Application of fire safety engineering principles to the design of buildings —

Part 0: Guide to design framework and fire safety engineering procedures

ICS 13.220.01

Confirmed
December 2011

British Standards

Committees responsible for this Published Document

The preparation of this British Standard was entrusted by FSH/24, Fire precautions in buildings, to Subcommittee FSH/24/1, upon which the following bodies were represented:

BASA — British Automatic Sprinkler Association

BRE/LPC Laboratories

DETR

Fire Safety Development Group

Home Office

Institute of Building Control

IFE — Institute of Fire Engineers

London Fire and Emergency Planning Authority

NHBC — National House-Building Council

Nuclear Industry Fire Safety

Fire Brigades Union

Timber Research and Development Association

This Published Document, having been prepared under the direction of the Health and Environment Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on

23 September 2002

The following BSI references relate to the work on this Published Document:

Committee reference: FSH/24/1

ISBN 0 580 40169 3

Amendments issued since publication

Amd. No.	Date	Comment

Contents

Foreword

This Published Document (PD) was published under the Fire Standards Policy Committee and is published as part of the PD 7974 series. Other parts published or about to be published are as follows:

— *Part 1: Initiation and development of fire within the enclosure of origin;*

— *Part 2: Spread of smoke and toxic gases within and beyond the enclosure of origin;*

— *Part 3: Structural response and fire spread beyond the enclosure of origin;*

— *Part 4: Detection of fire and activation of fire protection systems*;

— *Part 5: Fire service intervention;*

— *Part 6: Evacuation;*

— *Part 7: Probabilistic risk assessment.*

These Published Documents are intended to be used in support of BS 7974:2001, *Application of fire safety engineering principles to the design of buildings — Code of practice*.

It has been assumed in the drafting of this PD that the execution of its provisions is entrusted to appropriately qualified and competent people.

Drafting of this publication was completed in July 2001.

Acknowledgement is made to the contribution of Dr D. Charters of Arup Fire and Mr J. Barnfield of Tenos Ltd. in the preparation of this publication.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Published Document does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to ii, pages 1 to 45 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

1 Scope

This Published Document provides guidance on the use of BS 7974:2001 as a framework for an engineering approach to the achievement of fire safety in buildings. It gives guidance on the application of scientific and engineering principles to the protection of people and property from fire. It also gives a structured approach to assessing the effectiveness of the total fire safety system in achieving the design objectives.

It provides guidance on the design and assessment of fire safety measures in buildings. It provides some alternative approaches to existing codes and guides for fire safety and also allows the effect of departures from more prescriptive codes to be evaluated.

It recognizes that a range of alternative and complementary fire protection strategies can achieve the design objectives.

This Published Document is intended to provide a framework for a flexible but formalized approach to fire safety design that can also be readily assessed by the statutory authorities.

It is intended that this Published Document, when used by persons suitably qualified and experienced in fire safety engineering, will provide a means of establishing acceptable levels of fire safety economically and without imposing unnecessary constraints on other aspects of building design.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this Published Document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 7974:2001, *Application of fire safety engineering principles to the design of buildings — Code of practice.*

PD 7974-1, *Application of fire safety engineering principles to the design of buildings — Part 1: Initiation and development of fire within the enclosure of origin* (Sub-system 1).

PD 7974-2, *Application of fire safety engineering principles to the design of buildings — Part 2: Spread of smoke and toxic gases within and beyond the enclosure of origin* (Sub-system 2).

PD 7974-3, *Application of fire safety engineering principles to the design of buildings — Part 3: Structural response and fire spread beyond the enclosure of origin* (Sub-system 3).

PD 7974-4, *Application of fire safety engineering principles to the design of buildings — Part 4: Detection of fire and activation of fire protection systems* (Sub-system 4).

PD 7974-5, *Application of fire safety engineering principles to the design of buildings — Part 5: Fire service intervention* (Sub-system 5).

PD 7974-6, *Application of fire safety engineering principles to the design of buildings — Part 6: Evacuation* (Sub-system 6).

PD 7974-7, *Application of fire safety engineering principles to the design of buildings — Part 7: Probabilistic risk assessment.*

3 Terms and definitions

For the purpose of this Published Document, the following terms and definitions apply.

3.1
available safe egress time
ASET
calculated time available between ignition of a fire and the time at which tenability criteria are exceeded in a specified space in a building

3.2
code compliant
where a building or part of a building complies with the recommendations of an appropriate prescriptive code

3.3
compartment
building or part of a building comprising one or more rooms, spaces or storeys, constructed to prevent the spread of fire to or from another part of the building, or an adjoining building

3.4
common mode failure
failure that is the result of an event(s) that, because of dependencies, causes a coincidence of failure states of components in two or more separate channels of a redundancy system, leads to the defined system failing to perform its required function

3.5
detection time
interval between the onset of combustion and its detection by an automatic system or otherwise

3.6
deterministic study
methodology, based on physical relationships derived from scientific theories and empirical results that, for a given set of initial conditions, will always produce the same outcome

3.7
enclosure
space defined by boundary elements (on all sides) around the point of origin of the fire

3.8
escape time
calculated time from ignition until the time at which all the occupants of a specified part of a building are able to enter a place of safety

3.9
exit
doorway or other suitable opening giving access towards a place of safety

3.10
fire hazard
source of possible injury or damage

3.11
fire load
sum of the calorific energies which could be released by the complete combustion and all the combustible materials in a space, including the facing of the walls, partitions, floors and ceilings

3.12
risk
product of the probable rate of occurrence of a hazard causing harm and the degree of severity of the harm

3.13
fire safety engineer
person suitably qualified and experienced in fire safety engineering

3.14
fire safety manual
document providing all necessary information for the effective fire safety management of the building

3.15
fire safety engineering
application of scientific and engineering principles to the protection of people, property and the environment from fire

3.16
fire safety strategy
combination of fire safety measures that has been shown by reference to prescriptive codes or a fire engineering study to be capable of satisfying the specified fire safety objectives

3.17
fire scenario
set of circumstances (taking account of the building, its contents and occupants) chosen as an example that defines the development of fire and its effects in a building or part of a building

3.18
management
persons or person in overall control of the premises whilst people are present, exercising this responsibility either in their own right or by delegation (of statutory duty)

NOTE This could be the owner.

3.19
means of escape
means whereby safe routes are provided for persons to travel from any point in a building to a place of safety

3.20
place of safety
predetermined place in which persons are in no immediate danger from the effects of fire.

NOTE The place of safety may be inside or outside the building depending upon the evacuation strategy.

3.21
pre-movement time
time interval between the warning of fire being given, by an alarm or by direct sight of smoke or fire, and movement towards an exit

3.22
probabilistic study
methodology to determine statistically the probability and outcome of events

3.23
tenability limit
maximum exposure to fire hazards that can be tolerated without causing incapacitation

3.24
travel distance
actual distance that needs to be travelled by a person from any point within a building to the nearest exit, having regard to the layout of walls, partitions and fittings

3.25
trial design
group of fire safety measures which, in the context of the building parameters, might meet the specified fire safety objectives

3.26
worst case scenario
set of credible conditions that, when taking account of the building, its contents and occupants, gives rise to the highest level of fire risk

4 Background

4.1 General

Historically, fire safety measures have been specified by reference to prescriptive codes that provide standard solutions for a given set of building parameters. For many buildings of straightforward construction, layout and use, prescriptive codes and standards provide the designer with an acceptable solution.

However, these codes have to account for a wide range of buildings and will often not provide the optimum solution in terms of:

a) life safety;

b) property protection;

c) cost-effective fire protection;

d) operational requirements.

The prescriptive approach often does not meet the needs of building owners, designers or approvals bodies, particularly for more complex buildings or processes or where there is a potential for substantial financial loss arising from a relatively small fire.

Similarly, prescriptive codes for fire protection systems such as sprinklers, detectors and smoke control do not always take account of all significant design factors (e.g. the effect of height on the speed of sprinkler activation and consequential extinguishing effectiveness).

Some of the advantages and disadvantages of the traditional prescriptive codes are summarized in Table 1.

Table 1 — Advantages and disadvantages of prescriptive codes

Advantages	Disadvantages
Simple to use	Often not flexible
Embody past experience	Unable to anticipate all eventualities
Provide a consensus view	Do not necessarily provide optimum solution
	Might lag many years behind design practice

A particular weakness in the prescriptive approach was recognized in the conclusions of the Cullen report into the Piper Alpha offshore disaster which stated that:

"Many regulations are unduly restrictive in that they are of a type that impose "solutions" rather than "objectives" and are out of date in relation to technological advances. There is a danger that compliance takes precedence over wider safety considerations…"

This conclusion is equally applicable to building design and BS 7974:2001 has been developed to provide an objectives-based approach to fire safety in buildings. It gives guidance on the application of engineering principles to the protection of people and property from fire. However, fire safety engineering (FSE) is a developing discipline and BS 7974:2001 should not be regarded as yet another prescriptive set of rules but as a structured framework for the evaluation of the interactions between fire, people and buildings.

Figure 1 illustrates the main features of the fire-people-building system. The framework presented in BS 7974:2001 is intended to ensure that these are adequately evaluated and that specified fire safety objectives are achieved.

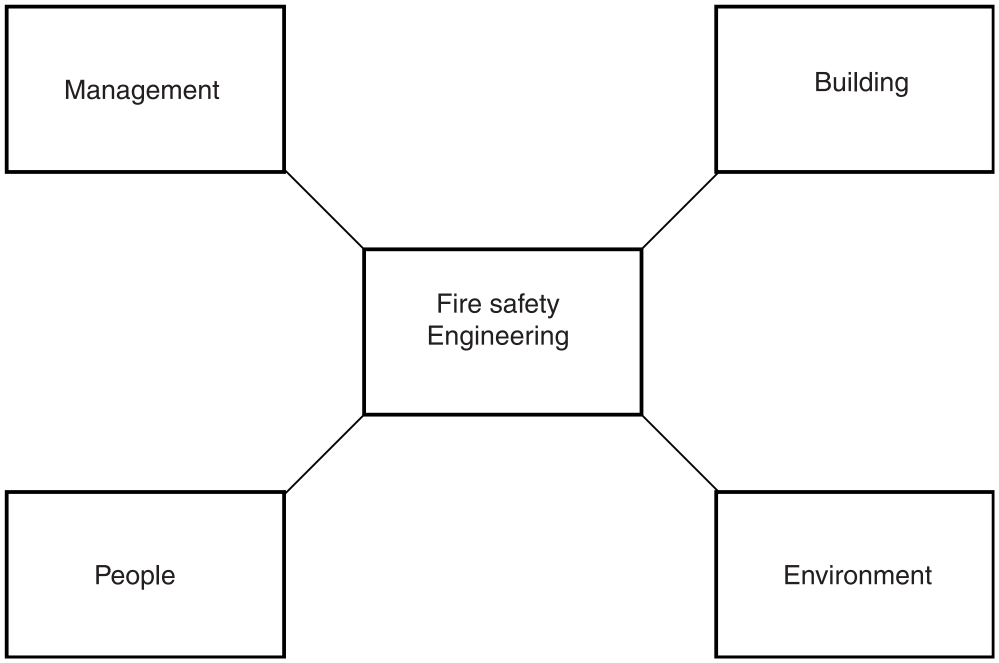


Figure 1 — Main factors involved in a fire safety engineering study

4.2 Benefits of fire safety engineering

A fire safety engineering approach that takes into account the total fire safety package can provide a more fundamental and economic solution than traditional approaches to fire safety. It might be the only viable means of achieving a satisfactory standard of fire safety in some large and complex buildings.

The objectives of BS 7974:2001 and this Published Document (PD) are to:

a) provide a structured framework for assessing the interaction between buildings, people and fire;
b) enable an objective assessment of the fire safety measures required to achieve defined objectives;
c) assist in developing alternatives to prescriptive codes and enable the effect of these to be evaluated;
d) facilitate innovation in design without compromising safety;
e) identify requirements for further research.

BS 7974:2001 provides a performance-based approach to design in which the specific fire hazards and their potential consequences are identified and fire safety measures can be introduced, as necessary, to ensure that the design objectives are met. It also enables the results of recent research into fire and human response to be translated directly into the building design process.

A FSE approach might initially result in higher design costs due to the increased engineering effort but the potential improvement in safety and the construction and operational savings can far exceed the increased design cost.

The main benefits and disadvantages of fire safety engineering compared to the more traditional prescriptive approach are summarized below in Table 2.

Table 2 — Advantages and disadvantages of fire safety engineering approach

Advantages	Disadvantages
Fire safety measures tailored to risk and specified objectives	Suitably qualified and experienced personnel are required to carry out and assess FSE studies
Facilitates innovation in building design without compromising safety	Might involve increased design time and costs
Fire protection costs can be minimized without reducing safety	Lack of data in some fields
Provides a framework to translate recent research into practice	Might be restrictive unless future flexibility of use is explicitly considered as a design objective
Enables alternative fire safety strategies to be compared on cost and operational grounds	
Enables cost and benefits of loss prevention measures to be assessed.	
Requires design team and operator to explicitly consider fire safety	

4.3 Common misconceptions

4.3.1 *General*

There are a number of common misconceptions regarding the use of FSE rather than traditional prescriptive approaches and some of these are discussed in this section.

4.3.2 *"An FSE design is more dependent upon management controls"*

Whether designed in accordance with prescriptive codes or FSE principles, good fire safety management is essential to the safe operation of any building. The FSE approach presented in BS 7974:2001 requires that management issues are taken into account and any specific management requirements are addressed explicitly.

4.3.3 *"FSE should not be applied to just one aspect of the design"*

The most common use of FSE is to justify one or two specific departures from prescriptive codes. There is generally no need to apply FSE to all aspects of a project if it is otherwise code-compliant.

4.3.4 *"An FSE design provides less flexibility for future use"*

During the QDR, the team should identify potential future changes of use and should, where practical, ensure that the design will accommodate these. If this is not feasible, any potential restrictions should be highlighted. A lack of flexibility is a function of poor engineering design rather than an inherent function of FSE.

4.3.5 *"An FSE design is more dependent upon the correct performance of fire protection systems"*

There is no reason why a wedged-open fire door or poorly maintained sprinkler system should be any less of a problem in a code compliant building than in a building designed on the basis of FSE principles.

BS 7974:2001 requires a "what if study" to be carried out to assess the potential impact of system failures and, therefore, the impact of such failures will often be less in a building designed on FSE principles.

4.3.6 *"The accuracy of many FSE calculations is unknown"*

The accuracy of the calculation procedures presented in the PDs supporting BS 7974:2001 (and other appropriate publications which have been subject to peer review) will generally be sufficiently accurate for engineering design purposes if they are used within their limits of applicability.

However, the old adage of "garbage in – garbage out" applies and, in most cases, uncertainties in the calculation procedures will be outweighed by any errors in the initial assumptions (e.g. the rate of fire growth).

4.3.7 *"An FSE solution always requires calculations and a numerical solution"*

BS 7974:2001 provides a design framework and does not necessarily require a quantified analysis.

Very often, it will be possible to reach a solution without recourse to numerical calculations. During the QDR process, it might be possible to establish simply by logical deduction that a trial design is at least as safe as the code compliant solution without the need for any calculations.

4.4 Structure of BS 7974:2001

BS 7974:2001 provides the basic framework for the application of FSE but it is supported by a series of Published Documents (PDs) that contain guidance on specific aspects of FSE. The PDs are a summary of current information. It is intended that they will be regularly updated as new data and analysis procedures become available. Whilst the PDs provide useful information and guidance, the use of other data and calculation techniques are equally acceptable, provided that their validity and applicability has been adequately demonstrated. Figure 2 shows the basic structure of BS 7974:2001 and its supporting Published Documents.

5 Design approach

5.1 Experience and qualifications

The complexity of the interactions between people, buildings and fire is such that no single set of calculation procedures can be applied to all types of buildings in all circumstances. Therefore, FSE requires a greater degree of care and responsibility by the designer than does the application of prescriptive codes. It is therefore essential that the application of FSE be entrusted to suitably qualified and experienced personnel.

In assessing the suitability of FSE design, personnel professional qualifications (e.g. Chartered Membership of the Institution of Fire Engineers) and experience of fire safety engineering on projects of similar scale and complexity should be taken into account.

5.2 Framework

BS 7974:2001 provides a performance based framework for an engineering approach to fire safety in buildings. It can be used to show that statutory requirements can be satisfied but may also be used as part of a cost–benefit analysis to establish the value of property protection measures or to evaluate the environmental impact of fire.

The design framework may be applied to the design of new buildings or the appraisal of existing buildings. Whilst FSE procedures may be used to evaluate the entire set of fire people and building interactions, in many practical applications their most common use will be to evaluate specific departures from prescriptive codes (e.g. the evaluation of extended travel distances in an otherwise code compliant building).

The general approach to FSE described in BS 7974:2001 and this PD may be applied to all types and uses of buildings or to facilities such as tunnels and process plants. However, the risks associated with installations used for the bulk processing of explosives or flammable liquids and gases will necessitate special consideration which is beyond the scope of BS 7974:2001 and its supporting documents.

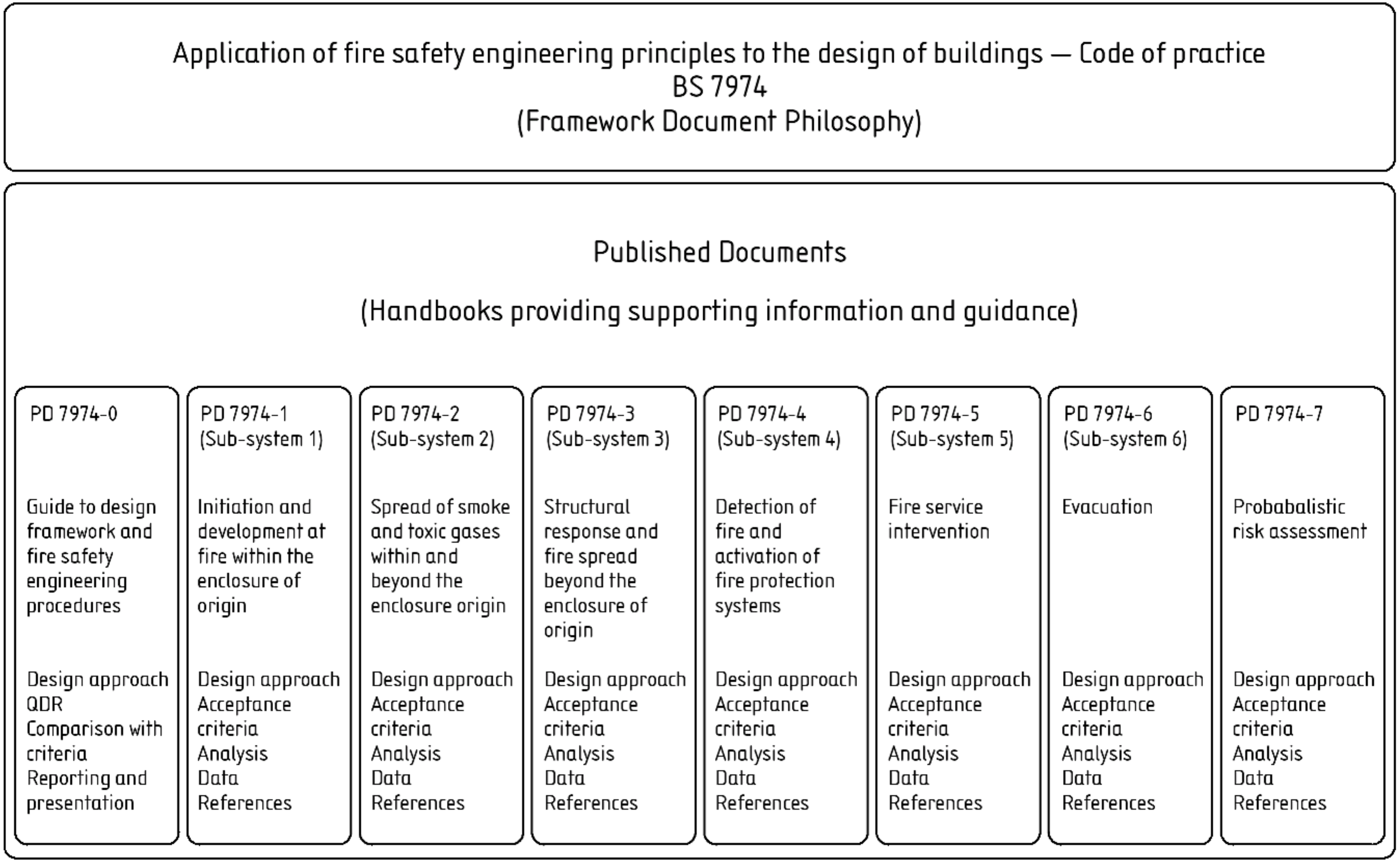
The basic design process presented in BS 7974:2001 comprise the following main stages, as illustrated in Figure 3:

a) Qualitative Design Review (QDR);

b) quantitative analysis;

c) assessment against criteria;

d) reporting of results.



Application of fire safety engineering principles to the design of buildings — Code of practice
BS 7974
(Framework Document Philosophy)

Published Documents

(Handbooks providing supporting information and guidance)

PD 7974-0	PD 7974-1 (Sub-system 1)	PD 7974-2 (Sub-system 2)	PD 7974-3 (Sub-system 3)	PD 7974-4 (Sub-system 4)	PD 7974-5 (Sub-system 5)	PD 7974-6 (Sub-system 6)	PD 7974-7
Guide to design framework and fire safety engineering procedures	Initiation and development at fire within the enclosure of origin	Spread of smoke and toxic gases within and beyond the enclosure origin	Structural response and fire spread beyond the enclosure of origin	Detection of fire and activation of fire protection systems	Fire service intervention	Evacuation	Probabalistic risk assessment
Design approach QDR Comparison with criteria Reporting and presentation	Design approach Acceptance criteria Analysis Data References	Design approach Acceptance criteria Analysis Data References	Design approach Acceptance criteria Analysis Data References	Design approach Acceptance criteria Analysis Data References	Design approach Acceptance criteria Analysis Data References	Design approach Acceptance criteria Analysis Data References	Design approach Acceptance criteria Analysis Data References

Figure 2 — Structure of BS 7974:2001 and the Published Documents

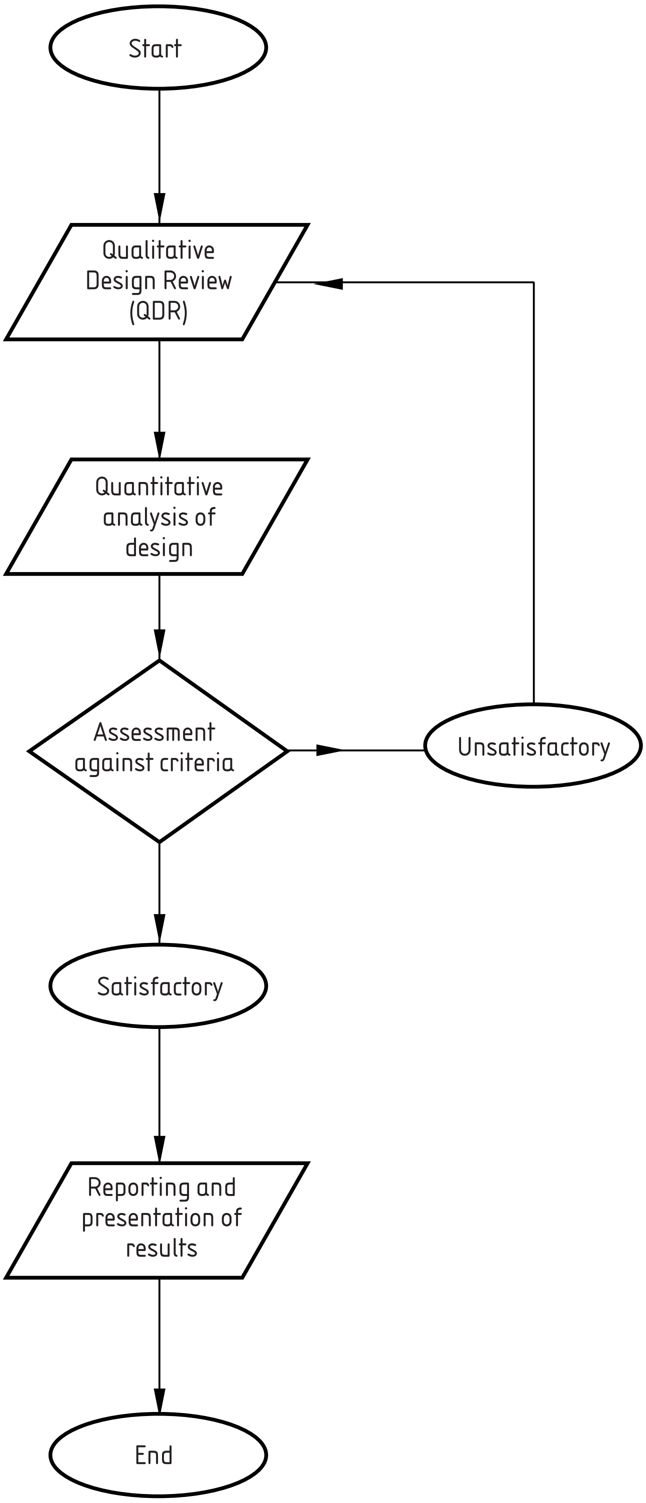


Figure 3 — Basic fire safety design process

5.3 Qualitative Design Review (QDR)

The first stage in any engineering design is to establish the basic parameters of the project. This includes a review of the scheme, identification of any overriding constraints and definition of the design objectives. This initial stage will draw on the expertise and experience of the engineer and design team. Quantification will normally only follow when the design parameters have been established. For the purposes of FSE, this preliminary stage is described in BS 7974:2001 as the Qualitative Design Review (QDR).

During the QDR process, the scope and objectives of the fire safety design are defined, performance criteria are established and one or more potential design solutions (trial designs) are proposed. Key information is also gathered to enable detailed evaluation of the design solutions in the quantitative analysis.

5.4 Quantitative analysis

Following the QDR, a quantified analysis can be carried out if necessary. It has been found convenient to split information on various aspects of FSE into a number of separate parts, referred to as sub-systems in BS 7974:2001. Guidance on each of the sub-systems is published in the supporting series of PDs.

The PDs provide selected guidance on the underlying principles and the type of calculations that may form part of a fire engineering study. However, it should be noted that the use of data and calculation procedures from other sources is not precluded and can often be essential to reach a solution.

One or two of the sub-systems may be used when analysing a particular aspect of design or they may all be used in combination as part of an overall fire engineering evaluation of fire safety in a building.

The quantitative analysis may use probabilistic or deterministic calculation procedures or a combination of both.

5.5 Assessment against criteria

5.5.1 *General*

Following the quantified analysis, the results need to be compared with the acceptance criteria identified during the QDR.

If none of the trial designs satisfies the specified acceptance criteria, the QDR and quantification process should be repeated until a fire safety strategy has been found that satisfies the design criteria.

Three basic approaches can be considered by the QDR team when setting acceptance criteria:

a) comparative;

b) deterministic;

c) probabilistic.

One or more of these approaches may be utilized as part of a FSE study. Whichever approach is adopted, the criteria should, in general, satisfy the objectives of legislation and/or client requirements depending on the defined fire safety objectives.

5.5.2 *Comparative criteria*

It can often be difficult to establish the level of safety achieved in absolute terms. However, it might be relatively straightforward to demonstrate that the design provides a level of safety equivalent to that in a building that complies with recognized prescriptive codes. A comparison may be made on the basis of deterministic or probabilistic approaches or a combination of both.

5.5.3 *Deterministic criteria*

In a deterministic study, the objective is to show that on the basis of the initial (usually worst case scenario) assumptions a defined set of conditions will not occur (e.g. the smoke layer will not fall below head height during the evacuation period).

5.5.4 *Probabilistic criteria*

In a probabilistic study, criteria are set to ensure that the probability of a given event occurring is acceptably low. The risk criteria are usually expressed in terms of the annual probability of the unwanted event occurring (e.g. the probability of death in fire is less than 10^{-6} per annum). Guidance regarding probabilistic risk assessment techniques is given in PD 7974-7.

5.5.5 *General*

Table 3 illustrates the different types of acceptance criteria that may be adopted.

Table 3 — Typical examples of acceptance criteria

		Fire safety objectives	
		Deterministic	**Probabilistic**
Analysis method	**Comparative**	Time available for escape is at least equal to that in an equivalent code compliant building	Level of risk to life equivalent to code compliant building
	Absolute	The time available for escape exceeds the time to untenable conditions	Expected number of casualties per year.

5.6 Reporting and presentation

Most buildings designed in accordance with the provisions of BS 7974:2001 will be subject to review and approval. It is therefore essential that the findings of the fire engineering study and any assumptions made are presented in a form that can be readily understood and thoroughly checked by a third party. A clear, concise and complete report is therefore an essential requirement for an FSE study.

BS 7974:2001 does not recommend a fixed format for the report but does make recommendations regarding the minimum information that should be documented.

6 Qualitative Design Review

6.1 Overview

6.1.1 *General*

The interaction of fire, buildings and people gives rise to an almost infinite number of possible scenarios and it is not feasible to evaluate every conceivable case. Therefore, before attempting to carry out a detailed quantified study, the significant fire hazards should be identified, the problem simplified and the required extent of quantification established. This process is described as the Qualitative Design Review (QDR).

The QDR is essentially a qualitative process that draws upon the experience and knowledge of the fire safety engineer and a team of others involved in the design and operation of the building.

6.1.2 *QDR Team*

For very large and complex projects, it is recommended that the QDR be carried out by a study team involving one or more fire safety engineers, other members of the design team and a member of operational management. It might also be appropriate to include representatives of approval bodies or the insurers to ensure that their views can be accounted for.

For smaller projects or where FSE is being applied to a limited and well defined aspect of a project, the QDR may be carried out by a smaller study group which in many cases might only involve the fire safety engineer and architect. However, the same basic review process should be followed to ensure that no significant factors are missed.

The QDR team on a major project might include the following:

a) fire safety engineer (chair);

b) architect;

c) services engineer;

d) structural engineer;

e) member of operational management;

f) approvals body and/or insurer.

6.1.3 *QDR process*

The QDR is a structured technique that allows the team to think of the possible ways in which a fire hazard might arise and establish a range of strategies to maintain the risk at an acceptable level. The fire safety design can then be evaluated quantitatively or qualitatively against the objectives and criteria set by the team. The QDR should be conducted in a systematic way to reduce the chance of a relevant item being missed.

Whilst the QDR is essentially a qualitative process, it can often be useful to carry out quick calculations to resolve a difference of opinion between team members or to establish the most significant scenarios for detailed quantification.

The main stages in the QDR are:

a) review of architectural design and occupant characteristics;

b) establish fire safety objectives;

c) identify fire hazards and possible consequences;

d) establish trial fire safety designs;

e) identify acceptance criteria and methods of analysis;

f) establish fire scenarios for analysis.

This list suggests the general order in which each aspect of the QDR might be carried out but, in practice, it is likely that the order of events will change to suit the circumstances. However, whichever order is adopted, it should be ensured that each stage has been adequately completed and that no important factors are missed.

Finally, all findings should be clearly recorded so that the underlying philosophy and assumptions that underpin the FSE study are explicit and can be readily checked by a third party.

The activities involved in each stage of the QDR are described below.

6.2 Architectural design and occupant characteristics

Ideally, the architectural design should be reviewed at the early outline stage of scheme development to ensure that the fire safety measures and architectural design are developed in harmony.

The first stage in the QDR is for the architect/designer to describe the project by reference to general arrangement drawings, models, etc., and to highlight any architectural or client requirements that might be significant in the development of the fire safety strategy.

In an existing building, the fire safety design will often be constrained by the location of existing stairs and walls and the type of construction materials used. However, in a new building, there is potentially much greater flexibility and the team should seek to identify any aspects of the design that may be readily amended and which can enable fire safety measures to be simplified.

All the relevant information about the building, its occupants and uses, should be provided to the QDR team including information on:

a) building structure and layout;

b) use(s) and contents of the building;

c) fire service access to the building;

d) occupants (including any special requirements for people with disabilities);

e) ventilation systems;

f) unusual fire hazards;

g) planning constraints (e.g. listed buildings of historical merit);

h) client requirements including possible future options;

i) personnel who can supply further information as required.

Table 4 provides a list of the type items that might need to be considered when reviewing the architectural design. The list is not exhaustive but provides a guide to the range of factors that need to be considered. In a limited FSE study, many of these items will not have a direct bearing on the outcome but it is still useful to have a full understanding of the building and the way in which it will work before embarking on an FSE study.

At the end of the QDR process, it might be necessary to obtain additional information regarding the building and its environment in a form suitable for quantification. The extent of the information required will depend upon the fire safety objectives and the analysis approach adopted. The characterization of the environment might need to include external influences such as the effects of the wind, temperature and snow, and internal influences such as temperature and air movement.

6.3 Fire safety objectives

6.3.1 *General*

At an early stage of the design process, the objectives of the fire safety design should be clearly defined. Whilst the protection of life is the main objective of fire safety legislation, the financial impact of fire on a business as a result of direct property damage or lost production might also be important considerations.

Some businesses (e.g. an international hotel chain) might also be susceptible to intangible losses if their reputation is damaged as a result of a major and well-publicized fire.

In some cases, it can be relatively straightforward to comply with the statutory provisions for life safety (e.g. a warehouse) by reference to prescriptive codes, but a FSE assessment can be particularly useful in assessing the costs and benefits of fire protection for loss prevention purposes.

A fire in a building used for the processing or storage of quantities of toxic or radioactive materials can have an adverse impact on the local environment. FSE engineering techniques can assist in an environmental impact assessment.

The FSE procedures presented in BS 7974:2001 may be used to develop a total fire safety strategy or may simply be used to consider one aspect of the design (e.g. extending travel distances in an otherwise code compliant design). It is, therefore, essential that the objectives for a FSE study are established and agreed with interested parties at an early stage during the QDR

The fire safety objectives that might typically be addressed in an FSE study are:

a) life safety;

b) loss control;

c) environmental impact.

This list is not exhaustive and not all items need necessarily be considered in a particular study.

6.3.2 *Life safety objectives*

The occupants of a building, fire-fighters and members of the public who are in the vicinity of a building can be put at risk by fire. The main life safety objectives might include provisions to ensure that:

a) the occupants are ultimately able to leave the building in reasonable safety;

b) firefighters can operate without undue risk to:

  — assist evacuation when necessary;
  — effect rescue when necessary;
  — prevent conflagration

c) collapse does not endanger people (including fire-fighters) who are likely to be in or near the building.

Modern fire safety legislation often includes functional objectives and, where statutory compliance is one of the goals of an FSE study, reference should also be made to the specific requirements of the relevant legislation.

Table 4 — Typical items to be considered during review of architectural design

Area of review	Items to be considered
Building design	Number of storeys (above and below ground) General dimensions Nature of construction Geometry and interconnection of spaces Internal subdivision of building Normal circulation routes Escape routes Provision for dispersal of people from vicinity of building Fire brigade response time Access for fire appliances Fire-fighting access within the building Location relative to other buildings or site boundary Any other factor that may influence the fire safety design
Occupants	Number and distribution Single or multiple tenancy or use Mobility State of wakefulness Familiarity with the building Social groupings Roles and responsibilities of key individuals Commitment to an activity (e.g. eating in a restaurant) Presence of a focal point (e.g. stage) Any other factor that may influence the fire safety design (see PD 7974-6 for guidance on the influence of these factors on human response)
Room or compartment	Unusual fire hazards (e.g. flammable liquids stored in offices) Potential ignition sources Combustible contents Fire load density Wall lining Ceiling linings Ambient noise levels Ventilation systems Possible fire and smoke spread routes Escape routes Any other factor that may influence the fire safety design
Other factors	Contacts for provision of additional information Quality and extent of continuing management control Planning constraints (e.g. listed building of historical interest) Future changes of layout or that may be anticipated Fire protection systems specified by client (e.g. sprinklers for loss prevention)

6.3.3 *Loss prevention*

The effects of a fire on the continuing viability of a business can be substantial and consideration may be given to minimize the damage to:

a) the structure and fabric of the building;

b) the building contents;

c) the ongoing business viability;

d) the corporate image.

Statutory requirements are generally intended to protect life and to prevent conflagration; however, in a particular scheme, it might also be desirable to take measures to reduce the potential for large financial losses. The QDR team should identify clearly the objectives of the fire safety strategy, taking account of statutory requirements and the level of property protection required by the client.

6.3.4 *Environmental impact*

A conflagration involving several buildings or the release of quantities of hazardous materials can have a significant impact on the environment. Consideration may, therefore, need to be given to the limitation of:

a) the effects of fire on adjacent buildings or facilities;

b) the release of hazardous materials into the environment;

c) methods of fire-fighting (e.g. avoidance of river pollution).

6.4 Fire hazards and consequences

6.4.1 *Hazards*

A systematic review of the scheme should be conducted to establish the fire-related hazards within the building and their potential consequences. The review should take account of factors such as:

a) ignition sources;

b) combustible contents;

c) materials of construction;

d) nature of the activities in the building;

e) any unusual factors.

Table 5 summarizes some of the main items that may be considered in carrying out the hazard assessment.

Table 5 — Typical items to be considered during hazard identification

Ignition sources	Combustible materials
Smokers' materials	Flammable liquid products (paints, adhesive, thinners, etc.)
Naked flames	Flammable liquids (petrol, diesel, paraffin)
Electric, gas or oil heaters	Flammable chemicals
Hot work processes	Wood
Cooking	Paper products
Engines or boilers	Plastic and rubber (particularly as foam)
Machinery or office equipment	Flammable gases
Lighting equipment	Furniture
Friction from drive belts	Textiles
Reactive dusts	Packaging materials
Static electricity	Combustible waste materials
Metal impact	MDF, hardboard, timber plastic, etc. linings
Arson	GRP and other plastics cladding materials

The above list is not exhaustive and the QDR team should attempt to identify all the significant hazards. In evaluating the significance of a fire hazard, the QDR team should take particular account of the influence of each hazardous item on the achievement of the specified fire safety objectives. It should be remembered that an unlikely event can result in the greatest loss and should not be discounted without careful consideration.

The consideration of hazards should not only be restricted to the ignition and spread of fire but should include hazards that can impede evacuation (e.g. tripping hazards in plant room escape routes or a disorientating layout).

When carrying out a comparative or deterministic study, it might be sufficient to record that the hazards are generally typical of the generic building type (e.g. office) and note in detail only those hazards that are unrepresentative of the main use (e.g. the storage of flammable fluids in part of an office building).

6.4.2 *Consequences*

The potential consequences arising from the realization of the hazards should be reviewed qualitatively by the QDR team to identify events that are likely to give rise to a significant risk.

The consequences of a particular fire hazard (e.g. smoking) will vary significantly depending upon the contents and construction of a building, and the QDR team should identify the chain of events that is likely to give rise to significant consequences, e.g:

a) cigarette dropped by employee;

b) ignites waste material;

c) fire spreads rapidly across combustible wall lining;

d) building and contents written off.

This review of the hazards and consequences might immediately suggest possible solutions (trial designs) which in this case could be the banning of smoking, over-cladding the combustible wall lining or elimination of waste storage within the building.

6.5 Trial fire safety designs

6.5.1 *General*

In many cases, it will be necessary to amend the architectural design or provide various fire safety measures to achieve the fire safety objectives. A trial design is simply a group of fire safety measures that, in the context of the building parameters, might meet the specified fire safety objectives.

To enable the optimum solution to be identified, the QDR team should establish one or more trial fire safety designs for the purposes of more detailed analysis and quantification.

To meet the specified design objectives, it is more than likely that several trial designs can be identified that may provide an acceptable solution. The members of the study team should use their knowledge and expertise to make sensible judgements on the suitability of various alternatives. In many cases, a good first step is to base a trial design on the recommendations of an established prescriptive code. This can serve as a basis for a comparative study or simply to highlight specific areas of non-compliance.

In developing trial designs, the QDR team should not just consider adding additional fire protection systems, but should also review the potential for reducing or eliminating some of the hazards by amending the construction or layout of the building. When practical, reducing any hazards inherent in the design of a building is often preferable to adding additional fire protection measures.

Whilst under- or overspecifications can be identified in the quantification process following the QDR, this can be time consuming and it is desirable that the QDR team identify cost-effective trial designs that are likely to satisfy the fire safety objectives and criteria. There are other factors apart from fire safety that determine whether a particular design is acceptable and trial designs that are impractical or that conflict with design or operational requirements should be ruled out unless there is no other practical alternative. The alternative trial designs should be compared with each other in terms of cost and practicality. To limit the number of evaluations required to find an acceptable solution, the first trial design evaluated might be the one that is likely to meet the meet the fire safety and other design objectives at lowest cost.

6.5.2 *Fire safety systems*

Table 6 provides a list of items that can be considered when developing the trial designs. This list is not exhaustive but provides a guide both to the types of systems that can be considered and to the basic information required to enable a quantified study to be carried out.

Fire safety engineering techniques may be used to justify deviations from prescriptive design codes for fire safety systems (e.g. the BS 5839 series for fire detection systems or the BS 5306 series for extinguishing systems). However, in many cases, it will be sufficient to specify fire protection systems in terms of such prescriptive codes.

Table 6 — Possible options for development of trial design

Fire protection system	Possible QDR considerations
Control on materials	Use of non-combustible materials in: — construction — linings Flame retardant materials: — furniture — furnishings
Automatic suppression	Localized or extensive Extinguishing medium Nozzle spacing
Detection	Detector types Locations Zoning Response characteristics
Compartmentation	Fire resistance Location boundaries Cavity barriers Fire stopping
Automatic systems	Dampers Shutters Magnetic door hold open devices Fans Vents
Smoke control	Extraction Pressurization De-pressurization Containment Reservoir volume
Alarm and warning systems	Sounder or public address Zoning Investigation periods
Evacuation strategy	Phased Simultaneous Progressive horizontal Management procedures
Escape routes	Exit widths Travel distances Stairways Lifts – protected Refuges for disabled Escape lighting
First aid fire-fighting	Extinguishers/hose reels Availability of trained staff
Fire service facilities	Access routes Rising mains Fire-fighting shafts Smoke extraction
Fire safety management	Management plan Staff availability Third party audit of procedures Maintenance schedules

6.5.3 *"What if events"*

As part of the hazard assessment process an assessment of "what if events" should be made. The objective is to identify system failures or foreseeable events that might have a significant influence on the outcome of the study.

An example would be "what if" a fire resisting roller shutter between compartments fails to operate. The answer could be that it has no impact on life safety but it would lead to increased property damage.

Some examples of typical "what if events" are:

a) fire door propped open;

b) combustible displays introduced into sterile areas;

c) compartment walls penetrated and not made good;

d) materials of greater than specified flammability;

e) power supply to smoke vents fails;

f) sprinklers ineffective due to poor maintenance;

g) sensitivity detection systems adversely affected by movement of ventilation air;

h) the fire is located where it will block an exit;

i) management fails to implement fire safety procedures.

In a probabilistic risk assessment (PRA), the likelihood and consequences of such failures will generally be quantified. However, in a deterministic study, the team should make a judgement as to whether the "what if" event is likely to significantly effect the overall fire risk. In this respect, consideration should be given to whether:

a) the event is credible;

b) the consequences of the event are tolerable or no worse than in a code compliant design;

c) additional fire protection measures are essential to provide a degree of redundancy.

Where a comprehensive fire safety management plan is implemented and subject to third party review, the benefits of this should be taken into account when assessing the likely efficiency of the evacuation process or the reliability of installed fire protection systems.

6.5.4 *Common mode failures*

In some instances, the failure of one system will have an adverse effect on the efficiency of another fire protection measure. For instance, an open fire door will not only be an ineffective barrier to fire spread but will also undermine the performance of a gaseous extinguishing system due to escape of the extinguishing agent.

Similarly, unless provided with suitable backup protection, failure of the power supply could lead to the failure of a number of fire safety systems.

Particular care must be taken by the QDR team to ensure that potential common mode failures are identified and accounted for in the analysis. Guidance on the assessment of common mode failures is given in PD 7974-7.

6.6 Acceptance criteria and methods of analysis

6.6.1 *General*

The objectives established in the second stage of the QDR are very broad and relatively easy to agree upon. However, these objectives are not sufficiently specific to provide a basis for an engineering design. Whatever fire protection measures are provided, there is no such thing as zero risk. The possibility of death, injury or property damage can never be totally eliminated. It is, therefore, essential to establish criteria that can be used to assess whether the fire safety objectives have been adequately achieved. This can be accomplished by converting the fire safety objectives into engineering terms by setting design targets and performance criteria.

For example, when considering a large single storey warehouse, the life safety and property protection objectives might be converted into engineering terms as indicated in Table 7.

Table 7 — Examples of setting objectives, targets and criteria

Objective	Design target	Performance criteria
The occupants are ultimately able to leave the building in reasonable safety.	Maintain tenable conditions on escape routes until the occupants have all evacuated.	Ensure smoke layer remains: > 2.5 m above floor level < 200 °C until completion of evacuation.
Maintain at least one (of two buildings) in operation.	Ensure that heat radiation does not significantly damage adjacent building.	Ensure that incident heat radiation on roof or walls of adjacent building $< 10\ \mathrm{kW/m^2}$.
	Ensure that external cladding is not ignited by burning brands.	Ensure external cladding is resistant to pilot ignition at radiation levels $\leqslant 10\ \mathrm{kW/m^2}$.

NOTE The table is for illustrative purposes only and reference should be made to the relevant PDs or other publications for guidance on criteria appropriate to a specific project.

In the above example, the performance criteria have been set in deterministic terms but BS 7974:2001 enables the adequacy of a design to be demonstrated using one of three approaches:

a) comparative (demonstrate equivalency with established prescriptive codes using deterministic or probabilistic methods);

b) deterministic (show that a defined set of conditions will not occur in the worst case scenario);

c) probabilistic (establish that the frequency of an unwanted event is acceptably small).

The type of acceptance criteria adopted is intimately linked with the method of analysis and the fire safety engineer should identify the most appropriate method of analysis. Note that it might be necessary to use different approaches for each of the trial designs under consideration.

Detailed guidance is given on the various methods in PD 7974 parts 1 to 6. and PD 7974-7 also provides guidance on the application of probabilistic techniques. General guidance on selecting the most appropriate approach is given below and in Clause **7**.

6.6.2 *Comparative studies*

In some projects, it is possible that the recommendations of prescriptive codes will provide a near optimum solution and that FSE techniques will not be necessary. Therefore, the need or otherwise for using FSE should ideally be identified before the QDR is carried out. However, the QDR team could also define the acceptance criteria in terms of compliance with a prescriptive code in which case no further analysis would be necessary.

Where there are limited departures from the prescriptive code, the acceptability of a particular design may be evaluated by comparing the level of performance achieved in a notional code compliant building with that of the non-compliant building under consideration. Often this comparison can be made without recourse to calculation. Where calculations are necessary, a deterministic approach is likely to be the simplest method but a comparison can also be made on a probabilistic basis. A comparative study will generally require less extensive analysis than a deterministic or probabilistic study based on absolute criteria.

Before it can be demonstrated that a solution offers at least the same level of safety as a prescriptive code, there should be a clear understanding of the intent of that code. During the QDR, the team should consider the intentions of each recommendation as a particular provision might have more than one objective. Once this has been done, alternative design solutions may be developed that address the specific underlying objectives. The fire safety engineer should demonstrate that the solution proposed would be at least as effective and as reliable as the prescriptive approach where effectiveness is a measure of the performance and reliability of the solution.

Because the aim of the comparative approach is to show equivalency between the compliant and the non-compliant building, the assessment is not usually sensitive to the initial assumptions (e.g. the expected rate of fire growth or pre-movement time). Any errors in the assumptions will equally affect the code compliant and non-compliant design and should not affect the relative ranking of the two designs.

The main advantages and disadvantages of comparative study are summarized in Table 8.

Table 8 — Advantages and disadvantages of comparative study

Advantages	Disadvantages
Relatively quick Consistent with established prescriptive codes Not usually dependent on initial assumptions May be used where definitive design data is not available Explicit safety factors not required Allows the use of probabilistic risk assessment without the need for absolute acceptance criteria	Generally only suitable for one or two significant departures or several minor deviations from prescriptive codes Might incorporate the weaknesses of the prescriptive code

Essentially, if it is explicitly demonstrated by logical deduction or calculation that the proposed design provides an equivalent or superior level of fire safety to a building complying with an appropriate prescriptive code, the comparative criteria will be met.

6.7 Deterministic studies

6.7.1 *General*

Deterministic procedures are based on physical, chemical and thermodynamic relationships derived from scientific theories and empirical correlations. A deterministic analysis involves the evaluation of a set of circumstances (usually worst credible case) that will provide a single outcome, i.e. the design will either be successful or it will not.

6.7.2 *Criteria for life safety*

6.7.2.1 *Introduction*

To ensure the safety of the occupants of a building, it is necessary to establish that they are able to reach a place of safety before untenable conditions occur.

The time necessary for evacuation of the occupants to a place of safety will depend on a number of factors relating to the occupants, the building and the rate at which the fire gives rise to untenable conditions.

The aim is to ensure that all persons can leave a threatened part of a building in reasonable safety without assistance and the aim is generally to ensure that the time available for escape is greater than the time required for escape:

$$\text{ASET} > \text{RSET}$$

where:

ASET is the available safe egress time (before untenable conditions occur);
RSET is the required safe egress time.

6.7.2.2 *Tenability conditions*

Untenable conditions can be caused by a number of factors and in a life safety analysis consideration should be given to the following hazards:

a) loss of visibility;

b) exposure to toxic and irritant products;

c) exposure to heat;

d) structural failure.

PD 7974-6 provides limiting conditions for the human tolerance of toxic gases, irritants, smoke obscuration, radiant heat flux and smoke temperature.

The inhalation of smoke and toxic gases can impair movement but might not cause total incapacitation that would prevent escape. In principle, it is possible to take account of the inhalation of toxic gases on the speed of the escape. However, in most circumstances, if the design is sufficiently conservative, such a detailed evaluation is not justified. For the purposes of design, it may generally be assumed that the response of the occupants is unchanged until untenable conditions are achieved, after which movement ceases.

The QDR team should establish which potential threats are significant and require quantification but, in most circumstances, it will be loss of visibility due to the spread of smoke that determines the initial threat to life and consequently the available safe egress time (ASET).

6.7.2.3 *Structural failure*

In tall buildings subject to phased evacuation, hospitals, etc., the occupants might need to remain in the building for an extended period while fire-fighting operations take place. Therefore, where failure of the structure will threaten the life of the occupants who might have to remain in the building for a prolonged period, the structure should be capable of resisting a burn-out.

Consideration should be given to the introduction of an explicit safety factor into the design where the consequences of failure are likely to be particularly significant (e.g. the collapse of very high buildings onto occupied areas). The potential for and consequences of a catastrophic failure of this kind should be taken into account by means of a sensitivity analysis.

The criterion for structural fire resistance might be stated as follows:

$$L_{\mathrm{crit}} \geq \lambda_{\mathrm{str}} L$$

where:

L_{crit} is the fire load required to cause structural failure;
L is the design fire load (typically 80 % fractile);
λ_{str} is a design safety factor (if required).

Detailed guidance on structural performance in fire is given in PD 7974-3.

6.7.3 ***Loss control***

Minimum provisions for life safety usually arise from statutory requirements but the benefits of additional provisions for property protection need to be judged in the context of the impact of fire on a business and the cost of additional fire protection measures. If it is desired to make a comparison of the costs and benefits of additional fire protection measures, this is best done using probabilistic procedures.

However, it is feasible to use a deterministic approach to property protection. For instance, the client objective might be to maintain continuity of operations by limiting production down-time to a maximum of one week. In some circumstances, this might be most easily achieved by transferring operations to another location. If the business is dependent upon a unique piece of electronic equipment which can be damaged by corrosive combustion products such as hydrogen chloride (HCl) gas, one of the design targets may be set in terms of maintaining concentrations of the gas below a specified level.

The QDR team should define the extent of acceptable damage. Some examples of how the various property protection objectives might be converted into deterministic engineering criteria are indicated in Table 9.

Table 9 — Example conversion of property protection objectives into engineering criteria

Objective	Design target	Performance criteria
Protect the building structure	Ensure that structural collapse does not occur as a result of a complete burn out	$L_{\mathrm{crit}} \geqslant L$
Limit the loss of the building contents	Ensure that no more than 33 % of stock is destroyed by fire and smoke damage	$A_f < 3\ 000\ m^2$
Maintain ongoing business viability	Ensure that no more than 50 % of operational facilities are affected by a fire	Fire in production line A to have nil effect on production line B
Maintain the corporate image	Ensure that any fire does not cause multiple fatalities or reach sufficient size to draw media attention	Fire confined to room of origin and $A_f < 100\ m^2$ and means of escape comply with prescriptive codes

L_{crit} is the fire load required to cause structural failure;
L is the design fire load (80 % fractile);
A_f is the plan area of the fire.

6.7.4 *Environmental impact*

A fire in a building containing large quantities of toxic or radioactive material could have a significant impact on the environment in terms of contamination of the air, land and water.

Acceptable concentration limits for airborne contamination can be obtained from the literature and models are available to enable the distribution of airborne contamination to be assessed.

Ground and water contamination can be difficult to evaluate and where this is likely to be a significant issue specialist expertise should be sought.

6.7.5 *Advantages and disadvantages of deterministic studies*

The main advantages and disadvantages of a deterministic study are summarized in Table 10.

Table 10 — Advantages and disadvantages of deterministic study

Advantages	Disadvantages
Considerable data available	Very dependent on initial assumptions
Wide range of well validated calculation procedures available	Provides no measure of costs and benefits
Widely used for life safety evaluation	Limited benefit for loss control purposes
Provides a simple yes/no result	

6.8 Probabilistic criteria

6.8.1 *General*

In practice, there are many factors that can influence the development of a building fire and the behaviour of the occupants. The factors will vary according to the circumstances at the time of the fire (e.g. whether first-aid fire-fighting has been unsuccessful or fire doors are propped open).

In a probabilistic risk assessment (PRA) study, the objective is to estimate the likelihood of a particular unwanted event (e.g. death) occurring. This can be achieved by the use of statistical data regarding the frequency of fire starts and the reliability of fire protection systems combined with a deterministic evaluation of the consequences of the range of possible fire scenarios. This type of approach can, to some degree, take account of the uncertainties that characterize real fires and the complex interactions between the factors involved

The risk associated with fire in a building takes into account the likelihood of fires occurring and their potential consequences, e.g. the potential number of deaths. Hence, it is possible to define risk as a function of the hazard, its probability and consequences:

$$\text{risk} = f\,(\text{hazard frequency, consequences})$$

Potentially, a PRA study provides a powerful means of assessing the fire risk and the benefits of various fire protection measures. However, for a comprehensive assessment of fire hazards considerable statistical data is often required to obtain a meaningful result. Because of the lack of a comprehensive statistical database and the engineering design effort required, PRA techniques are generally only used in very specialist applications.

However, a simplified approach can be useful in assessing the relative costs and benefits of various fire protection measures provided for property protection purposes or as part of a comparative study. Detailed guidance on PRA techniques is given in PD 7974-7 but the main advantages and disadvantages of a PRA are summarized in Table 11.

Table 11 — Advantages and disadvantages of probabilistic stud

Advantages	Disadvantages
Provide comparison between dissimilar fire protection systems	Limited statistical data
Provides a numerical value of risk	Time consuming analysis
Can quantify the probability of unlikely events with severe consequences	
Can quantify the risk associated with failure of one or more fire-protection systems	
Provides data for cost–benefit analysis	

6.8.2 *Life safety criteria*

When carrying out a probabilistic risk assessment (PRA), the objective is usually to show that the frequency of a given event occurring (e.g. injury, death or large life loss) is acceptably small.

In the UK, the average annual risk of death to an individual from fire is approximately 1.5×10^{-5} from fires in the home and 1.5×10^{-6} in other instances.

Society is far less tolerant of incidents, however infrequent, that can give rise to more than a small number of casualties (e.g. bus accidents compared with car accidents). The implications of a major accident are much wider than those of an injury to a particular individual. Any large-scale accident raises questions of responsibility for safety and public accountability in a way that accidents to individuals generally do not.

Guidance on the selection of suitable acceptance criteria for PRA purposes is given in PD 7974-7.

6.8.3 *Criteria for property protection*

Risk criteria for property protection may be set by the QDR team in conjunction with the client who could have specific views regarding the acceptable level of risk.

Where a fire is not likely to have a catastrophic effect on the continuing operation of a business, i.e. if the facilities are duplicated at several locations or can be quickly be reinstated, risk criteria may be set on the basis of ensuring that the cost of fire protection is balanced by the potential reductions in losses.

A decision to provide additional fire protection measures for property protection purposes may be taken on the grounds that the cost of fire protection measures for loss prevention purposes will be less than the potential savings over the lifetime of the building. The main factors that might be taken into account in this type of analysis are summarized in Table 12.

Table 12 — Benefits and costs of fire protection measures for property protection

Fire protection benefits	Fire protection costs
Reduction in direct fire losses	Installation costs
Reduction in business interruption	Maintenance costs
Maintenance of corporate image	Operational impact (e.g. reduced efficiency resulting from split location of stocks)

To estimate the potential financial losses and compare them with the benefits of installing various fire protection systems, the concept of Average Potential Loss (APL) may be utilized. The APL is simply a means of expressing the fire risk in monetary terms over the expected lifetime of the building and is given by:

$$\mathrm{APL} = V\ \mathrm{DL}\ F_{\mathrm{mf}}$$

where:

V is the cost to the business of losing the building and contents (in £);
DL is the design life of the building (in years);
F_{mf} is the frequency of a major fire (in fires per year).

If a total loss of the building and its contents can result in closure of the business, the value of V should reflect the potential future loss of profits as well as the direct cost of the building and contents.

For a large organization, spreading the operations between several locations might be more cost effective than operating at one location that is protected with a comprehensive set of fire protection measures. However, where the number of locations is such that fires are likely to occur regularly, it might be desirable to provide additional fire protection measures to minimise the potential for regular bad publicity.

More detailed, guidance on the application of PRA techniques to FSE design is given in PD 7974-7.

6.9 Fire scenarios for analysis

6.9.1 *General*

The number of possible fire scenarios in even a relatively simple building can become very large and it is not feasible (or necessary) to assess the effects of them all. Therefore, when carrying out a comparative or deterministic study, it is usual to identify one or more worst case scenarios for detailed evaluation.

In some cases (e.g. a single compartment building), it will be feasible to identify one scenario that clearly represents the worst case. However, in a complex building, it might be necessary to establish a number of scenarios for detailed assessment.

Depending upon the objectives of the FSE study the definition of a fire scenario will need to take account of some or all of the following factors:

a) design fire;

b) fire location;

c) occupant characteristics.

6.9.2 *Design fire*

6.9.2.1 *General*

Most fires can be characterized by the following phases:

— incipient phase: slow initial growth phase characterized by smouldering, or limited flaming;

— growth phase: the fire propagation period as the fire grows prior to flashover or full fuel involvement;

— fully developed phase: characterized by a substantially steady (maximum) burning rate in either ventilation or fuel bed controlled fires;

— decay phase: the period of declining fire severity;

— extinction: energy is no longer being released.

PD 7974-1 gives guidance on how to establish the following characteristics of a fire but the QDR team should seek to establish the basic parameters.

In a life safety analysis in which it is desired to evaluate the ability of the occupants to escape from the enclosure of fire origin, it will normally only be the incipient and growth phases of the fire that are of relevance (after flashover or full involvement, the possibility of escape can be discounted).

When considering the response of separating or structural elements, it will generally be the fully developed that is of significance.

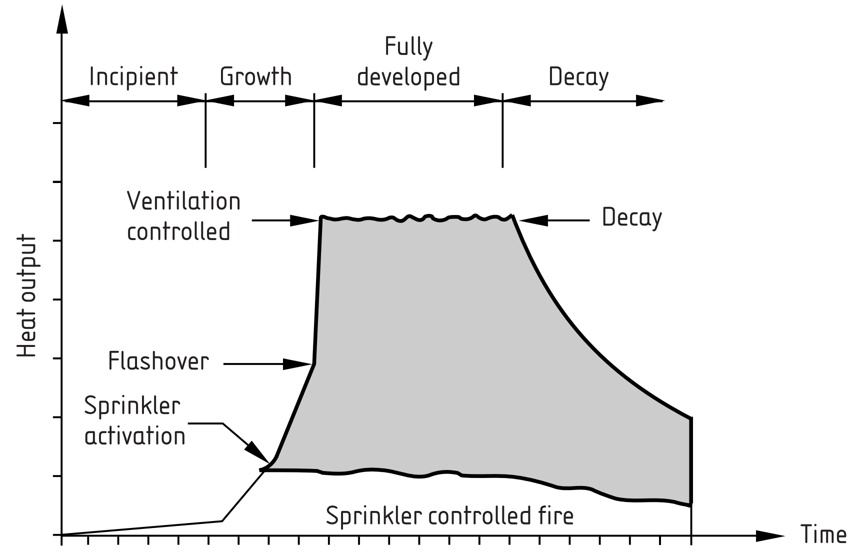


Figure 4 — Stages in the development and decay of a fire.

6.9.2.2 *Growing fire*

Where it is possible to establish the item likely to be first ignited, the initial rate of fire growth can be determined from test data. The fire development is defined in terms of the actual heat release rate versus time. However, in most circumstances, only the general nature of the combustible materials will be known and the first item to be ignited will be indeterminate.

Most fires that do not involve flammable liquids or gases will initially grow relatively slowly. As the fire increases in size, the rate of growth accelerates. This can be dependent on many factors including:

a) nature of combustibles;
b) geometric arrangement of the fuel;
c) ignitability of the fuel;
d) rate of heat release characteristics of the fuel;
e) ventilation;
f) external heat flux;
g) exposed surface area.

6.9.2.3 *Design fire growth rates*

For design purposes, fires are often assumed to grow proportionately to the square or exponent of time. Guidance on the use of characteristic fire growth curves is provided in the PD 7974-1 but, when carrying out the QDR, the team should consider the expected rate of fire growth in each fire scenario. This can be assessed qualitatively in terms of five main categories of fire growth:

a) smouldering;
b) slow;
c) medium;
d) fast;
e) ultra-fast.

The characteristic fire growth rates presented in Table 13 give an indication of the rate of growth that may be anticipated in a number of typical building uses that may be used for the purposes of the QDR. For quantification purposes, reference should be made to PD 7974-1.

Table 13 — Typical design fire growth rates

Occupancy type	Fire growth rate
Picture gallery	Slow
Dwelling	Medium
Office	Medium
Hotel reception	Medium
Hotel bedroom	Medium
Shop	Fast
Industrial storage	Ultra fast
NOTE See also PD 7974-1.	

6.9.3 *Fully developed fire*

6.9.3.1 *General*

The quantity of combustibles (fire load) within a room or enclosure will influence the duration and severity of a fire. Fire load data are therefore required in order to evaluate the duration and severity of a fully developed fire.

Information on fire load densities in different generic occupancies is given in PD 7974-1. Generally the 80 % fractile value is used in deterministic studies (i.e. the fire load that is not exceeded in 80 % of rooms). Guidance on fire spread beyond the enclosure of origin and the response of structures is given in PD 7974-3.

6.9.3.2 *Protected fire loads*

Combustible materials stored within containers that have a degree of resistance to fire (e.g. steel filing cabinets) will be protected to some degree and will not be fully consumed in a fire. The effective fire load might, therefore, be less than that of the total quantity of combustible materials present.

6.9.4 ***Factors affecting fire growth and severity***

6.9.4.1 *Ventilation*

The ventilation conditions can have a significant influence on the development and ultimate severity of a fire. The potential ventilation paths that should be considered within the QDR might include:

a) open doors;

b) mechanical ventilation systems;

c) windows (after breakage);

d) failed enclosing elements (e.g. roof collapse).

Automatic closure of fire resisting roller shutters or dampers in ducts can substantially reduce the ventilation available and should be identified in the QDR.

6.9.4.2 *Extinguishing systems*

The activation of automatic extinguishing systems should extinguish or at least control the growth of a fire. The impact of extinguishing systems on fire development is described in detail in PD 7974-1 and PD 7974-4.

6.9.5 ***Fire location***

The location of the design fire should be specified and the QDR should identify the geometry of the space and, where necessary, the location of fire origin within the room, i.e. whether a fire in the centre, beside a wall or in a corner should be considered. In a life safety analysis, a fire located adjacent to the widest exit route will generally represent the worst case scenario as it will mean that the exit will not be available for escape.

The location of the fire within the building will also influence the time required by the fire service to begin to fight the fire once they have arrived on site. For example, the fire service set-up time might be much longer for a fire on the upper floors of a high-rise building than for a single storey building.

6.9.6 ***Occupant characteristics***

Variations in evacuation response time are related to the type of occupancy, population and physical setting. For this reason, it is important to review the occupancies in relation to the factors that are most likely to influence human behaviour and movement.

Research into escape behaviour in fires and evacuations suggests that, in addition to means of escape design parameters (such as travel distance, number and position of exits and exit widths), the following factors can influence the response of people in different occupancies in a fire emergency:

a) occupant familiarity with the building;

b) occupant alertness;

c) occupant mobility;

d) social affiliation of occupants;

e) role and responsibility of occupants;

f) position of occupants within building;

Guidance regarding the impact of these factors is given PD 7974-6 but the QDR team should, when appropriate, make an assessment of these factors.

6.9.7 ***Occupant numbers***

The number of occupants in a space will often have a direct impact on the time required to evacuate via the available exits. For the purposes of a comparative or deterministic life safety study, the worst case scenario should include an assessment of the maximum likely number of occupants present in the building or part of a building.

7 Quantitative analysis

7.1 Overview

Following the QDR, a quantified analysis can be carried out, if necessary, to verify the adequacy of the trial designs established during the QDR. It has been found convenient to split the analysis procedures into a number of segments (or sub-systems). each covering a specific aspect of fire safety design. Basic design data, example calculation procedures and the general principles associated with each sub-system are given in the associated published documents (PDs).

This clause provides outline guidance on how the sub-systems may be used as part of a deterministic or comparative study. PD 7974-7 provides guidance on the application of probabilistic risk assessment techniques.

7.2 Sub-systems and Published Documents

7.2.1 *Sub-system 1: Initiation and development of fire within the enclosure of origin (PD 7974-1)*

Sub-system 1 provides information on the factors that effect the ignition and development of fire (in the enclosure of fire origin) and guidance on the choice of design fires.

The sub-system provides guidance on how the following may be evaluated as a function of time:

a) rate of heat release;

b) mass production rate of smoke;

c) mass production rate of fire effluents (e.g. carbon monoxide);

d) flame size and temperature;

e) temperature within enclosure;

f) time to flashover;

g) area of fire involvement;

In sub-system 1, it is assumed that the fire grows unimpeded by extinguishing activities such as sprinklers or fire brigade intervention. The above outputs may therefore be modified by information from sub-system 4 or sub-system 6.

7.2.2 *Sub-system 2: Spread of smoke and toxic gases within and beyond the enclosure of origin (PD 7974-2)*

Using the data output from sub-system 1, this sub-system provides guidance on evaluating and controlling the movement of fire effluents outside of the flaming region. The main areas covered are as follows:

a) spread of smoke and other fire effluents within and beyond the enclosure of fire origin;

b) the characteristics of smoke at defined locations;

- — mass flow;
- — volume flow;
- — temperature;
- — velocity;
- — optical density;
- — concentration of particulates and effluent gases;

c) smoke control methods;

- — smoke containment;
- — smoke clearance;
- — smoke dilution;
- — smoke exhaust ventilation;
- — pressure differential systems;

d) modelling techniques.

7.2.3 *Sub-system 3: Structural response and fire spread beyond the enclosure of fire origin (PD 7974-3)*

Using inputs primarily from sub-system 1, this sub-system includes guidance on assessing fire spread beyond the enclosure of fire origin and the structural response of the building (or its individual elements) to fire. The guidance covers the following main items:

a) mechanisms of fire spread;
  - radiation;
  - movement of hot gases;
  - flame spread across combustible surfaces;
  - burning brands or molten droplets, etc.;
  - penetration and collapse of barriers (walls, floors, doors, etc.);

b) fire exposure conditions (fire severity);
  - standard fire test conditions;
  - design fires;
  - structural response;
  - material response;
  - single elements;
  - two or more interacting elements;

c) complete structure.

7.2.4 *Sub-system 4: Detection of fire and activation of fire protection systems (PD 7974-4)*

This sub-system primarily utilizes data generated from sub-system 2 to provide guidance on evaluating the response of fire detectors, sprinklers, automatic smoke vents, etc. to heat, smoke and other fire effluents. It also provides guidance on assessing the impact of extinguishing systems on fire development.

The information that can be obtained from sub-system 4 as a function of time and/or fire size includes:

a) fire detection;

b) activation of fire control devices;
  - sprinklers;
  - roller shutters;
  - smoke vents;
  - magnetic door catches, etc.;

c) fire service notification;

d) modification of fire parameters;
  - sprinklers;
  - gaseous extinguishing systems.

7.2.5 *Sub-system 5: Fire service intervention (PD 7974-5)*

Sub-system 5 provides guidance on estimating the likely response and effectiveness of the fire service and can be used to obtain information on the following items:

a) arrival time;

b) time of intervention;

c) extinguishing capability;

d) reinforcement of fire fighting capabilities;

e) fire control time.

7.2.6 *Sub-system 6: Evacuation (PD 7974-6)*

This sub-system relates to the behaviour of people in response to fire or a warning of fire and the physical effects of heat, smoke and toxic gases. The information, which can be obtained by reference to this sub-system, includes:

a) physical escape parameters;
   - travel time (time required to reach an exit);
   - flow time (time required to pass through exit opening);

b) psychological escape parameters;
   - pre-movement time;
   - effect warning system type;

c) escape time;

d) human tenability limits;
   - visibility;
   - toxic and irritant combustion products;
   - radiant heat;
   - air temperature.

7.2.7 *Probabilistic risk assessment (PD 7974-7)*

PD 7974-7 provides guidance on how to quantitatively analyse the risk from fire associated with a building, its contents occupants taking account of the installed fire protection systems. PD 7974-7 also provides information on the uncertainty associated with deterministic calculations.

The information, which can be obtained by reference to this sub-system, includes:

a) the frequency with which fires can occur;

b) failure probabilities of fire protection systems;

c) the level of fire risk associated with a building its contents and occupants;

d) assessment of uncertainties in deterministic calculations.

7.3 Use of sub-systems

7.3.1 *General*

Each of the sub-systems may be used in isolation but, for most practical design purposes, two or more sub-systems will be needed to carry out an FSE analysis.

The design data and calculation procedures in the PDs for sub-systems 1 to 6 include implicit safety factors and are intended, when used together, to provide a satisfactory engineering solution without the need for additional explicit factors of safety. However, in some circumstances, it might be appropriate to provide an additional factor of safety where the consequences of failure are potentially catastrophic (e.g. the structural collapse of a high rise city centre building).

During the QDR, the main input data for a quantified study will have been established (e.g. building parameters, trial designs, fire scenarios). The basic calculation approach (e.g. comparative, deterministic or probabilistic) should also have been identified.

Differing types of FSE study will require different calculation approaches and before embarking on a series of calculations it is first necessary to establish:

a) the required numerical outputs;

b) the relationship between sub-systems;

c) appropriate calculation procedures.

7.3.2 *Numerical outputs*

The first step in the quantification process is to establish what numerical outputs are required as this will determine which sub-system calculations are to be used.

When considering a life safety assessment, a common approach is to ensure that the design targets have been met by demonstrating that:

ASET > RSET

ASET (available safe egress time) is the length of time available before untenable conditions are reached and might be defined in terms of:

a) the smoke layer height (z) descending to within 2.0 m of floor level; and

b) the visibility distance (S) falling below 10 m; or

c) the smoke layer temperature (θ_c) exceeding 200 °C.

The time dependent values of each of these items would be outputs from sub-system 2 but would require inputs from sub-system 1 to complete the calculations.

RSET (required safe egress time) represents be defined as the time taken (from ignition) for all of the occupants to reach a place of safety and this information can be obtained from sub-system 4 and sub-system 6.

When considering the potential for structural failure the design target might be to demonstrate that:

$t_{fr} > t_e$

where:

t_{fr} is the fire resistance of an element of structure;

t_e the time equivalent fire severity of a compartment fire.

Both of these outputs can be obtained from sub-system 3. These outputs are single value (limit state) outputs relating to a single structural element, but it is also possible to carry out a time dependent evaluation. This could provide the time temperature history for the fire and enable the dynamic response of a framework of structural element(s) to be evaluated. This latter approach is likely to require a more complex analysis but can provide a more informative and less conservative outcome.

It is the responsibility of the fire safety engineer to establish the most appropriate outputs for the particular study but guidance on the selection of appropriate calculation techniques is given in each of the PDs.

7.3.3 *Relationship between sub-systems*

Whilst the required outputs in the above examples come directly from one or two sub-systems, there might be a complex series of interactions involving all of the sub-systems. For instance, the activation of sprinklers (sub-system 4) and fire service intervention (sub-system 5) might influence the rate of fire growth given by sub-system 1. The potential complexity of the links between the various sub-systems is illustrated by means of a flow chart in Figure 5.

This flow chart illustrates the order in which the sub-systems would normally be evaluated. The solid lines indicate the order of calculation and the links that are normally required from other sub-systems. The dotted lines indicate the links that may need to be included depending upon the complexity of the analysis being undertaken.

Evaluating all of the possible interactions is often not practical because of a lack of data or the computational effort required. However, by making appropriate simplifications and utilising a worst case scenario, it is generally possible to simplify the calculation process to manageable proportions.

A life safety analysis may involve using five of the six sub-systems (fire service intervention is normally discounted when designing for life safety purposes) whereas when considering structural failure it might only be necessary to consider sub-systems 1 and 3.

The choice of which sub-systems are utilized and the manner in which they are linked in the calculation process will therefore depend upon the type of problem being considered and the extent to which it is simplified in the QDR and subsequent quantification process.

The way in which sub-systems might be linked together in typical life safety and structural analyses (where the development of fire is not controlled by active suppression systems) are illustrated in Figure 6 and Figure 7 respectively. However, these examples do not represent the only acceptable method and it is the responsibility of the fire safety engineer to establish the most appropriate approach.

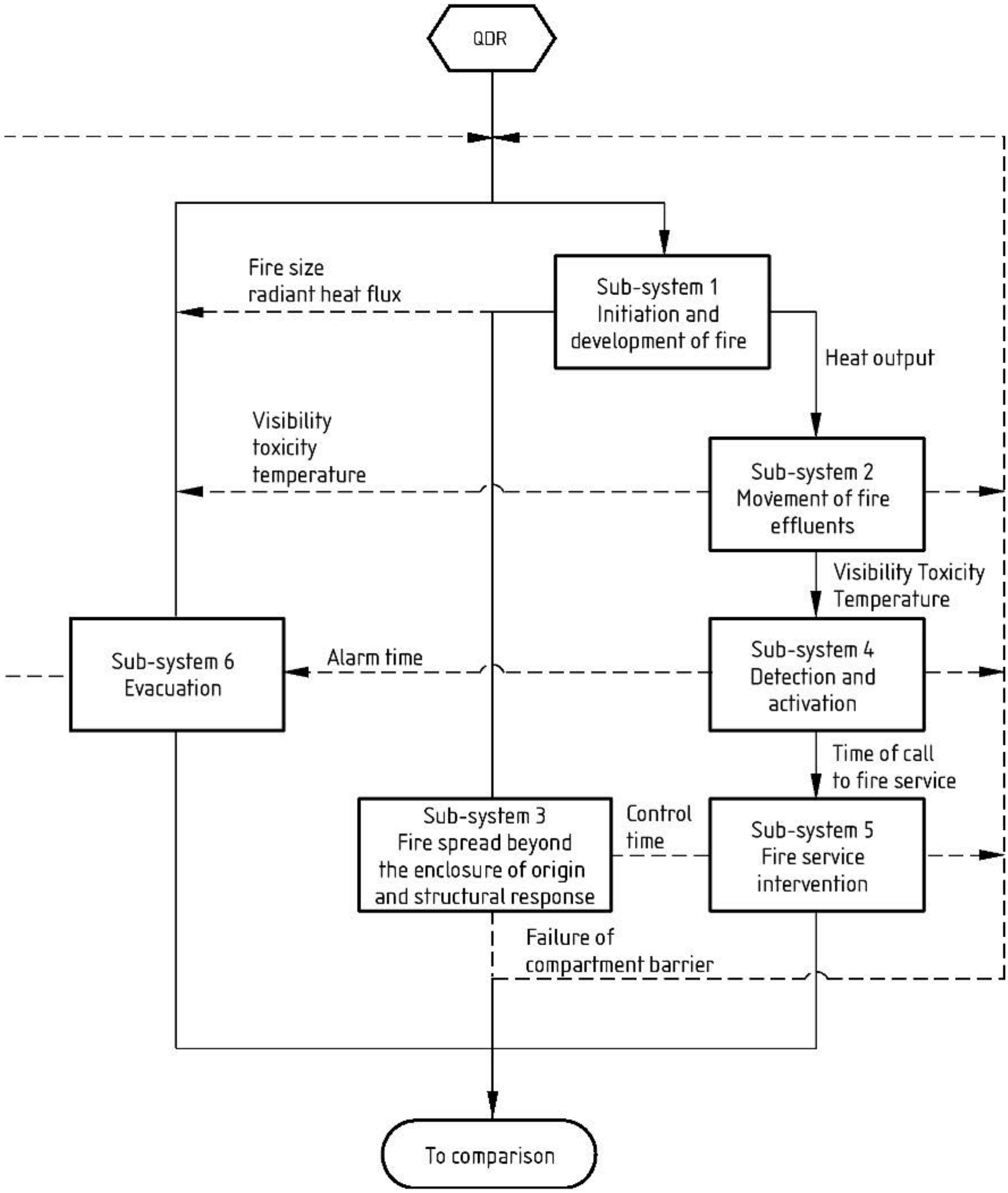


Figure 5 — Illustration of the complexity of the linkages between the sub-systems that might arise if the study is not simplified.

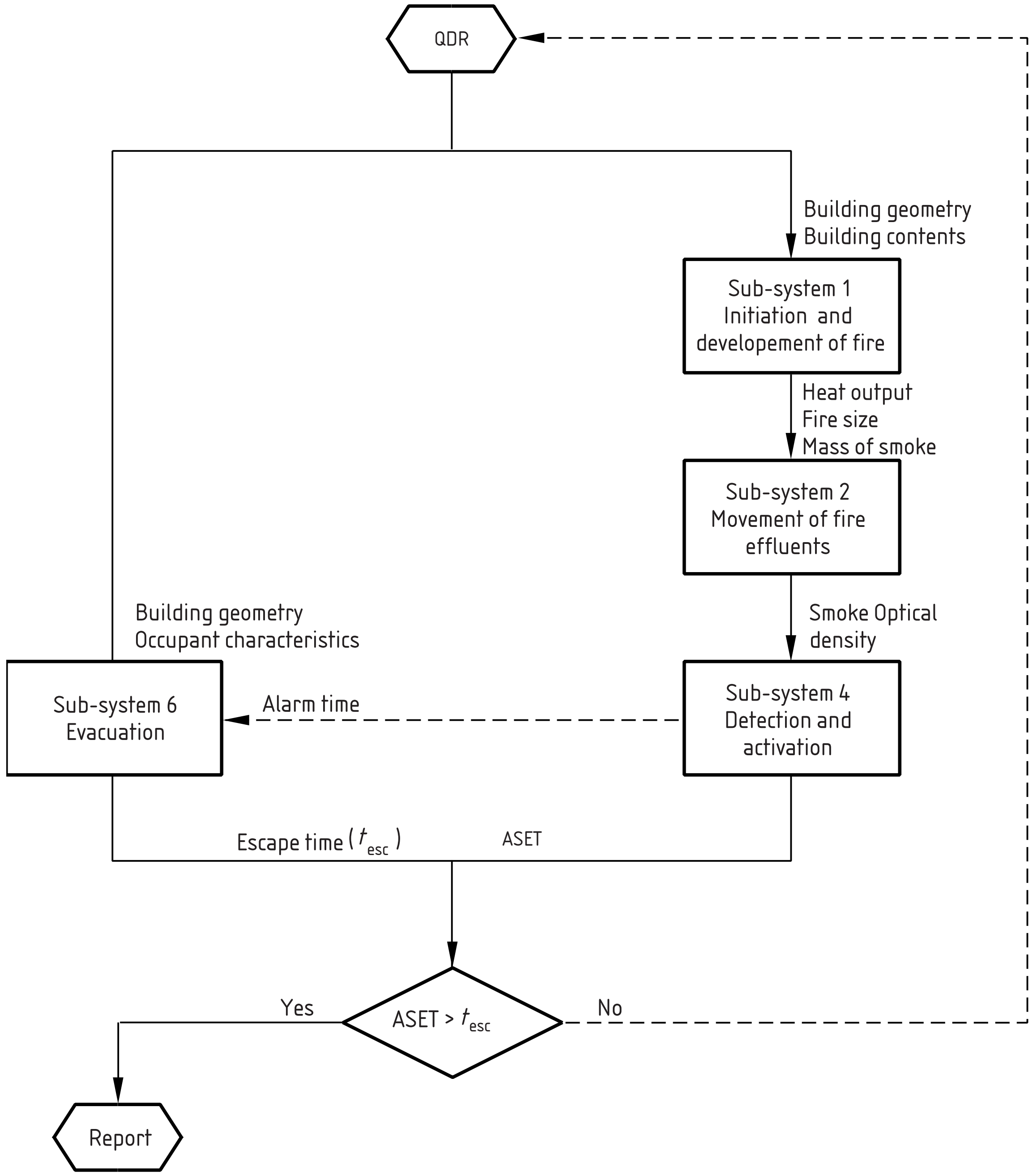


Figure 6 — Illustration of how the sub-system procedures might be simplified to assess the adequacy of means of escape from the room of fire origin.

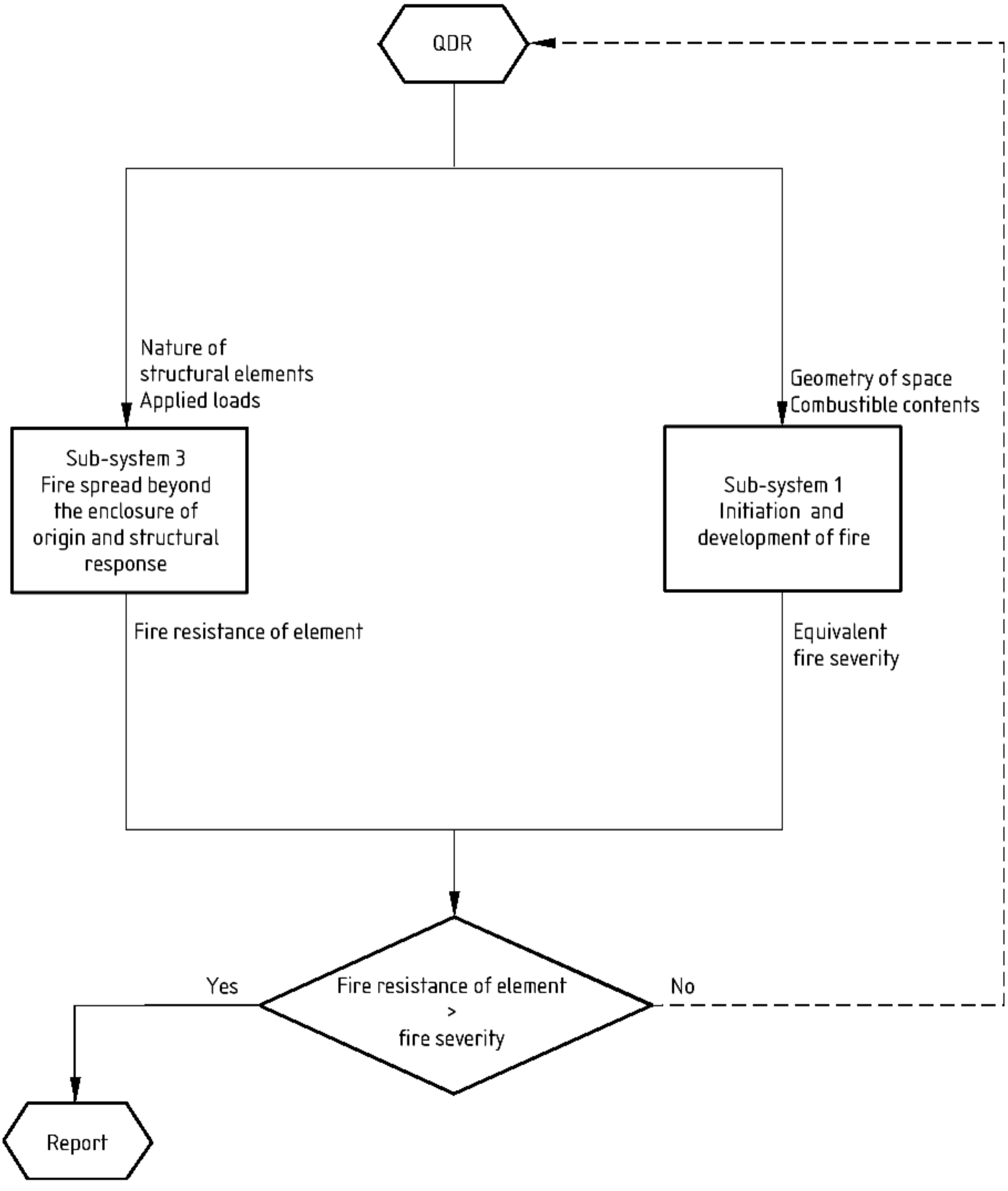


Figure 7 — Illustration of how the sub-system procedures might be utilized to assess the ability of a building structure to resist a compartment burnout.

7.3.4 *Deterministic calculation procedures*

7.3.4.1 *General*

Deterministic procedures quantify fire growth, fire spread, smoke movement and the consequences of these for the building and its occupants. They are based on physical, chemical and thermodynamic relationships derived from scientific theories and empirical methods. A deterministic analysis involves the evaluation of a set of circumstances that will provide a single outcome, i.e. a decision whether the design will either be successful or not.

Several deterministic techniques are available for evaluating the development and effects of fire and the movement of people, some of which are described in PD 7974, parts 1 to 6.

The sub-system calculations may be used to provide a time-based analysis where the inputs and outputs of each sub-system vary as a function of time. This approach normally requires a computer-based analysis with repeated loops through each set of sub-systems at defined time intervals. An alternative approach is to use a limit state method to determine the conditions under which a given event can occur (e.g. flashover).

7.3.4.2 *Computer-based analysis*

At their simplest, computer programs for FSE purposes use computer code or spreadsheet software to process one or more empirical algorithms to obviate the need for laborious hand calculations.

At the other extreme are complex models, where a domain is subdivided into a large number (tens or hundreds of thousands) of discrete control volumes filling the computational domain. The fundamental physical equations for the conservation of mass, momentum, energy and chemical are then solved for each discrete control volume. This type of model includes Computational Fluid Dynamics (CFD) for the modelling of smoke movement and finite element analysis to assess heat transfer or structural response to fire.

The principle of subdividing a steel column (the calculation domain) into a number of discrete control volumes is illustrated in Figure 8.

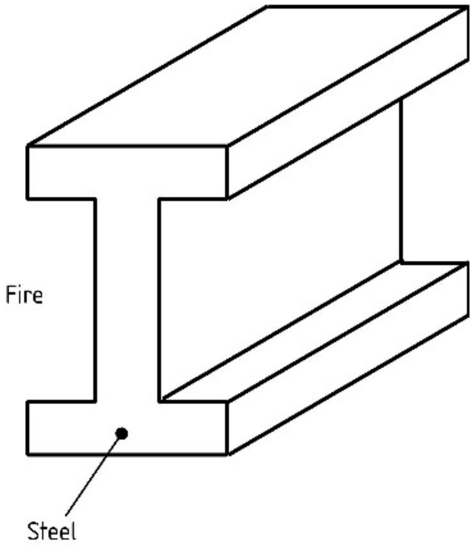


Figure 8 — Illustration of subdivision of calculation domain in a complex model

Between these two extremes are zone models for smoke spread and other models of similar complexity. These intermediate models generally subdivide the computations into two or three discrete zones and link a number of well-established empirical algorithms together to carry out repeated calculations at defined time steps. This can provide a reasonable simulation of transient conditions but does not provide any indication of the variation of conditions in a zone.

The subdivision of the computational domain into two zones in an intermediate type model is illustrated in Figure 9.

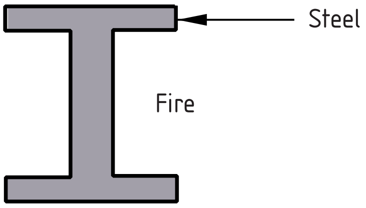


Figure 9 — Subdivision of calculation domain into two zones in an intermediate model.

7.3.4.3 *Choice of calculation method*

In many cases, hand calculations or intermediate computer models will provide adequate accuracy. This type of model can provide results quickly and simply and are extremely useful where the problem under consideration is consistent with the empirical relationships utilized.

Intermediate models generally assume a uniform (average) distribution of conditions (e.g. temperature) throughout a zone. For many design purposes, this simplification is acceptable but care should be taken to ensure that localized variations do not have a significant effect on the design (e.g. localized high temperatures cause an extract fan to burn out).

Models and correlations need to be chosen to ensure that they are suitable for the particular scenario under consideration. For instance, hand calculations or simple or intermediate computer models may be suitable for assessing the movement of smoke where the flow path is straightforward but, where the smoke cascades past several overhanging balconies (see Figure 10b), the only viable way of reaching a solution may be to utilize a complex Computational Fluid Dynamics model.

A detailed description of the various modelling techniques and their suitability for particular applications is given in PD 7974, parts 1 to 6 but, in adopting any modelling technique, the user should ensure that:

a) it has adequate predictive capability;

b) it is appropriate to the scenario under consideration;

c) computer models have been adequately assessed and verified.

Guidance on the assessment and verification of computer-based fire models is given in Annex A.

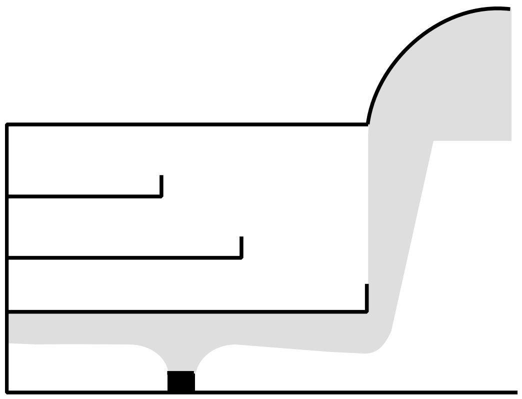


Figure 10a — Simple flow geometry

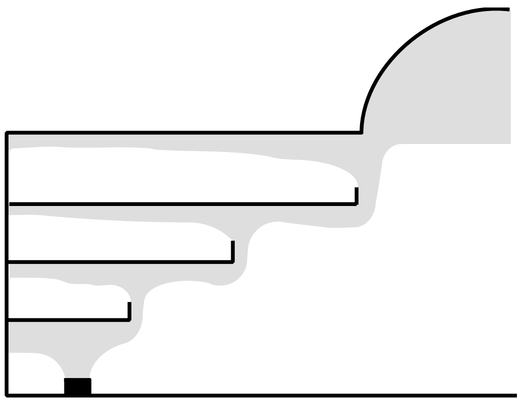


Figure 10b — Flow geometry with multiple spills likely to require evaluated using zone modelling complex modelling techniques (e.g. CFD) techniques

7.3.5 *Predictive ability*

The empirical relationships presented in the parts of PD 7974 (and other established published works that have been subject to independent peer review) may be assumed to have adequate predictive ability for most FSE design purposes, provided that the relationships are used within the stated limits of applicability.

However, where a model or correlation has not been subject to independent validation or is used outside its limits of applicability, its ability to accurately predict outcomes should be assessed in terms of its theoretical basis and an empirical comparison with data gathered experimentally or from real fires. Where some doubt remains regarding the predictive ability of a model, its use might still be reasonable provided that suitable safety factors are included in the analysis.

It is important to understand how variation between predicted and measured values is likely to effect the outcome. For instance, a model or correlation that overpredicts the volume rate of smoke production would generally be conservative and provide an intrinsic safety factor in the design of natural smoke vents. However, this same correlation would tend to under-predict smoke temperature which could lead to an under specification of the temperature rating of a mechanical extraction fan.

7.3.6 *Sensitivity analysis*

Deterministic design will involve uncertainties. In most cases, this will be adequately accounted for by the use of worst case initial assumptions (e.g. selecting a fire growth rate that is at the upper bound of expectations).

However, if this approach is not suitable, then the primary sources of uncertainty might need to be addressed; these are associated with:

a) input parameters;

b) necessary simplifications in the modelling techniques;

c) limitations of empirical relationships.

An indication of such sensitivity may be gained by investigating the response of the output parameters to changes in the individual input parameters. This will act as a guide to the level of accuracy required of the input data.

The objective of a sensitivity analysis is to check the robustness of the results and to investigate the criticality of individual input parameters.

If a single system or assumption is shown to be critical to the outcome of the FSE analysis, consideration should be given to providing a degree of redundancy in the design or to carrying out a probabilistic study.

7.3.7 *Uncertainties due to QDR simplifications*

The simplifications and assumptions made in the QDR to aid the full analysis should be tested for their criticality to the fire safety design. For example, it might have been assumed that an enclosure remains an enclosure, and that the possibility of an open door may be ignored. However, an alternative scenario would assume the door is open and the effect of confinement can be assessed. This type of issue should normally be dealt with by the QDR team in the "what if" assessment.

7.3.8 *Uncertainties due to input parameters*

Provided that the modelling techniques are appropriately chosen, it is probable that uncertainties in the initial assumptions will be the most significant. When modelling for life safety purposes, the two factors that are most likely to impact on the outcome are:

a) rate of fire growth (sub-system 1);

b) pre-movement time before the occupants respond to an alarm and move towards an exit (sub-system 6).

In a deterministic study, particular care should therefore be taken to establish the adequacy of these assumptions. However, in a comparative study, the effects of any errors in these assumptions are likely to cancel out and should have little impact on the ranking of the outcomes between the code compliant and the FSE solution.

7.3.9 *Uncertainties due to modelling or empirical relationships*

Where there is doubt about the applicability of a particular calculation technique, further confidence in the results can be gained by comparing the outcome of one model with another which is based upon different empirical relationships or calculation approaches.

Any significant discrepancies may be accounted for by choosing the most onerous of the results or by introducing an appropriate safety factor.

7.4 Probabilistic methods

In practice, there are many factors that can influence the development of a building fire and the escape of occupants. These factors will vary according to the circumstances at the time of the fire (e.g. whether first-aid fire-fighting has been unsuccessful or fire doors are propped open).

In a PRA study, the objective is to estimate the likelihood of a particular unwanted event occurring. This can be achieved by the use of statistical data regarding the frequency of fire starts and the reliability of fire protection systems combined with a deterministic evaluation of the consequences of the range of possible fire scenarios. This type of approach can, to some degree, take account of the uncertainties that characterize real fires and the complex interactions between the factors involved. PRA can be used to evaluate the effect of variable factors such as fire growth rate, pre-movement time, the number of occupants, etc.

Using PRA procedures, it is possible to estimate the probability of death or injury or the potential for extensive property damage that can result from fire. This information may then be used to estimate potential financial losses and enable a cost–benefit study to be carried out to establish the value of installing additional fire protection measures.

PRA can be an important decision-making tool provided that its limitations are recognized. Even if only limited data are available, meaningful calculations may be possible using numerical estimates based on experience and judgement. Because the judgements required to generate these estimates relate to specific items, they are likely to lead to a more accurate assessment than a judgement relating to the overall problem.

By assigning probabilities of failure to fire-protection measures and frequencies of occurrence to unwanted events, it is possible to assess the likelihood of a particular set of consequences. Probabilistic risk assessment (PRA) can be used as a basis to:

a) estimate the frequency of high-consequence events (e.g. multiple fatalities);

b) establish the most cost-effective design;

c) compare the effectiveness of dissimilar fire-protection systems (e.g. sprinklers versus compartmentation);

d) evaluate the likelihood of failure of one or more fire-protection systems.

The risk associated with fire in a building takes into account the likelihood of fires occurring and their potential consequences is given by:

risk = *f* (hazard, frequency, consequences).

When calculating the risk associated with a particular hazard, it is more usual to write:

risk = Σ (probability × consequence), for all consequences.

The PRA process involves determining:

a) what fire scenarios can occur;

b) the likely frequency of each scenario;

c) the total risk associated with fire;

d) the measures needed to reduce the risk to acceptable levels.

Detailed guidance on the application of PRA techniques is given in PD 7974-7.

8 Assessment against criteria

Following the sub-systems analysis, the results should be compared with the acceptance criteria identified during the QDR.

If none of the trial designs satisfies the specified acceptance criteria, the QDR and quantification process should be repeated to establish the available options. The options might include:

a) development of additional trial designs;

b) adoption of a more discriminating design approach (i.e. using deterministic techniques instead of a comparative study or probabilistic instead of deterministic procedures);

c) re-evaluation of design objectives (e.g. if cost of fire protection measures for property outweigh the potential benefits).

When a satisfactory solution has been identified, the resulting fire safety strategy and the FSE process that produced it should be fully documented as described in Clause **9**.

9 Reporting and presentation

9.1 General

Most buildings designed in accordance with the provisions of BS 7974:2001 will be subject to review and approval. It is therefore essential that the findings of the fire safety engineering study and any assumptions made are be presented in a form that can be clearly and readily understood by a third party. It is also important that the necessary fire safety systems are adequately specified.

When checking that a design complies with traditional codes and guidance documents, it is relatively straightforward to establish whether the various provisions of these have been correctly implemented. However, BS 7974:2001 provides for a flexible approach to design using performance-related objectives rather than prescriptive solutions. It is not, therefore, possible for an approvals body simply to compare the proposed design against a set of well-defined requirements. It is essential that the results of a fire engineering study are fully documented.

The FSE report should set out clearly the basis of the design, the calculation procedures used and any assumptions made during the study.

The format of the report will depend on the nature and scope of the fire engineering study and the house style of the fire safety engineer, but it should typically contain the following information:

a) objectives of the study;

b) building description;

c) results of the QDR;

d) quantified analysis;

e) comparison with acceptance criteria;

f) fire safety strategy;

g) management requirements;

h) conclusions;

i) references;

j) qualifications and experience of the fire safety engineer(s).

It is important that the report draws a clear distinction between life safety, property protection and environmental protection so that building owner, manager and approval body can clearly identify the purpose of the proposed measures.

9.2 Objectives of study

This section of the report should set out the overall objectives of the fire safety engineering study whether in terms of compliance with statutory requirements for life safety or the clients desire to reduce the potential for financial loss, etc.

9.3 Building description

The report should provide a general overview of the layout, construction and proposed use of the building. A more detailed description should be given of those aspects of the scheme that relate to the reasons for, and the outcome of, the FSE study (e.g. travel distances well in excess of the recommendations of prescriptive codes).

9.4 Results of QDR

A detailed statement of the main factors considered in the QDR should be provided together with the reasons for proposing and rejecting the various fire scenarios and trial designs.

In general, the following minimum information should be provided:

a) membership of the QDR team;

b) clear statement of fire safety objectives;

c) results of the architectural and building review;

d) the significant hazards and possible consequences;

e) one or more trial designs;

f) specification of the fire scenarios for analysis;

9.5 Quantified analysis

The basis for choosing the adopted quantification techniques should be given and any assumptions or engineering judgements made in their application should be clearly stated.

Full details of the calculation procedures should be provided. Sufficient detail of the data inputs and boundary conditions should be provided to ensure that a third party can review or repeat the calculations without the need for reference to the author of the report.

All empirical relationships and computer models used in the analysis should be fully referenced. Where independent validation of a model or calculation procedure is not available, or it is being used outside the suggested limits of applicability, clear justification for its use should be provided in the context of the particular study.

To improve the comprehension of a report, it is often advisable to provide an overview of the calculation procedures in the main body of the report but to relegate full details of any calculations into appendices.

The main items that should be included when reporting the quantified analysis include:

a) assumptions;

b) engineering judgements;

c) calculation procedures;

d) validation of methodologies;

e) sensitivity analyses.

It should be noted that, in many FSE studies, it is possible to reach a solution by logical deduction without the need for any quantification.

9.6 Comparison with acceptance criteria

The outcome of the quantified analysis should be compared with the acceptance criteria and this should be described for each of the specified fire safety objectives.

9.7 Fire safety strategy

The fire safety strategy for the building will be based on the successful trial design and is likely to comprise a range of physical fire safety measures and management procedures. A description of these measures should be provided, together with performance specifications and any recommended deviations from the relevant system codes, e.g:

The sprinkler system should comply with BS 5306: Part 2 except that sprinkler heads are not required above the swimming pool.

9.8 Fire safety management

The role of fire safety management is both critical and integral to successful fire safety whether the design is based upon prescriptive codes or fire safety engineering design. Therefore, BS 7974:2001 assumes that all aspects of the fire safety engineering strategy are capable of being maintained and deployed over the lifetime of the building.

If there are any specific aspects of the design that are particularly dependent upon a high standard of fire safety management, this should be clearly highlighted and a separate fire safety management manual should be prepared. The basis on which the fire safety design of a large or complex building has been achieved should also be recorded in the fire safety manual, which should be kept on the premises concerned, for the benefit of the management of the premises.

Further information regarding the documentation of fire safety management procedures will be provided in the BS 9999 series of standards.

9.9 Conclusions

The report should draw together the main findings of the fire engineering study and should highlight any aspects of the proposed design that are likely to impact on the use of the building in terms of:

a) fire protection requirements;

b) limitations on likely future use;

c) specific management requirements.

9.10 References

To ensure that the report can be fully checked by a third party, detailed references should be given for all documents and procedures used in the report. These should include details of:

a) architectural and engineering drawings (including revision numbers);

b) design documentation (e.g. engineering specifications);

c) technical papers and reports.

9.11 Qualifications and experience of fire safety engineer

In most FSE studies, it will be necessary to make some engineering judgements and the expertise of the fire safety engineer will often play a major part in defining the initial design assumptions. To enable a third party to establish that the FSE study has been carried out by a person with appropriate expertise, the name, qualifications and experience of the individual fire safety engineer(s) responsible for the study should be provided.

Annex A (normative)
Assessment and verification of FSE models

A.1 General

The term "model" encompasses all computer models using physical, mathematical and numerical assumptions and approximations to describe a particular fire process or occupant response.

In order to check that a computer model can satisfactorily represent physical reality, a process of verification is necessary to test the adequacy of a model's theoretical basis and implementation.

At their simplest, computer programs for FSE purposes may use computer code or spreadsheet software to process one or more empirical equations and simply obviate the need for laborious hand calculations. At the other extreme are complex computational fluid dynamics, finite element and exit models which can incorporate many "hidden" assumptions and use potentially unstable solvers.

Between these two extremes are intermediate models such as zone models for smoke spread and other models of similar complexity. The intermediate models generally link together a number of well-established algorithms and carry out repeated calculations at defined time steps to simulate transient conditions.

A.2 Assessment and verification procedures

Whenever possible, the software source code should be a part of the evaluation, but it is recognized that the source code is often not available when commercial software is used.

A verification methodology can be designed to reveal inappropriate methods or erroneous assumptions that can arise from any of the following sources:

a) the use of inappropriate algorithms or wrong physics to describe the processes that are being modelled;

b) the use of incorrect or unsubstantiated constants or default values;

c) simplification of the phenomena which the model is attempting to represent;

d) the use of inappropriate numerical algorithms for solving equation sets;

e) errors in the computer code.

The techniques for detecting errors in a model can be classified as:

a) review of the theoretical basis of the model;

b) inter-model comparison;

c) empirical validation.

d) code checking;

e) checks for numerical accuracy;

f) sensitivity analysis.

A.3 Review of the theoretical basis of the model

For complex models, the theoretical basis of the model should be reviewed by one or more experts fully conversant with the chemistry and physics of fire phenomena but not involved with the production of the model. This review should include an assessment of the completeness of the documentation, particularly with regard to the assumptions and approximations.

Reviewers should judge whether there is sufficient scientific evidence in the open literature to justify the approaches and assumptions being used. Data used for constants and default values in the code should also be assessed for accuracy and applicability in the context of the model.

A.4 Comparison with other programmes

The predictions of one model (under "test") are compared with those from other models supplied with identical data. If these other programmes have themselves undergone validation, they can serve as benchmarks against which the programme under test can be judged. If used with care and judgement, inter-model comparisons can reveal areas where programmes are inadequate.

A.5 Empirical verification

The comparison of the predictions of a model with data gathered experimentally is the primary way users feel confident in a model's predictive capability. This is particularly important when assessing complex models.

When a phenomenon is not well or fully understood, empirical verification provides a way of testing that its representation in the model (programme) is adequate for the intended use of the programme.

Fire tests used for making comparisons with mathematical fire model predictions should be carefully planned, executed and documented. To be useful to the model user, fire test data should be readily accessible.

Users must refer to the documentation provided by the test laboratory for detailed information on experimental procedures and the precision of the instrumentation used. Available fire test values are stored in a common format, and are readily available to computer models, plotting programmes and report generators.

A.6 Code checking

The code can be checked on a structural basis either totally manually or by using code- checking programmes to detect irregularities and inconsistencies within the computer code. Ensuring that the techniques and methodologies used to check the code, together with any deficiencies found, are clearly identified and recorded will increase the level of confidence in the programme's ability to process the data reliably.

A.7 Numerical accuracy

Mathematical models are usually expressed in the form of differential or integral equations. When checking complex models, analytical solutions are hard or even impossible to find. Numerical techniques are needed for finding approximate solutions. The algorithms used should be checked to ensure that they will always converge with sufficient accuracy and stability to a real solution.

There might also be a problem when the magnitude of variables varies by orders of magnitude. In a good algorithm, the variables are scaled to be of the same order of magnitude if possible.

Checking the rate of convergence by repeating the calculations with various discretization steps can increase confidence in the numerical method. If the errors decrease with decreasing step size, the method is consistent.

Most complex computer packages provide diagnostic information on the progress of residual errors for each of the equations solved. However, it is important to be satisfied that the overall mass and energy balances for the whole domain are within acceptable bounds. Compartment mass outflows should balance mass inflows, and heat lost into the structure taken together with heat lost from the compartment through its opening should balance that generated by the fire.

It is important to ensure that the solution is "well behaved". This might include inspection, for example, to ensure that it is free from spurious oscillations, that the characteristics of the fire source, especially its buoyancy flux and flame length, are correctly simulated, and that predicted downstream temperatures away from the areas of chemical reaction are less than those at the source. If problems of this nature do occur, then consideration should be given to reducing the grid spacing and/or time step.

There might be occasions when the computer simulation using field modelling may suggest unexpected behaviour. If a physical simulation were to produce something unexpected, the engineer would exert his ingenuity to explain what has been observed or what has been measured and relate it to the practical problem at hand. However, with a numerical simulation, such an eventuality is more disturbing since it can have two explanations: either it is genuine and would have been observed in a physical simulation, or it is some sort of misleading numerical artefact. The possibility of the latter cannot be completely discounted with such complex numerical simulations as those involved in computer fluid dynamics (CFD). It is therefore essential to "shadow" the numerical solution, where possible, with known simple calculation methods.

In general, the result of a measurement is only an approximation or estimate of the specific quantity subject to measurement, and thus the result is complete only when accompanied by a quantitative statement of uncertainty.

A.8 Sensitivity analysis

A sensitivity analysis of a model is a study of how changes in model parameters affect the results generated by the model.

Model predictions can be sensitive to uncertainties in input data, to the level of rigour employed in modelling the relevant physics and chemistry, and to the use of inadequate numerical treatments.

A well-designed and executed sensitivity analysis serves to:

a) identify the dominant variables in the models;

b) define the acceptable range of values for each input variable;

c) demonstrate the sensitivity of output variables to variations in input data;

d) inform and caution any potential users about the degree and level of care to be taken in selecting inputs and running the model;

e) provide insights as to which parameters should be monitored in large-scale fire experiments.

Conducting a sensitivity analysis of a complex fire model is not a simple task. The selection of parameters to be investigated will be aided by the knowledge and familiarity of the investigator with fire dynamics in single-compartment, multi-compartment and complex spaces.

A distinction should also be made between parameters that are internal and those that are external to the model. The former provide an insight on how well the physics and the mathematics utilized in the model reflect real fire behaviour and should be subject to verification.

A.9 Extent of verification

The extent of model verification by the author(s) and third parties will inevitably be dependent upon the complexity of the model and the extent of "hidden" assumptions and algorithms.

The extent of verification required might also depend on the consequences of error. In some designs, the inherent factors of safety might be such that modelling errors are not significant. In other cases, the opposite might be true.

Generally a minor change in the initial assumptions (e.g. fire growth rate) will have a much greater effect than the errors and uncertainties in a well-constructed model.

Table A.1 indicates the level of model assessment and verification that would ideally be recommended for each category of computer model. However, it is recognized that the producers of commercial software are unlikely to make their code available to third parties for detailed checking.

Table A.1 — Recommended levels of assessment and verification of computer models

Verification procedure	Simple	Intermediate	Complex
Review of theoretical basis	I	I/T	T
Comparison with other programs	—	I	T
Code checking	I	T	T
Empirical verification	—	—	T
Numerical accuracy	I	I/T	T
Sensitivity analysis	—	—	T

KEY

T Independent third party verification

I In-house verification and assessment

— Desirable but not essential

blank

Bibliography

BS 5306 (all parts), *Fire extinguishing installations and equipment on premises.*

BS 5839 (all parts), *Fire detection and alarm systems for buildings.*

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001.
Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001.
Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

Details and advice can be obtained from the Copyright & Licensing Manager.
Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553.
Email: copyright@bsi-global.com.

BSI
389 Chiswick High Road
London
W4 4AL