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

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Committees responsible for this British Standard

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Department for Transport, Local government and the Regions (DTLR)
Fire Safety Development Group
Home Office
Institute of Building Control
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National House-building Council (NHBC)
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Contents

Foreword

This British Standard has been prepared by Technical Committee FSH/24/1. It supersedes DD 240-1:1997 and DD 240-2:1997 which will be withdrawn on 31 December 2002. Additional guidance on fire safety engineering, sub-systems and risk assessment will be provided in a series of new Published Documents (PD 7974-0, PD 7974-1, PD 7974-2, PD 7974-3, PD 7974-4, PD 7974-5, PD 7974-6 and PD 7974-7).

BS 7974 is intended to provide a framework for the application of fire safety engineering principles to the design of buildings. It is supported by the PD 7974 series of Published Documents that contain guidance and information on how to undertake detailed analysis of specific aspects of fire safety engineering in buildings. PD 7974-0 to -7 provide a summary of the state of the art and it is intended that they will be updated as new theories, calculation methods and/or data become available. PD 7974 is structured as follows:

— *Part 0: Guide to the design framework and fire safety engineering procedures;*

— *Part 1: (Sub-system 1) Initiation and development of fire within the enclosure of origin;*

— *Part 2: (Sub-system 2) Spread of smoke and toxic gases within and beyond the enclosure of origin;*

— *Part 3: (Sub-system 3) Structural response and fire spread beyond the enclosure of origin;*

— *Part 4: (Sub-system 4) Detection of fire and activation of fire protection systems;*

— *Part 5: (Sub-system 5) Fire service intervention;*

— *Part 6: (Sub-system 6) Evacuation;*

— *Part 7: Probabilistic fire risk assessment.*

This code of practice can be used to identify and define one or more fire safety design issues to be addressed using fire safety engineering. The appropriate part(s) of PD 7974 can then be used to set specific acceptance criteria and undertake detailed analysis.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

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

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Attention is drawn to the following statutory regulations: Building Regulations [1], [2], [3], Fire Precautions Act [4] and Fire Precautions (Workplace) Regulations 1997 (as amended) [5].

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 28, an inside back cover and a back cover.

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

Introduction

This code of practice provides a framework for developing a rational methodology for design of buildings using a fire safety engineering approach based on the application of scientific and engineering principles to the protection of people, property and the environment from fire.

For most buildings the prescriptive recommendations on design in existing codes and guides as given in BS 5588-0 may be found to be adequate but this code of practice can be used for developing and assessing fire safety engineering proposals.

A fire safety engineering approach that takes into account the total fire safety package can often provide a more fundamental and economical solution than more prescriptive approaches to fire safety (see BS 5588-0). It may in some cases be the only viable means of achieving a satisfactory standard of fire safety in some large and complex buildings.

Fire safety engineering can have many benefits. The use of this code of practice will facilitate the practice of fire safety engineering and in particular it will:

a) provide the designer with a disciplined approach to fire safety design;

b) allow the safety levels for alternative designs to be compared;

c) provide a basis for selection of appropriate fire protection systems;

d) provide opportunities for innovative design;

e) provide information on the management of fire safety for a building.

Fire is an extremely complex phenomenon and gaps still exist in the available knowledge. This code of practice is intended to provide a framework for a flexible but formalized approach to fire safety design that can also be readily assessed by the approvals bodies.

This code of practice is supported by a series of Published Documents that contain guidance and information on how to undertake detailed analysis of specific aspects of fire safety engineering. This does not preclude the use of appropriate methods and data from other sources. Figure 1 shows the structure of the code of practice and the Published Documents. This code of practice:

— provides means of establishing acceptable levels of fire safety economically and without imposing unnecessary constraints on aspects of building design;

— provides guidance on the design and assessment of fire safety measures in buildings;

— gives a structured approach to assessing the effectiveness of the total fire safety system in achieving the design objectives;

— provides a framework for and describes the philosophy of fire safety engineering;

— outlines the principles involved in the application of the philosophy to the fire safety engineering of particular buildings;

— can be used to identify and define one or more fire safety design issues to be addressed using fire safety engineering;

NOTE The appropriate part(s) of PD 7974 can then be used to set specific acceptance criteria and undertake detailed analysis.

— 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; and

— recognizes that the design objectives may be achieved by a range of alternative and complementary fire protection strategies.

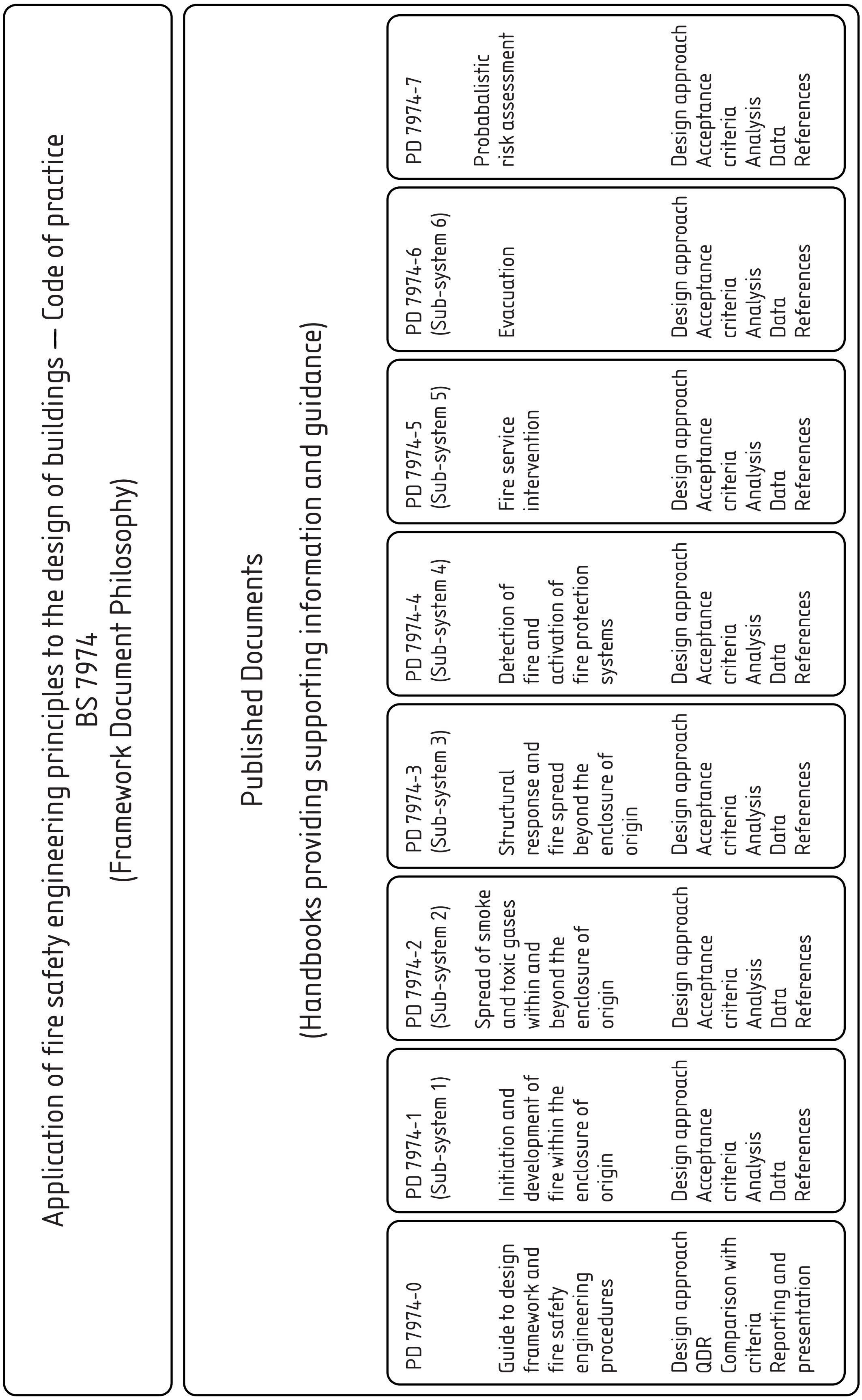

Figure 1 — The structure of the code of practice and the Published Documents

1 Scope

This code of practice provides a framework for an engineering approach to the achievement of fire safety in buildings by giving recommendations and guidance on the application of scientific and engineering principles to the protection of people, property and the environment from fire. This code of practice applies to the design of new buildings and the appraisal of existing buildings.

This code of practice does not provide specific guidance on buildings used for the bulk storage or processing of flammable liquids or explosive materials. The intrinsic risks associated with such buildings will often necessitate special consideration, which is beyond the scope of this document.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of this British Standard. 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 5588-0, *Fire precautions in the design, construction and use of buildings — Part 0: Guide to fire safety codes of practice for particular premises/applications.*

3 Terms and definitions

For the purposes of this British Standard the following terms and definitions apply.

3.1
approvals body
organization responsible for approving the fire safety aspects of a building

NOTE Examples of approvals bodies are the local authority building control, approved inspectors, and the fire authority.

3.2
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

3.3
calorific value
total amount of heat released when a unit quantity of a fuel (measured at 25 °C and atmospheric pressure) is oxidized during its complete combustion in oxygen under specified test conditions

NOTE In a fire only a proportion of this energy will be released.

3.4
compartment
building or part of a building constructed to prevent the spread of fire to or from another part of the same building or an adjoining building

3.5
escape time
calculated time from ignition until the time at which all the occupants of a specified part of a building are able to reach a place of safety

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)

3.8
evacuation time
interval between the time of a warning of fire being transmitted to the occupants and the time at which all of the occupants are able to reach 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 from fire

3.11
fire load
quantity of heat which could be released by the complete combustion of all the combustible materials in a volume including the facing of all boundary surfaces

3.12
fire load density
fire load divided by the floor area

3.13
fire risk
product of probability of occurrence of a fire to be expected in a given technical operation or state in a defined time, and consequence or extent of damage to be expected on the occurrence of a fire

3.14
fire safety engineer
person suitably qualified and experienced in fire safety engineering (see also Foreword)

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

3.17
fire scenario
set of circumstances, chosen as an example, that defines the development of fire and the spread of combustion products throughout a building or part of a building

3.18
flashover
sudden transition from a localized fire to the ignition of all exposed flammable surfaces within an enclosure

3.19
management
person or persons in overall control of the premises whilst people are present, exercising this responsibility either in their own right, e.g. as the owner, or by delegation (of statutory duty)

3.20
means of escape
means whereby safe routes are provided for persons to travel from any point in a building to a place of safety

3.21
phased evacuation
process by which a limited number of floors (usually the fire floor and the storey above) is evacuated initially and the remaining floors are evacuated when necessary

3.22
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.

3.23
pre-movement time
time interval between the warning of fire being given (by an alarm or by direct sight of smoke or fire) and the first move being made towards an exit

3.24
probabilistic risk assessment
methodology to determine statistically the probability and outcome of events

3.25
smouldering
combustion of a material without flame and light being visible

3.26
tenability criteria
maximum exposure to hazards from a fire that can be tolerated without causing incapacitation

3.27
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

3.28
travel time
time needed once movement has begun, for all of the occupants of a specified part of a building to move to a place of safety

3.29
trial fire safety design
package of fire safety measures which in the context of the building may meet the specified fire safety objectives

4 Application

4.1 General

This code of practice provides a framework for an engineering approach to fire safety which may be applied to both the design of new buildings and the appraisal of existing buildings, and to show that regulatory and/or financial requirements can be satisfied. The use of this framework is not a guarantee that the resulting design will be adequate. Approvals bodies should be consulted before final decisions are taken about the fire safety design.

The engineering approach may be used in conjunction with other guidance documents (see BS 5588-0). It may also be used to justify alternative approaches to those in other guidance documents.

The framework for an engineering approach to fire safety described in this code of practice should be applied using the following three main stages (see Figure 2).

a) Qualitative design review (QDR)

The scope and objectives of the fire safety design are defined, performance criteria established and one or more potential design solutions proposed. Key information is also gathered to enable evaluation of the design solutions in the quantitative analysis.

b) Quantitative analysis

Engineering methods are used to evaluate the potential solutions identified in the QDR. Quantitative analysis can be time-based analysis using appropriate sub-systems (see **4.2**) to reflect the impact of the fire on people and property at different stages of its development. Steady state and limit state analysis can also be used.

c) Assessment against criteria

The output of the quantitative analysis is compared to the acceptance criteria identified in the QDR to test the acceptability of the proposals.

In order to substantiate a fire safety engineered design these three distinct stages should be worked through. Each of the stages should be fully documented so that they are readily accessible to a third party, e.g. approvals bodies, insurers, owner occupiers of buildings.

4.2 The sub-systems

To simplify the evaluation of the fire safety design, the fire safety engineering process should be further broken down into six sub-systems (SS). The sub-systems can be used individually to address specific issues or together to address all of the main aspects of fire safety.

NOTE Figure 3 indicates some of the potential interactions between sub-systems.

The sub-systems should be used as follows.

a) SS1: initiation and development of fire within the enclosure of origin (see PD 7974-1)

SS 1 provides guidance on evaluating fire growth and/or size within the enclosure taking into account the four main stages of fire development:

1) pre-flashover (including early growth and development);

2) flashover;

3) fully developed fire (where all the fuel is burning);

4) decay.

b) SS2: spread of smoke and toxic gases within and beyond the enclosure of origin (see PD 7974-2)

SS 2 provides guidance by which the following may be evaluated:

1) the spread of smoke and toxic gases within and beyond the enclosure of fire origin;

2) the characteristics of the smoke and the toxic gases at the location of interest.

c) SS3: structural response and fire spread beyond the enclosure of origin (see PD 7974-3)

SS3 provides guidance so that the following can be evaluated:

1) the fire severity, in terms of temperature and heat flux within the enclosure; and

2) the ability of the elements forming the enclosure, directly or in part, to withstand exposure to the prevailing fire severity.

d) SS4: detection of fire and activation of fire protection systems (see PD 7974-4)

SS4 gives guidance on the calculation of the following with respect to time:

1) detection of the fire;

2) activation of the alarm and fire protection systems, e.g. sprinklers, smoke venting systems, roller shutters, etc.;

3) fire service notification.

e) SS5: fire service intervention (see PD 7974-5)

SS5 provides guidance on the evaluation of the rate of build up of fire extinguishing resources of the fire service, including the activities of in-house or private fire brigades and in particular:

1) the time interval between the call to the fire service and the arrival of the fire service pre-determined attendance;

2) the time interval between the arrival of the fire service and the initiation of attack on the fire by the fire service;

3) the time intervals related to the build up of any necessary additional fire service resources;

4) the extent of firefighting resources and extinguishing capability available at various times.

f) SS6: evacuation (see PD 7974-6)

SS6 provides guidance on how to assess the response of people to fire, including their evacuation time from any space inside a building. Once the evacuation time has been established it can be compared with the outputs from sub-systems 1 to 4 within the quantitative analysis. Criteria for acceptance are contained in this sub-system.

NOTE 1 The various parts of PD 7974 (PD 7974-1 to -6 respectively) for these sub-systems give selected data and engineering relationships (including information on their applicability) that may be used for design. However, this code of practice recognizes the use of alternative information.

All six sub-systems together can be used to produce a time-based analysis of fire safety.

NOTE 2 Figure 4 shows an example of a time line comparison between fire development and evacuation/damage to property.

4.3 PD 7974-0 and PD 7974-7

In addition to PD 7974-1 to -6 that cover the sub-systems, two other documents, PD 7974-0 and PD 7974-7, address other aspects of fire safety engineering.

a) PD 7974-0: guide to design framework and fire safety engineering procedures

Part 0 provides a commentary on how the principles of engineering can be applied to fire safety, including an overview of the interaction of sub-systems, the selection of appropriate analytical approaches and the selection of methods.

b) PD 7974-7: probabilistic fire risk assessment

Part 7 provides guidance on how to analyse the risk to a building and its contents, occupants and fire control systems with the intention of determining:

1) the frequency that certain fire scenarios can occur;

2) the level risk associated with fire; and

3) the extra measures required to reduce any unacceptable risks.

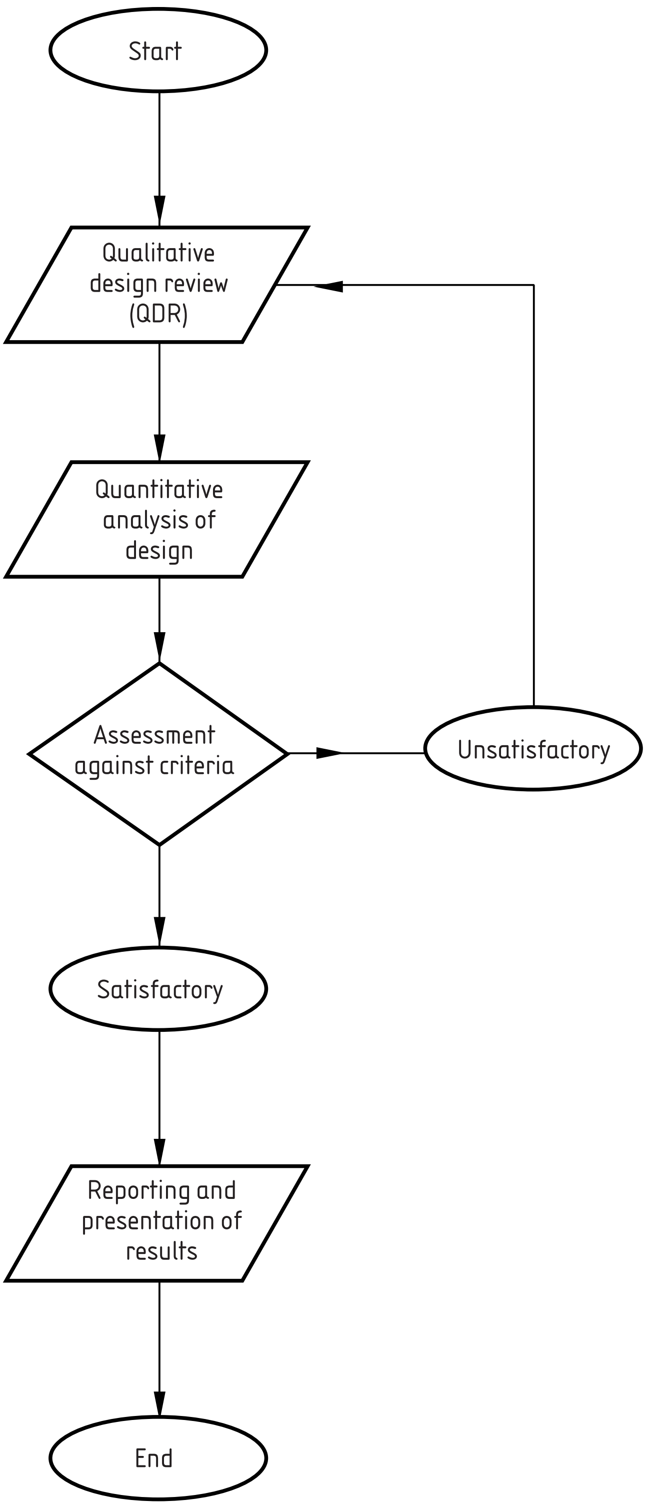

Figure 2 — Basic fire safety engineering process

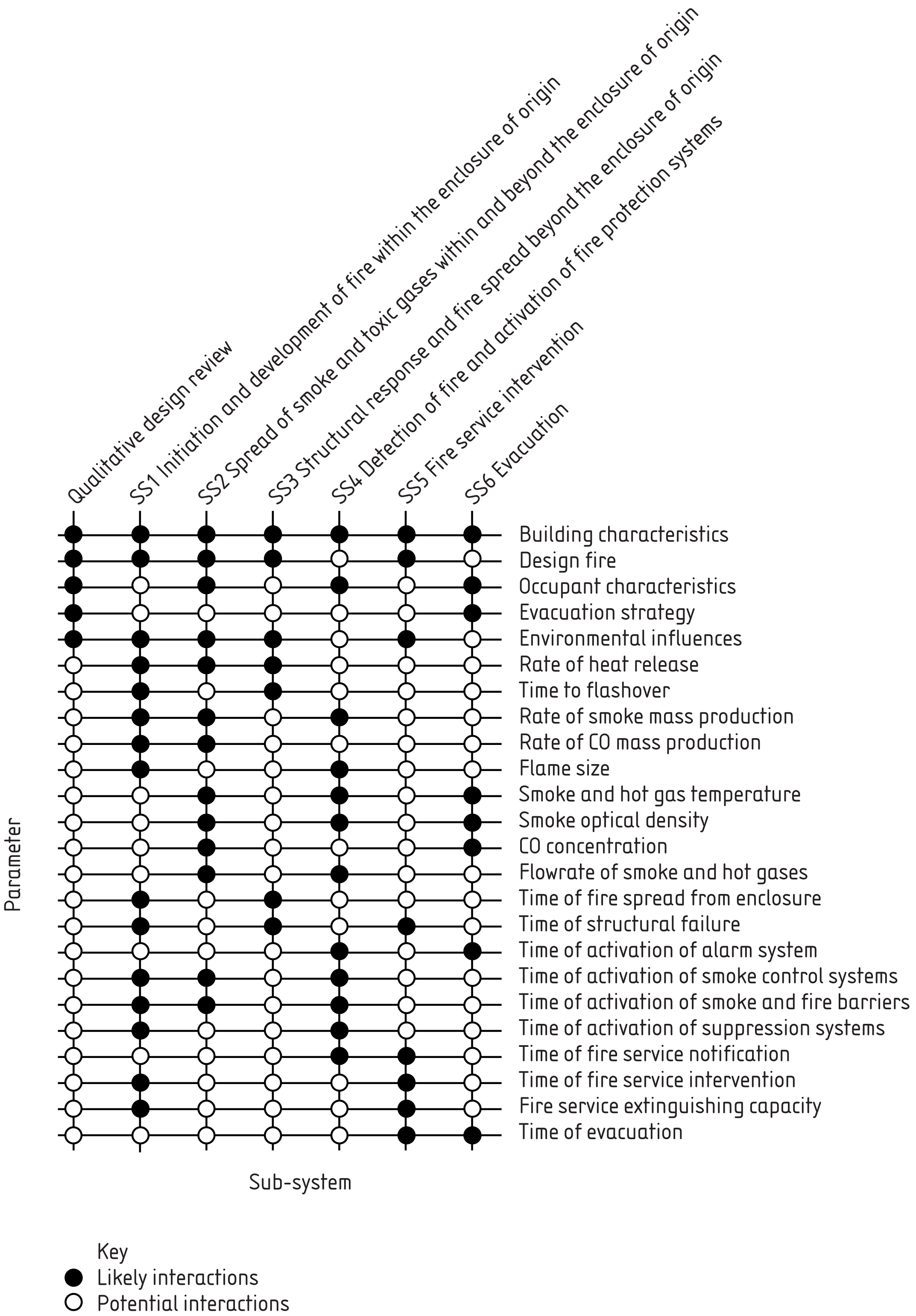

Figure 3 — Illustration of likely interactions between sub-systems

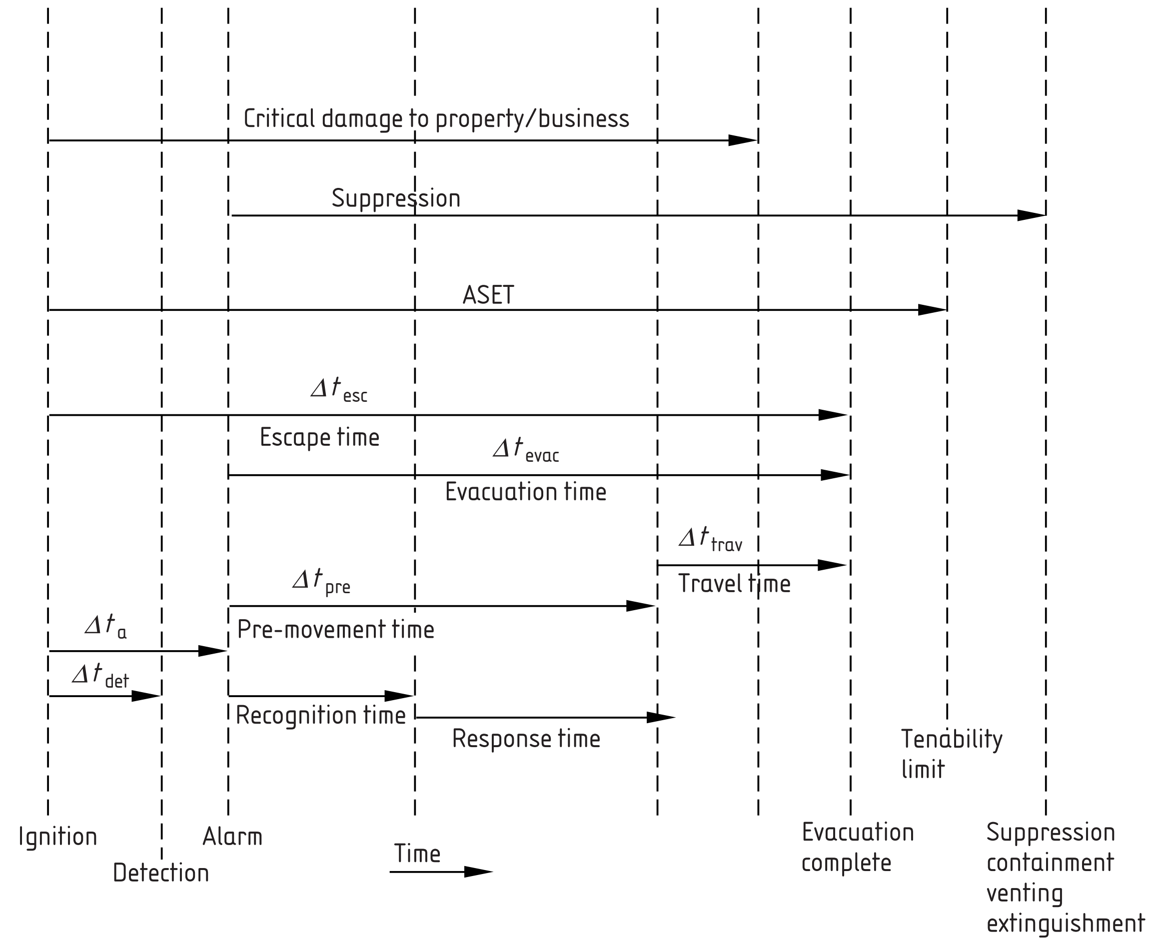

Figure 4 — Example of time line comparison between fire development and evacuation/damage to property

5 Reporting and presentation

5.1 General

As most buildings designed in accordance with the recommendations of this code of practice will be subject to review and approval, it is essential that the findings of the fire safety engineering study and any assumptions made are presented in a report that can be clearly and readily understood. It is also important that the necessary fire systems can be clearly specified.

When checking that a design conforms to traditional codes and guidance documents, as given in BS 5588-0, it is straightforward to establish whether the various provisions of these have been correctly implemented. This code of practice, however, provides for a flexible approach to design using performance-related objectives rather than prescriptive solutions. It is, therefore, not possible for an approvals body simply to compare the proposed design against a set of well-defined recommendations. For this reason, the results of a fire engineering study should be fully documented so that they can be readily assessed by a third party, e.g. approvals bodies. The report should set out clearly the basis of the design, the calculation procedures used and any assumptions made during the study.

5.2 Contents

The format of the report should contain some or all of the following information, depending on the nature and scope of the fire engineering study:

a) objectives of the study;

b) description of the building;

c) results of the QDR:

   1) membership of the QDR team;

   2) fire safety objectives;

   3) results of the hazard analysis;

   4) trial fire safety designs;

   5) acceptance criteria;

   6) fire scenarios for analysis;

d) analysis:

   1) assumptions;

   2) engineering judgements;

   3) calculation procedures;

   4) validation of methodologies;

   5) sensitivity analyses;

e) comparison of results of analysis with acceptance criteria;

f) conclusions:

   1) fire protection requirements;

   2) management requirements;

   3) any limitations on use;

g) references:

   1) drawings;

   2) design documentation;

   3) technical literature.

The report should draw a clear distinction between life safety, property protection and environmental protection so that the building owner, management and approvals body clearly understand the purpose of proposed measures.

5.3 Briefing for owner/occupier

The basis on which the fire safety design of a large or complex building has been achieved should be documented in a fire safety manual, which should be kept on the premises concerned for the benefit of the management of the premises.

The report of the fire engineering study should be incorporated into the fire safety manual. The general management and operational procedures in the fire safety manual should be written with reference to the fire engineering study report.

The fire safety manual should contain the technical specifications for all aspects of the building and should include the following:

a) fire safety policy statement;

b) fire safety specification for the building;

c) safety management structure;

d) continuing control and audit procedures;

e) actions to be taken in a fire emergency;

f) fire drills;

g) housekeeping;

h) planned maintenance procedures;

i) staff training;

j) security;

k) contingency plans for salvage and damage control;

l) record keeping.

NOTE For further information see BS 5588-0.

5.4 Audit

In order to maintain the effectiveness of the fire safety strategy, it is essential that regular and effective testing and maintenance procedures are conducted.

In large or complex buildings an independent audit should be carried out. The frequency of such audits should be determined according to the nature and complexity of the building concerned. However, audits should be carried out every one to five years.

Audits should include checking that policies adopted by those responsible for the management of fire safety are appropriate, that these policies are being implemented effectively, that testing of systems and equipment is being carried out in accordance with the relevant standards in BS 5588-0, and that legislative responsibilities (see [1], [2], [3], [4] and [5]) are being met.

6 Qualitative design review (QDR)

6.1 General

The QDR, a qualitative process that draws upon the experience and knowledge of the team members, should be used to identify the inputs to the quantitative analysis and acceptance criteria.

6.2 Personnel involved in conducting the QDR

For large and complex projects the QDR should 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. This ensures that all individual aspects of the design can be considered in the context of the fire safety objectives and that the impact of proposed solutions on other aspects of the design are fully appreciated. It may also be appropriate to include representatives of the approvals body in the QDR team.

For smaller projects the QDR may be carried out by a smaller study group but the same basic review process should be followed. The make-up of the QDR team should be based on the nature and size of the project and on the extent of the analysis conducted. The QDR team should always include a fire safety engineer and the person(s) who will carry out the quantified analysis [which may be the same person(s)].

The QDR is a 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 against the objectives and criteria set by the team. The QDR should be conducted in a systematic way to ensure that no relevant item is omitted.

6.3 Timing of QDR

Ideally, the QDR should be carried out early in the design process so that any substantial findings can be incorporated into the design of the building before the working drawings are developed. However, in practice, the QDR process is likely to involve some iteration as the design process moves from broad concept to greater detail.

6.4 Procedure for undertaking the QDR

6.4.1 *General*

The following steps should be taken when conducting the QDR:

a) review the architectural design of the building;

b) establish the 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.

All findings should be clearly documented as outlined in clause **5** so that the underlying philosophy and assumptions that underpin the design can be clearly understood by a third party, e.g. an approvals body.

6.4.2 *Review of architectural design of the building*

6.4.2.1 *General*

In the first stage of the QDR the project should be described by reference to schematic drawings, models, etc., and any architectural or client requirements that may be significant in the development of a fire safety strategy should be highlighted.

All the relevant available information about the building, its use and its anticipated contents, should be provided and reviewed.

NOTE 1 PD 7974-0 contains a checklist which can be used when reviewing the architectural design.

This review may also include:

a) *building characterization*, i.e. the layout and geometry of the building, details of the construction, the nature and extent of the loads acting on the structure (e.g. dead loads and imposed loads) and the degree of fire loading present;

b) *environmental influences*, such as wind and snow, which influence fire safety design through their effect on structural load levels, smoke ventilation systems and the nature of external flame envelopes issuing from the windows of the building;

c) *occupant characterization*, i.e the type of occupancy, the building population and its distribution, the likelihood of the fire alarm being raised manually, the type of fire detection and alarm system;

d) *management of fire safety*, i.e. the likely extent and nature of management in the building.

NOTE 2 PD 7974-0 provides guidance on building characterization, environmental influences and occupant characterization.

6.4.2.2 *Management of fire safety*

6.4.2.2.1 *General*

Management of fire safety is both critical and integral to successful fire safety engineering design as this code of practice assumes that the provision of all elements in a fire safety engineering strategy is capable of being maintained and implemented effectively over the life of the building.

NOTE It is on this basis that the recommendation is made in **6.2** that a representative of those responsible for the management of fire safety is included in the QDR process.

6.4.2.2.2 *Management*

The following factors should be taken into account when assessing the likely nature and extent of management in a building:

a) ownership, i.e. to what extent the ownership is known;

b) the number of managers of fire safety responsible for the building and to what extent this is known;

c) the level of resources and authority of the manager(s) of fire safety;

d) the level of staffing (i.e. staff-occupant ratio);

e) the level of fire safety training;

f) the level of security;

g) the level of control over work, e.g. repairs to structure;

h) the effectiveness of communications procedures;

i) the frequency of maintenance and testing of fire safety systems;

j) the level of liaison with the fire brigade;

k) the level of contingency planning;

l) the level of degraded system planning;

m) the level of planning for abnormal occupancies;

n) the level of independence of testing and auditing of the management system;

o) the level of management of risk; and

p) the level of management of fire load.

If the answers to these questions are generally positive, then greater reliance may be made on management procedures.

6.4.3 ***Establish the fire safety objectives***

6.4.3.1 *General*

At an early stage of the design process, the objectives of the fire safety design should be clearly defined and the acceptance criteria established. The protection of life is the main objective of fire safety legislation; however, the effects of fire and its products on the ongoing operations of a business and the direct property losses should also be considered.

The appropriate objectives and criteria for the particular study should be established during the qualitative design review (QDR). As the framework in this code of practice may be used either to develop a complete fire safety strategy or to consider one aspect of the design, it is, therefore, important to establish that the objectives and associated acceptance criteria are appropriate to the particular aspect(s) of the design under consideration.

The main fire safety objectives that may be addressed when carrying out a fire engineering study are:

a) life safety;

b) loss control; and

c) environmental protection.

NOTE This list is not exhaustive; not all items may be appropriate to a particular study.

6.4.3.2 *Life safety objectives*

The occupants of a building, firefighters 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 may include provisions to ensure that:

a) the occupants are able ultimately to leave the building in reasonable safety[1)] or the risk to occupants is acceptably low;

b) firefighters are able to operate in reasonable safety;

c) collapse does not endanger people (including firefighters) who are likely to be near the building[1)].

[1)] Generally covered by legislation (see [1], [2], [3], [4] and [5]).

6.4.3.3 *Loss prevention*

The effects of a fire on the continuing viability of a business can be substantial and consideration should be given to minimizing 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[2)] are generally intended to protect life and to prevent conflagration; however, in a particular scheme it may also be desirable to take measures to reduce the potential for large financial losses.

6.4.3.4 *Environmental protection*

As a conflagration involving several buildings or the release of quantities of hazardous materials may have a significant impact on the environment, consideration should 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.

6.4.4 ***Identification of fire hazards and possible consequences***

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

a) ignition sources;

b) combustible contents;

c) materials of construction;

d) nature and activities in the building;

e) general building layout;

f) any unusual factors.

The list of factors in a) to f) is not exhaustive and all significant fire hazards for the individual building should be identified. In evaluating the significance of a fire hazard particular account should be taken of the influence of each hazardous event on the possible consequences and the achievement of the fire safety objectives under consideration (see PD 7974-0).

6.4.5 ***Establish trial fire safety designs***

In many cases the architectural design of the building should be amended or additional fire protection measures should be provided to achieve an acceptable level of safety. To enable the quantification study to be carried out, the QDR team should establish one or more trial fire safety designs (fire protection strategies) for the purposes of more detailed analysis and quantification.

Cost-effective strategies that satisfy the fire safety objectives and criteria should be selected. Strategies should be compared with each other in terms of cost and practicability.

Table 1 provides a checklist of items that should be considered when developing the trial design. This list is not exhaustive but provides a guide both to the types of systems that should be considered and to the basic information needed to enable a quantified study to be carried out.

2) Generally covered by [1], [2], [3], [4] and [5].

Table 1 — Checklist for development of trial design

Fire protection system	Examples of information to be provided by QDR
Automatic suppression	Extinguishing medium Design standard
Detection	Detector types Locations Zoning Response characteristics
Compartmentation	Fire resistance Location Boundaries Cavity barriers Fire stopping
Automatic systems	Dampers Shutters Automatic door hold-open devices Fans Vents
Smoke control	System type: extraction/pressurization/containment
Alarm and warning systems	Sounder or public address Zoning Investigation delay period
Evacuation strategy	Phased, simultaneous or progressive horizontal Management procedures
Means of escape	Escape routes Exit widths Travel distances Stairways Occupant capacity Lifts – protected Refuges for disabled persons
First aid firefighting	Extinguishers/hose reels Availability of trained staff
Fire service facilities	Access routes Rising mains Firefighting shafts Smoke extraction
Management of fire safety	Management plan Staff availability Staff training Audit of procedures Maintenance schedules

6.4.6 ***Identification of acceptance criteria and methods of analysis***

6.4.6.1 *Identification of acceptance criteria*

6.4.6.1.1 *General*

Whatever measures are taken to reduce the consequences of fire, the possibility of death or injury cannot be totally eliminated as zero risk does not exist. It is, therefore, essential to establish the criteria against which the adequacy of a design can be judged using data determined by one or more of the following methods:

a) deterministic (including, when appropriate, safety factors);

b) probabilistic (risk-based);

c) comparative criteria;

d) financial criteria.

Criteria should be identified which can be used to assess that the requirements of legislation have been satisfied.

6.4.6.1.2 *Criteria for deterministic studies*

6.4.6.1.2.1 *General*

For the purposes of a deterministic study the QDR should establish the worst credible fire scenarios that are to be considered in detail. The addition of safety factors may be needed to take account of:

a) uncertainty in calculation procedures; and/or

b) the consequences of failure of the design.

Where there is doubt as to the reliability of input data or calculation procedures a conservative approach, to err on the side of safety, should be adopted.

6.4.6.1.2.2 *Life safety criteria*

Generally, life safety criteria should be set to ensure that a fire safety solution offers at least the same level of safety as a prescriptive code (see BS 5588-0).

Limiting conditions for asphyxiant (narcotic) gases, irritants, smoke obscuration, radiant heat flux and smoke temperatures should be set (see PD 7974-6).

NOTE The conditions are proposed as limits beyond which severe incapacitation may occur in some people. The effects of these toxic products depend partly upon the accumulated dose to which a person is exposed and partly upon the exposure concentration.

For irritant products the concentration at which pain to the eyes, nose, throat and lungs is likely to impede or prevent escape should be considered. Prolonged exposure to a dose of irritants can also cause incapacitation or death, however, this is unlikely to be the case, provided that the concentration limits are not exceeded.

With regard to smoke obscuration, it is considered that below a certain level for irritant smoke people behave as if in darkness. For large rooms, people should be able to see much further in order to orient themselves and find exits. People are also reluctant to enter heavily smoke-logged escape routes.

Radiant heat above a certain level causes intense skin pain followed by burns within a few seconds, but lower fluxes can be tolerated for longer periods. For very short exposures, such as the time required to pass the open doorway of a compartment containing a fire, a higher flux may be tolerable.

For exposure to convected heat, severe pain to naked skin and burns occur after a variable time depending upon the temperature. An upper temperature limit exists for respired air that can be tolerated. This depends upon the length of exposure time and the level of saturation with water vapour.

Conducted heat is an important factor only when skin is in contact with hot surfaces. However, even brief contact with metal above a critical temperature can cause burns. Full details of limiting air and contact temperatures are given in PD 7974-6.

6.4.6.1.2.3 *Loss prevention and environmental protection criteria*

Property in and around a building that can be fire damaged can be grouped into three areas: building, contents and the environment.

NOTE 1 Typical examples of objects contained in these groups are given in Table 2.

These objects have different degrees of susceptibility to fire damage caused by heat and smoke. For instance, a fire that results in an enclosure or a compartment flashover is likely to damage all the linings, fixtures and fittings, services and contents, so that they have to be replaced. Structural elements may sustain some damage, although may not need replacing. Smoke spread to other areas of the building may result in damage to other linings, fixtures, fittings and contents.

Table 2 — Property groups found in and around a building

Group	Sub-group
Building	Sub-structure
	Super-structure
	Internal finishes
	Fixtures and fittings
	Services, supply and distribution
Contents	Electrical appliances
	Records
	Production equipment
	Raw materials
	Finished products
	Unique objects
Environment	Water
	Soil
	Air quality
	Neighbouring buildings

The value of a fire-damaged object can be considered not only as a direct financial replacement cost, but also as a loss of an asset and productive time. All objects are part of the complete property package and are integral to the purpose of a building. Time lost replacing key fire damaged objects can be considerable, resulting in business interruption.

Irrespective of the fire damage to a building or its contents, the disruption of services caused by a fire, for example when evacuation is necessary, can cause large financial loss. Examples include financial trading operations, and any retailing operation in which custom is lost to competitors.

Methods that can be employed to alleviate losses due to fire include:

a) selecting materials with resistance to fire;

b) providing fire protection systems (see Table 1);

c) contingency planning.

Consideration should be given to reducing the effects of objects, events and layouts that escalate fire damage.

In order to set the building scheme limits for minimal property and environmental loss, a risk assessment should be carried out. During this risk assessment attention should be paid to the value of the property in and around a building and the effects of fire.

Acceptable limits for property and business damage that should be specified for a building scheme may include:

— number of specific valuable objects that it is acceptable to damage (to a certain degree);

— maximum zone of direct fire damage;

— maximum zone of smoke and hot gas damage;

— maximum zone of water damage;

— maximum time periods for recovery from the fire.

NOTE 2 Zones are often described by their floor areas.

6.4.6.1.3 *Criteria for probabilistic studies*

When carrying out a probabilistic risk assessment, the objective is usually to show that the likelihood of a given event occurring (e.g. injury, death, large life loss, large property loss and environmental damage) is acceptably or tolerably small (see PD 7974-1).

NOTE 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 nature of firefighting activities precludes a quantitative estimate of the risk to firefighters associated with a particular building.

6.4.6.1.4 *Criteria for comparative studies*

In many projects it is likely that the provisions of existing codes of practice and other guidance (see BS 5588-0) will be largely followed and that fire engineering techniques will not be necessary (or may be used only to justify limited departures from the codes). At its simplest the QDR team may, therefore, define the acceptance criteria in terms of compliance with existing code recommendations. The acceptability of a particular design may be evaluated by means of a comparison. The level of safety provided by alternative fire safety strategies can be compared with that achieved by the well established codes. This approach involves deterministic and/or probabilistic techniques and requires less extensive analysis than a full study. The objective of a comparative study is to demonstrate that the building, as designed, presents no greater risk to the occupants than a similar type of building designed in accordance with a well established code.

Most existing codes and guides (see BS 5588-0) allow elements of trade-off and/or alternative measures. Examples can be found for fire resistance, compartment sizes and building separation. In a comparative study these examples may be applicable without the need for detailed analysis.

6.4.6.1.5 *Financial criteria*

The framework described in this code of practice may be used to estimate the probability and extent of smoke and fire damage to the structure and contents of a building. This information may then be used in a cost-benefit study to assess the value of additional fire protection measures.

6.4.6.2 *Identifying appropriate methods of analysis*

Having established one or more trial designs and the significant fire scenarios, the QDR team should determine the depth and scope of quantification required and identify appropriate methods of analysis.

NOTE 1 The QDR study may remove the need for further detailed analysis where, for instance, the qualitative study has shown a level of safety which is equal to that in prescriptive codes and guidance documents (see BS 5588-0).

The type of analysis methods that the QDR team may use include:

a) simple calculations;

b) a computer-based deterministic analysis;

c) a simple probabilistic study, e.g. comparative probabilistic risk assessment;

d) a full probabilistic study.

In some circumstances where a quantitative analysis is not appropriate a detailed qualitative study of fire tests may provide an effective means of arriving at a design solution.

NOTE 2 A deterministic study using comparative criteria will generally require fewer data and resources than a probabilistic approach and is likely to be the simplest method of achieving an acceptable design. A full probabilistic study is only likely to be justified when a substantially new approach to building design or fire protection practice is being adopted (see PD 7974-0 and PD 7974-7).

6.4.7 *Establish fire scenarios for analysis*

6.4.7.1 *General*

As the number of possible fire scenarios in a building can become very large, possibly infinite and neither the data nor the resources are available to attempt to quantify them all, the detailed analysis and quantification of fire scenarios for a specific building should be limited to the most significant fire scenarios.

The characterization of a fire scenario for analysis purposes should include a description of the following, where appropriate:

- — type of fire;
- — internal ventilation conditions;
- — external ventilation conditions;
- — performance of each of the safety measures;
- — type, size and location of the ignition source;
- — distribution and type of fuel;
- — fire load density;
- — fire suppression;
- — state of doors;
- — breakage of windows;
- — building ventilation system.

The possible consequences of each fire scenario should also be considered.

Where alternative fire safety design options are being compared against a reference case, e.g. a prescriptive solution (see BS 5588-0), the quantification can often be simplified. In such instances it may only be necessary to consider a single fire scenario if this will provide sufficient information to evaluate the relative levels of safety of the trial design and the reference case.

The QDR team should establish the important fire scenarios to analyse and those that do not require analysis.

The QDR team should take account of the possibility of failures of protection systems and management procedures when establishing the sequences of events to be considered. In a deterministic or comparative study it is usual to identify a number of worst-case scenarios for further evaluation. However, events with a very low probability of occurrence should not be analysed unless their outcome is potentially catastrophic and a reasonably practicable remedy is available.

The qualitative analysis and identification of significant fire scenarios should identify the important fire development scenarios and describe them in a manner suitable for the quantification process.

6.4.7.2 *Design fires*

6.4.7.2.1 *General*

To evaluate the effects of a developing fire one or more design fires on which to base the analysis should usually be defined. A design fire can be characterized in terms of:

- — heat release rate;
- — toxic species production rate;
- — smoke production rate;
- — fire size (including flame length);
- — time to key events, such as flashover.

Where it is possible to estimate the item likely to be first ignited, the initial rate of fire growth may be determined from test data, the fire development being 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.

A more complete description of a design fire may include one or all of the following phases:

a) *incipient phase*: characterized by a variety of combustion processes which may be smouldering, flaming or radiant;

b) *growth phase*: covering the fire propagation period up to flashover (if appropriate) or full fuel involvement;

c) *fully developed phase*: characterized by substantially steady burning rates, may occur in ventilation or fuel bed controlled fires;

d) *decay phase*: covering the period of declining fire severity;

e) *extinction*: when there is no more energy being released.

NOTE Guidance on growing and fully developed fires and on fire location is given in **6.4.7.2.2**, **6.4.7.2.3** and **6.4.7.2.4**.

6.4.7.2.2 *Growing fire*

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:

— nature of combustibles;

— geometric arrangement of the fuel;

— ignitability of the fuel;

— rate of heat release characteristics of the fuel;

— ventilation;

— external heat flux;

— exposed surface area.

For design purposes fires are usually assumed to grow either exponentially or proportionately to the square of the time.

NOTE 1 Guidance on the use of characteristic fire growth curves is provided in PD 7974-1.

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 or more categories of fire growth, including:

a) smouldering;

b) slow;

c) medium;

d) fast;

e) ultra-fast.

NOTE 2 The characteristic fire growth rates are necessarily idealized but are based upon research involving both tests and analysis of real fires and are considered to represent a reasonable basis for design.

6.4.7.2.3 *Fully developed fire*

To simplify calculations, particularly for smoke control design, it may be possible to assume a fully developed fire with constant heat output from the time of ignition. The value of the rate of heat output should correspond to the largest size to which the fire is expected to grow within the appropriate period.

6.4.7.2.4 *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.

The location of the fire within the building should be considered in the QDR as location influences 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.

6.5 Document outputs of QDR

The QDR provides a largely qualitative set of outputs, which form the basis for the quantified analysis. The QDR team should typically provide the following information:

a) results of the architectural review;

b) a clear statement of the fire safety objectives;

c) the significant hazards and their possible consequences;

d) one or more trial fire safety designs;

e) acceptance criteria and suggested methods of analysis;

f) specifications of the fire scenarios for analysis.

Following the QDR, the team should decide which trial design(s) is likely to be optimum. The team should then decide whether quantitative analysis is necessary to demonstrate that the design meets the fire safety objective(s).

7 Quantitative analysis

7.1 General

Following the QDR a quantitative analysis should be carried out. The analysis should be split into a number of separate parts, referred to as sub-systems in this code of practice. The sub-systems are intended to provide guidance on the type of calculations that may be carried out in support of a fire engineering study and to present the general principles and procedures appropriate to the aspect of fire engineering covered by that part of the analysis. The sub-systems may each be used in isolation when analysing a particular aspect of design or all six may be used together as part of an overall fire engineering evaluation of a building.

The sub-systems are as follows:

a) sub-system 1: initiation and development of fire within enclosure of origin (PD 7974-1);

b) sub-system 2: spread of smoke and toxic gases within and beyond enclosure of origin (PD 7974-2);

c) sub-system 3: fire spread beyond enclosure of origin (PD 7974-3);

d) sub-system 4: detection and activation of fire protection systems (PD 7974-4);

e) sub-system 5: fire service intervention (PD 7974-5);

f) sub-system 6: evacuation (PD 7974-6).

The various sub-systems may be linked together in the design process. The basic interactions of each sub-system are identified in the information matrix which is illustrated in Figure 3.

The various aspects of the analysis (or in effect each sub-system) may be quantified by either:

— deterministic studies; or

— probabilistic risk assessment.

In practice, the analysis may be an amalgam of some deterministic elements and some probabilistic elements. Deterministic models are based on physical, chemical, thermodynamic and human behavioural relationships, derived from scientific theories and empirical calculations (see PD 7974-1 to -7).
The alternative strategy is to treat a fire as a series of random events and assess the possible outcome in a probabilistic manner in order to estimate the likelihood of a particular unwanted event occurring.

7.2 Deterministic design procedures

7.2.1 *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. the design will either be successful or not.

7.2.2 *Deterministic techniques*

Several techniques are available for evaluating the development and effects of fire and the movement of people. Some of these techniques are described in the sub-systems (see PD 7974-1 to -6).

7.2.3 ***Fire scenarios***

The interaction of fire, buildings and people can give rise to a very complex system. In order to evaluate fire safety in large complex buildings by deterministic calculations some conservative simplifications should be made. In theory several factors may contribute to the fire scenarios, but in practice the contribution of many factors will be insignificant. By carefully selecting when and where to apply calculations, and then adopting the calculation technique appropriate to the particular problem being considered, a more flexible, pragmatic and equally safe solution can be reached.

NOTE Guidance on the selection of significant scenarios and initial assumptions is given in PD 7974-0.

When considering scenarios in isolation, the worst credible conditions for assigning values to the variables should be chosen. However, it should be recognized that when considering several scenarios, using a series of unlikely events leads to an over-conservative design. On the other hand, using average values for the variables does not lead to a design that is likely to provide an acceptable level of safety.

The key to a successful analysis relies upon rationalizing the problem qualitatively, in the context of the particular fire safety requirements, during the QDR. Attention may then be focused on the quantitative interpretation of the design and in particular the uncertainties that the quantification may involve.

7.2.4 ***Limits of application***

Often the experimental work used to develop empirical relationships is carried out in scaled-down facilities in research establishments. It should be recognized that the application of the analysis models resulting from such work may be limited by the degree of extrapolation that can be made, e.g. in terms of the size of the room or the range of factors that have been examined. Where extrapolation of test data is used it should be justified.

Deterministic techniques provide a useful indication of the development and effects of fire but the nature of fire is such that the results are unlikely to be precise. Normally, analysis models provide conservative predictions within their range of application. In all situations, where there is any doubt as to the validity of a model, the user should establish how the experimental work was carried out and justify the solution, for example by a sensitivity analysis.

7.3 Probabilistic design procedures

7.3.1 ***General***

NOTE The purpose of this clause is to illustrate how some of the techniques of probabilistic risk assessment can be applied to fire safety engineering problems. Although a detailed description of the procedures and techniques involved in probabilistic risk assessment is beyond the scope of this code of practice, a variety of accepted text books are available on this topic (see PD 7974-7).

In practice many factors may influence the development of a building fire and the escape of occupants. These 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). A probabilistic risk assessment study should aim 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 reliability of fire protection systems (see PD 7974-7) 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 desired level of safety can be determined by making comparative judgements using currently available statistics (see PD 7974-7) as a reference point.

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 and extent of property loss. Hence it is possible to define risk as a function of hazard, probability and consequences or the extent of property loss.

Using the framework presented in this code of practice it is also possible to estimate the extent of property damage that may result from a fire and its products. 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.

Owing to gaps in statistical data it is sometimes difficult to estimate an absolute value of fire risk associated with a particular building. However, risk-based analysis provides an effective basis for specifying or assessing different fire protection strategies (e.g. sprinklers versus compartmentation).

Although a large number of factors may potentially contribute to the development and consequences of a fire, in practice many of the factors will be insignificant. By carefully selecting when and where to apply calculations, and then adopting the calculation technique appropriate to the problem under consideration, a pragmatic solution can be developed.

The probabilistic risk assessment should be preceded by the QDR for two main reasons:

a) to ensure that the problem is fully understood and that the analysis addresses the relevant aspects of the fire safety system; and

b) to simplify the problem and reduce as far as possible the calculational effort required.

8 Assessment against criteria

8.1 General

Following the quantitative analysis based on the six sub-systems (see PD 7974-1 to -6), the results should be compared with the acceptance criteria identified during the QDR. Three basic types of approach can be considered:

a) deterministic;

b) probabilistic;

c) comparative.

If, following the quantitative analysis, it is demonstrated that 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 acceptance safety criteria and other design requirements (see Figure 2).

In a deterministic study the objective is to show that on the basis of the initial (usually "reasonable worst case") assumptions a defined set of conditions will not occur. In a probabilistic study, such criteria are set 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.

It can often be difficult to establish the level of safety achieved in absolute terms. However, it may be relatively straightforward to demonstrate that the design provides a level of safety equivalent to that in a building that conforms to more prescriptive codes (see BS 5588-0). For instance, in a large exhibition hall travel distances may be extended and result in an increased evacuation time. However, if the hall has a high roof it may be possible to demonstrate that the time required for the smoke to fill the large volume will more than compensate for the expected increase in evacuation time. Since the study is purely comparative, any assumptions such as those regarding fire growth rates and the choice of smoke modelling procedures, are unlikely to have a significant influence on the outcome.

Before it can be demonstrated that a solution offers at least the same level of safety as a prescriptive code (see BS 5588-0) there should be a clear understanding of the intent of that code. During the QDR the team should consider the intentions of each relevant recommendation as a particular provision may have more than one objective. Once this has been conducted, alternative design solutions may be developed that address the specific underlying objectives. The fire safety engineer should demonstrate that the solution proposed will be at least as effective and reliable as the conventional approach.

As a range of uncertainties exist in fire engineering calculations, it may, be appropriate to include explicit safety factors in the analysis. For example, it is possible to calculate with a high degree of accuracy the minimum time (i.e. the flow time) required for people to travel to and pass through a particular exit. However, it is known that people tend to leave a building by the routes with which they are familiar and it is often difficult to determine how many people will use each of the available exits. The calculation procedures and design assumptions presented in the sub-systems (see PD 7974-1 to -6) are generally conservative.

8.2 Deterministic criteria

8.2.1 *Comparison of results with design criteria (life safety)*

8.2.1.1 *General*

Typically, in a deterministic study it should be assessed that all persons can leave a threatened part of a building in reasonable safety without assistance. The onset of hazardous conditions and the time required for people to escape from area should be compared.

8.2.1.2 *Tenability conditions*

NOTE Information is available in PD 7974-6 on the tenability criteria for exposure to toxic gases, heat and loss of visibility.

As failure of structural elements before evacuation is complete can also present a threat to life, the study should, therefore, address all likely exposure to hazardous conditions in fire such as:

a) loss of visibility;

b) exposure to toxic and irritant products;

c) exposure to heat;

d) structural failure.

The QDR should attempt to establish which potential threats are significant and require quantification. In most circumstances loss of visibility due to the spread of smoke will determine the initial threat to life and consequently the available safe egress time (ASET). However, if it can be shown that the fire will be extinguished before toxic conditions or excessive temperatures are reached then loss of visibility will not be a life safety criterion.

When designing for life safety, the aim should be to ensure that:

$$\mathrm{ASET} > \Delta t_{\mathrm{esc}} \qquad (1)$$

where

Δt_{esc} $= \Delta t_{\mathrm{a}} + \Delta t_{\mathrm{evac}}$;

Δt_{esc} is the escape time from ignition to evacuate to a place of safety;

Δt_{evac} is the time required from alarm for occupants to evacuate to a place of safety;

Δt_{a} is the time from ignition to alarm.

The inhalation of smoke and toxic gases can impair movement but may not cause total incapacitation which would prevent escape. In principle it would be 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.

8.2.1.3 *Structural failure*

Where the failure of the structure will threaten the life of individuals inside and outside the building, adequate fire resistance should be provided. In buildings where phased evacuation is adopted and in buildings such as hospitals, some of the occupants may remain in the building for an extended period while firefighting operations take place elsewhere in the building. The consequences of structural failure should be taken into account in the sensitivity analysis (see PD 7974-3).

8.2.2 ***Comparison of results with design criteria (loss prevention and environmental protection)***

8.2.2.1 *General*

It should be demonstrated that the objectives and criteria set for the building scheme are met. For example, the calculated projected floor area of fire damage should be less than or equal to and preferably less than property damage limits specified.

Deterministic calculation can define the extent of the fire damage. Damage is caused by the release of heat and smoke from the fire. The calculated amount and the distribution of heat and smoke can be related to damage in and around the building (this includes property damage to the building, contents and environment).

Objects exposed to heat, radiative and convective, can as a result suffer irreversible damage. As the temperature and time of exposure increases, the damage is expected to increase. Smoke released from fires contains gases, liquids and small particulate matter. This smoke travels away from the fire in convective flow resulting in contamination of the building, contents and environment. Hot fire brands can travel away from the fire and cause remote ignition.

A fire may spread unchecked through many enclosures or it may be confined to a small zone. Containment can be achieved by:

a) low fuel loading;

b) large separations between fuel loads;

c) compartmentation;

d) the operation of active fire protection (e.g. sprinklers);

e) active firefighting.

Firefighting media, as well as limiting the extent of the fire, cause some property damage. The media quantity and their effect on the building, contents and environment can be found by deterministic evaluation.

8.2.2.2 *Property damage*

The extent of acceptable damage is defined by the QDR team for specific objects or zones (described by their enclosure floor areas). The calculated deterministic values for fire heat and smoke damage should not exceed these limits.

8.2.2.3 *Environmental damage*

As the extent of acceptable contamination of the air, land and water will have been set for the building scheme, calculated deterministic values can predict the mass release of substances and their projected distribution at locations of interest. Calculated contamination values should not exceed environmental limits.

8.2.2.4 *Structural damage*

The degree of anticipated structural damage can be found by deterministic calculations. As well as the property loss associated with structural damage other aspects should be considered such as building restoration, recovery time, and the potential for very large release into the environment.

8.3 Probabilistic (risk) criteria

In a probabilistic study criteria are set (see PD 7974-7) such 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.

8.4 Comparative criteria

In a comparative study, it should be relatively straightforward to demonstrate that the design provides a level of safety equivalent to that in a building that conforms to more prescriptive codes (see BS 5588-0), by comparing the output of the detailed analysis.

However, there should be a clear understanding of the intent of that prescriptive code. The fire safety engineer should demonstrate that the solution proposed will be at least as effective and reliable as the conventional approach (see BS 5588-0).

8.5 Safety factors and uncertainty

In developing the solution to a fire safety engineering problem the following sources of uncertainty should be considered:

a) the choice and definition of the scenario(s);

b) the formulation of an appropriate conceptual model (see PD 7974-0 to -7) for a chosen scenario;

c) the formulation of the associated computational model; and

d) the input data and other chosen parameters.

In principle, the magnitude of uncertainty associated with each stage and component of a solution should be quantified and combined to provide an overall level of uncertainty. This overall level may then provide the basis for choice of safety factor to be used when applying the solution in practice.

NOTE It is not yet possible to quantify levels of uncertainty for all stages of the design process; these problems are addressed, in part, in PD 7974-7. Any safety factors incorporated in a proposed solution will involve a degree of professional judgement by the design engineer and, consequently, also by those responsible for assessing and approving the solution.

Wherever possible, this judgement should be informed by an understanding of the underlying basis and limitations of chosen scenarios, models and data, and should be made explicit in the reporting and presentation of the final design.

8.6 Sensitivity analysis

As deterministic design involves uncertainties, these can usually be dealt with by taking a conservative approach, e.g. selecting a fire growth rate that is faster than would normally be expected. However, if the deterministic design approach is not suitable, the primary sources of uncertainty, associated with the following, should be addressed:

a) the input parameters, i.e. uncertainties associated with the initial qualitative interpretation of the problem in the QDR;

b) the simplified assumptions made in developing the deterministic techniques to make the analysis possible.

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 should be not simply to check the accuracy of the results but also to investigate the criticality of individual parameters. For example, it may be important to establish how critical a system is to the final consequences. If a single system or assumption is shown to be critical to the overall level of safety achieved, consideration should be given to providing a degree of redundancy in the design or to carrying out a probabilistic study (see **7.3**).

The simplifications and assumptions made in the QDR to aid the analysis should be tested for their criticality to the fire safety design. For example, it may 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.

Bibliography

Standards publications

BS 6399-2:1997, *Loading for buildings — Part 2: Code of practice for wind loads.*

PD 7974-0:2002, *Application of fire safety engineering principles to the design of buildings — Part 0: Guide to the design framework and fire safety engineering procedures.*

PD 7974-1:2002, *Application of fire safety engineering principles to the design of buildings — Part 1: (Sub-system 1) Initiation and development of fire within the enclosure of origin.*

PD 7974-2:2002, *Application of fire safety engineering principles to the design of buildings — Part 2: (Sub-system 2) Spread of smoke and toxic gases within and beyond the enclosure of origin.*

PD 7974-3:2002, *Application of fire safety engineering principles to the design of buildings — Part 3: (Sub-system 3) Structural response and fire spread beyond the enclosure of origin.*

PD 7974-4:2002, *Application of fire safety engineering principles to the design of buildings — Part 4: (Sub-system 4) Detection of fire and activation of fire protection systems.*

PD 7974-5:2002, *Application of fire safety engineering principles to the design of buildings — Part 5: (Sub-system 5) Fire service intervention.*

PD 7974-6:2002, *Application of fire safety engineering principles to the design of buildings — Part 6: (Sub-system 6) Evacuation.*

PD 7974-7:2002, *Application of fire safety engineering principles to the design of buildings — Part 7: Probabilistic fire risk assessment.*

Other documents

[1] GREAT BRITAIN. The Building Regulations 1991. London: The Stationery Office.

[2] GREAT BRITAIN. The Building Standards Scotland, 1990. Edinburgh: The Stationery Office.

[3] NORTHERN IRELAND. The Building Regulations (Northern Ireland), 1994. Belfast: The Stationery Office.

[4] GREAT BRITAIN. Fire Precautions Act 1971. London: The Stationery Office.

[5] GREAT BRITAIN. Fire Precautions (Workplace) Regulations 1997 (as amended). London: The Stationery Office.

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BSI — British Standards Institution

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