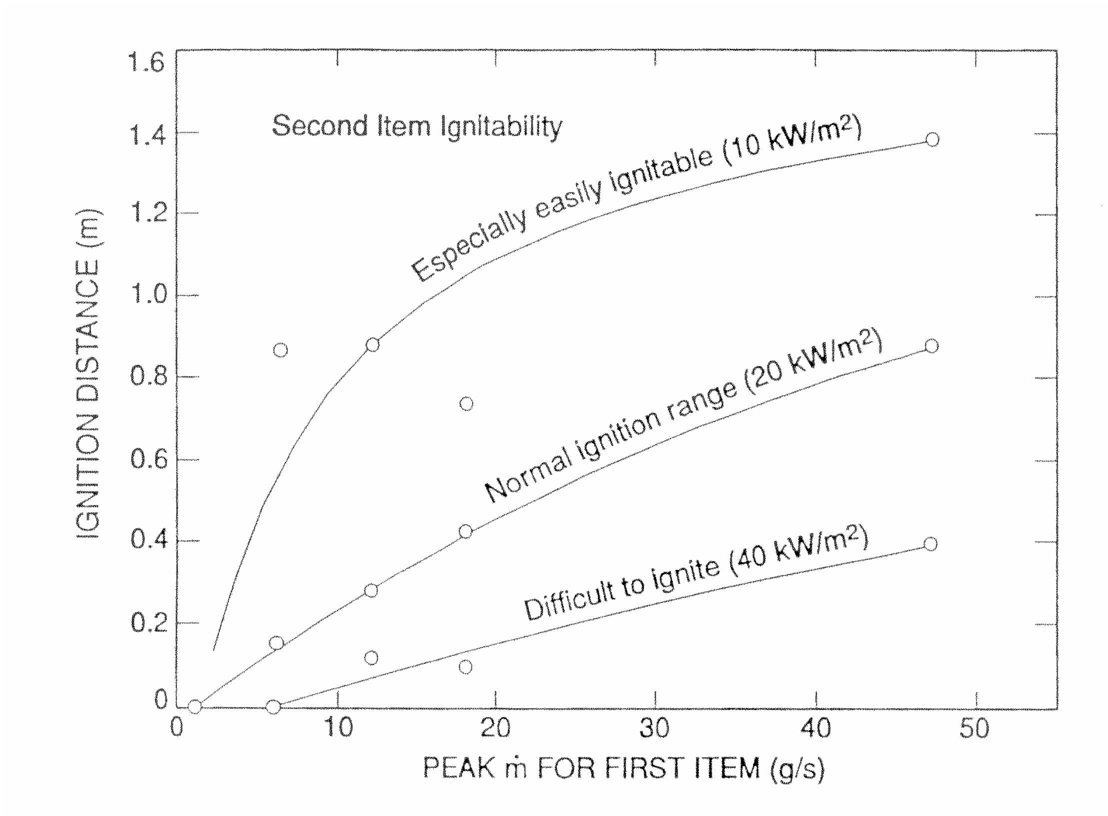
At present there are no quantitative methods available for predicting the potential for ignition. Sources of fire statistics may be used to obtain data concerning the frequency of ignition, various classes of buildings and the nature of the materials ignited. These data may be employed to provide quantified evidence of fire ignition frequencies for probabilistic studies. The data may also be used to make qualitative evaluations and to examine the relative impacts of materials and systems. Qualitatively, however, consideration needs to be given to the presence of potential ignition sources, as in most instances combustible fuels and oxygen are likely to be present. The presence of open flames, sparks, temperatures capable of causing ignition and oxidising materials need to be considered.

Some typical figures for ignition temperature of solids are given in Part 3 of these Guidelines. Sources such as the SFPE Handbook (DiNenno 2002) and Drysdale (1999) provide details of the theory of ignition of gases, liquids and solids and suitable data. These data may be used to examine the ignition of the first item and the ignition of subsequent fuel packages.

For the case of direct flame contact, the ignition time of the second item can be assumed to be the time at which the contact occurs (This assumption is conservative because time is required to pyrolyse fuel and to heat the decomposition products to their ignition temperature).

For radiant ignition, it is assumed that prior to flashover, the radiation from the upper layer and the room surfaces is negligible. Thus, the radiant energy transfer to the surface of the second item all comes from the flame above the first item. Based on this assumption, Babrauskas (1981) developed a simple procedure for estimating the ignition of the second item.

In this procedure (see Figure 2.4.2), the radiant fluxes necessary to ignite various items are assumed. Fluxes are given for easily ignited items, such as thin curtains or loose newsprint, for 'normal' items, such as upholstered furniture and for difficult-to-ignite items, such as wood of approximately 50 mm (2 in) or greater thickness. The mass loss rate of the burning item necessary to produce these ignition fluxes at various separation distances between items is presented in Figure 2.4.2. Thus the time to ignition of the second item is the time at which the mass loss rate of the burning object first reaches the value necessary to produce the required flux at the distance between the objects.



Conversion factors:

$1kW/m^2$	≈	$317BTU/hr\ ft^2$
1m	≈	3.281ft
1g/s	≈	0.0022lb/s

Figure 2.4.2 Relationship between peak mass loss rate and ignition distance for various ignitability levels (radiant flux) (Babrauskas 1981)

An engineering guide developed by the Society of Fire Protection Engineers (SFPE 2001) discusses five more detailed methods for determining piloted ignition of materials subjected to radiant heat. For each method, data requirements and sources are provided and limitations evaluated. Part 3 of this document provides experimental data for numerous materials for use in the methods presented.

Methods of Mikkola and Wichman (1989) consider both thermally thin and thermally thick materials.

The method of Tewarson (2002) for thermally thin materials is presented employing a Thermal Response Parameter (TRP). A table of data is provided for this method, developed using the Factory Mutual Research Corporation Flammability Apparatus.

The method of Quintiere and Harkleroad (1985) employed data from the Lateral Ignition and Flame Spread Apparatus using a simplified thermally thick solution.

The method of Janssens (1991) provides a simplified thermal model for piloted ignition of wood products.

The method of Toal *et al.* (1989) extends the Flux Time Product (FTP) originally developed by Smith and Green (1987) for use with data from the cone calorimeter and the ISO Ignitability Apparatus.

Predictions in the SFPE Guide using the five methods are compared to experimental data and example calculations are presented.

2.4.2.1 Flame heights

For some ignition calculations and for operation of flame detectors, a method for estimating flame height is required.

The visible flames above a fire source comprise the combustion reaction zone and an inert zone where combustion is essentially complete. Typically, the luminosity of the lower part of the flaming region is fairly steady while the upper part is intermittent.

Given the rate of heat release, the average height of the continuous flaming region for an unconfined plume may be calculated using the equation below (McCaffrey 1979):

$$L_c = C_1\, Q^{2/5}$$

where

L_c	is the height of continuous flame	m	ft
C_1	is the coefficient	0.08 m/kW$^{2/5}$	0.268 ft/(Btu/s)$^{2/5}$
Q	is the total rate of heat release	kW	Btu/s

The height of the intermittent flame region may be calculated using the equation below (McCaffrey 1979):

$$L_i = C_1\, Q^{2/5}$$

where

L_i	is the height of intermittent flame	m	ft
C_1	is the coefficient	0.20 m/kW$^{2/5}$	0.67 ft/(Btu/s)$^{2/5}$
Q	is the total rate of heat release	kW	Btu/s

The intermittency at height *z* above the fire source is defined as the fraction of time that at least part of the flame lies above *z*. The flame height *L* may be taken as a mean value distance above the fire source where the intermittency of the flame is 0.5. Heskestad (2002) has proposed the following correlation based on experimental data on horizontal surface fires:

$$L_i = -1.02D + C_1\, Q^{\,2/5}$$

where

L_i	is the height of intermittent flame	m	ft
D	is the effective diameter of the fire source (such that $\pi D^2/4$ = area of fire source)	m	ft
C_1	is the coefficient	0.235 m/kW$^{2/5}$	0.787 ft/(Btu/s)$^{2/5}$
Q	is the total rate of heat release	kW	Btu/s

A condition is imposed on this correlation in order to ensure that negative flame heights are avoided:

$$D < C_1\, Q + C_2$$

where

C_1	is a constant	0.007 m/kW	0.0242 ft/(Btu/s)
C_2	is a constant	0.8 m	2.625 ft

For radiation calculations, the flame height and fire diameter can be used to determine the flame radiation area.

2.4.2.2 Flame temperature

The rise in the centreline flame temperature can be estimated using the expression (Heskestad 2002):

$$\Delta T_0 = C_1\, [(T_\infty + C_2)/(g c_p^{\,2} \rho_\infty^{\,2})]^{1/3}\, Q_c^{\,2/3} (z - z_0)^{-5/3}$$

where

ΔT_0	is the rise in centreline flame temperature	K	°F
C_1	is a constant	9.1	0.0784
T_∞	is the ambient temperature	K	°F
C_2	is a constant	0	460
g	is the acceleration of gravity	m/s^2	ft/s^2
c_p	is the specific heat of air	kJ/kg·K	Btu/lb°F
ρ_∞	is the ambient density	kg/m^3	lb/ft^3
Q_c	is the convective heat release rate	kW	Btu/s
z	is the elevation above the fire source	m	ft
z_0	is the height or virtual origin above top of combustible (discussed in section 2.5.1.1)	m	ft

However, this relationship is only accurate up to a temperature rise of 500K (440°F) and should not exceed 900K (1160°F). Between 500K and 900K the relationship will conservatively over-estimate ΔT_0. For the purpose of calculating radiation levels, the flame temperature can be averaged over various heights along the plume (e.g. at the midpoint and the upper and lower quarter points).

2.4.2.3 Radiation from flames

Four methods for assessing flame radiation to external targets from pool fires have been evaluated and discussed in an engineering guide developed by the Society of Fire Protection Engineers (SFPE 1999). Two of the methods are characterised as 'screening' methods and two are identified for more detailed calculations. The discussion of each method includes a description of the correlation or model and the reference sources. Data requirements and data sources for use on each method are discussed along with the assumptions, validation, limitations and factors of safety for their use. Validation is based on the ability of the method to predict experimental results. The SFPE Engineering Guide provides a tabular summary of experimental data with references and worked examples of the methods; see also the SFPE Engineering Handbook (Beyler 2001).

One screening method (Shokri and Beyler 1989) is a simple correlation based on experimental data from large-scale pool fire experiments. The other screening method is a widely used point source model (Drysdale 1999). This method employs a simple inverse square relationship between the point source and the target rather than complex configuration equations.

The two detailed methods presented include one based on pool fire data that assumes the flame to be a cylindrical black body with an average emissive power (Shokri and Beyler 1989). The second detailed method (Beyler 2002) is for estimating thermal radiation from pool fires for no wind conditions and for wind-blown flames. This method assumes that the flame is either a vertical or tilted cylinder and requires that the flame height be determined.

Another simplified method (Drysdale 1999) considers the area of the fire flame radiant source as a rectangular panel of base width equal to the effective fire diameter and the height of the panel the height of the flame. With the average centreline flame temperature *($T_f = T_\infty + (\Delta T_0)_{av}$)* the radiant flux of the fire onto a point remote from the fire can be calculated using the equation:

$$q_r = \phi \, \sigma \, \varepsilon \, T_f^4$$

where

q_r	is the radiant flux	W/m^2	Btu/m^{2}s
ϕ	is the configuration factor		
σ	is the Stefan-Boltzman constant	5.68x10^{-8} W/m^2/K^4	4.758x10^{-13} Btu/ft^{2}sR^4
ε	is the emissivity of the source		
T_f	is the source temperature	K	R (=°F+ 460)

The most commonly used configuration factor is for a rectangular-shape surface to a parallel small element on a perpendicular to one corner (Tien *et al*. 2002):

$$\phi = \frac{1}{2\pi}\left\{\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left[\frac{Y}{\sqrt{1+X^2}}\right]+\frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left[\frac{X}{\sqrt{1+Y^2}}\right]\right\}$$

where

$X = a/c$ *and* $Y = b/c$

as illustrated in Figure 2.4.2.3a.

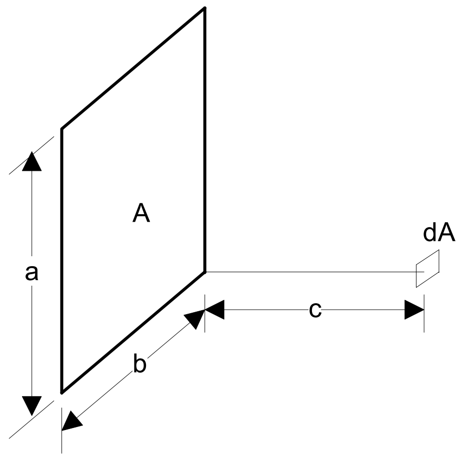


Figure 2.4.2.3a. Receiver dA on perpendicular from corner of Panel A

However, the peak radiant heat flux on a target will occur when the target point lies on a perpendicular to the centre of the radiant panel. Configuration factors based upon Figure 2.4.2.3a may be used by considering that the radiating panel can be represented by four rectangular panels subtending a perpendicular at their common corner (See Figure 2.4.2.3b).

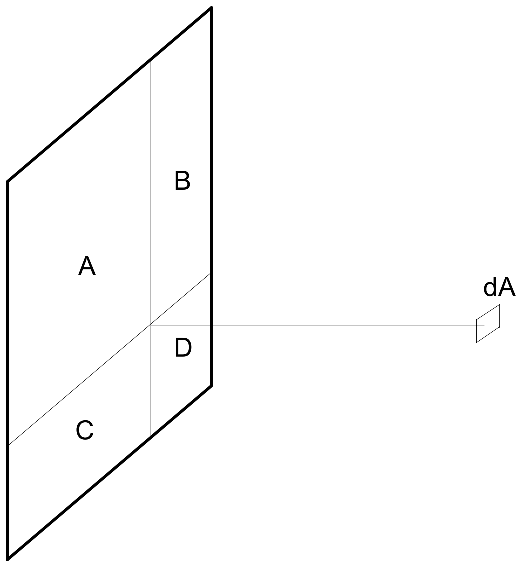


Figure 2.4.2.3b. Additive nature of configuration factors

Under these conditions, the configuration factors are additive (or subtractive) (Holman 1992). Thus, the effective configuration factor ϕ_e for the four panels radiating to an element dA, as shown in Figure 2.4.2.3b, is:

$$\phi_e = \phi_A + \phi_B + \phi_C + \phi_D$$

The emissivity of the source (flames) may be conservatively taken as 1.0, which is representative of thick luminous flames.

A similar approach can be adopted for multiple radiating openings in a building where it is assumed that fire has spread to both spaces behind the openings. Radiant heat flux from multiple openings, such as the windows in the walls of a building, can be considered by the appropriate use of configuration factors. For example, the effective configuration factor for the two openings shown in Figure 2.4.2.3c below is calculated as discussed below.

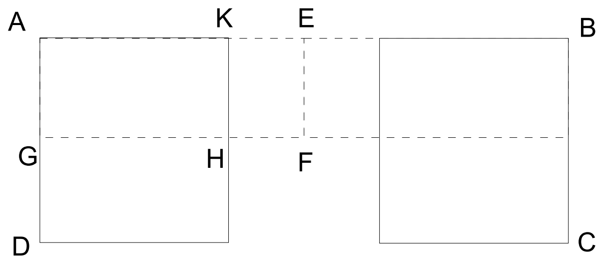


Figure 2.4.2.3c. Calculation of configuration factors for multiple openings

The heat flux on a receiving point is greatest when that point lies on a line perpendicular to the centre of symmetry of the openings (point F in Figure 2.4.2.3c).

The calculation of the overall configuration factor for ABCD is based upon the four quadrants equivalent to AKHG. That is:

$$\phi_{ABCD} \quad = 4 \times \phi_{AKHG}$$

The effective configuration factor for quadrant AKHG is:

$$\phi_{AKHG} \quad = \phi_{AEFG} - \phi_{KEFH}$$

Alternatively, a simpler approach may be adopted by simply multiplying the configuration factor for ϕ_{AEFG} by the proportion of the radiating area, i.e. A_{AKHG}/ A_{AEFG}. Hence:

$$\phi_{ABCD} = 4\phi_{AEFG} \times A_{AKHG}/ A_{AEFG}$$

2.4.2.4 Radiation from hot layer

The radiation from the hot upper layer can be similarly calculated if the temperature of the smoke layer and the depth of the layer are known, using (Drysdale 1999):

$$q_r = \phi\, \sigma\, \varepsilon_s\, T_s^4$$

where

q_r	is the radiant flux from the hot layer	W/m^2	Btu/ft^{2}s
ϕ	is the configuration factor		
σ	is the Stefan-Boltzman constant	5.68x10^{-8} W/m^2/K^4	4.758x10^{-13} Btu/ft^{2}sR^4
ε_s	is the emissivity of the smoke layer		
T_s	is the smoke layer temperature	K	R

and (Tien *et al.* 2002):

$$\varepsilon_s = (1 - e^{-\kappa S})$$

where

κ	is the effective absorption or extinction coefficient of smoke	m^{-1}	ft^{-1}
S	is the physical path length (i.e. depth of smoke layer)	m	ft

Unless a more accurate estimate for κ is available, a value of $\kappa = 0.8$ is recommended for solid wood fuels. (Refer Table 1-4.3 of SFPE Handbook 2002 for other values).

2.4.3 Pre-flashover

2.4.3.1 Flame spread

There are a number of well-validated approaches to determine rates of flame spread in the pre-flashover phase of a fire and these are discussed in detail in texts such as Drysdale (1999) and the SFPE Handbook (DiNenno 2002).

2.4.3.2 Fire growth

The rate of fire growth in the pre-flashover phase of a fire is one of the major determinants of the performance of a fire safety design. It is therefore critical that fire engineers investigate carefully the possible fire growth rates.

There is an absence of good data on growth rates, particularly in occupancies other than residential. Engineers should consult the SFPE Handbook (DiNenno 2002) and other sources to address this crucial design issue.

The methods of determining the rate of fire growth are given in order of preference:

- carefully designed full scale experiments
- furniture calorimeter data
- statistical data / fire incidents
- t^2 fires.

a. Smouldering fires

For smouldering fires, the model developed by Quintiere *et al.* (1985) is sometimes used. This model describes the pyrolysis rate in terms of mass loss with time using the expression:

$$dm/dt = C_1\, t + C_2\, t^2 \qquad for\ 0 < t < 60\ min$$
$$dm/dt = C_3 \qquad for\ 60 < t < 120\ min$$

where

dm/dt	is the pyrolysis rate	g min-1	lb min^{-1}
C_1	is the coefficient	0.10 g min^{-2}	0.0002 lb min^{-2}
C_2	is the coefficient	0.0185 g min^{-3}	4.08×10^{-5} lb min^{-3}
C_3	is the coefficient	73 g min^{-1}	0.161 lb min^{-1}

b. t^2 fires

Where relevant experimental data and or statistical information is not available pre-flashover fires may be characterised by a quadratic function [NFPA 204] of the form:

$$Q = Q_g \left(\frac{t}{t_g} \right)^2$$

where

Q	is the rate of heat release	kW	Btu/s
Q_g	is the reference heat release rate at t_g	1055 kW	1000 Btu/s
t	is the time from the 'effective ignition time'	s	s
t_g	is the characteristic time of growth to Q_g	s	s

Many natural fires follow this law in the initial growth phase, the 'growth time' being indicative of the rate of burning and spread. NFPA Standard 204 categorises t^2 fires into four categories with the growth times shown in Table 2.4.3.2(a) that may be used as the basis of design.

Table 2.4.3.2. Characteristic time of growth to Q_g

Fire category	Growth time t_g[s]
Ultrafast	75
Fast	150
Medium	300
Slow	600

Guidance on which fire category to choose for various fuel packages in occupancies can be found in NFPA 204.

Fire experiments indicate that there is a period of slow burning following ignition that precedes the stage of a fire where the fire growth may be represented by the simple mathematical functions described above. This initial phase is referred to as the 'incubation', 'induction' or 'establishment' phase of fire growth. For practical purposes, the duration of the incubation phase of a fire cannot be determined reliably. In most fire engineering design fires, this incubation phase is ignored and this is usually a conservative assumption.

In some circumstances, the actual fuel items likely to ignite are known or have been identified in the scenario development as part of the FEB process. In these cases, it may be acceptable to adopt the test data as the basis of the design fire and selection of an appropriate t^2 curve.

2.4.3.3 Source concentration of toxic species

The source concentration of toxic species is determined by considering the yield of toxic species from an analysis of the combustion reaction or experimental data relating to the nature of combustibles. The principal toxic species in most fires is carbon monoxide and analysis can generally be restricted to this species unless the materials involved are atypical (for example smouldering of polyurethane foam can yield significant Hydrogen Cyanide HCN).

The concentration of carbon monoxide can be estimated from the carbon monoxide yield factor and the equation:

$$Conc_{CO} = \frac{Y_{CO} m_f}{V_t}$$

where

$Conc_{CO}$	is the concentration of carbon monoxide	kg/m^3	lb/ft^3
Y_{CO}	is the carbon monoxide yield factor	g/g	lb/lb
m_f	is the mass of fuel burnt	kg	lb
V_t	is the volume of smoke	m^3	ft^3

Values of Y_{CO} may be obtained from Part 3 of these Guidelines.

The concentration in parts per million (ppm) at 20 °C (68 °F) may be obtained from (BSI 1997):

$$CO = C_1 \times 10^6 \, Conc_{CO}$$

where

CO	is the concentration of carbon monoxide	ppm	ppm
C_1	is a constant	0.858 m^3/kg	13.74 ft^3/lb

2.4.3.4 Smoke yield

The mass production rate of smoke can be estimated by using a smoke mass conversion factor that represents the fraction of the burning material that is converted to smoke. Data on smoke mass conversion factors is provided in Part 3 of these Guidelines. The mass production rate of smoke is given by:

$$\dot{M}_s = \frac{EQ}{H_c X_c}$$

where

$\dot{M}_s$	is the mass production rate of smoke	kg/s	lb/s
E	is the smoke mass conversion factor	kg/kg	lb/lb
Q	is the heat release rate of the fire	MW	Btu/s
H_c	is the heat of combustion of the fuel	MJ/kg	Btu/lb

X_c	is the combustion efficiency		

The mass concentration of the smoke at the source may be obtained by dividing the mass production rate of smoke by the volumetric flow rate of fire effluents:

$$C_m = \frac{\dot{M}_s}{\dot{V}_f}$$

where

C_m	is the mass concentration of smoke	kg/m³	lb/m³
$\dot{M}_s$	is the mass production rate of smoke	kg/s	lb/s
$\dot{V}_f$	is the volumetric flow rate of fire effluents	m^3/s	ft^3/s

2.4.4 Flashover

Simple correlations, as discussed below, have been developed to predict the onset of flashover. These correlations must be viewed as approximations to the more definitive determinations based upon calculations of ignition resulting from the heat flux to the fuel surface. Prediction based upon hot layer temperatures is generally preferred as it has a more direct relationship to radiation from the hot layer that causes the flashover phenomenon.

The time of flashover may be taken to be the time at which the hot layer temperature in the enclosure reaches 600^{o} C (1110°F) or when the rate of heat released from the fire is equal to that required to cause flashover (see 2.4.4.2). Another criterion often used is the time at which the radiation at the floor from the hot layer reaches 20 kW/m^2 (1.8 Btu/ft^2s).

2.4.4.1 Hot layer flashover prediction

When sustained flames from burning contents reach the ceiling and the rate of heat release is sufficient to give a hot gas layer temperature of 600°C (1110°F), flashover may be assumed to occur. However, if flames from the combustibles do not reach the ceiling or the temperature remains below 600°C (1110°F) , flashover may still occur (flashover can take place, under some circumstances, at 500°C (930°F)). Zone or field models may be used to estimate the hot-layer temperature.

2.4.4.2 Flashover correlation

Thomas has developed an empirical correlation for the energy release rate required to cause flashover in a compartment (Walton & Thomas 2002). The correlation is based on small compartments and its application to large or high compartments is not appropriate. The energy release rate for flashover is given by:

$$Q = C_1 A_{encl} + C_2 A_v \sqrt{h_v}$$

where

Q	is the energy release rate	kW	Btu/s
C_1	is a constant	7.8	0.687
A_{encl}	is the area of the enclosure	m^2	ft^2
C_2	is a constant	378	18.4

A_v	is the total area of vents	m^2	ft^2
h_v	is the effective height of the opening	m	ft

and where A_{encl} is given by:

$$A_{encl} = 2\,[L\,W + (L + W)\,H_{encl}] - A_v$$

where

L	is the length of enclosure	m	ft
W	is the width of enclosure	m	ft
H_{encl}	is the height of the opening	m	ft

2.4.5 Fully developed fires

Fully developed fires will be controlled by the available ventilation or fuel. The heat release rate at ventilation control and fuel control can be calculated and the lesser of two figures used as the peak heat release rate for the fully developed fire.

2.4.5.1 Ventilation controlled fire

The ventilation-controlled rate of burning for cellulosic fuels in a compartment is best determined from the air flowing into the compartment or may be predicted by fire models that provide data for vent flows. The air inflow can be approximated to be (Drysdale 1999):

$$m_{air} = C_1\,A_v\sqrt{h_v}$$

where

m_{air}	is the mass flow of air into compartment	kg/s	lb/s
C_1	is the coefficient	0.52 kg $s^{-1}m^{-5/2}$	0.0588 lb s^{-1} $ft^{-5/2}$
A_v	is the area of vent	m^2	ft^2
h_v	is the height of vent	m	ft

The mass loss rate of fuel burning may then be estimated from the combustion reaction. The stoichiometric ratio is approximately 5.7 for cellulosic fuels. However, under ventilation-limited conditions, the effective fuel/air ratio is approximately 1.3 times the stoichiometric ratio (Babrauskas 1981). This yields an approximate expression for the rate of fuel consumed:

$$m_{vf} = C_1\,A_v\sqrt{h_v}$$

where

m_{vf}	is the rate of fuel consumption	kg/s	lb/s
C_1	is the coefficient	0.12 kg $s^{-1}m^{-5/2}$	0.0136 lb $s^{-1}ft^{-5/2}$

This may be converted to heat release rate by multiplying by the effective heat of combustion. For cellulosic fuels burnt under ventilation-controlled conditions, the effective heat of combustion may be taken as 18 MJ/kg (7744 Btu/lb). Hence, for a ventilation-controlled cellulosic fire, the heat release rate may be approximated by:

$$Q_v = C_1\,A_v\sqrt{h_v}$$

where

Q_v	is the heat release rate	MW	Btu/s
C_1	is a constant	2.16 MW m$^{-5/2}$	105 Btu s^{-1}ft$^{-5/2}$

2.4.5.2 Fuel controlled fire

The burning rate of fuel-controlled fires is difficult to predict on a theoretical basis. To a large extent it depends on the nature and geometric arrangement of the fuel. Various attempts have been made to predict the burning rates of uniform fuels such as timber cribs. Examples of expressions for the burning rates may be found in standard texts (Babrauskas 2002, Drysdale 1999). It should be noted that the burning of timber cribs is a relatively unique fuel arrangement and the use of formulae derived from their burning to determine burning rates of other fuels should be used with caution.

Data has been published on the measured burning rates of numerous fuel packages that may be used to provide a guide for design fires (Babrauskas 2002, Sardquivst 1993). These data reflect fuel controlled burning that may not be applicable to the environment to which the data are applied where there could be ventilation control to inhibit burning or radiation feedback to enhance the burning rate. Because the items for which burning rate data have been obtained may not reflect the fuel loads under consideration, appropriate engineering judgement should be applied to the adopted burning rate data.

2.4.5.3 Calculation of time-temperature graphs

In assessing the probable severity of a fire in an enclosure it is necessary to make some determination of the likely time-temperature relationship. Various methods have been proposed to obtain such data. These are invariably empirical in derivation and their derivation may be based on limited and specific conditions that may not be wholly applicable to the issue.

A Swedish method involving sets of time-temperature graphs that have been prepared for different ventilation and fuel load density conditions is referred to by Drysdale (1999). Another approach to predict the time-temperature curve in the enclosure was proposed by Lie (1994) and is also referred to in Drysdale (1999). In this method, the curve predicted is meant to represent the time-temperature curve, 'whose effect, with reasonable probability, will not be exceeded in the life of the building'.

2.4.6 Decay phase

When 80% of the fuel has been consumed the fire may be assumed to decay at:

- a linear rate
- a rate determined experimentally
- any rate that can be justified

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Chapter 2.5

Smoke development and Spread and Control

Sub-system B

Sub-system B (SS-B) is used to analyse the development of smoke, its spread within the fire enclosure and beyond, and the properties of the smoke at locations of interest. This sub-system is also used for assessing the performance of smoke management that may limit the development of smoke or prevent its spread to areas where occupants or valuable property are exposed.

This chapter provides guidance on methodologies that may be used to quantify smoke development, spread and control. The quantified results are used to evaluate the tenability of physical conditions in the areas concerned. The results are also used in other sub-systems to predict relevant processes and times of events.

Chapter 1.5 of Part 1 of these Guidelines describe the process by which the analysis of smoke development, spread and control is typically undertaken.

Part 3 of these Guidelines provide a selection of data that may be used in applying these, or any other applicable, methodologies.

Smoke generation, transport and the associated physical phenomena can be predicted using hand calculations or computer simulations. It has been an increasing trend for fire engineers to use computerised fire models to evaluate fire hazards. Some of the fire models in the literature have accompanying manuals containing the equations (either fundamental or empirical) and the computation algorithms used in the models. Simple calculation methods may sometimes be useful for obtaining estimates of the physical conditions in the area of interest. Some methods for calculating smoke movement are presented briefly or referenced in the sections below.

It is envisaged that future additions to these Guidelines will cover computerised fire models (both zone and field) that are commonly used by fire engineers.

2.5.1 Smoke development in the enclosure of fire origin

Under the influence of buoyancy, combustion products of a fire will rise to the upper part of the enclosure of origin. Given the heat release rate of the fire, the amount of smoke generated per unit time is proportional to the air entrainment into the fire plume. During this vertical rise of smoke under buoyancy, the mass flow of air entrained usually greatly exceeds the mass flow of burned fuel. The latter term is therefore usually ignored.

Textbooks such as the SFPE Handbook (DiNenno 2002), Klote and Milke (2002), Evans and Klote (2003) and Drysdale (1999) provide a wide range of methodologies used for the analysis of smoke development and spread to include:

- smoke production rate
- smoke layer height
- upper layer temperature
- smoke movement

Heat release rate, smoke (soot particle) yield and species yield methodologies have been given in Chapter 2.4 of these Guidelines and provide necessary input data for these methodologies.

Flame zone and ceiling jet calculations yield data for evaluation of fire resistance, smoke detector and sprinkler activation. These topics are dealt with in Chapters 2.6 and 2.7.

2.5.1.1 Smoke production rate

The smoke production rate, which can be determined by calculating the air entrainment rate into a fire plume, is a primary parameter in the design of a smoke management system. Plume models are used to calculate the air entrainment rate. A number of plume models exist in the literature for 'weak' plumes, where the gas temperature at the plume centre is not much higher than the ambient temperature, and for 'strong' plumes (Heskestad 2002). The simplified axisymmetric equation of Thomas (1981) or the axisymmetric plume equation of NFPA 92B (NFPA 2000) may be used if the fire is away from walls and air entrainment into the plume can occur from all sides.

An example of the more sophisticated plume models is the McCaffrey plume model. Based on experimental observations, McCaffrey (1983) developed a plume model to determine the mass entrainment rate in three distinctive regions above a fire source, namely, the persistent flame region, the intermittent flame region and the buoyant plume region, equations for which are shown below:

$$m_e = \begin{cases} C_1 z_p^{0.566} Q, & \text{for } 0 \le z_p < 0.08 \\ C_2 z_P^{0.909} Q, & \text{for } 0.08 \le z_p < 0.20 \\ C_3 z_p^{1.895} Q, & \text{for } 0.20 \le z_p \end{cases}$$

where

m_e	is the mass entrainment rate	kg/s	lb/s
C_1	is a constant	0.011	0.0256
C_2	is a constant	0.026	0.0605
C_3	is a constant	0.124	0.288
z_p	is a characteristic parameter	m/kW$^{0.4}$	ft/(Btu/s)$^{0.4}$
Q	is the heat release rate	kW	Btu/s

The characteristic parameter z_p of the plume model is evaluated from:

$$z_p = \frac{z}{Q^{0.4}}$$

where

z	is the distance from the heat source	m	ft

Another plume model uses the following approach to determine the mass entrainment rate. The mass entrainment rate into the plume is calculated according to the position of the smoke layer interface height relative to the mean flame height.

$$m_e = \begin{cases} C_1 Q_c^{1/3}(z - z_o)^{5/3}[1 + C_2 Q_c^{2/3}(z - z_o)^{-5/3}], & \text{for } z > L \\ \dfrac{C_3 Q_c z}{C_4 Q_c^{2/5} + z_o}, & \text{for } z \le L \end{cases}$$

where

m_e	is the mass entrainment rate	kg/s	lb/s
C_1	is a constant	0.071	0.022
Q_c	is the convective heat release rate	kW	Btu/s
z	is the smoke layer interface height	m	ft
z_o	is the virtual origin	m	ft
C_2	is a constant	0.027	0.02026
L	is the mean flame height	m	ft
C_3	is a constant	0.0054	0.0126
C_4	Is a constant	0.166	0.556

The convective heat release rate Q_c is a fraction of the total heat release rate and is often approximated as 70% of the latter, that is:

$$Q_c = 0.7Q$$

The mean flame height *L* is determined using:

$$L = C_1 Q^{2/5} - 1.02D$$

and virtual origin z_o using (Heskestad 2002):

$$z_o = C_2 Q^{2/5} - 1.02D$$

where

Q	is the total heat release rate	kW	Btu/s
C_1	is a constant	0.235	0.787
D	is the base diameter	m	ft
C_2	is a constant	0.083	0.278

If a fire is restricted by a wall or a corner, air entrainment into its plume will be reduced. The entrainment rate can be calculated using the concept of reflection (Mowrer and Williamson 1987).

2.5.1.2 Smoke layer height

The height of the smoke layer in an enclosure can also be calculated using simple hand calculations. Smoke layer height is a function of time as well as fire size and rate of smoke exhaust.

For the situation of no smoke venting in large malls and atrium spaces, simple empirical correlations are available for quantifying this smoke filling process and the smoke layer interface height as a function of time for given heat release rate (Milke 2002). The first correlation is for ‘steady state’ fires where the heat release rate is invariant with time.

$$\frac{z}{H} = C_1 - 0.28\ln\left(\frac{tQ^{1/3}H^{-4/3}}{A/H^2}\right)$$

where

z	is the height of smoke above fire	m	ft
H	is the height of ceiling above fire	m	ft
C_1	is a constant	1.11	0.67
t	is the time	s	s
Q	is the heat release rate	kW	BTU/s
A	is the cross-section area of the compartment	m^2	ft^2

The above equation is valid for $z/H \geq 0.2$.

For fires where the heat release rate is increasing proportionally with time squared (see Section 2.4.2.4b), the smoke layer height can be calculated using the following equation:

$$\frac{z}{H} = C_1\left(\frac{tH^{2/5}}{t_g^{2/5}A^{3/5}}\right)^{-1.45}$$

where

z	is the height of smoke above fire	m	ft
H	is the height of ceiling above fire	m	ft
C_1	is a constant	0.91	0.23
t	is the time	s	s
t_g	is the characteristic fire growth time	s	s
A	is the cross-section area of the compartment	m^2	ft^2

The above equation is valid for $z/H \geq 0.2$ and A/H^2 between 0.9 and 14.

Calculations of smoke layer height using these two equations that result in values of z/H>1 imply that the smoke layer has not begun to descend. That is, these two empirical correlations provide a measure of the smoke transport time from the fire to the ceiling of the compartment.

2.5.1.3 Upper layer temperature

McCaffrey *et al*. (1981) developed the following equation for predicting the upper layer temperature in an enclosure:

$$\Delta T_g = C_1 \left(\frac{Q}{\sqrt{g} c_p \rho_\infty T_\infty A_o \sqrt{H_o}} \right)^{2/3} \left(\frac{h_k A_T}{\sqrt{g} c_p \rho_\infty A_o \sqrt{H_o}} \right)^{-1/3}$$

where

ΔT_g	is the temperature of upper layer above ambient	K	°F
C_1	is a constant	480	14.2
Q	is the total heat release rate of fire	kW	Btu/s
g	is the acceleration due to gravity	9.8 m/s^2	32.2 ft/s^2
c_p	is the specific heat of gas	kJ/kg K	Btu/lb °F
ρ_∞	is the density of ambient air	kg/m^3	lb/ft^3
T_∞	is the ambient temperature	K	°F
A_o	is the area of openings	m^2	ft^2
H_o	is the height of openings	m	ft
h_k	is the effective heat transfer coefficient	kW/m^{2}K	Btu/s ft^2 °F
A_T	is the surface area of compartment	m^2	ft^2

The method calculates the heat transfer coefficient using a 'steady state' approximation when the exposure time is greater than the thermal penetration time and an approximation of a semi-infinite solid when the exposure time is less than the thermal penetration time. That is,

$$h_k = \begin{cases} \dfrac{k}{\delta}, & \text{for } t \geq t_p \\ \sqrt{\dfrac{k \rho c}{t}}, & \text{for } t < t_p \end{cases}$$

and the thermal penetration time t_p is defined by the following equation:

$$t_p = \frac{\rho c \delta^2}{4k}$$

where

k	is the thermal conductivity of compartment surfaces	kW/m K	Btu/s ft °F
δ	is the thickness of compartment surfaces	m	ft
ρ	is the density of compartment surfaces	kg/m^3	lb/ft^3
c	is the specific heat of compartments surface materials	kJ/kg K	Btu/lb °F
t	is the exposure time	s	s
t_p	is the thermal penetration time	s	s

2.5.1.4 Smoke movement

Where the smoke leaves the fire enclosure through door openings, air entrainment into the door jet and mixing due to counter current flow occurs. A method for calculating air entrainment into a door jet using the McCaffrey plume model is given by Peacock *et al*. (1993).

Detailed mechanisms for spread of smoke are discussed in the *SFPE Handbook of Fire Protection Engineering* (DiNenno 2002) and Klote and Milke (2002). There are mathematical relationships and models developed to predict spread of smoke in buildings.

Hand calculations of smoke spread from other than the enclosure of fire origin are more difficult and therefore are rarely used. The uncertainties associated with the calculated results are also greater than the results for the enclosure of fire origin.

Horizontal smoke movement through an opening is governed mainly by the pressure difference that exists across the opening. When a compartment has a single opening of constant width, the mass flow rate out of the opening can be calculated using (Rockett 1976, and Emmons 2002):

$$m_o = C_1 C w \sqrt{g\rho(\rho_a - \rho)}\left(h_v - h_n\right)^{3/2}$$

where

m_o	is the mass flow rate	kg/s	lb/s
C_1	is a constant	0.943	0.953
C	is the opening /orifice coefficient		
w	is the opening width	m	ft
g	is the gravitational constant	$9.8 m/s^2$	$32.2 ft/s^2$
ρ	is the density of air /smoke at the source of the flow	kg/m^3	lb/ft^3
ρ_a	is the ambient air density	kg/m^3	lb/ft^3
h_v	is the vent top edge height	m	ft
h_n	is the neutral plane height above the opening bottom edge	m	ft

A default value for the opening/orifice coefficient (C) is 0.68.

The location of the neutral plane does not usually differ much from the location of the smoke layer interface. However, there is a minimum limit for the neutral plane height (Mowrer 1992):

$$h_{n,\min} \approx 0.44 h_v$$

The limiting neutral plane height is reached when smoke layer temperature is sufficiently higher than ambient (greater than 200 °C or 390 °F) and the interface height is sufficiently low.

Vertical smoke movement within buildings is normally through horizontal vents in ceilings or vertical spaces such as elevator shafts, stairwells and service ducts. In tall buildings, temperature differences between inside and outside the building will give rise to buoyancy-induced pressure differences known as stack effect. Equations that can be used to calculate the stack effect are given in references such as Klote and Milke (2002).

When there is sufficient buoyancy force and make-up air to an enclosure or a compartment space, vertical smoke flow through a horizontal vent can be estimated using the following equation:

$$m_v = C_d \rho_a A_{va} \frac{\sqrt{2gT_\infty \Delta T d}}{T}$$

where

m_v	is the vertical smoke flow	kg/s	lb/s
C_d	is the coefficient of discharge		
ρ_a	is the ambient air density	kg/m^3	lb/ft^3
A_{va}	is the effective aerodynamic area of vent	m^2	ft^2
g	is the gravitational constant	m/s^2	ft/s^2
T_∞	is the ambient temperature	K	R
ΔT	is the smoke layer temperature rise	K	R or °F
d	is the smoke layer depth	m	ft
T	is the smoke layer temperature	K	R

A default value for the coefficient of discharge (C_d) is 0.61.

A representative smoke layer temperature rise can be estimated as follows:

$$\Delta T = \frac{KQ_c}{c_p m_e}$$

where

K	is the fraction of adiabatic temperature rise		
Q_c	is the convective heat release rate	kW	Btu/s
c_p	is the specific heat of air at constant pressure	kJ/kg.K	Btu/lb °F
m_e	is the mass flow rate	m	ft

There is little research regarding values of the fraction of adiabatic temperature rise (K). However, K=0.5 is often used.

Vent flows through ceilings or floors can be very complicated. Two phenomena have been observed, puffing and exchange flow. The former is closely related to the combustion process in the enclosure of fire origin and the latter occurs when the fluid configuration across the vent is unstable. Cooper (1996) gives a detailed account of the calculation of exchange flows through horizontal vents.

2.5.2 Smoke management

The general objective of smoke management is to remove heat and minimise the concentration of smoke in certain designated areas in buildings subjected to fires. There are a variety of smoke management techniques for smoke hazard mitigation. These techniques generally fall into the following categories:

- natural ventilation
- zone pressurisation
- extraction
- dilution
- containment.

For natural heat and smoke venting calculations, refer to NFPA92B (NFPA 2000) and NFPA 204 (NFPA 2002). Methods for quantifying the effects of mechanical smoke management sub-systems can be found in Klote and Milke (1992) and Cooper (1996). Containment is discussed by England *et al*. (2000).

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Chapter 2.6

Fire Spread and Impact and Control

Sub-system C

Sub-system C (SS-C) is used to describe and define fire spread and management following the development stages of fire growth.

This chapter provides guidance on predicting the likelihood of fire spreading beyond the fire enclosure, based upon the severity of the fire developing in or projecting from the fire enclosure. Procedures are described to provide the means of predicting the fire severity on the basis of the characteristic fire profile defined in Part 2.4. Procedures that are not based on a fire profile, particularly those that have been developed specifically to assess the performance of structural elements in fire, are also included.

Designing fire resistance of structures in a performance environment is a three step process: defining the fire boundary conditions that the structure will be exposed to, determining the thermal and then structural response.

Guidance on heat transfer calculations for fire conditions is available in a number of publications such as Drysdale (1999), Holman (1992), Lie and Williams-Leir (1979) and Lie (1992) and the SFPE Handbook (Rockett and Milke 2002). Such procedures may be used as part of a study to evaluate:

- the temperature of steel members protected with insulation materials
- the temperature rise on the unexposed face of separating elements
- the temperature of steel or concrete members with complex shapes, such as shelf-angle floors, composite steel and concrete

The results of heat transfer calculations may then be used in other calculations to determine the time to failure of loadbearing elements.

Chapter 1.6 of Part 1 of these Guidelines describe the process by which fire spread and management are used to assess the likelihood of fire spread beyond the initial fire enclosure and the possible impact of the fire on an enclosure.

Part 3 provides data that may be used in applying these, or any other applicable, methodologies.

2.6.1 Fire severity

The fire resistance (also referred to as fire endurance, fire resistance level (FRL) or fire resistance rating (FRR), as determined in the standard test procedure (e.g. ISO 834 (ISO, 1975), ASTM E119 (ASTM, 1988), AS1530.4 (SA, 1997)), may not be representative of the actual fire conditions in a specific building and therefore should only be used in fire engineering studies in conjunction with the appropriate fire severity analysis. Various methodologies are available for the calculation of the fire severity.

For the purpose of evaluating the performance of structural elements and barriers, fire severity is commonly described in terms of the temperature or heat flux versus time in the enclosure. The procedures for determining the temperature or heat flux- time profile may be categorised into:

- full-scale or near-full-scale experiments
- mathematical procedures

The mathematical procedures include:

- basic heat balance
- simplified relationships
- computer modelling

The SFPE (2004) has recently published an engineering guide on estimating fire boundary conditions. Design methods, their limitations and examples of their application are given for fully developed exposure fires and for fire plumes, the two fire exposures of most importance in the design of structures for fire.

2.6.1.1 Basic heat balance

When used to analyse fire severity, mathematical models generally take the following into consideration:

- rate of heat release from the fire
- rate of heat loss by radiation through openings
- rate of heat loss by convective flow through openings (including cooling of the hot gases by incoming air)
- rate of heat loss by conduction into the enclosing boundaries; and sometimes including the effects of radiation exchange between these bounding surfaces and the intervening hot gases.

These factors form the basis for evaluating the temperature–time profile using a heat balance approach. All of these factors represent heat losses from the fire as derived in Chapter 2.4 where further information on methods to derive post-flashover compartment fire temperatures may be found.

Pettersson *et al.* (1976) have used such an approach to derive temperature–time curves as a function of fire load and ventilation conditions for a fire compartment.

2.6.1.2 Simplified relationships

A number of simplified empirical relationships for predicting fire severity have been developed, particularly for evaluating the stability of structural members in fire. These are described in Chapter 2.6.

Due to the extensive amount of published data collected over many years from standard fire resistance tests, relationships have been developed to provide an alternative means of relating real fires to the results of the standard temperature/time furnace tests, although the 'real fires' are based mainly on wood crib tests on 'standard' enclosures.

2.6.1.3 Time Equivalence Formula

A common approach is to use the time equivalence formula obtained from the Eurocode (EC1, 2002). This formula gives the equivalent structural fire severity for an enclosure based on fuel load, ventilation conditions, and lining materials.

The equivalent structural fire severity is defined as the time of exposure to the standard fire resistance test which results in the same thermal impact as a complete burnout of the compartment in a real fire. It is an empirical correlation, derived from tests and calculations of the temperature of protected steel beams exposed to a range of real fires. Assemblies provided with a fire resistance equal to or greater than the equivalent structural fire severity are generally expected to be able to withstand a complete burnout of the compartment.

Although the time-equivalence formula is based on the thermal performance of insulated steel members, it is widely used for fire containment and structural performance of many different materials. The formula contains a number of assumptions and approximations, but is generally accepted as capable of providing a first-order estimate of the required performance.

The Eurocode time-equivalent formula is:

$$t_e = e k_b w_f$$

where

t_e	is the equivalent time of fire exposure to the standard test	min	min

e	is the fire load density based on the fuel load averaged over the floor area, for all fire loads that may contribute energy to the combustion process	MJ/m^2	Btu/ft^2
k_b	is a conversion factor that relates to the thermal properties of the enclosure boundaries by means of the thermal inertia $\sqrt{\lambda \rho c_p}$ (see recommended values below)	min $m^{2.3}/MJ$	min $ft^{2.3}/Btu$
w_f	is a ventilation factor that allows for the size of the opening	$m^{-0.3}$	$ft^{-0.3}$

and where

$\sqrt{\lambda \rho c_p}$	is the thermal inertia	$J/s^{1/2}m^2K$	$BTU/s^{1/2}ft^2R$

where

λ	is the thermal conductivity	W/mK	Btu/s ft R
ρ	is the density	kg/m^3	lb/ft^3
c_p	is the specific heat	J/kgK	Btu/lb R

and where

w the ventilation factor for the profile of the opening is given as:

$$w = \left(\frac{6.0}{H}\right)^{0.3}\left[0.62 + \frac{90(0.4-\alpha_v)^4}{1+b_v\alpha_h}\right] \qquad > 0.5$$

$$\alpha_v = \frac{A_v}{A_f} \qquad 0.05 \le \alpha_v \le 0.25$$

$$\alpha_h = \frac{A_h}{A_f} \qquad \alpha_h \le 0.20$$

$$b_v = 12.5\left(1+10\alpha_v - \alpha_v^2\right)$$

where

A_f	is the floor area of the enclosure	m^2
A_v	is the area of vertical window and door openings	m^2
A_h	is the area of horizontal openings in the roof	m^2
H	is the height of the enclosure	m

Recommended values for k_b are (Kirby et al, 1999):

k_b [min/MJ/m^2]	$\sqrt{\lambda\rho c_p}$ [$J/s^{1/2}m^2K$]	k_b [min/Btu/ft^2]	$\sqrt{\lambda\rho c_p}$ [$BTU/s^{1/2}ft^2R$]
0.080	<720	$1x10^{-3}$	<0.0352
0.055	720…2500	$8x10^{-4}$	0.0352...0.1223
0.045	>2500	$5.7x10^{-4}$	>0.1223

2.6.1.4 Computer modelling

Computer models provide a convenient means of predicting the severity of fire in an enclosure. Important factors governing the predictive capabilities of computer models include the level of the assumptions and simplifications of the physical and chemical processes that constitute the models and the data used for the models. Care must be exercised with the choice of data, particularly those that vary with temperature. The accuracy and significance of the input data may be assessed by carrying out analyses on the sensitivity of the computer model predictions to variations in the input data.

The two types of computer models for fire analysis—zone models and field models—are described in various texts. To provide acceptable outcomes for fully developed post-flashover fires these models should take into account the following factors (as discussed in 2.6.1.1):

- rate of heat loss by radiation through openings
- rate of heat loss by convective flow through openings (including cooling of the hot gases by incoming air)
- rate of heat loss by conduction into the enclosing boundaries

More sophisticated models may also take the following into account:

- rate of accumulation of heat in the hot gases of the enclosure
- rate of release of unburnt pyrolyzates in a ventilation controlled environment
- effect of radiation feedback on the combustion rate

Most computer models developed for determining post-flashover temperatures consider the room to be a well-mixed reactor (i.e. a single zone). It may be possible to use two-zone models but this must be done with care as many of the pre-flashover assumptions no longer apply. Examples of computer programs that solve the heat balance equations to generate post-flashover fire temperatures include COMPF2 (Babrauskas, 1979), OZONE (Cadorin, 2003), FASTLite (NIST, 1996) and Branzfire (Wade, 2003). Also refer to Chapter 2.4 for further discussion on post flashover compartment fire temperatures.

2.6.2 Fire Resistance

Once the severity of the fire is known or estimated, the fire engineer is required to ensure that, where required, elements of building construction are specified that will achieve the necessary level of fire resistance.

If a heat balance calculation or computer modelling has been used to generate the fire gas temperatures, then the fire resistance of building elements can be determined by calculation based on thermal and/or structural analysis at elevated temperatures, using the actual fire loads and the expected fire severity, assuming an appropriate methodology exists for the calculation, and so will depend on the characteristics of the construction element of interest.

If the time-equivalent method of assessing fire severity has been used, then the fire resistance of building elements may be determined by:

- Carrying out full-scale tests on single elements using standard fire resistance test methods; or
- By calculation based on thermal and/or structural analysis at elevated temperatures assuming a standard time-temperature fire curve. Again, this presumes that an appropriate methodology exists for the calculation.

Fire resistance criteria generally include one or more of the following (depending on whether the construction element is to provide a separating function or a loadbearing function (or both):

- *Insulation* – required for separating elements or barriers in order to limit the amount of heat conducted through the assembly to prevent ignition of combustible materials in the adjoining enclosures.
- *Integrity* – required for separating elements or barriers to prevent cracks or holes developing that would allow the passage of flame or hot-gases through the assembly, leading to ignition of combustible materials and/or development of untenable conditions on the adjoining enclosure.
- *Structural Adequacy* – required for building elements that carry applied loads to prevent premature structural collapse and subsequent fire spread to other enclosures.

The results of a standard fire resistance test will usually list each of these criteria separately (as applicable).

2.6.3 Structural performance

The limit state of failure is reached when the load-bearing capacity of the structural element, frame or assembly decreases under fire conditions to a level at which it can no longer support its dead load and the other loads applied. The properties and behaviour of the common construction materials under fire conditions differ and hence different approaches to analysing them have been developed.

Buchanan (2001b) provides a comprehensive overview of structural design for fire safety including discussion of a range of methodologies applying to different materials and structural systems. He also emphasises that structural design for fire conditions is conceptually similar to structural design for ambient/normal temperatures, with the main differences being:

- Applied loads are usually less
- Need to consider forces due to thermal expansion

- Strength of materials are reduced at elevated temperature
- Cross sectional areas may be smaller due to charring or spalling
- Deflection usually not important unless it affects strength
- Smaller safety factors may be appropriate due to low probability of fire
- Failure mechanisms may be different under fire conditions

Unless appropriately trained, the role of fire engineers is generally limited to predicting the thermal effects of fire on structural elements. Structural engineers should be employed to use the corresponding material properties to analyse the behaviour of a structure in which elements are subjected to fire impact.

The American Society of Civil Engineers has published a standard on the calculation of structural fire resistance (ASCE/SFPE 29, 1999). This standard is a collection of the various methods now available to predict the performance of steel, concrete, masonry and timber structures in response to the standard fire resistance test.

2.6.3.1 Steel

Steel structures that are unprotected, unless carefully detailed, usually do not perform well when exposed to fire as a result of the rapid heating of the steel members. However some unprotected steel structures can survive well if the fire severity is low, and the structural system allows the thermal stresses to be redistributed.

Eurocode 3: Design of steel structures (EC3, 2002) is a suitable guide for design of steel structures as it summarises the results of a large international co-operative research programme over recent times. Buchanan (2001b) draws upon this also, providing a comprehensive summary of the various design approaches that can be used.

There are two main approaches for calculating fire resistance of steel structures:

- Simple calculation models for single elements
- General method for analysing complex structures (requiring a computer program)

Simple calculation methods for both unprotected and protected steel elements normally use a quasi steady-state, lumped heat capacity analysis method in conjunction with a limiting (or failure) temperature. This methodology enables the time-temperature profiles in an assumed infinite length of steel with a defined cross-section to be determined, given the time-temperature regime of the environment to which the section is exposed. The method is therefore applicable to all time-temperature regimes. The maximum steel temperature reached during the fire is compared to the limiting steel temperature (dependent on the amount of applied load). Examples of such analysis methods can be found in the SFPE handbook Milke(2002), Drysdale (1999), Buchanan (2001b), Petterson et al (1976) and ECCS (1985).

Means of determining a limiting temperature for steel sections under load are given in Australian Standard AS4100 (SA 1998) and ECCS (1985).

These simple methods are not suitable, as there are significant temperature gradients across the cross-section of the element, such as a beam with the top flange supporting a concrete slab. In these cases, finite element analysis is appropriate.

More detailed methods of analysis (general method) are necessary for steel frames where deformations are imposed on the structure and the stress/strain and internal forces on each member are calculated using elevated temperature material properties. Again, this requires specialist computer programs used by structural engineers.

Steel Protection Systems – There are many fire protection systems available to enhance the fire resistance of steel structures. These include concrete encasement; board systems using calcium silicate, gypsum plasterboard or other materials; spray-applied protection; or intumescent paints. The majority of such systems are proprietary and the manufacturer’s technical specifications should be consulted for details regarding scope of use, approved applicators, application rates, testing and approval details and any limitations, etc.

When calculation methods are used for protected steel systems, it is important that the robustness or ‘stickability’ of the protection material be considered to ensure that the material will remain in place throughout the fire exposure period. The protection material must be able to adequately withstand the deformations and deflections expected under full-scale fire conditions. Usually fire tests are necessary to confirm this is the case.

External Steelwork – beams and columns located externally on a building may be exposed to fire mainly as a result of flames projecting through openings in the external wall. Methods for estimating the temperatures of external steel have been developed by Law and O’Brien (1981). Information relevant to these methods is also included in Eurocodes 1 (EC1, 1994) and 3 (EC3, 1995).

Steel-Concrete Composite Construction – such as concrete slabs cast in-situ over a steel decking and beams acting compositely with the slab to resist flexure. Design information is available in Eurocode 4 (EC4, 1994). Manufacturers of proprietary systems will often provide fire resistance data in their technical literature.

Concrete-Filled Hollow Steel Sections – these can be filled with plain or reinforced concrete to enhance fire resistance. The concrete provides a heat sink slowing the temperature rise of the exposed steel. Design information can be found in Eurocode 4 (EC4, 1994), Lie and Kodur (1996) and Kodur (1999).

Water-Filled Hollow Steel Sections – an expensive but innovative approach to protecting hollow steel sections is to fill them with water. Design information is available from Bond (1975).

2.6.3.2 Concrete

Plain concrete is essentially isotropic on a macro-scale. Reinforced concrete, the common application of concrete, is non-isotropic due to the presence of discrete steel reinforcement. The predominant impacts of fire on reinforced concrete are thermal bowing and the gradual heating of the reinforcement with the consequent loss of section properties as a result of the temperature rise in the reinforcement steel. Most of the design data for reinforced concrete members is based on fire exposure regimes defined in national and international standards. National codes also often list generic fire resistance ratings for concrete construction. Simplified design processes to achieve fire resistance for reinforced concrete members are given in Australian Standard AS 3600 (SA, 2001a), New Zealand NZS 3101 (SNZ, 1995), Eurocode 2 (EC2, 1993) or NBCC (NRC, 1995). Commonly, minimum dimensions and minimum cover to reinforcing steel are provided in a tabulated form.

Determining the fire resistance of concrete structures requires consideration of different functional requirements depending on the type of element and its location in the building.

Slabs – the thickness and concrete aggregate type have the greatest influence on the ‘insulation’ of concrete slabs. To achieve ‘structural adequacy’; the applied load, amount/location of reinforcing steel, concrete compressive strength and slab dimensions and edge support conditions also need to be considered. It is usual to assume that ‘integrity’ requirements will be automatically met if the required ‘insulation’ and ‘structural adequacy’ has been achieved.

Beams – similar principles apply as for slabs, except that only ‘structural adequacy’ need be considered since, unlike slabs, beams do not provide a fire separation function unless they are integral with a slab.

Columns – usually columns are designed based on minimum dimensions and cover to reinforcing specified in national codes or standards. There are also empirical formulas that have been proposed (Lie, 1989; Lie and Irwin, 1993; Wade et al, 1997) based on multiple regression analysis of the results of standard fire resistance tests that take into account factors such as concrete strength, reinforcement ratio, concrete cover, effective length, steel strength and column dimensions. All these methods relate to performance under standard fire test conditions. To calculate performance where fire severity is assessed using energy balance calculations requires the use of special purpose computer software.

Walls – ‘insulation’ ratings for walls, as for slabs, is mainly determined by the thickness and concrete aggregate type. Determination of ‘structural adequacy’ under fire conditions is more complicated than for slabs because of the need to account for loading eccentricities and buckling failures, as well as accounting for the level of applied load, amount/location of reinforcing steel, concrete compressive strength and wall height and support arrangements. As for slabs, it is usual to assume that ‘integrity’ requirements will be automatically met if the required ‘insulation’ and ‘structural adequacy’ have been achieved.

Lightweight concrete – Lightweight concrete exhibits improved fire resistance compared to normal weight concrete due to its lower density and thermal inertia.

High-strength concrete – Additives such as silica fume and water-reducing admixtures are used to create concrete with compressive strength in the range 50 to 120 MPa. High strength concrete is more susceptible to a loss in strength at temperatures up to 400C compared to normal strength concrete. In some cases explosive spalling can be a problem. Tomasson (1998) gives some design recommendations.

Spalling is a potential problem since it results in reduced cross sectional area and exposes the reinforcing steel to higher temperatures than anticipated during design. It is more prevalent with new concrete with high moisture content. The most economic method to reduce the likelihood of spalling is the addition of fine polypropylene fibres to the concrete mix (0.15 to 0.3%). The fibres melt as the concrete is heated and leave cavities within the concrete through which water vapour can escape (Kodur, 1997).

Prestressed Concrete – Prestressed concrete is more vulnerable in fire because the prestressing steel is cold-worked and loses strength more rapidly at elevated temperatures, compared to hot-formed mild steel reinforcing bars. Similar methods of design can be applied to prestressed concrete as for reinforced concrete provided the appropriate elevated material properties for the prestressing steel are used.

To aid in the selection of an appropriate calculation method, Buchanan (2001b) offers the following advice.

- For simply-supported slabs or tee-beams exposed to fire from below, structural design need only consider the effect of elevated temperatures on the yield strength of the reinforcing steel. Simple hand calculations are possible.
- For continuous slabs or beams, hand calculations are still possible but should consider the effects of elevated temperature on the compressive strength of the concrete.
- Similar methods can be applied to walls and columns but they may be less accurate due to deformations leading to instability caused by non-uniform heating.
- For moment resisting frames, or structural members affected by axial restraint, it is recommended to use special-purpose computer programs for structural analysis under fire conditions.

Further information is given in Fleischmann and Buchanan (2002), Buchanan (2001) and Wade (1991a, 1991b, 1994).

2.6.3.3 Heavy Timber

Heavy timber construction covers the use of large dimension sawn timber of glue-laminated structural members. In this context the minimum dimension should be not less than 80mm (Buchanan, 2001b). The effect of fire on timber sections is to initiate charring. This has the effect of reducing the effective section dimensions with a consequent loss of load-bearing ability. The charring rates of timber are predominantly controlled by the timber density and are relatively constant once charring has started and the heat input from the environment is sufficient to sustain charring. The boundary between the layer of char and the remaining wood is quite distinct and corresponds to a temperature of about 300 C.

Methods for determining the fire resistance of solid structural timber members can be found in White (2002) and Australian Standard AS 1720.4 (SA, 1990). Eurocode 5 (EC5, 2003) also has a method for calculating the charring rate in realistic parametric fires.

2.6.3.4 Masonry

Brick masonry generally performs well in fire provided that thermal bowing of the wall is not excessive. Ceramic bricks are produced by firing clay and therefore remain stable when exposed to fire.

Concrete masonry usually consists of hollow lightweight concrete blocks mortared together. The cores may be steel reinforced and filled with concrete, particularly in seismic areas. Similar fire behaviour to reinforced concrete can be assumed, when the blocks are reinforced and fully grouted.

There are few methodologies available to determine the structural fire resistance of masonry structures. Some design information may be obtained from Australian Standard AS 3700 (SA, 2001b).

2.6.3.5 Lightweight Timber / Steel Frame Assemblies

This type of construction typically includes walls and partitions using sawn timber or thin-gauge steel studs with a sheet lining on each side, most commonly a gypsum plasterboard material. Floors typically include wood joists with plywood or particleboard on the floor surface and gypsum plasterboard on the underside. Provided the correct materials are used and they are well-constructed, this type of lightweight construction can perform well in a fire. Fire resistance of light frame structures are most commonly derived from standard fire resistance tests leading to proprietary ratings. However, generic ratings are also common in North America.

While more detailed thermal/structural calculation models have been developed they tend to mainly be used for research and for specialised assessments rather than for routine design.

Thermal calculation models have been developed by Clancy (1999), Collier (1996), Takeda and Mehaffey (1998), and Sultan (1996), while Gerlich *et al* (1996) provide information on design methods for light steel frame walls. These models may be less reliable than those used for concrete and steel, because the wall lining may deteriorate with time or fall off completely in a manner that is not always predictable.

2.6.3.6 Computer Modelling

Finite-element programs used extensively for analysis of steel and concrete structures exposed to fire include SAFIR (Franssen *et al*, 2000) and VULCAN (Rose *et al,* 1998).

2.6.4 Fire spread

Predicting fire spread involves evaluating both enclosure fire conditions and the behaviour of the materials bounding the enclosure with respect to the fire. Fire spread or growth within an enclosure may be considered on the basis of methods included in Chapter 2.4 of this part. Methods of determining the time-temperature curve for an enclosure fire were discussed in Chapter 2.4 of these Guidelines.

2.6.4.1 Fire size and temperature

Fire spread due either radiation or direct fire impingement, may be calculated if the shape, size and temperature profile of the flames and/or hot gases including horizontal projections from openings can be determined. The expected flame height and horizontal projection from the opening can be calculated, as can the temperatures at any point along the fire (refer Chapter 2.4 of Part 2 of these Guidelines). Further guidance on the calculation procedures is given by Law and O'Brien (1981) and AISI (1983), although only those parts relating to fire properties need be used. These calculation methods were principally developed to quantify the nature of fires emerging from external windows, but may also be used for fires emerging from internal openings such as doors.

2.6.4.2 Barrier failure

Barrier failure leading to fire spread may be caused by failure of membrane load-bearing or non load-bearing components, such as walls, or as a result of structural failure, such as beams or columns, or the presence of open doors and windows. To make an evaluation of fire spread it is necessary to have information concerning the fire properties of the materials involved. Some information may be obtained from the relevant Australian Standards noted in Section 2.6.2. Other means of predicting temperatures and performance of materials may be obtained from sources such as the *SFPE Handbook of Fire Protection Engineering* (DiNenno, 2002), the *Fire Engineering Design Guide* (Buchanan, 2001a), *NFPA Fire Protection Handbook* (Cote 1997) and the joint Warrington and BCC publication *Guide for the Design of Fire Resistant Barriers and Structures* (England *et al.* 2000).

The recommended approach to determining the appropriate fire resistance for a barrier to resist fire spread and contain the fire to the compartment of origin is to determine the equivalent structural fire severity (time-equivalent) as discussed previously and then select an appropriate barrier with a specification that will achieve at least this level of performance.

There may be some instances where a barrier is required to resist fire for a certain period of time and the fire safety engineer wishes to determine the expected time to barrier failure when subjected to a fire of known severity. Nyman (2002) has proposed a method for estimating barrier failure times provided the fire severity and the standard fire resistance of the assembly are known. The method assumes that a barrier will fail when the same cumulative radiation flux or dosage is experienced by the barrier compared to that measured in a standard fire resistance test at the time of failure. The method is also discussed by Gerlich *et al* (2004). It is appropriate when the failure mechanism is due to heat conduction through the barrier and may be non-conservative for some load-bearing structural elements.

2.6.4.3 Fire spread to adjacent buildings

There are several methodologies or commentaries in the literature relating to methods used to develop prescriptive code requirements in various countries (e.g Read (1991); Barnett and Wade (2002); England (2004)). These methods may incorporate certain assumptions regarding fire brigade intervention, design radiation flux levels, extent of flame projection from openings and location and extent of permitted damage to neighbouring property in order to ensure that the overall outcomes meet regulatory and community expectations regarding 'cost and benefit' to the respective country. While fire safety engineers may take these factors into consideration when selecting the methodology and criteria to use for a specific building, a first-principles case-specific approach to preventing fire spread to adjacent buildings is generally preferred.

SFPE has published an engineering guide to piloted ignition of solid materials under radiant exposure giving the techniques and data available to engineers for predicting the time to piloted ignition of solids exposed to flame radiation and for determining the safe separation distances required to prevent ignition. The guide reviews the concept of minimum ignition level and reviews five methods to calculate the time to ignition under constant radiative heat flux. The guide includes sample results for each method and an Appendix of relevant material properties (SFPE, 2002).

SFPE (1999) has also published guidance for assessing flame radiation to external targets from pool fires. It summarizes accepted calculation methods for radiant heat transfer from pool fires to targets located outside of a flame. For each method, the data requirements, data sources, inherent assumptions and limitations are summarized.

Calculations for determining minimum separation distances often require calculation of radiation view factors. These calculations can be quite complex.

2.6.4.4 Radiation and flying brands

It is often difficult to establish, with any certainty, the distance that a burning brand rising in the thermal plume may be carried in the wind. British Standard BS 476: Part 3 (BSI 1975) describes a test method which may be used to assess the ignitability and fire spread characteristics of external surfaces of roofs when subjected to radiation from a fire in an adjacent building and piloted ignition from flying brands.

2.6.4.5 Fire spread in large enclosures

The relationships for enclosure temperatures given in Chapter 2.4 are based on experiments in enclosure sizes with floor areas of approximately 10 m^2 (110 ft^2) or less, although some of the relationships have also been shown to compare well with experiments for floor areas of up to 50 m^2 (540 ft^2)(see Latham *et al.* 1987).

When considering large open-plan enclosures of greater than150 m^2 (1620 ft^2), typical of modern office floor layouts, the time for fire to spread to the rest of the enclosure becomes significant relative to the duration of the fully developed stage of a localised fire. If simultaneous burning is assumed for enclosures with large floor areas, unrealistically high temperatures in the enclosures will be obtained.

Estimates of fire spread rates may be evaluated from large open-plan office enclosure fires (Thomas *et al.* 1992 and Nelson 1989). As a first approximation, the design fire for large enclosures may be approximated by dividing the floor area into grids of 10–50 m^2 (110 ft^2 - 540 ft^2) and then constructing an overall heat release rate by integrating the heat release rate for each grid with appropriate time offsets estimated for the fire to spread from one grid to the next. The enclosure temperatures can then be predicted with an appropriate fire model, using the integrated heat release rate as input.

If the type and arrangement of the combustibles are known, better estimates of the spatial development of the fire can be made, based on ignition criteria and heat release rates of the individual objects. The location of the combustibles would need to be predictable over the life of the building for this process to be warranted.

2.6.5 References

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Chapter 2.7

Fire Detection, Warning and Suppression

Sub-system D

Sub-system D (SS-D) is used to analyse the time of detector activation and warning as well as the effect of suppression systems.

This chapter provides methodologies for quantifying the following parameters of Sub-system SS-D:

- activation time of fire detectors, alarms and sprinklers
- effect of automatic fire suppression

The use of other methodologies selected by the fire engineer is not precluded.

Chapter 1.7 of Part 1 of these Guidelines describes the process by which the analysis of fire detection, warning and suppression is typically undertaken.

Part 3 provides a selection of data that may be used in applying these, or any other applicable methodologies.

2.7.1 Fire detection and warning

The prediction of the activation time of a fire detector requires knowledge of the rate of fire growth (e.g. flame size, temperature, smoke profiles, and heat release rate), characteristics of the automatic fire detector and details of the building geometry.

Fire detectors are generally categorised into the following types (Moore 1997):

- heat (or thermal) detectors, both fixed temperature (static) element detectors and rate-of-rise-of-element detectors
- smoke detectors, for example, ionisation chamber smoke detectors, optical scatter smoke detectors, optical obscuration (beam) smoke detectors and aspirating (or sampling) smoke detectors
- gas sensing detectors
- flame detectors, for example, ultraviolet flame detectors and infra-red flame detectors

For coincident detection systems, two or more detectors are required to operate before an alarm is recognised. Such a system may depend on the activation of either two similar detectors at different locations or two dissimilar detectors before the signal is confirmed.

Methodologies for calculating activation of various types of detectors are presented in the following sections.

2.7.1.1 Heat detectors

Heat detectors respond to heat transfer from the ceiling jet as illustrated in Figure 2.7.1.1. Response depends on the temperature and velocity of the ceiling jet at the detector location, as well as the detector characteristics. The temperature and velocity of the ceiling jet is not uniform and the distance of the heat sensitive element down from the ceiling is an important parameter controlling detector response time.

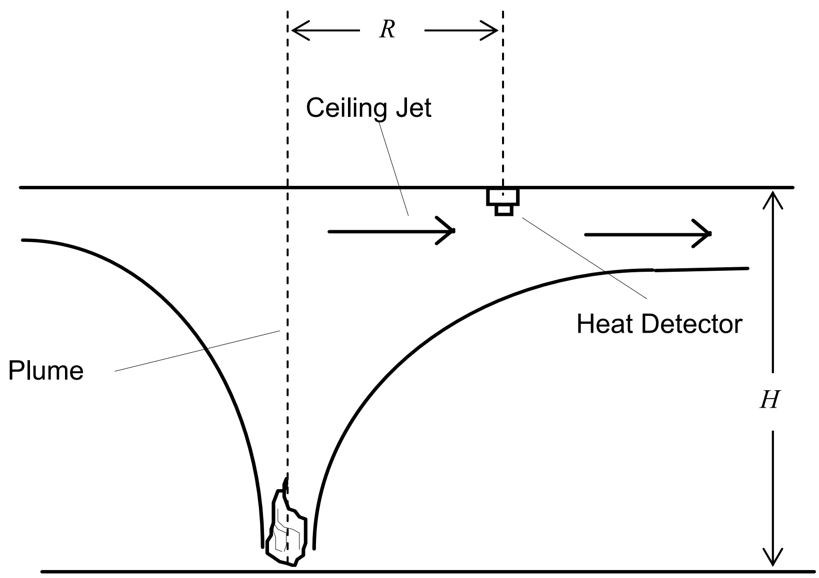

Figure 2.7.1.1 Heat transfer from ceiling jet

The time of detection for heat detectors may be determined by hand calculations or computer models based on some original calculations by Alpert (1972), Hekestad and Delichatsios (1978) and others.

The basic response equation for a heat-sensing device (whether heat detector or sprinkler head) is given by the lumped mass heat transfer equation as follows:

$$\frac{dT_d}{dt} = \frac{\sqrt{u}(T_g - T_d)}{RTI}$$

where

T_d	is the detector temperature	°C	°F
t	is the time	s	s
u	is the velocity of gases surround the detector	m/s	ft/s
T_g	is the temperature of the gases surround the detector	°C	°F
RTI	is the response time index	$m^{0.5}$ $s^{0.5}$	$ft^{0.5}$ $s^{0.5}$

The RTI for a heat-sensitive element is a measure of its sensitivity and may be determined experimentally.

With a known RTI value and time-dependent gas velocity and temperature data, the equation can be solved numerically to yield the temperature of the detector. A detector is deemed to activate when its temperature reaches the activation temperature if it is a fixed temperature detector or when the rate of rise of its temperature exceeds the activation rate of rise, if it is a rate-of-rise type of detector. The activation temperature or the activation rate of rise and the response time index RTI are intrinsic properties of heat detectors.

In order to determine the detector operating time t_{op}, that is, when T_d reaches the detector operating temperature, the changing values of T_g and u with time must be known at the detector location. This requires information about the fire heat release rate, entrainment coefficients, ceiling height, and radial distance from the plume to the detector location.

Room enclosures

For typical room enclosures, the Alpert (1972) ceiling jet model can be used to calculate, at the location of the detector, the gas temperature:

$$T_g - T_\infty = \begin{cases} \dfrac{C_1 Q^{2/3}}{H^{5/3}}, & \text{for } R/H \le 0.18 \\[2ex] \dfrac{C_2 (Q/R)^{2/3}}{H}, & \text{for } R/H > 0.18 \end{cases}$$

where

T_g	is the gas temperature	°C	°F
T_a	is the ambient temperature	°C	°F
C_1	is a constant	16.9	14.9
Q	is the total heat release rate of the fire	kW	Btu/min
H	is the height above the fire origin	m	ft
C_2	is a constant	5.38	4.74
R	is the radial distance from the fire plume	m	ft

The Alpert model can also be used to calculate the gas velocity:

$$u = \begin{cases} C_3\left(\dfrac{Q}{H}\right)^{1/3}, & \text{for } R/H \le 0.15 \\ \dfrac{C_4 Q^{1/3}\sqrt{H}}{R^{5/6}}, & \text{for } R/H > 0.15 \end{cases}$$

where

u	is the velocity of the ceiling jet	m/s	ft/s
C_3	is a constant	0.95	1.2
C_4	is a constant	0.20	0.25

The equations above are based on some fundamental assumptions:

- flat smooth ceilings
- unconfined gas flow
- strong plume (flaming) fires
- axisymmetric plumes (not near walls or corners)
- the heat sensitive element is located in the peak velocity and peak temperature region of the ceiling jet

Partially confined ceilings and corridors
For partially confined ceilings and corridors, where the flow of gases is partially confined by ceiling beams or walls to form a channel, as in a corridor, the equations of Delichatsios (1981) can be used to establish the temperature of the gas flow. These equations still assume that no significant gas layer has developed before the detector activates. For smaller rooms or long activation times where the Delichatsios equation may not be valid, the equations of Evans (1984) or Cooper (1984) can be used to determine a fire source and heat release rate.

High ceilings
For high ceilings and large volumes (for example atria), when using t^2 design fires, the temperature rise of the smoke layer required to activate a sprinkler at a radius to ceiling height ratio of less than 0.6 can be estimated using NFPA 92B (NFPA 2000a):

$$\Delta T = \frac{C_1}{t_g^{4/5} H^{3/5}}\left(\frac{t}{t_g^{2/5} H^{4/5}} - C_2\right)^{4/3}$$

where

ΔT	is the temperature rise at the ceiling	C	°F
C_1	is a constant	2090	27,400
t	is the time	s	s
C_2	is a constant	0.57	0.22
t_g	is the characteristic time fire growth time	s	s
H	is the height above the fire origin	m	ft

The above equation is generally valid if:

$A/H^2 \le 7.4$
$t \le 480$
$v_r \le 1$

where

A	is the horizontal cross-section area of the enclosure	m^2	ft^2
v_r	is the ventilation rate	air changes/hr	air changes/hr

2.7.1.2 Smoke detectors

The various types of smoke detectors and their different responses to various forms of smoke make it difficult to provide one approach to predicting smoke detector operating times. In addition, there is a dearth of well-developed prediction methods and hence reliance has to be placed on some crude approximations. A conservative prediction should therefore be adopted.

Point detectors

Point (spot) detectors because their operation is a function not only of the optical density of the smoke but also of:

- the size distribution of smoke particles produced
- the light scattering properties of the smoke particles
- the performance of the ionisation chamber.

Two approaches for determining detector activation time may be adopted, namely, equivalence to a heat detector and optical density measurements.

In the temperature equivalence approach (Heskestad 1981) it is assumed that the smoke detector operates at 13°C (23°F) above ambient temperature.

Thus for ΔT = 13 °C (23°F) and a low RTI (< 10 $m^{0.5}s^{0.5}$ or 18 $ft^{0.5}s^{0.5}$), an estimate of the time to smoke detection may be obtained when using one of the heat detector computer models. Extensions of this approach have been proposed by Evans (1984).

This temperature equivalence approach assumes that temperature rise and smoke concentration correlate.

In the optical density approach, the optical density for activation can be used to estimate the time for detection by reference to the optical density of smoke in the hot layer or, preferably, in the ceiling jet. This second parameter may be obtained from SS-B. The detector is deemed to activate whenever the following condition is satisfied:

$$D > D_{act}$$

where

D	is the optical density in the smoke layer	m^{-1} or db/m	ft^{-1} or db/ft
D_{act}	is the optical density required for activation	m^{-1} or db/m	ft^{-1} or db/ft

If the extinction coefficient is known, the following conversion can be used to determine D:

$$D = \frac{K}{2.3}$$

where

K is the extinction coefficient

Care should be taken to include a reasonable time delay between the arrival of smoke of the required optical density at the smoke detector location and its entry into the detector to cause activation.

Beam detectors

For beam detectors, the calculation principle for activation is essentially the same as that for point (spot) detectors. Beam detectors will give an alarm when the beam is attenuated by a given quantity of smoke. If the beam length and the sensitivity of a beam detector, expressed as I/I_o, are known, the optical density at which the detector activates can be determined from the following relationship:

$$D_{act} = \frac{1}{L}\log\frac{I}{I_o}$$

where

D_{act}	is the optical density required for activation	m^{-1} or db/m	ft^{-1} or db/ft
I	is the intensity of light with smoke present	W/m^2	Btu s^{-1} m^{-2}
I_0	is the intensity of light with no smoke	W/m^2	Btu s^{-1} m^{-2}
L	is the beam length	m	ft

If the extinction coefficient is known, the value for I/I_o can be determined from the following equation (Mulholland 2002):

$$\frac{I}{I_o} = e^{-KL}$$

where

K is the extinction coefficient

The detector is deemed to activate whenever the following condition is satisfied:

$$D > D_{act}$$

where

D	is the optical density in the smoke layer	m^{-1} or db/m	ft^{-1} or db/ft
D_{act}	is the optical density required for activation	m^{-1} or db/m	ft^{-1} or db/ft

Aspirating detector

An aspirating (air sampling) detector system is one in which air is normally drawn through a pipework system and sampled at a central point by a sensitive light scattering detector (Massingberd-Mundy 1996). For analysis purposes, each sampling point can be modelled as an imaginary point (spot) detector.

The response level of aspirating detectors to optical smoke density can be set individually for each installation; they are often up to 10 times as sensitive as point (spot) detectors. However, because of the dilution of smoke and finite travel speed along the pipework, there is usually a considerable time delay in the activation of the system. When a large pipework system is installed, the location of the fire source may not be detected easily.

To predict the activation time of an aspirating system, one may use the manufacturer's specification and smoke parameters obtained from SS-B.

2.7.1.3 Gas sensing detectors

For gas sensing detectors there is no acceptable methodology to determine activation times.

2.7.1.4 Flame detectors

A flame detector can be considered as a point receiving radiation emitted from a flame responding to a specific flame temperature and emissivity. The intensity of radiation received may be calculated using the procedures described in Sub-system SS-C (Chapter 2.6).

The sensitivity of a flame detector can vary according to the direction of the received radiation, and the off-axis sensitivity should be considered in the design process. The relevant standards, handbooks and manufacturer’s data should be taken into account when analysing and designing flame detection systems.

2.7.2 Automatic suppression

There is a wide range of automatic suppression equipment. This equipment has either built-in fire sensing elements or is activated by signals from separate detectors or other means. Prediction of activation times of suppression has been covered in the previous section of this Chapter.

This section is about determining the effect of automatic suppression. The activation of suppression may achieve one of the three outcomes described in Step 5 of Section 1.7.4.1 of these Guidelines and illustrated in Figure 2.7.2. The time for activation is evaluated from the detection analysis in Section 2.7.1.

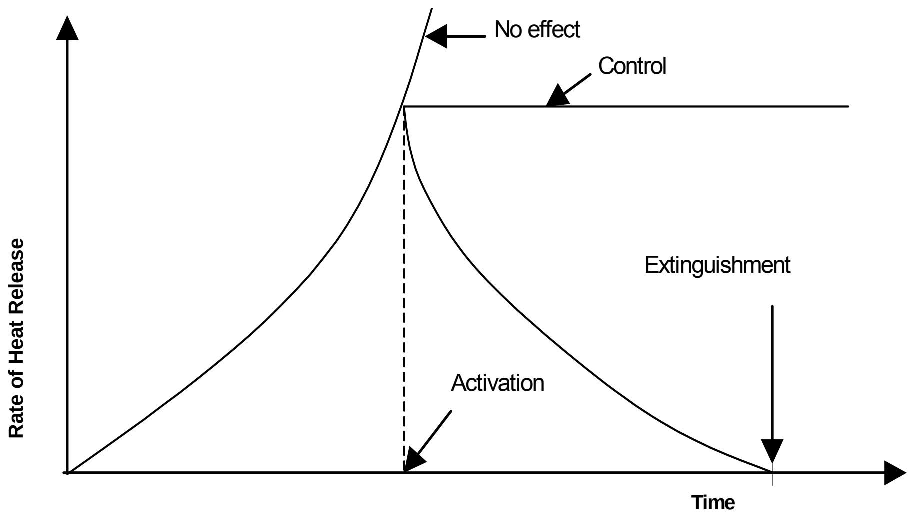

Figure 2.7.2 Possible effects of suppression on a design fire

The effect of suppression on the temperature of the hot gases, smoke layer formation and visibility is difficult to determine but Cooper (1995) gives a method.

2.7.2.1 Sprinklers

For sprinklers, it can be assumed that suppression commences when activation occurs provided:

- the enclosure height is low
- the size of enclosure is small
- the fire size is relatively low
- significant shielding of the fire is not expected
- the fire is likely to be extinguished with one or a few sprinkler heads.

However, this assumption may not apply in typical commercial and industrial applications, where roof heights may be high and where fire sizes and fire growth rates may be large.

Calculations relevant to the extinguishment outcome (see Figure 2.7.2) for 'extra light hazard' sprinklers can be done using one of the two following equations, in situations where the suppression can be assumed to occur at the time of activation (see above).

Madrzykowski and Vittori (1992) developed the following equation:

$$Q(t) = Q_{act} e^{-0.023\Delta t}$$

where

$Q(t)$	is the heat release rate at time t	MW	Btu/s
T	is the time	s	s
Q_{act}	is the heat release rate at time of sprinkler activation	MW	Btu/s
Δt	is the time after sprinkler activation	s	s

Evans (1993) developed the so-called NIST equation which takes into account variations in spray density.

$$Q(t) = Q_{act} \exp\left(-\frac{\Delta t w^{1.85}}{C_1} \right)$$

where

C_1	is a constant	3	5.8
w	is the spray density	mm/s	gps/ft^2

Conventional automatic sprinklers may only control fires (see Figure 2.7.2) by opening a number of sprinkler heads and pre-wetting surrounding fuel to prevent fire spread.

A conservative value of the sprinkler activation time may be determined by choosing a larger radial distance (R) (see Figure 2.7.2.1) as input into the detector model. The larger value of R will lead to an increased estimate of sprinkler activation time and hence conservative evaluation of post activation heat release rate.

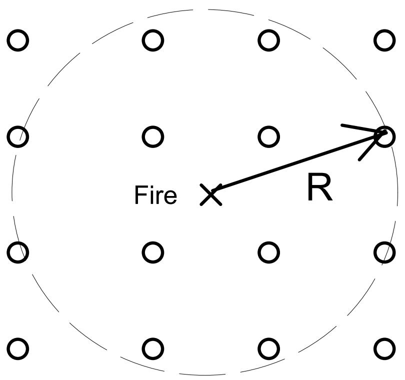

Figure 2.7.2.1. Selection of radial distance R for delayed activation

The probability of achieving suppression can be determined using the WPI-Fitzgerald methodology (Fitzgerald and Wilson 1993) for automatic sprinkler suppression that takes into account fire growth, water supply requirements and the degree of maintenance. It uses available statistical data and engineering judgement to estimate the probability of successful automatic suppression.

2.7.2.2 Other suppression systems

Calculations of the impact of other means of suppression, such as inert gaseous, chemical gaseous and water-mist, should be based on their design specifications and the relevant standards, for example, Australian Standard AS4214 (AS 1995) and NFPA 2001 (NFPA 2000b). These calculations are not currently covered in these Guidelines; see bibliography at the end of this chapter.

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Chapter 2.8

Occupant Evacuation and Control

Sub-system E

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 of the events that comprise evacuation in order to determine the overall time required for occupants to reach a place of safety. The latter time is generally referred to as the Required Safe Evacuation Time (RSET).

This chapter describes a selection of methodologies that may be used in undertaking the analysis but does not preclude the use of other methodologies that might be chosen by the fire engineer.

Chapter 1.8 of Part 1 of these Guidelines describes the process by which occupant evacuation analysis is typically undertaken.

Part 3 provides a selection of data that may be used in applying these, or other applicable, methodologies.

The components of RSET, as discussed in Chapter 1.8 of these Guidelines are:

- cue period (T_c)
- response period (T_r)
- delay period (T_d)
- movement period (T_m)

Various phases that comprise one or more of the above periods are:

- detection phase = T_c
- pre-movement phase = $T_r + T_d$
- movement phase = T_m
- evacuation phase = $T_r + T_d + T_m$
- RSET = $T_c + T_r + T_d + T_m$

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. For some buildings, such as high-rise or hospitals, this evacuation may be staged to start initial evacuation only of those nearest the fire and most at risk.

In high-rise buildings with appropriate emergency warning and intercommunication, the evacuation may be managed by trained personnel, with occupants on floors furthest from the fire placed initially on alert and evacuated progressively only if the fire continues to develop. For hospitals, the initial response is for nursing staff to move patients horizontally to an adjacent smoke zone or fire compartment. Only if the fire threat continues to develop are these patients moved further and other floors or fire compartments evacuated.

In particular types of buildings, the concept of a ‘fire safe refuge’, where occupants go to a special fire compartment to await rescue by the fire service, rather than evacuate, is sometimes used.

A further and more recent development is the ‘protect in place’ concept, particularly for residential buildings that are fully sprinklered. Occupants are encouraged to remain where they are rather than try to evacuate through potentially smoke-filled corridors or stairs.

In all buildings, consideration should be given to the question of providing safety for persons with disabilities who can represent a significant proportion of all building occupants. Use of refuges and, more recently, use of lifts (elevators) for evacuation of people with disabilities are areas of growing interest and research.

While many of these newer occupant management and evacuation concepts are still developing, these Guidelines are restricted to addressing the situation where evacuation of occupants to a place of safety is adopted as the approach in a fire emergency.

2.8.1 Detection phase

There are a number of methods and tools to calculate or obtain the Detection Phase time and these are discussed in Chapter 2.7.

2.8.1.1 Pre-movement phase

There are only a limited number of non-validated 'quasi-methodologies' available for the calculation of the pre-movement phase times and its components, the response and delay periods. Hence, no particular methodology is included in these Guidelines.

It is recommended that fire engineering practitioners rely on studies in publications such as SFPE Handbook (Bryan 2002 and Proulx 2002) and data generated by various researchers and published in scientific journals and publications, such as the Proceedings of IAFSS and Human Behaviour in Fire Symposia, in order to estimate pre-movement times. Part 3 contains information on the available data and sources.

A probabilistic method was presented during the 1st Human Behaviour in Fire Symposium (MacLennan *et al* 1998). This method is based on obtaining a data distribution and establishing the pre-movement times using the relevant function. For a particular type of occupancy and design occupant group, the times for the first person to move is obtained from the literature on as many studies as possible. These times are then associated to a distribution. The most suitable distribution for this purpose was identified as a Weibull distribution.

2.8.2 Movement phase

There are various tools (models and methodologies) available to calculate movement times. The most common techniques use a ball bearing or hydraulic approach that provides total movement times for all occupants of the building under ideal conditions. Evacuation times obtained may be less than the real evacuation times as they do not take the behaviour of occupants into consideration.

The current models have evolved from various people movement studies and maybe classified as follows:

- hydraulic flow models or flow models based on carrying capacity of independent egress way components and flow models based on empirical studies of crowd movement
- network optimisation models.

Three fundamental characteristics of flow models are:

- density (number of persons in a unit area of walkway)
- speed (distance covered by a person in a unit time)
- flow (number of people that pass some reference point in a unit time).

The relation between these characteristics, along with path width, is defined by the following equation:

$$flow = speed \times density \times width \quad \text{(Proulx 2002)}$$

Models which use effective width rather than path width represent an improvement and are based on empirical studies of crowd movement on travel paths as well as the data about the means of egress flow as a function of travel path width (Proulx 2002).

Flow models that look at the relationship between speed of movement and the population density of the evacuating stream of persons assume that:

- all persons start to evacuate at the same instant

- occupant flow will not involve any interruptions caused by decisions of the individuals involved
- all or most of the persons involved are free of disabilities that would significantly impede their ability to keep up with the movement of a group.

A methodology that adopts these assumptions and uses an effective width approach is described by Nelson and Mowrer in the SFPE Handbook (Nelson and Mowrer 2002). This methodology is based on hydraulic flow and effective width concepts. The main assumptions of this model are:

- the prime controlling factor will be either the stairways or the door discharging from them
- queuing will occur and therefore specific flow will be the maximum specific flow in some instances
- all occupants start egress at the same time
- the population will use all facilities in the optimum balance.

Network models make specific assumptions about the occupants:

- the evacuations would take place in an 'appropriate manner'
- all occupants will decide and commence evacuation at the same instant
- occupants will have an excellent knowledge of the building
- occupants will always select the shortest evacuation path.

These models are useful for large buildings with a large number of occupants and are also useful in demonstrating possible bottle-necks during evacuations. However, while the information obtained from these models can be used to test the effectiveness of possible evacuation routes, they fail to give a realistic indication of evacuation times as they omit all behavioural aspects of evacuation. A network optimisation model developed by Francis and Kisko (1982) determines an evacuation routing of the people that minimises the time to evacuate the building.

When used with sufficient levels of competency and provided with input based on well researched, published and evaluated data, the movement times calculated by most of these models can be used without having to resort to large safety factors.

There are a number of issues that should be taken into consideration in deciding which model or method to use and how to provide input to the model.

- The model or method to be used should be sufficiently sophisticated for the occupancy being investigated. A simple method or model used to analyse complex layouts and large populations will probably fail to identify specific problems such as bottlenecks and excessive queuing.
- The extent (i.e. to a safe area or to outside) and the nature (i.e. zone, staged, full) of the movement process should be decided upon during the FEB stage.
- The movement period calculations should be based on the characteristics of the design occupant group that is most likely to have the most significant impact on the overall movement process. Thus, their travel speed should be adopted as input to models. This may eliminate the need to adjust the final movement period value.
- The input regarding the building (i.e. the travel path lengths or widths) must reflect research findings such as the effective width concept.
- Using an expensive and highly sophisticated computer model does not guarantee accurate results. Thus, all output from models must be qualitatively or quantitatively reviewed and verified.

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Chapter 2.9

Fire Services Intervention

Sub-system F

Sub-system F (SS-F) is used to analyse the effects of the intervention activities of a fire service on a fire. This process enables estimates to be made of the events that comprise the intervention as well as the effectiveness of suppression activities.

This chapter describes a selection of methodologies that may be used in undertaking the analysis but does not preclude the use of other methodologies that might be chosen by the fire engineer.

Chapter 1.9 of Part 1 of these Guidelines describes the process by which fire service intervention analysis is typically undertaken.

Part 3 provides a selection of data that may be used in applying these, or other applicable, methodologies.

This chapter provides guidance on methodologies that may adopted for quantifying:

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

The components of the fire service intervention that will need quantification may be grouped under two main headings:

- pre- 'fire control and extinguishment' activities
- fire control and extinguishment

The first group of activities relates mostly to the series of events that take place from the time the fire service is notified to the time it is ready to attack the fire. The effect of fire service activities does not lend itself easily to quantification and many aspects of the procedure will need to be based on qualitative judgement rather than numerical calculations. The major tool available for practising engineers in Australia to conduct a fire service intervention evaluation is the Fire Brigade Intervention Model (FBIM) that was developed and produced by the Australian Fire Authorities Council (AFAC 2004).

FBIM also provides guidance on how to quantify fire control and extinguishment events and times. However, various other methods based on thermodynamics and heat transfer theory may be utilised for this purpose.

2.9.1 Fire Brigade Intervention Model (FBIM)

The performance objectives of many building codes require, amongst other things, that the design allow for fire service intervention. The Australasian Fire Authorities Council (AFAC) has developed a universal model that quantifies the time taken by a fire service to undertake its activities. The Fire Brigade Intervention Model (FBIM) is an event-based methodology that encapsulates fire service activities from time of notification to control and extinguishment. It has been developed primarily for use in a performance-based environment to quantify the functional role of a fire service.

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.

The FBIM assumes the following prioritised outcomes:

- the safety of building occupants who must be able to leave the building (or remain in a safe refuge accessible by fire fighters for rescue later) without being subjected to untenable conditions
- the protection of fire fighters who must be given a reasonable time to search for any trapped occupants, before conditions hazardous to their safety occur
- the protection of adjacent compartments and buildings from fire spread due to radiation, flame impingement, flying brands or structural collapse

To support these 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 and 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 AFAC 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.

2.9.1.1 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 that may be the site boundaries).

Fig 2.9.1.1 shows the FBIM flow charts and possible interactions between these charts. The heavy line denotes the primary charts associated with a building code that has no requirement for protecting the environment, the building or its contents.

2.9.1.2 FBIM application

The FBIM can be used as a whole or in part to generate information with respect to the following:

- the time taken for fire service personnel to reach a particular location in a building
- the water flow rate required for fire extinguishment or control that is necessary to compensate for deletion of a sprinkler system
- 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

2.9.2 Fire control and extinguishment

Chart 15 of FBIM (AFAC 2004) provides a methodology to calculate the amount and rate of water needed to be applied to fires with varying heat release rates. Various other methods based on heat transfer theory may be adopted to calculate these variables.

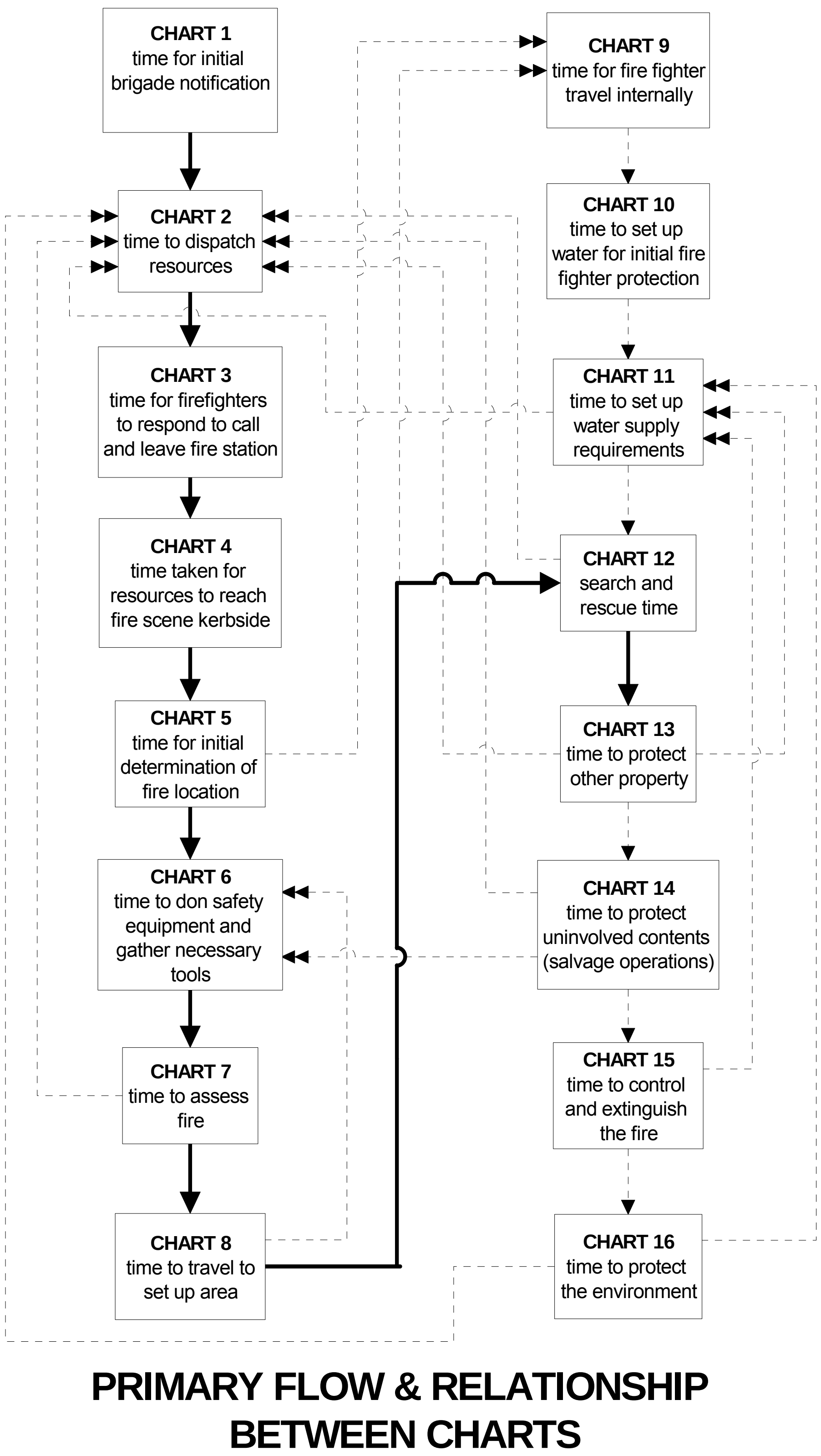

Figure 2.9.1.1 FBIM flow charts

2.9.3 References

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Part 3
Data

International
Fire Engineering
Guidelines

Table of Contents

These Guidelines have four parts each of which is a separate entity. For a detailed Table of Contents, refer to the beginning of each Part and each Chapter.

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Chapter 3.1

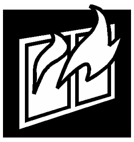
Overview

These Guidelines have four parts, each with its own table of contents. It has been designed for ease of use and cross-referencing with graphics that should be self-explanatory, for example:

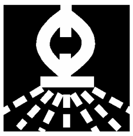
- **graphic identification** of sub-systems, as shown below:

Sub-system A
SS-A
Fire Initiation & Development & Control

Sub-system B
SS-B
Smoke Development & Spread & Control



Sub-system C
SS-C
Fire Spread & Impact & Control



Sub-system D
SS-D
Fire Detection, Warning & Suppression

Sub-system E
SS-E
Occupant Evacuation & Control

Sub-system F
SS-F
Fire Services Intervention

- **shaded boxes** that contain examples or commentary
- **abbreviated flow charts** in the margins with the relevant boxes shaded

Part 0 provides background information and guidance that is integral to an understanding of the entire Guideline.

Part 1 describes the process by which fire engineering is typically undertaken.

Part 2 describes a selection of methodologies that may be used in undertaking the fire engineering process.

This Part 3 provides a selection of data that may be used in applying the methodologies of Part 2 or other chosen methodologies. This does not preclude the use of other data that might be chosen by the fire engineer and that are acceptable to regulatory authorities or certifiers.

Caution should be used in applying data because it may not be relevant as a result of:

- **new methodologies**
- **new technologies**
- **new materials**
- **varying regulatory requirements**
- **cultural differences**
- **construction practices.**

The present compilation is in no way meant to be comprehensive and reflects the manner in which it was prepared (see below). It is envisaged that further material will be added over time as it is developed, recognised or made available.

The material selected at the time of writing is mainly that extracted from the FCRC Fire Engineering Guidelines 1996. In addition, some material from the FCRC research projects has been included.

Chapter 3.2
Probability of Fire Starts

This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapter 2.4 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.2.1 Probability data—fire starts

The following sets of data may be used for methodologies for which the probability of events occurring is required. However, caution should be used in applying this data as the probability of fire starts may have changed with new technologies and new materials. More recent statistical data on fire events may be obtained from relevant national and international publications.

Table 3.2.1a. Overall probability of fire starting in various types of occupancies: BSI (2001)

Occupancy	*Probability of starts per occupancy* Starts y^{-1}
Industrial	4.4×10^{-2}
Storage	1.3×10^{-2}
Offices	6.2×10^{-3}
Assembly entertainment	1.2×10^{-1}
Assembly non-residential	2.0×10^{-2}
Hospitals	3.0×10^{-1}
Schools	4.0×10^{-2}
Dwellings	3.0×10^{-3}

The data provided in Table 3.2.1a has been categorised independently of compartment size. However, the probability of a fire starting may be a function of building area. Where data are available on the number of fire starts per unit floor area, these should be used in preference to the generalised information presented in Table 3.2.1a. Table 3.2.1b contains information relating the frequency of fire starts to the floor area in the UK.

Table 3.2.1b. Probability of fire starting within given floor area for various types of occupancy BSI (2001).

Occupancy	*Probability of fire starting* Starts y^{-1} m^{-2} floor area
Offices	1.2×10^{-5}
Storage	3.3×10^{-5}
Public assembly	9.7×10^{-5}

Conversion factor:
$1m^2 \approx 10.8 ft^2$

The same UK document also advises that the probability of a fire starting in a building can be represented as follows (BSI 2001):

$$P_i = a\, A_F^{\ b}$$

where:

- P_i is the probability of a fire starting (in starts yr^{-1})
- A_F is the floor area of the enclosure (in m^2)
- a is a constant related to the occupancy
- b is a constant related to the occupancy

Table 3.2.1c gives values of the constants *a* and *b* for a number of different types of industrial premises.

Table 3.2.1c. Probability of fire starting in various types of occupancy of a given size BSI (2001)

Occupancy		*a*	*b*	*Probability of fire in building of floor area 1000 m^2 starts yr^{-1}*
All manufacturing industry		0.0017	0.53	0.066
Selected industries				
	Food, drink, tobacco	0.0011	0.60	0.069
	Chemical and allied	0.0069	0.46	0.165
	Mechanical engineering	0.0001	0.75	0.018
	Electrical engineering	0.0006	0.59	0.035
	Vehicle manufacture	0.0001	0.86	0.038
	Metal goods	0.0016	0.54	0.067
	Textiles	0.0075	0.35	0.084
	Paper, printing, publishing	0.00007	0.91	0.038
	Other manufacturing	0.0084	0.41	0.143

Results from Finland (Rahikainen and Keski-Rahkonen 1998) are shown in Figure 3.2.1a and Figure 3.2.1b. The occurrence of fire per unit floor area clearly decreases monotonically with increase in building size, but gross ignition probability for an entire building (Figure 3.2.1a) generally increases with floor area. The results below 100 m^2 would refer to small out-buildings, which will form a different population group from normally-occupied buildings.

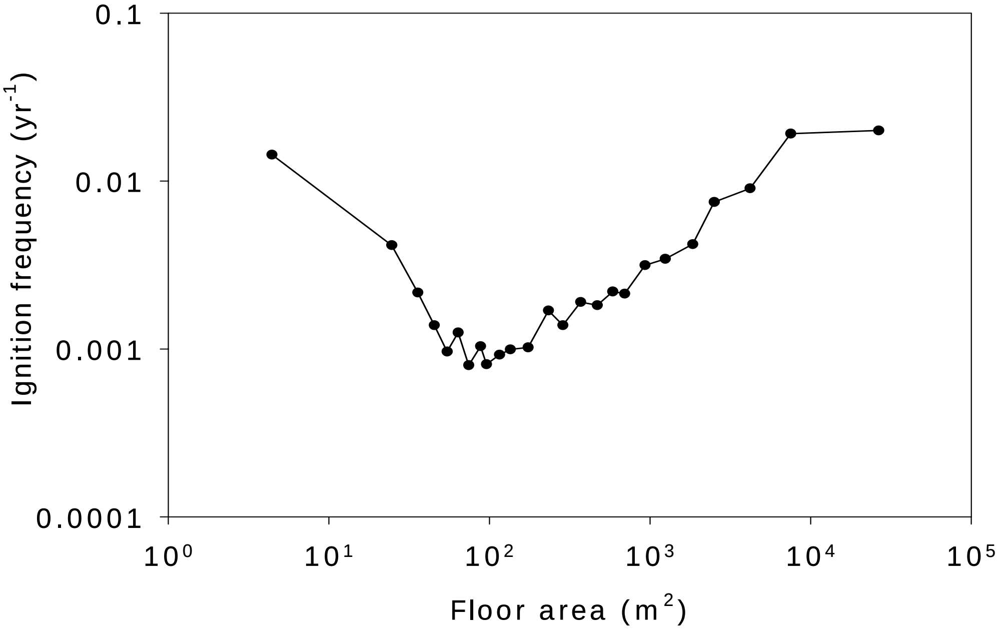


Figure 3.2.1a. Ignition frequency in Finnish buildings, as a function of floor area of building

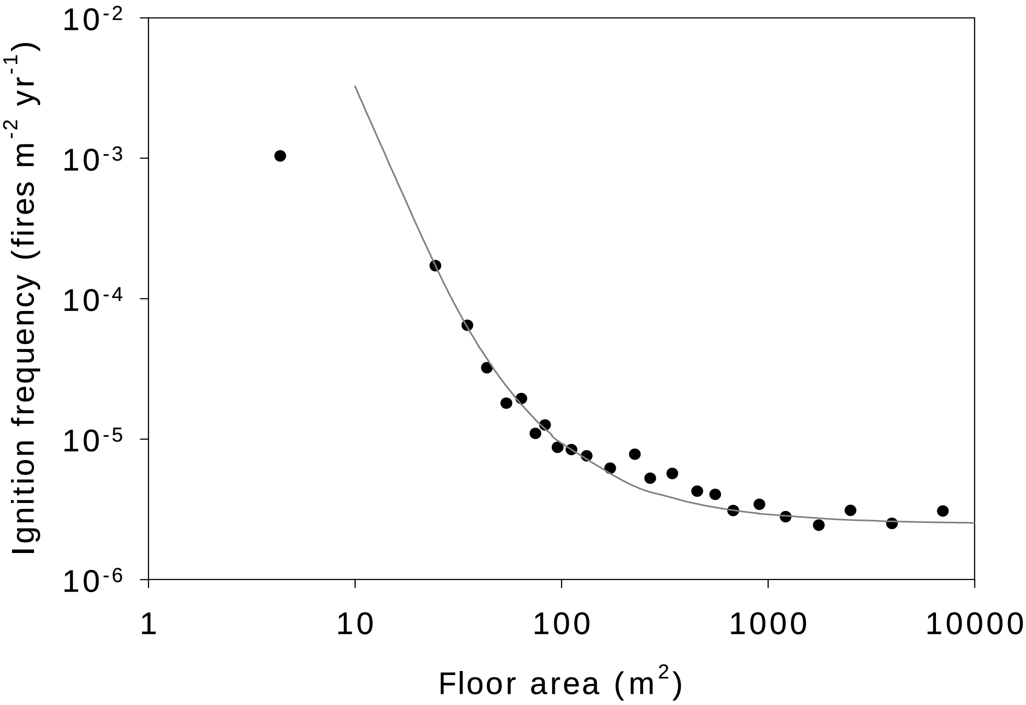


Figure 3.2.1b. Ignition frequency in Finnish buildings, normalized per unit floor area

Conversion factor:
$1m^2 \approx 10.8\ ft^2$

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Chapter 3.3

Properties of Materials and Products

This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapter 2.4 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.3.1 Ignitability

Ignition requires the presence of fuel, oxidizer and source of heat. In most environments, the second factor is assured, but the accidental or deliberate combination of fuel and source of heat is required to start a fire. The source of heat is often external, but a certain fraction of fires occur due to self-heating, wherein the source of heat is the chemical reactivity of the fuel itself. Fuel can be gaseous, liquid, or solid. A list of materials which, under certain circumstances, are capable of self-heating has been published by NFPA (NFPA 2003). Self-heating is a characteristic which not only depends on the chemical nature of the substance, but also on the size and shape of the aggregation. Quantitative methods for evaluating self-heating are given in the 'Ignition Handbook' (Babrauskas 2003).

With gaseous fuels, the safety strategy normally consists of avoidance of a concentration within the flammable limits of the fuel. In practice, this generally means keeping the concentration well below the lower flammability limit, since it is hard to devise a robust strategy of ensuring that a mixture above the upper flammability limit will not become diluted and enter the flammable region. If a fuel/oxidizer mixture is within the flammable region, extremely-weak sources of energy (millijoules) can typically suffice to cause ignition. Extensive tabulations of the energy required for ignition of various fuel-gas/air mixtures are available (Babrauskas 2003).

Liquid fuels generally present a similar safety issue to gases. If sufficient fuel is volatilised to cause the vapour/air mixture to be within its flammable region, very low energy ignition sources can suffice to ignite. Tabulations of flammability limits for a wide variety of liquid fuels have been published (Babrauskas 2003): a selection of data for some of the more common fuels is given in *Table 1*.

Table 1 Flammability limits, autoignition temperature, flash point and boiling point for some common gases and vapors

Substance	**LFL (vol%)**	**UFL (vol%)**	**AIT (ºC) in air**	**Flash point (ºC)**	**Boiling point (ºC)**
acetaldehyde	4.0	60	175	-38	21
acetic acid	5.4	16	465	43	118
acetone	2.6	12.8	465	-18	56
acetonitrile (methyl cyanide)	4.4	16	524	13	82
acetylene	2.5	100	305		-83
acrolein	2.8	31	278	-26	52
acrylonitrile (vinyl cyanide)	3.0	17	481	0	113
ammonia	15	28	651		-33
aniline	1.2	8.3	530	70	184
benzaldehyde	1.3	7.8	192	64	179
benzene	1.3	7.9	580	-11	80
1,3-butadiene	2.0	12	418	-76	-4.4
butane	1.8	8.4	408	-60	-0.6
1-butene (butylene)	1.6	10	384	-79	-6.3
carbon disulfide	1.3	50	100	-30	46
carbon monoxide	12.5	74	609		-192
chlorobenzene	1.4	7.1	674	29	132
chlorotrifluoroethylene	24.0	40.3			-28
cyanogen	6.6	32	850	-62	-22
cyclobutane	1.8	11.1	427e	-64	12
cycloheptane	1.1	6.7	155e	6	118

cyclohexane	1.3	7.8	259	-18	81
cyclopentane	1.5	9.4	385	-37	49
cyclopropane	2.4	10.4	498		-33
decaborane	0.2			80	213
decane	0.75	5.6	232	46	174
diethyl ether	1.9	36	195	-45	35
1,2-dimethoxyethane	1.9	18.7	202	-6	85
dimethoxymethane (formal; methyl formal; methylal)	2.2	13.8	237	-32	43
dimethyl acetylene (2-butyne)	1.4	41.8	323e	-31	27
dimethyl sulfoxide	2.6	28.5	215	95	189
p-dioxane (1,4 dioxane)	2.0	22	266	12	101
divinyl ether (vinyl ether)	1.7	27	360	<-30	28
n-dodecane	0.6	4.7	204	74	215
ethane	3.0	12.4	515	-135	-89
ethanol	3.3	19	365	13	79
ethyl acetate	2.2	11.5	427	-4	77
ethylene	2.7	36	449	-136	-104
ethylene glycol	3.5	21.6	400	114	198
formaldehyde	7.0	73	430	-19	-19
furan	2.3	14.3		-36	31
heptane	1.05	6.7	223	-4	98
1-heptanol	1.0	7.2	282e	73	176
hexane	1.2	7.4	223	-23	69
hydrazine	4.7	100	270	38	114
hydrogen	4.0	75	520		-253
hydrogen cyanide	5.6	40	538	-18	26
hydrogen sulfide	4.0	44	260		-61
iso-octane	0.95	6	415	-12	99
methane	5.0	15	640	-188	-164
methanol	6.7	36	470	11	65
methyl acetylene (propyne)	1.7	12.5	340		-24
methyl bromide	10	15	537	-40	3.6
methyl chloride	10.7	17.4	632	-40	-24
methylene chloride	15.9	19.1	556		40
nitrobenzene	1.8	9.1	482	87	211
nitromethane	7.3	22.2	419	35	101
octane	0.95	6.5	220	14	126
pentane	1.4	7.8	260	-49	36
phosphine	1.0		100		-88
propane	2.1	9.5	500	-104	-42
propionaldehyde (propanal)	2.9	17	207	-9	49
propylene	2.4	11	458	-108	-47
propylene oxide	2.8	37	464	-37	34
silane	1.0	100	-100		-112
styrene	1.1	6.1	490	31	145
tetrahydrofuran	2.0	11.8	321	-14	66
toluene	1.2	7.1	480	4	111
2,4-toluene diisocyanate	0.9	9.5		121	251
1,1,1-trichloroethane (methyl chloroform)	6.8	10.5	485		74
trichloroethylene	8	10.5	419	32	87
vinyl acetate	2.6	13.4	427	-8	72
vinyl chloride	3.6	33	472		-14
vinyl toluene	0.8	11	494	49	170

p-xylene	1.1	6.5	496	27	138

Solid fuels present a fire engineering problem which is generally less difficult. Most solids require temperatures in the several-hundred-degree-C range for ignition, as shown in Table 2 (Babrauskas 2003). Wood is the material that is probably the single most-frequently encountered ignitable substance in fire engineering. Its ignition behaviour is complex and not yet fully quantified. If heated at the lowest possible heat flux capable of causing ignition, a temperature of 250ºC suffices for ignition, under either piloted or autoignition conditions (Babrauskas 2003). Raising the applied heat flux causes the ignition temperature to increase, as indicated by the range of values shown in Table 2.

Table 2 *Ignition temperatures of various solids grouped by category*

Category of solid	**Ignition temperature (ºC)**	
	Piloted	**Auto ignition**
thermoplastics	369 ± 73	457 ± 63
thermosetting plastics	441 ± 100	514 ± 92
elastomers	318 ± 42	353 ± 56
halogenated plastics	382 ± 70	469 ± 79
wood, paper, cotton	250 - 365	250 - 400

In many cases, it is more convenient to consider the engineering requirements from the viewpoint of the heat flux which must be incident upon the solid material to cause ignition, rather than the temperature to which its surface must rise. *Table 3* contains a listing of these values for some common materials (Babrauskas 2003). Most studies on ignition of wood have involved exposures of 20 min or less. But a day-long exposure gave the 4.3 kW m^{-2} value shown in the Table, and this should be used for guidance when exposure times involve a few hours or days. The ignition response of wood materials subjected to heating for months-to-years is governed by its self-heating behaviour. For self-heating materials, there is not a unique ignition temperature: instead, the maximum temperature at which such materials can be stored without incurring the risk of ignition is dependent on the size of the aggregation. For wood materials subjected to such protracted heating, a maximum temperature of 77ºC has been recommended (Matson, Dufour, and Breen 1959); this value has been confirmed in recent research (Babrauskas 2003).

Table 3 Heat flux required for radiant ignition of plastics and wood

Material	**Minimum flux for ignition (kW m^{-2})**	
	Piloted	**Autoignition**
ABS	< 20	
chlorosulfonated polyethylene	16	
EVA	13 – 16	
nylon 6	< 20	
phenolic, foam	22 – 45	
PMMA	8 – 11	
polycarbonate		47
polyester	< 20	
polyetheretherketone	35	
polyethylene	17	
polyisocyanurate	< 10	23 – 24
polyoxymethylene	11	
polypropylene	11	
polystyrene, foam	15 – 25	27
polystyrene, solid	14	
polytetrafluoroethylene	33	
polyurethane, flexible	< 10 to 16	16
polyurethane, flexible FR	< 10 to 21	20
polyurethane, rigid	< 10	22 – 26
polyurethane, rigid FR		26

PVC: electrical conduit	15	35
PVC: flexible floor covering	< 10	35
PVC: floor tile	22	55
PVC: misc.	8	
PVC: misc., FR	11	
wood—heated for less than 30 min	12	20
wood—heated for several hours	4.3	4.3

Conversion factors:

1kW/m^2 ≈ 317 BTU/ft^2.hr

^{o}C ≈ 1.8^{o}F+32

Most of the data concerning the product yields from burning materials has been obtained under well-ventilated burning conditions. These conditions may not apply to many building fires. Data on product yields for well-ventilated burning may be obtained from such sources as Tewarson (2002) and BSI (2001).

Poorly ventilated fires may produce species yields many times greater than well-ventilated fires. The production of carbon monoxide is especially dependent on the ventilation conditions. In post-flashover fires, studies (Babrauskas 1995) have shown that the yield of CO can generally be approximated as being 0.2 g CO produced/g fuel lost, irrespective of the test results for the material under well-ventilated conditions.

3.3.2 Calorific values and efficiency of combustion

Typical calorific values of various fuels, which may be used in the calculation of fire load densities, are provided in Table 3.3.3 (CIB 1983). A large tabulation has been published by NFPA (NFPA 2003).

Table 3.3.2. Calorific values of typical materials

Gases	*Calorific value* (MJ/kg)
Acetylene	48
Butane	46
Carbon monoxide	10
Hydrogen	120
Propane	46
Methane	50
Ethanol	27

Conversion factor:1MJ/kg ≈ 430 Btu/lb

Liquids	*Calorific value* (MJ/kg)
Gasoline	44
Diesel oil	41
Linseed oil	39
Methanol	20
Paraffin oil	41
Spirits	29
Tar	38
Benzene	40
Benzyl alcohol	33
Ethyl alcohol	27
Isopropyl alcohol	31

Conversion factor: 1MJ/kg ≈ 430 Btu/lb

Solids	*Calorific value* (MJ/kg)
Anthracite	34
Asphalt	41
Bitumen	42
Cellulose	17
Charcoal	35
Clothes	19
Coal, coke	31
Cork	29
Cotton	18
Grain	17
Grease	41
Kitchen refuse	18
Leather	19
Linoleum	20
Paper, cardboard	17
Paraffin wax	47
Foam rubber	37
Rubber isoprene	45
Rubber tyre	32
Silk	19
Straw	16
Wood	18
Wool	23
Particle board	18

Conversion factor:
1MJ/kg ≈ 430 Btu/lb

Plastics	*Calorific value* (MJ/kg)
ABS	36
Acrylic	28
Celluloid	19
Epoxy	34
Melamine resin	18
Phenol formaldehyde	29
Polyester	31
Polyester fibre reinforced	21
Polyethylene	44
Polystyrene	40
Polyisocyanurate foam	24
Polycarbonate	29
Polypropylene	43
Polyurethane	23
Polyurethane foam	26
Polyvinyl chloride	17
Urea formaldehyde	15
Urea formaldehyde foam	14

Conversion factor:
1MJ/kg ≈ 430 Btu/lb

3.3.3 References

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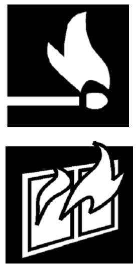
Chapter 3.4

Fire Loads



This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapters 2.4 or 2.6 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.4.1 Fire load densities

It should be noted that in some cases the data in the tables below are conflicting and this reflects variability that occurs from country to country and the different survey methodologies employed.

The following (variable) fire load densities in Table 3.4.1a are taken from studies undertaken in Switzerland during the period 1967–69 and are defined as density per unit floor area (MJ/m^2). These data are reproduced in the Warrington-BCC document 'Fire resistant barriers and structures' (England *et al.* 2000).

Note that for the determination of the variable fire load of storage areas, the values given in the following table have to be multiplied by the height of storage in metres. Areas and aisles for transportation have been taken into consideration in an averaging manner.

The data from this source were compared with data given in various sources. This comparison results in the following suggestions.

- For well-defined occupancies that are rather similar or with very limited differences in furniture and stored goods, for example, dwellings, hotels, hospitals, offices and schools, the following estimates may suffice:

Coefficient of variation	= 30%–50% of the given average value
90% fractile value	= (1.35–1.65) x average value
80% fractile value	= (1.25–1.5) x average value
Isolated peak values	= 2 x average value

- For occupancies that are rather dissimilar or with larger differences in furnishings and stored goods, for example, shopping centres, department stores and industrial occupancies, the following estimates are tentatively suggested:

Coefficient of variation	= 50%–80% of given average value
90% fractile value	= (1.65–2.0) x average value
80% fractile value	= (1.45–1.75) x average value
Isolated peak values	= 2.5 x average value

However, caution should be used in applying this data as fire loads have changed with new technologies and new materials. Papers such as those by Korpela and Keski-Rahkonen (2000) should also be consulted.

Table 3.4.1a. Fire load densities

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Academy	300	
Accumulator forwarding	800	
Accumulator mfg	400	800
Acetylene cylinder storage	700	
Acid plant	80	
Adhesive mfg	1000	3400
Administration	800	
Adsorbent plant for combustible vapours	>1700	
Aircraft hangar	200	
Airplane factory	200	
Aluminium mfg	40	
Aluminium processing	200	
Ammunition mfg	special	
Animal food preparing, mfg	2000	3300
Antique shop	700	
Apparatus forwarding	700	
Apparatus mfg	400	
Apparatus	600	
Apparatus testing	200	
Arms mfg	300	
Arms sales	300	
Artificial flower mfg	300	200
Artificial leather mfg	1000	1700
Artificial leather processing	300	
Artificial silk mfg	300	1100
Artificial silk processing	210	
Artificial stone mfg	40	
Asylum	400	
Authority office	800	
Awning mfg	300	
Bag mfg (jute. paper. plastic)	500	
Bakery	200	
Bakery. sales	300	
Ball bearing mfg	200	
Bandage mfg	400	
Bank, counters	300	
Bank offices	800	
Barrel mfg, wood	1000	800
Basement, dwellings	900	
Basket ware mfg	300	200
Bed sheeting production	500	1000
Bedding plant	600	
Bedding shop	500	
Beer mfg, brewery	80	
Beverage mfg, non-alcoholic	80	
Bicycle assembly	200	400
Biscuit factories	200	
Biscuit mfg	200	
Bitumen preparation	800	3400
Blind mfg, venetian	800	300
Blueprinting firm	400	

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Boarding school	300	
Boat mfg	600	
Boiler house	200	
Bookbinding	1000	
Book-store	1000	
Box mfg	1000	600
Brick plant, burning	40	
Brick plant, clay preparation	40	
Brick plant, drying kiln with metal grates	40	
Brick plant, drying kiln with wooden grates	1000	
Brick plant, drying room with metal grates	40	
Brick plant, drying room with wooden grates	400	
Brick plant, pressing	200	
Briquette factories	1600	
Broom mfg	700	400
Brush mfg	700	800
Butter mfg	700	4000
Cabinet making (without wood yard)	600	
Cable mfg	300	600
Cafe	400	
Camera mfg	300	
Candle mfg	1300	22400
Candy mfg	400	1500
Candy packing	800	
Candy shop	400	
Cane products mfg	400	200
Canteen	300	
Car accessory sales	300	
Car assembly plant	300	
Car body repairing	150	
Car paint shop	500	
Car repair shop	300	
Car seat cover shop	700	
Cardboard box mfg	800	2500
Cardboard mfg	300	4200
Cardboard products mfg	800	2500
Carpenter shed	700	
Carpet dyeing	500	
Carpet mfg	600	1700
Carpet store	800	
Cartwright's shop	500	
Cast iron foundry	400	800
Celluloid mfg	800	3400
Cement mfg	1000	
Cement plant	40	
Cement products mfg	80	
Cheese factory	120	
Cheese mfg (in boxes)	170	
Cheese store	100	

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Chemical plants (rough average)	300	100
Chemist's shop	1000	
Children's home	400	
China mfg	200	
Chipboard finishing	800	
Chipboard pressing	100	
Chocolate factory, intermediate storage	6000	
Chocolate factory, packing	500	
Chocolate factory, tumbling treatment	1000	
Chocolate factory, all other specialities	500	
Church	200	
Cider mfg (without crate storage)	200	
Cigarette plant	3000	
Cinema	300	
Clay, preparing	50	
Cloakroom, metal wardrobe	80	
Cloakroom, wooden wardrobe	400	
Cloth mfg	400	
Clothing plant	500	
Clothing store	600	
Coal bunker	2500	
Coal cellar	10500	
Cocoa processing	800	
Cold storage	2000	
Composing room	400	
Concrete products mfg	100	
Condiment mfg	50	
Congress hall	600	
Contractors	500	
Cooking stove mfg	600	
Coopering	600	
Cordage plant	300	600
Cordage store	500	
Cork products mfg	500	800
Cosmetic mfg	300	500
Cotton mills	1200	
Cotton wool mfg	300	
Cover mfg	500	
Cutlery mfg (household)	200	
Cutting-up shop, leather, artificial leather	300	
Cutting-up shop, textiles	500	
Cutting-up shop, wood	700	
Dairy	200	
Data processing	400	
Decoration studio	1200	2000
Dental surgeon's laboratory	300	
Dentist's office	200	
Department store	400	

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Distilling plant, combustible materials	200	
Distilling plant, incombustible materials	50	
Doctor's office	200	
Door mfg, wood	800	1800
Dressing, textiles	200	
Dressing, paper	700	
Dressmaking shop	300	
Dry-cell battery	400	600
Dry cleaning	300	
Dyeing plant	500	
Edible fat forwarding	900	
Edible fat mfg	1000	18900
Electric appliance mfg	400	
Electric appliance repair	500	
Electric motor mfg	300	
Electrical repair shop	600	
Electrical supply storage H < 3 m	1200	
Electro industry	600	
Electronic device mfg	400	
Electronic device repair	500	
Embroidery	300	
Etching plant glass/metal	200	
Exhibition hall, cars including decoration	200	
Exhibition hall, furniture including decoration	500	
Exhibition hall, machines including decoration	80	
Exhibition of paintings including decoration	200	
Explosive industry	4000	
Fertiliser mfg	200	200
Filling plan/barrels		
liquid filled and/or barrels incombustible	<200	
liquid filled and/or barrels combustible		
Risk Class I - IV	> 3400	
Risk Class V	> 1700	
Filling plan/small casks:		
liquid filled and casks incombustible	<200	
Risk Class I - V	< 500	
Finishing plant, paper	500	
Finishing plant, textile	300	
Fireworks mfg	special	2000
Flat	300	
Floor covering mfg	500	6000
Floor covering store	1000	
Flooring plaster mfg	600	
Flour products	800	
Flower sales	80	

Type of occupancies	Fabrication [MJ/m^2]	Storage [MJ/m^2/m]
Fluorescent tube mfg	300	
Foamed plastics fabrication	3000	2500
Foamed plastics processing	600	800
Food forwarding	1000	
Food store	700	
Forge	80	
Forwarding, appliances partly made of plastic	700	
Forwarding, beverages	300	
Forwarding, cardboard goods	600	
Forwarding, food	1000	
Forwarding, furniture	600	
Forwarding, glassware	700	
Forwarding, plastic products	1000	
Forwarding, printed matter	1700	
Forwarding, textiles	600	
Forwarding, tinware	200	
Forwarding, varnish, polish	1300	
Forwarding, woodware (small)	600	
Foundry (metal)	40	
Fur, sewing	400	
Fur store	200	
Furniture exhibition	500	
Furniture mfg (wood)	600	
Furniture polishing	500	
Furniture store	400	
Furrier	500	
Galvanic station	200	
Gambling place	150	
Glass blowing plant	200	
Glass factory	100	
Glass mfg	100	
Glass painting	300	
Glass processing	200	
Glassware mfg	200	
Glassware store	200	
Glazier's workshop	700	
Gold plating (of metals)	800	
Goldsmith's workshop	200	
Grain mill, without storage	400	
Gravestone carving	50	
Graphic workshop	1000	
Greengrocer's shop	200	
Hairdressing shop	300	
Hardening plant	400	
Hardware mfg	200	
Hardware store	300	
Hat mfg	500	
Hat store	500	
Heating equipment room, wood coal firing	300	
Heat sealing of plastics	800	
High-rise office building	800	

Type of occupancies	Fabrication [MJ/m^2]	Storage [MJ/m^2/m]
Homes	500	
Homes for aged	400	
Hosiery mfg	300	1000
Hospital	300	
Hotel	300	
Household appliances, mfg	300	200
Household appliances, sales	300	
Ice cream plant (including packaging)	100	
Incandescent lamp plant	40	
Injection moulded parts mfg (metal)	80	
Injection moulded parts mfg (plastic)	500	
Institution building	500	
Ironing	500	
Jewellery mfg	200	
Jewellery shop	300	1300
Joinery	700	
Joiners (machine room)	500	
Joiner (workbench)	700	
Jute, weaving	400	1300
Laboratory, bacteriological	200	
Laboratory, chemical	500	
Laboratory, electric, electronic	200	
Laboratory, metallurgical	200	
Laboratory, physics	200	
Lacquer forwarding	1000	
Lacquer mfg	500	2500
Large metal constructions	80	
Lathe shop	600	
Laundry	200	
Leather goods sales	700	
Leather product mfg	500	
Leather, tanning, dressing, etc.	400	
Library	2000	2000
Lingerie mfg	400	800
Liqueur mfg	400	800
Liquor mfg	500	
Liquor store	700	
Loading ramp, including goods (rough average)	800	
Lumber room for miscellaneous qoods	500	
Machinery mfg	200	
Match plant	300	800
Mattress mfg	500	500
Meat shop	50	
Mechanical workshop	200	
Metal goods mfg	200	
Metal grinding	80	
Metal working (general)	200	

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Milk, condensed, evaporated mfg	200	9000
Milk, powdered, mfg	200	10500
Milling work, metal	200	
Mirror mfg	100	
Motion picture studio	300	
Motorcycle assembly	300	
Museum	300	
Musical instrument sales	281	
News stand	1300	
Nitrocellulose mfg	Special	1100
Nuclear research	2100	
Nursery school	300	
Office, business	800	
Office, engineering	600	
Office furniture	700	
Office, machinery mfg	300	
Oilcloth mfg	700	1300
Oilcloth processing	700	2100
Optical instrument mfg	200	200
Packing, incombustible goods	400	
Packing material, industry	1600	3000
Packing, printed matters	1700	
Packing, textiles	600	
Packing, all other combustible goods	600	
Paint and varnish, mfg	4200	
Paint and varnish, mixing plant	2000	
Paint and varnish shop	1000	
Painter's workshop	500	
Pain shop (cars, machines, etc.)	200	
Paint shop (furniture, etc.)	400	
Paper mfg	200	10000
Paper processing	800	1100
Parking building	200	
Parquetry mfg	2000	1200
Perambulator mfg	300	800
Perambulator shop	300	
Perfume sale	400	
Pharmaceutical's, packing	300	800
Pharmaceutical mfg	300	800
Pharmacy (including storage)	800	
Photographic laboratory	100	
Photographic store	300	
Photographic studio	300	
Picture frame mfg	300	
Plaster product mfg	80	
Plastic floor tile mfg	800	
Plastic mfg	2000	5900
Plastic processing	600	
Plastic products fabrication	600	

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Plumber's workshop	100	
Plywood mfg	800	2900
Polish mfg	1700	
Post office	400	
Potato, flaked, mfg	200	
Pottery plant	200	
Power station	600	
Precision instrument mfg: (containing plastic parts)	200	
(without plastic parts)	100	
Printing, composing room	300	
Printing, ink mfg	700	3000
Printing, machine hall	400	
Printing office	1000	
Radio and TV mfg	400	
Radio and TV sales	500	
Radio studio	300	
Railway car mfg	200	
Railway station	800	
Railway workshop	800	
Record player mfg	300	
Record repository, documents	4200	
Refrigerator mfg	1000	300
Relay mfg	400	
Repair shop, general	400	
Restaurant	300	
Retouching department	300	
Rubber goods mfg	600	5000
Rubber goods store	800	
Rubber processing	600	5000
Saddlery mfg	300	
Safe mfg	80	
Salad oil forwarding	9oo	
Salad oil mfg	1000	18,900
Sawmill (without wood yard)	400	
Scale mfg	400	
School	300	
Scrap recovery	800	
Seed-store	600	
Sewing machine mfg	300	
Sewing machine store	300	
Sheet mfg	100	
Shoe factory, forwarding	600	
Shoe factory, mfg	500	
Shoe polish mfg	800	2100
Shoe repair with manufacture	700	
Shoe store	500	
Shutter mfg	1000	
Silk spinning (natural silk)	300	
Silk weaving (natural silk)	300	
Silverwares	400	
Ski mfg	400	1700
Slaughter house	40	

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Soap mfg	200	4200
Soda mfg	40	
Soldering	300	
Solvent distillation	200	
Spinning mill, excluding garneting	300	
Sporting goods store	800	
Spray painting, wood prods.	500	
Stationery store	700	
Steel furniture mfg	300	
Stereotype plate mfg	200	
Stone masonry	40	
Storeroom (workshop storerooms etc.)	1200	
Synthetic fibre mfg	400	
Synthetic fibre processing	400	
Synthetic resin mfg	3400	4200
Tar-coated paper mfg	1700	
Tar preparation	800	
Telephone apparatus mfg	400	200
Telephone exchange	80	
Telephone exchange mfg	100	
Test room, electric app.	200	
Test room, machinery	100	
Test room, textiles	300	
Theatre	300	
Tin can mfg	100	
Tinned goods mfg	40	
Tinware mfg	120	
Tyre mfg	700	1800
Tobacco products mfg	200	2100
Tobacco shop	500	
Tool mfg	200	
Toy mfg (combustible)	100	
Toy mfg (incombustible)	200	
Toy store	500	
Tractor mfg	300	
Transformer mfg	300	
Transformer winding	600	
Travel agency	400	
Turnery (wood working)	500	
Turning section	200	
TV studio	300	
Twisting shop	250	
Umbrella mfg.	300	400
Umbrella store	300	
Underground garage. private	>200	
Underground garage, public	<200	
Upholstering plant	500	
Vacation home	500	
Varnishing, appliances	80	
Varnishing, paper	80	

Type of occupancies	Fabrication [MJ/m²]	Storage [MJ/m²/m]
Vegetable, dehydrating	1000	400
Vehicle mfg, assembly	400	
Veneering	500	2900
Veneer mfg	800	4200
Vinegar mfg	80	100
Vulcanising plant (without storage)	1000	
Waffle mfg	300	1700
Warping department	250	
Washing agent mfg	300	200
Washing machine mfg	300	40
Watch assembling	300	40
Watch mechanism mfg	40	
Watch repair shop	300	
Watch sales	300	
Water closets	~ 0	
Wax products forwarding	2100	
Wax products mfg	1300	2100
Weaving mill (without carpets)	300	
Welding shop (metal)	80	
Winding room	400	
Winding, textile fibres	600	
Window glass mfg	700	
Window mfg (wood)	800	
Wine cellar	20	
Wine merchant's shop	200	
Wire drawing	80	
Wire factory	800	
Wood carving	700	
Wood drying plant	800	
Wood grinding	200	
Wood pattern making shop	600	
Wood preserving plant	3000	
Youth hostel	300	

Conversion factors:

1MJ ≈ 0.948 BTU
$1m^2 \approx 10.8 ft^2$
1m ≈ 3.28 ft

Further fire load densities for broad occupancy groupings are provided in Table 3.4.1b (CIB 1983). The values given in the table include only the variable fire loads (i.e. building contents). If significant quantities of combustible materials are used in the building construction this should be added to the variable fire load to give the total fire load.

The CIB compilation emphasises that, for design purposes, fire load density cannot prudently be chosen at the mean level—this would provide a negative safety factor for all values greater than the mean. At least the 95% fractile should be selected, although in some cases even higher values will be appropriate.

Table 3.4.1b. Fire load density in different occupancies

Densities in mega-joules per square metre				
Occupancy	*Mean* (MJ/m^2)	*Percent fractile* *****		
		80	90	95
Dwelling	780	870	920	970
Hospital	230	350	440	520
Hospital storage	2000	3000	3700	4400
Hotel bedroom	310	400	460	510
Offices	420	570	670	760
Shops	600	900	1100	1300
Manufacturing	300	470	590	720
Manufacturing and Storage[+] <150kg m^{-2}	1180	1800	2240	2690
Libraries	1500	2250	2550	---
Schools	285	360	410	450

Conversion factors:

1MJ ≈ 0.948 BTU
$1m^2 \approx 10.8 ft^2$

* The percent fractile is the value that is not exceeded in that percent of the rooms or occupancies.
[+] Storage of combustible materials.

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Chapter 3.5

Smoke Control Effectiveness

This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapter 2.5 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.5.1 Probability of successful operation

Techniques for smoke control exemplify the principle that the greater the complexity, the lesser the reliability.

In examining or gathering data concerning reliability, it is essential to define the 'function expected' used in determining whether an item of equipment has performed. This is particularly important when the reliability data refers to systems comprising many components and the failure of individual components may or may not reflect total failure of the system.

System reliability determinations can be very complex and are hindered by a dearth of data concerning the performance of systems or components. Some examples and data may be found from such sources as Klote and Milke (2002), Lees (1994), Milke and Klote (1998), Modarres and Joglar-Billoch (2002), and Morgan et al (1999).

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Chapter 3.6

Fire Severity and Spread through Separations

This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapter 2.6 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.6.1 Fire severity

Data on fuel load densities for various occupancies and calorific values of some typical fuels required for fire severity determinations may be obtained from Chapters 3.3 and 3.4 respectively of these Guidelines or other literature sources.

3.6.2 Full-scale or near full-scale experiments

Realistic data may be obtained from full-scale tests. It is essential to determine the extent to which the test data is applicable to the scenario being assessed.

Various full-scale or near full-scale experiments have been performed using timber cribs and other typical materials in realistic compartments, for example, studies on cars in car parks carried out in countries including the UK (Butcher *et al.* 1967), the USA (Gewain 1973), and Australia (Bennetts *et al.* 1985,1988), and Australian studies on office fires (Thomas *et al.* 1989a,b, 1992). These and similar experiments provide data that may be used in comparable situations for determining fire severity.

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Chapter 3.7

Effectiveness of Fire Alarm and Suppression

This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapter 2.7 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.7.1 Probabilities of detector / sprinkler activation

The rate of smoke detector malfunction has been estimated at 1.2 x 10^{-6}/hr (Steciak and Zalosh 1992). Eighteen months from the time of installation 7% of domestic smoke detectors in England and Wales were found to be not working; after 36 months this had risen to 11%.

The failure rate for new sprinkler heads to operate correctly has been estimated at 3.1 x 10^{-2} and for old sprinklers at 5.1 x 10^{-2} (Nash and Young 1991). With regard to a sprinkler system in an office building the probability of failure of the system has been estimated to be 0.0184 (Thomas *et al*. 1992).

3.7.2 Sensitivity of smoke detectors

The minimum levels of sensitivity required by AS1603.2 (SA 1997) are given in Table 3.7.2 for three sensitivity classes of detectors.

Table 3.7.2. Test limits for smoke detectors

Sensitivity class	*Detector type*		
	Photo-electric (optical)		*Ionisation*
	% / m	O.D. (db/m)	MIC_x
Normal	12–20	0.55–0.97	0.35–0.55
High	3–12	0.13–0.55	0.1–0.35
Very high	0–3	0–0.13	0–0.1

Conversion factors:
1m ≈ 3.28 ft
0.35 MIC_x ≈ 20 %/m ≈ 0.97 db/m
0.55 MIC_x ≈ 40 %/m ≈ 2.2 db/m

These test limits for the two types of detectors and three sensitivity classes are based on response in a standard smouldering fire. Similar limits would apply for photo-electric (optical) detectors in a flaming fire.

For flaming fires, ionisation detectors would normally operate before photo-electric detectors but for conservative design, the upper figures for each class of photo-electric (optical) detector should be used to predict time of operation.

Detectors tested to other procedures may not yield the same results as in the AS1603.2 procedure and Table 3.7.3 should be used only in the context of AS1603.2.

3.7.3 Probabilities of automatic suppression

Data are available from BHP (Thomas *et al*. 1992) based on fault tree analysis of sprinkler systems.

Data on successful control of fires are provided by Marryatt (1988), who concludes that control is achieved in over 99% of fires in sprinklered buildings. The statistics provide some indication of the probability that a fire would be controlled by one or more sprinkler heads (see Table 3.7.3). His compilation is only relevant to the Australian context and should not be extrapolated to other countries where different standards prevail.

Table 3.7.1. Percentage of fires controlled by one or more sprinklers (Marryatt 1988)

Number of heads required for control	*Percentage*
1	65
2-5	27
6-10	4.3
>10	3.7

For the purposes of these data the definition of control that was used was that the sprinklers would extinguish the fire or would have extinguished the fire without the intervention of fire brigade activities. Fires in buildings in which there were sprinklers but they failed to operate, or water supplies were not available, are not included and therefore the data may not reflect overall reliability of sprinkler systems.

For a halon system in a computer facility the mean probabilities of failure of the system to protect against fire damage for various scenarios has been estimated at 0.05 for an electrical cable fire, 0.13 for a waste-paper fire and 0.08 for a fire outside the compartment of interest (Steciak and Zalosh 1992).

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Chapter 3.8

Occupant Response and Evacuation

This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapter 2.8 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.8.1 Sources of data

There are some key resource materials that all professionals practising fire engineering should have access to in order to conduct evaluations involving human behaviour in fires.

Proceedings of the following conferences and symposia provide valuable data and information:

- 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

Papers of interest in the area of human behaviour in fire are regularly published in journals such as:

- *Fire & Materials*, Elsevier, Netherlands
- *Fire Safety Journal*, Elsevier, Netherlands
- *Fire Technology*, NFPA, USA
- *International Journal on Performance Based Fire Codes*, Hong Kong Polytechnic Institute, Hong Kong

A number of professional and academic organisations may also prove useful as sources of various data. Some of those organisations are listed below:

- CSIRO, Fire Science and Technology Laboratories, Australia
- Fire Protection Association, UK
- University of Maryland, USA
- NFPA, National Fire Protection Association, USA
- NRCC, National Research Council of Canada, Canada
- Scientific Services Laboratory—AGAL, Australia
- SFPE, Society of Fire Protection Engineers, USA
- Technical Research Center of Finland (VTT), Finland
- University of Canterbury, New Zealand
- University of Greenwich, UK
- University of Lund, Sweden
- University of Ulster, UK
- Victoria University of Technology, Australia
- Worcester Polytechnic Institute, Centre for Fire Safety Studies

There are a number of web sites where professionals can have access to various articles, reports and dissertations. These include:

- Australian Building Codes Board (Australia)—www.abcb.gov.au
- LUND University (Sweden)—www.brand.lth.se
- NIST BFRL (USA)—www.bfrl.nist.gov

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Chapter 3.9

Fire Services Intervention

This chapter of Part 3 provides a selection of data that may be used in applying the methodologies in Chapter 2.9 or other applicable methodologies. Other data may be used in an evaluation at the discretion of the fire engineer.

3.9.1 Data for pre-fire control and extinguishment activities

The most reliable source for this data is the fire services. The Fire Brigade Intervention Model—FBIM (AFAC 2004) offers a series of tables and graphs that provide data on various stages of fire services intervention. The data is statistically interpreted with tabulated mean and standard deviations for each sub-activity. In assessing fire service intervention it is recommended that the relevant technical department be contacted for confirmation of FBIM data and outputs. The numerical values have been prepared solely from Australian data. However, this is a unique effort and no other country has thus far been able to compile a quantitative guide. Thus, the values cited may have at least a semi-quantitative utility in other locales.

3.9.2 Fire control and extinguishment

The study by Särdqvist (1996) is the best reference for a theoretical study on the requirements of water (or other media) for fire extinguishment. A theoretical analysis is helpful in establishing a lower-bound limit, but actual values are best derived from studies on performance in real fires. Chart 15 of FBIM (AFAC 2004) provides data on the amount and rate of water that needs to be applied to fires with varying heat release rates. Various other heat transfer literature may be searched to obtain similar data.

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