

Fire safety engineering in buildings

Part 1. Guide to the application of fire safety engineering principles

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The preparation of this Draft for Development was entrusted to Technical Committee FSH/24, Fire safety engineering, upon which the following bodies were represented:

- AEA Technology

Architectural and Specialist Door Manufacturers Association

Association of British Theatre Technicians

Association of Building Component Manufacturers

Association of Building Engineers

Association of County Councils

Autoclaved Aerated Concrete Products Association

BAA plc

British Automatic Sprinkler Association

British Carpet Manufacturers Association Ltd

British Electrical Systems Association (BEAMA Ltd.)

British Fire Protection Systems Association

British Gas plc

British Iron and Steel Producers Association

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Building Research Establishment

Car Users Entrapment Extrication Society

Chemical Industries Association

Chief and Assistant Chief Fire Officers Association

Construction Fixings Association

Consumer Policy Committee of BSI

Convention of Scottish Local Authorities

Department of Health

Department of the Environment (Construction Sponsorship Directorate)

District Surveyors Association

Door and Shutter Manufacturers' Association

Eurisol — UK Mineral Wool Association

Fibre Cement Manufacturers Association Limited

Fire Brigades Union

Fire Safety Development Group

Health and Safety Executive

Heating and Ventilating Contractors' Association

Home Office

Home Office (Fire Service College)

Institute of Fire Prevention Officers

Institute of Fire Safety

Institution of Fire Engineers

Intumescent Fire Seals Association

London Fire and Civil Defence Authority

Loss Prevention Council
- Ministry of Defence

National House (Building Council)

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RAPRA Technology Ltd.

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Scottish Office (Building Directorate)

Scottish Office (Home and Health Department)

Security Systems and Alarms Inspection Board

Smoke Ventilation Association

Society of Chemical Industry

Steel Construction Institute

Timber Research and Development Association

University of Central Lancashire

Warrington Fire Research Centre

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- Chartered Institution of Building Services Engineers
- Institute of Building Control
- National Association of Fire Officers

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Foreword

This Part of DD 240 has been prepared by Technical Committee FSH/24.

The original intention was to prepare a British Standard on Fire Safety Engineering. However, after considering the comments received on the draft code of practice circulated for public comment, particularly those concerning the current state of knowledge on the use of fire safety engineering, the responsible committee decided that it should be published as a Draft for Development before it could be given the status of a British Standard. It should therefore be applied on a provisional basis, so that information and experience of its practical application may be obtained.

Attention is particularly drawn to clause 4: Application.

A review of this Draft for Development will be carried out not later than two years after its publication. Notification of the start of the review period, with a request for the submission of comments from users of this Draft for Development, will be made in an announcement in the appropriate issue of *BSI Update*.

According to the replies received, the responsible BSI committee will judge whether the Draft for Development can be converted into a British Standard or whether other action should be taken.

Observations which it is felt should receive attention before the official call for comments will be welcome. These should be sent to the Secretary of BSI Technical Committee FSH/24 at British Standards House, 389 Chiswick High Road, London W4 4AL.

This publication is not to be regarded as a British Standard.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 100, an inside back cover and a back cover.

Guide

Introduction

Fire safety has been of concern for many centuries. Earlier approaches were of a prescriptive nature, specifying acceptable materials or constructions. Not until testing facilities and standard methods of test were available did it become possible to make comparisons between different systems of construction. By the end of the 1970s, work carried out in Europe, North America and Far Eastern countries had provided a better understanding of fire behaviour, the performance of materials, the relevance of fire tests and the need to deal with new and unusual building problems.

Building regulations allow designers to provide a variety of solutions provided that they can satisfy the control authorities of the adequacy of their design. This freedom cannot be fully utilized however, as there is no established method for comparing alternative solutions. The introduction of a building regulation system based on functional requirements led to a study being undertaken on fire safety in buildings [1]. The whole basis of building control was examined and the essential components of a fire safety system were identified. An attempt was made to distinguish between the levels of requirement necessary for life safety purposes and for the prevention of conflagration. One of the more important findings of this study was that fire safety requirements need to be considered as a total system in which both the active and the passive measures are incorporated and in which flexibility is allowed in their exchange when equivalence can be shown. The report made a strong recommendation for the incorporation of fire engineering techniques in the provisions for fire safety.

European work on the harmonization of product standards in the construction field, as stated in the *Construction Products Directive* [2], has followed a course similar to that of the UK in producing functional requirements for fire safety in construction works. The Interpretive Document, *Safety in Case of Fire*, has attempted to translate these functional statements into guidance towards some of the tools that may be used. It has also recognized the role of fire safety engineering for this purpose and, whilst not in a position to refer to any documentation, has visualized the use of fire engineering techniques in providing safety solutions. The International Organization for Standardization (ISO) has set up a committee (ISO/TC 92/SC 4) to consider fire safety engineering. These recent developments prompted BSI to commission a multi-disciplined expert group to examine the whole issue of fire safety in buildings and other structures and to prepare a guidance document for designers and others involved in devising and approving fire safety systems for buildings. This Draft for Development is intended to make fire safety engineers aware of the relevant issues and the need to examine total fire safety systems. It provides a framework for developing a rational methodology for achieving fire safety.

A fire safety engineering approach that takes into account the total fire safety package can provide a more fundamental and economical solution than more prescriptive approaches to fire safety. It may be the only viable means of achieving a satisfactory standard of fire safety in some large and complex buildings. For most buildings, the prescriptive recommendations presented in existing codes and guides may be found to be adequate, but the use of this Draft for Development allows the more precise design necessary for the assessment of new and complex projects. It is intended that this Draft for Development be used by fire safety engineers both for developing and assessing proposals.

Fire safety engineering can have many benefits. The use of this Draft for Development 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 guidance on the management of fire safety for a building, taking account of changes of building use.

Fire is an extremely complex phenomenon and there are still many gaps in the available knowledge. This Draft for Development 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 Draft for Development, 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.

As mentioned in the foreword, the original intention was to prepare a British Standard Code of Practice on Fire Safety Engineering. After the draft code was circulated for public comment, worked examples to this draft were also circulated to the responsible committee and subcommittees. These worked examples aided readers in the understanding of the document. Owing to subsequent revision of the document, the worked examples are no longer valid for this Draft for Development, and so they are not being published by BSI. However, they did provide a useful exercise in demonstrating the application of fire safety engineering.

Two major comments submitted during the public enquiry stage related to the sources of data. Sources of the equations were requested and also an indication of the scope of applicability of each equation. These data have been provided and all sources are identified in the list of references at the back of this Draft for Development. Part 2 of DD 240 provides information on the scope of applicability and confidence limits of the equations included in Part 1.



1 Scope

This Part of DD 240 gives guidance on the application of scientific and engineering principles to the protection of people and property from fire. It thus provides a framework for an engineering approach to the achievement of fire safety in buildings, and for assessing the effectiveness of the total fire safety system in achieving the design objectives.

It includes 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 the design objectives can be achieved by a range of alternative and complementary fire protection strategies. It gives selected data and engineering relationships that may be used for design, but acknowledges the use of alternative information.

The guidance takes into account many factors, including building construction, means of escape, human factors, smoke control, fire detection, alarm systems and suppression, and their contribution to the achievement of the fire safety objectives.

The basic principles given apply to all types of buildings and their uses. However, it 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 usually require special consideration, which is beyond the scope of this document.

2 Informative References

This Part of DD 240 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this Draft for Development are listed on page 98.

Reference numbers in square brackets indicate that information or an equation in the text has been derived from the publication which is correspondingly numbered in the list of references.

3 Definitions and notations

For the purpose of this Draft for Development the following definitions and notations apply.

3.1 Definitions

3.1.1 ASET

The calculated time available between ignition of a fire and the time at which tenability criteria are exceeded in a specified space in a building.

3.1.2 calorific value

The 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.

3.1.3 clear width

The width of a corridor, stair, passage or doorway opening, measured at its narrowest point.

3.1.4 compartment

The space defined by fire-resisting boundary elements

3.1.5 critical fire load

The effective fire load required in a compartment to produce a fire of sufficient severity to cause failure of fire resisting barriers or structural elements.

3.1.6 design escape time

The 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.

3.1.7 detection time

The interval between ignition and the detection of combustion by an automatic system or otherwise.

3.1.8 deterministic study

A 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.

3.1.9 effective fire load density

The fire load density (see 3.1.18) within an enclosure or compartment, modified by factors which take account of the incomplete combustion of protected fire loads (see 3.1.31) and/or a reduction in the net quantity of heat released resulting from the presence of wet materials.

3.1.10 effective width

The clear width less the thickness of a notional boundary layer.

3.1.11 enclosure

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

3.1.12 equivalent fire load density

The fire load density (see 3.1.18) expressed as an equivalent mass of wood rather than in terms of its calorific value.

3.1.13 escape time

The interval between ignition and the time at which all occupants are able to reach a place of safety.

3.1.14 evacuation time

The interval between the time at which a warning of fire is transmitted to the occupants and the time at which all of the occupants are able to reach a place of safety.

3.1.15 exit

A doorway or other suitable opening giving direct access to a place of safety (see **3.1.28**).

3.1.16 fire hazard

The potential for injury and/or damage from fire.

3.1.17 fire load

The quantity of heat which could be released by the complete combustion of all the combustible materials in a volume, including the facings of all bounding surfaces.

3.1.18 fire load density

The fire load per unit floor area.

3.1.19 fire risk

The product of:

- a) the probability of occurrence of a fire in a given technical operation or state; and
- b) the consequence or extent of damage to be expected on the occurrence of a fire.

3.1.20 fire safety engineer

A person suitably qualified and experienced in fire safety engineering.

3.1.21 fire safety manual

A document detailing the fire safety management procedures that should be implemented on a continuing basis.

3.1.22 fire scenario

A set of circumstances that defines the development of fire and the spread of combustion products throughout a building or part of a building.

3.1.23 flashover

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

3.1.24 management or manager

The persons or person in overall control of the premises while people are present, exercising this responsibility either in their own right or by delegation.

3.1.25 means of escape

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

3.1.26 occupant capacity

The maximum number of persons assumed to be present within an enclosure or compartment for the purposes of design.

3.1.27 phased evacuation

A procedure by which a limited number of floors is evacuated initially and the remaining floors are evacuated when necessary.

3.1.28 place of safety

A predetermined place in which persons are in no immediate danger from the effects of a fire.

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

3.1.29 pre-movement time

The interval between the time at which a warning of fire is given and the time at which the first move is made towards an exit.

3.1.30 probabilistic study

A methodology to determine statistically the probability and outcome of events.

3.1.31 protected fire load

The quantity of combustible material that is unlikely to become fully involved in a fire, owing to:

- a) the characteristics of the material; or
- b) the form in which the material is stored; or
- c) the characteristics of any containers in which the material is stored; or
- d) the protection of the material by fire suppression systems.

3.1.32 separating element

An element that is required to satisfy the criteria of integrity and insulation in order to maintain separation between two adjacent areas of a building in the event of a fire.

3.1.33 smouldering fire

A slow, low-temperature, flameless form of combustion sustained by the heat evolved when oxygen directly attacks the surface of condensed-phase fuel.

NOTE. A smouldering fire is generally made evident by an increase in temperature and/or by smoke.

3.1.34 tenability limit

The maximum exposure to physical fire parameters that a person can tolerate without incapacitation.

3.1.35 travel distance

The actual distance that a person needs to travel within a building to the nearest exit, allowing for the layout of walls, partitions and fittings.

3.1.36 travel time

The time needed, once movement towards an exit has begun, for all the occupants of a specified part of a building to reach a place of safety.

3.2 Notations

α	is the fire growth parameter (in kJ/s^3)	D	is the optical smoke density (in dB/m)
δ	is the thickness of enclosure boundaries (in m)	D_a	is the optical density necessary to trigger an alarm (in dB/m)
ΔT_a	is the temperature rise necessary to trigger an alarm (in $^{\circ}\text{C}$)	D_m	is the mass optical density (in m^2/kg)
Δt_{evac}	is the evacuation time (in s)	D_s	is a linear dimension of the source (in m)
Δt_f	is the fire duration (in s)	f_b	is the mass of fuel burnt (in kg)
Δt_{trav}	is the travel time (in s)	g	is the acceleration due to gravity (9.81 m/s^2)
Δt_{det}	is the detection time (in s)	h	is the vertical distance between the fire source and the ceiling (in m)
Δt_{pre}	is the pre-movement time (in s)	h_b	is the height of the balcony above the base of the opening (in m)
Δt_{esc}	is the time taken from ignition for all occupants to evacuate to a place of safety (in s)	h_c	is the convective heat transfer coefficient (in $\text{W/m}^2\cdot\text{K}$)
Δt_a	is the time from ignition to alarm (in s)	h_k	is the effective heat transfer coefficient (in $\text{kW/m}^2\cdot\text{K}$)
ΔT	is the temperature change (in $^{\circ}\text{C}$)	h_w	is the height of ventilation openings (in m)
ε_f	is the emissivity of the flame	H_c	is the effective calorific value (in MJ/kg)
ε_r	is the resultant emissivity	H_u	is the calorific value of a dry material (in MJ/kg)
ε_s	is the emissivity of the smoke	I_0	is the radiated power received without smoke (in W)
$\varepsilon_{\text{smoke}}$	is the smoke mass conversion factor for an item (kg/kg)	I	is the radiated power received with smoke (in W)
θ_c	is the maximum temperature rise of the gases above ambient temperature (in K or $^{\circ}\text{C}$)	k_s	is the thermal conductivity (in $\text{kW/m}\cdot\text{K}$)
λ_f	is the thickness of the flame (in m)	K	is the effective emission coefficient (in m^{-1})
λ_s	is the depth of the smoke layer below the ceiling (in m)	L	is the equivalent fire load (in kg of wood)
ρ_0	is the density of air at ambient conditions (in kg/m^3)	L_c	is the separation of channelling screens (in m)
ρ	is density (kg/m^3)	m	is the mass flow rate (in kg/s)
σ	is the Stefan-Boltzmann constant ($5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4$)	m_c	is the total mass of combustible material in an enclosure (in kg)
φ	is the configuration factor	m_{co}	is the mass rate of carbon monoxide production (in kg/s)
A_f	is the total internal floor area of the enclosure (in m^2)	m_{effl}	is the mass of smoke effluent per mass of fuel consumed (in kg/kg)
A_{fire}	is the area of fire (in m^2)	m_f	is the rate of burning of fuel by mass (in kg/s)
A_i	is the total area of all air inlets (in m^2)	m_{fe}	is the wood-equivalent burning rate (in kg/s)
A_s	is the plan area of the source (in m^2)	m_o	is the horizontal mass flow rate from an opening (in kg/s)
A_t	is the area of enclosure surfaces, including area of ventilation opening (in m^2)	m_p	is the mass rate of smoke particulate production (in kg/s)
A_T	is $A_t - A_w$ (in m^2)	m_s	is the mass concentration of the smoke aerosol (in kg/m^3)
A_v	is the throat area of ventilators (in m^2)	m_{smoke}	is the mass flow rate of smoke (in kg/s)
A_w	is the area of ventilation openings (in m^2)	m_w	is the total mass flow rate in the buoyant layer at window or door plane (in kg/s)
b	is the depth of the balcony (in m)	M	is the moisture content (in % (m/m) by dry mass)
c_d	is the coefficient of discharge at the exit in the window or door plane	N_{cas}	is the number of casualties for the assumed occupancy
c_i	is the entry coefficient for inlets	N_{EXIT}	is the number of occupants able to escape to safety in ASET,
c_p	is the specific heat of air (in $\text{kJ/kg}\cdot\text{K}$)	N_{INIT}	is the initial number of occupants expected to be in the threatened area
c_{ps}	is the specific heat capacity (in $\text{kJ/kg}\cdot\text{K}$)	p	is the perimeter of the source (in m)
c_v	is the coefficient of discharge	P_c	is the probability of critical fire load being burnt
C_{CO}	is the concentration of carbon monoxide (in kg/m^3)	P_l	is the probability of critical fire load being present
$C_{\text{CO}\%}$	is the concentration of carbon monoxide (in %)	P_d	is the probability of death from the scenario
d	is the optical measuring length (in m)		
d_b	is the depth of the smoke layer beneath the ventilator (in m)		
d_c	is the distance front-to-back of the enclosure (in m)		
d_s	is the depth of the visible smoke layer at the opening (in m)		

P_f	is the probability of a fire which will lead to structural failure	w_c	is the width of the wall containing ventilation openings (in m)
P_{esc}	is the probability that the escape time will exceed ASET	w_s	is the width of flow at the exit (in m)
P_i	is the probability of a fire starting	Y_{CO}	is the carbon monoxide mass conversion rate (in kg/kg)
P_{scen}	is the probability of the specified fire scenario developing after ignition	z	is the height (in m)
q	is the heat flux per unit area (in W/m^2)	z_b	is the plume height above the balcony (in m)
q_{ki}	is the fire load density for the enclosure (in MJ/m^2)	z_g	is the plume height above the opening (in m)
Q	is the rate of heat release from the fire (in kW)	z_{fl}	is the height of the intermittent flame (in m)
Q''	is the rate of heat release per unit area of fire (in kW/m^2)	z_1	is the height of the flaming region (in m)
Q_b	is the rate of accumulation of heat and hot gases in the enclosure (in kW)	z_0	is the height of a virtual source from the base of the fire (in m)
Q_c	is the rate of heat release in the enclosure (in kW)		
$Q_{control}$	is the maximum rate of heat release at which the fire can be controlled (in kW)		
Q_{fbc}	is the rate of heat release under fuel-controlled conditions (in kW)		
Q_p	is the convective heat output (in kW)		
Q_{fo}	is the rate of heat release at flashover (in kW)		
Q_g	is the rate of heat release during the growth phase (in kW)		
Q_l	is the rate of heat loss by convection through openings (in kW)		
Q_r	is the rate of heat loss by radiation through openings (in kW)		
Q_{sup}	is the rate of heat release at which suppression activates (in kW)		
Q_{vc}	is the rate of heat release under ventilation-controlled conditions (in kW)		
Q_w	is the rate of heat loss by radiation and convection to the enclosing construction (in kW)		
$[RTI]$	is the response time index (in $m^{1/2}.s^{1/2}$)		
r	is the radial distance (in m)		
S	is the visibility distance (in m)		
t	is the time (in s or min)		
t_i	is the time of ignition (in s)		
t_{in}	is the time to incapacitation due to skin pain (in s)		
t_p	is the thermal penetration time (in s)		
T	is temperature (in $^{\circ}C$ or K)		
T_c	is the temperature of the smoke layer (in K)		
T_d	is the detector temperature (in K)		
T_g	is the temperature of the gas (in K)		
T_{max}	is the maximum expected gas temperature (in K)		
T_0	is the ambient air temperature (in $^{\circ}C$ or K)		
T_p	is the plume temperature (in $^{\circ}C$)		
T_s	is the temperature of the receiving surface (in K)		
U	is the instantaneous velocity of fire gases (in m/s)		
V	is the volume flow rate of smoke (in m^3/s)		
V_t	is the total volume of smoke (in m^3)		
w_o	is the width of the opening (in m)		

4 Application

4.1 General

This Draft for Development provides a framework for an engineering approach to fire safety in buildings. It can be used to show that regulatory or insurance requirements can be satisfied. As fire safety engineering is a developing discipline, and some of the judgements needed may be subjective, use of this framework does not guarantee that the resulting design will be acceptable. Approvals authorities should be consulted before final decisions are taken about the fire safety design. This Draft for Development may be applied to the design of new buildings and the appraisal of existing buildings. The engineering approach may be used in conjunction with other guidance documents. It may also be used to justify approaches alternative to those in other guidance documents.

The process described in this Draft for Development has four main stages:

- qualitative design review;
- quantitative analysis;
- assessment against criteria;
- reporting and presentation.

This basic process is illustrated in figure 1.

Fire is a transient process which impacts on a building and its occupants in different ways at different stages. The process of fire safety design is complicated by the fact that time is one of the key design parameters. When making a quantitative analysis of the effectiveness of a particular fire safety design solution, it is important to recognize the role of time and to consider the interaction of parameters within a consistent time framework. This Draft for Development presents a way of doing this.

The principle is shown in figure 2. A comparison is made between two time lines. One of these represents the course of the fire, in terms of its size, rate of burning, smoke or toxic gas concentrations or a combination of more than one of these or other characteristics. The other time line represents response to the fire by occupants, or by the building fabric or contents. The example in figure 2 concerns evacuation of occupants, but structural failure or the loss of a key service are among the other possibilities. More details of the evacuation process are shown in sub-system 6 (see [Figure 2](#)).

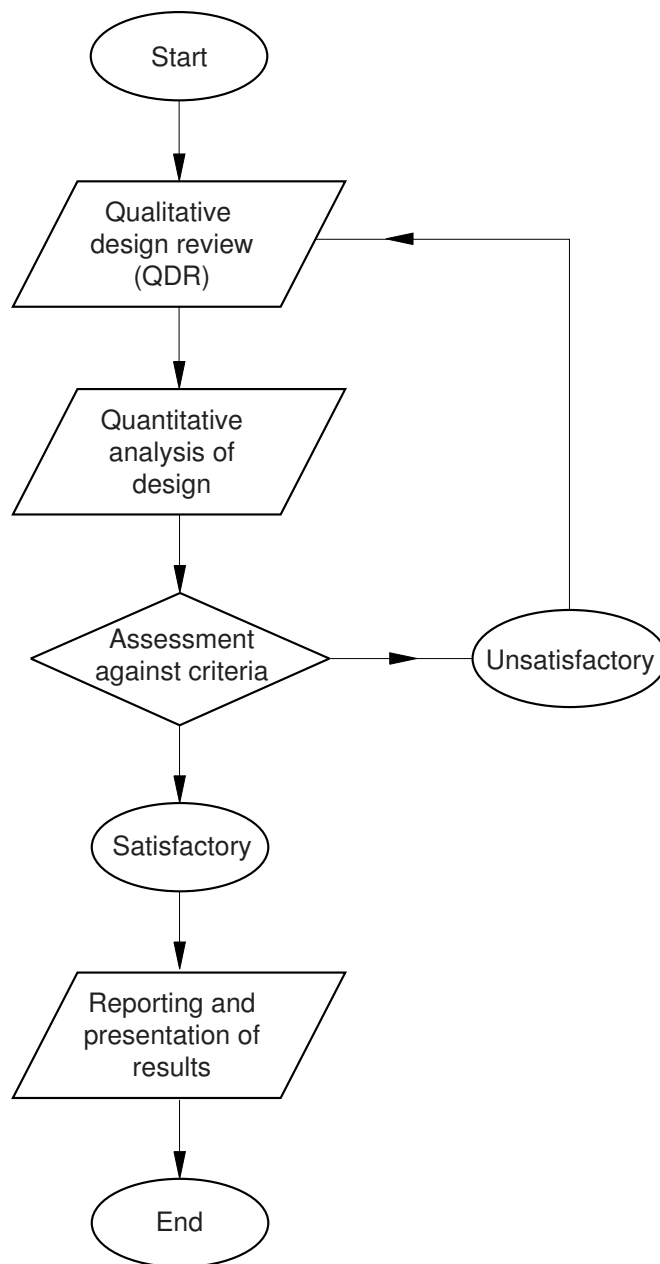


Figure 1. Basic fire safety design process

The fire safety design process begins with the qualitative design review (QDR). During the QDR the scope and objectives of the fire safety design are defined, performance criteria established and one or more potential design solutions proposed. In addition, key information is gathered to allow the potential design solutions to be evaluated in the quantitative analysis.

During the quantitative analysis the fundamentals of fire science are applied, using engineering methods to evaluate the potential solutions proposed in the QDR. The analysis is set out in six sub-systems. These reflect the impact of a fire on people and property at different stages in its development. The

sub-systems cover, in essence, fire growth and development, the spread of combustion products and fire from the enclosure of origin, fire detection and activation of fire safety systems, fire service intervention and the evacuation of occupants.

The quantitative analysis can take different forms according to the problem. At its most complicated, it may involve the calculation of changing conditions in many parts of the building, modelling the spread of combustion products and the behaviour of occupants. More often the quantified analysis is simpler. For example, the design fire scenario from the QDR may assume a certain fire growth rate and the analysis may only require calculation of the time in which conditions will become untenable in one area.

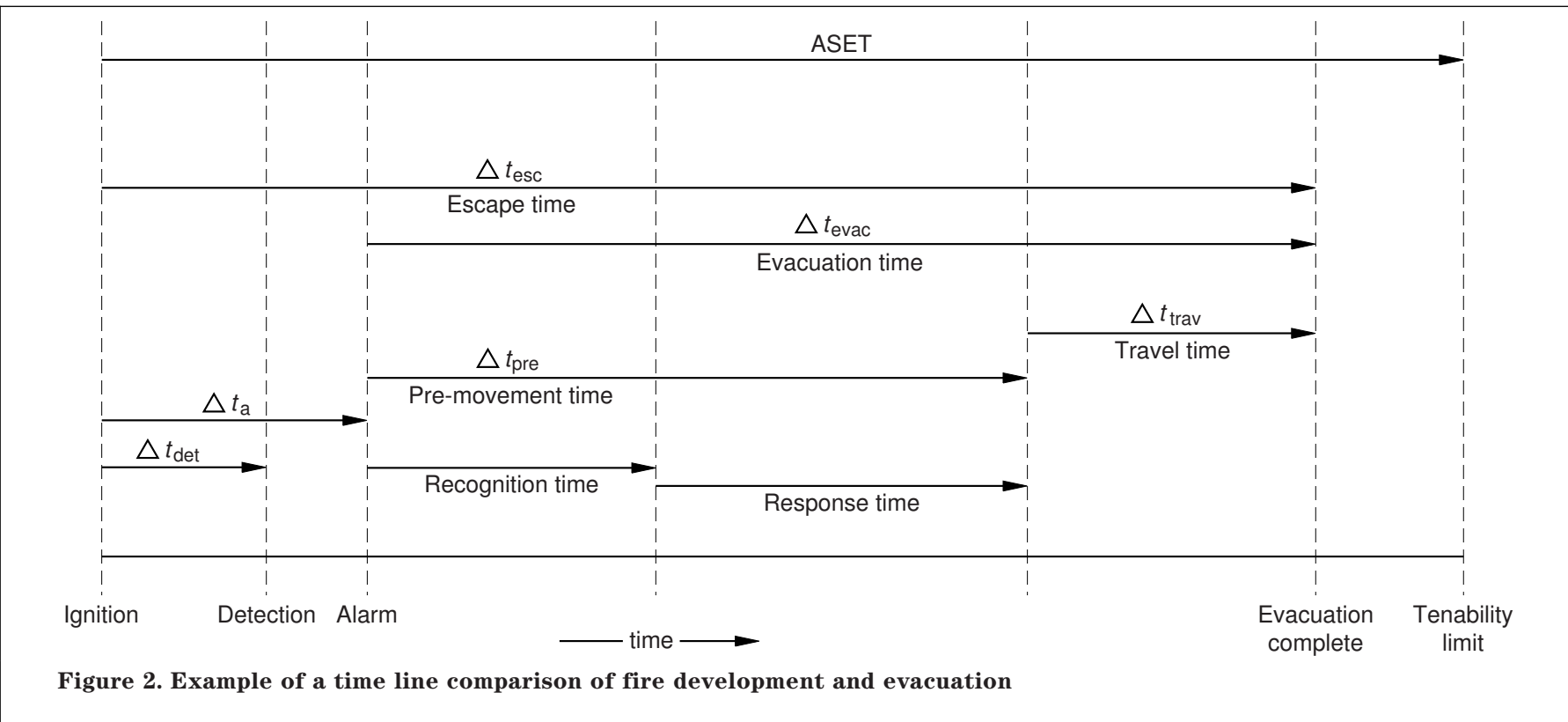


Figure 2. Example of a time line comparison of fire development and evacuation

During the quantitative analysis, a number of the design parameters need to be evaluated within a common time base. This is complicated by the continual interaction between many parameters. One approach suggested in this Draft for Development is to conduct the design process in a stepwise manner, whereby an analysis is undertaken of all relevant parameters during a single time step. To facilitate the handling of the large amounts of data generated by such an approach, it is suggested that an information bus, such as that shown in figure 3, is used. The information bus uses the analogy of a computer processor to illustrate the flow of information between sub-systems and the QDR.

The information bus contains all the relevant data on the state of the design during a given time step. As the quantified analysis proceeds and time steps are incremented, the information bus bar is updated to provide a complete snap-shot of the situation at that point in time. The information bus diagram shown in figure 3 is intended to be illustrative and should not be regarded as definitive. Other parameters and interactions may be needed for specific applications.

The nature and extent of the quantitative analysis will depend on the criteria against which a design is being judged. As an example, figure 4 shows a process by which a particular design solution for the safe evacuation of a building's occupants may be examined. It is assumed for the purposes of figure 4 that calculations will be carried out repeatedly over the requisite number of time steps until the relevant design criteria have been exceeded.

Because fire safety engineering is a relatively young discipline, there are inevitably some gaps in the understanding of fire and many areas where improvements in knowledge will take place. This may limit the application of fire safety engineering in particular cases. It is incumbent on fire safety engineers to be aware of improvements in knowledge and of any inherent limitations of the quantitative analysis they conduct, and to ensure that the fundamental objectives of the design are likely to be satisfied. The fire safety engineer is professionally accountable for the accuracy and validity of the quantitative analysis.

4.2 Qualitative design review (QDR)

The interaction of fire, buildings and people gives rise to a large number of possible scenarios. This, together with the wide range of building designs and uses, makes it impractical to establish a single set of calculations and procedures that can be applied directly to all buildings. 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. It is also essential to ensure that the calculation techniques are

appropriate to the problem under consideration. For this reason a formalized design review and hazard assessment procedure has been introduced into this Draft for Development.

The objective of the QDR is to review the architectural design, identify fire hazards and define the problem in qualitative terms suitable for detailed analysis and quantification. Another important function of the QDR is to establish one or more fire protection schemes (trial designs) that are considered likely to satisfy the fire safety criteria. On major projects the QDR should be carried out by a group that includes members of the design team and one or more fire safety engineers. It may also be desirable for a representative of the appropriate approval bodies, insurers and operational management to be involved in the QDR. The purpose of adopting a team approach is to ensure that all aspects of the design can be considered in the context of the fire safety objectives and criteria.

As tools for computation and data for quantification are not always available, engineering judgement can play an important part in the QDR.

4.3 Quantitative analysis

Following the QDR a quantitative analysis can be carried out. It has been found convenient to split the analysis into a number of parts, referred to as sub-systems in this guide (see clauses 11 to 16). 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 appropriate general principles and procedures. Each sub-system may be used in isolation when analysing a particular aspect of design, or all may be used together in an overall fire engineering evaluation of a building. The sub-systems are as follows:

- a) sub-system 1: initiation and development of fire within the enclosure of origin (clause 11);
- b) sub-system 2: spread of smoke and toxic gases within and beyond the enclosure of origin (clause 12);
- c) sub-system 3: fire spread beyond the enclosure of origin (clause 13);
- d) sub-system 4: detection and activation of fire protection systems (clause 14);
- e) sub-system 5: fire service intervention (clause 15);
- f) sub-system 6: evacuation (clause 16).

An example of how the various sub-systems are linked together in the design process is illustrated in figure 4. The basic data requirements and outputs of each sub-system are identified from the information bus which is illustrated in figure 3.

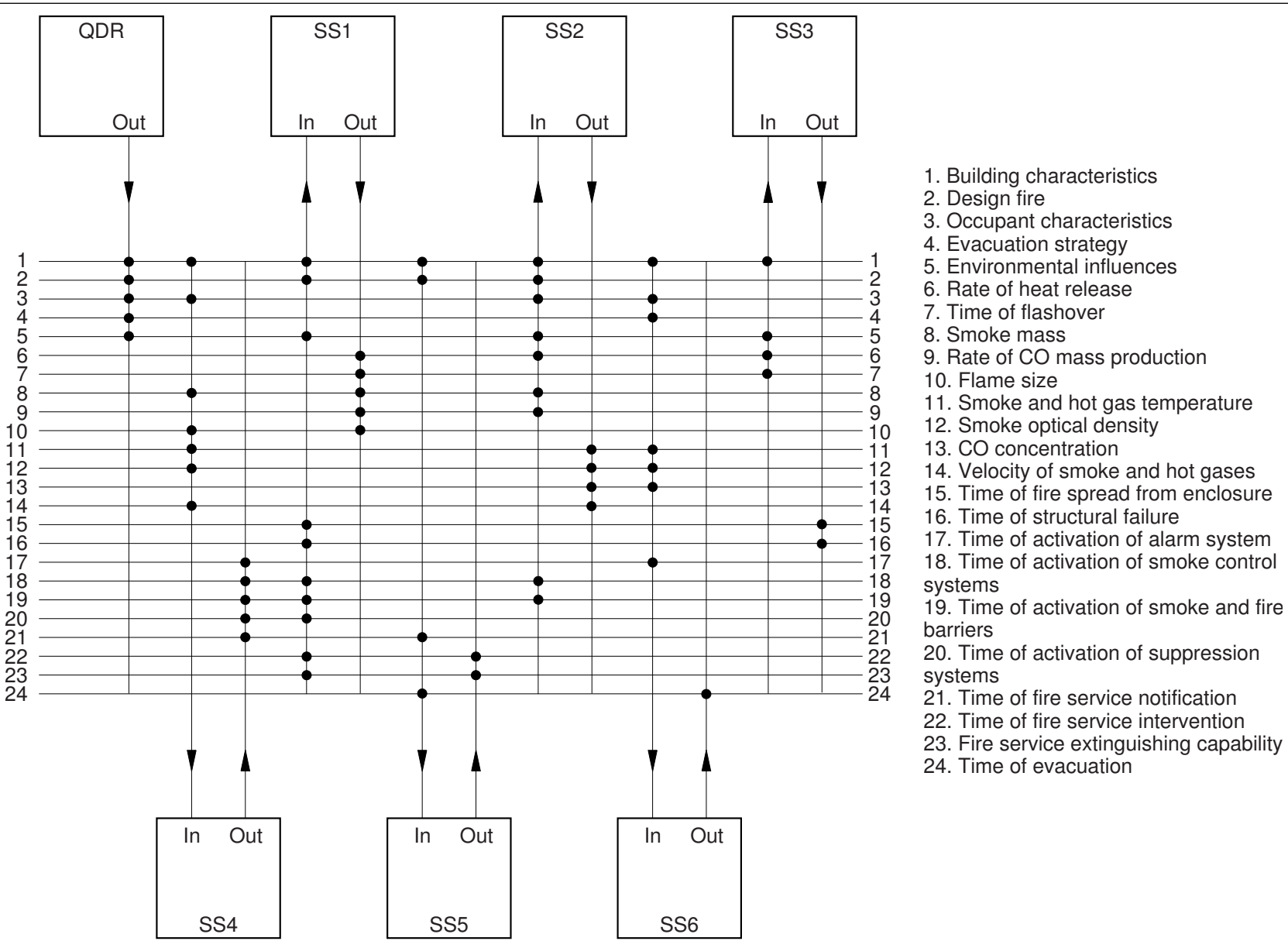


Figure 3. Information bus

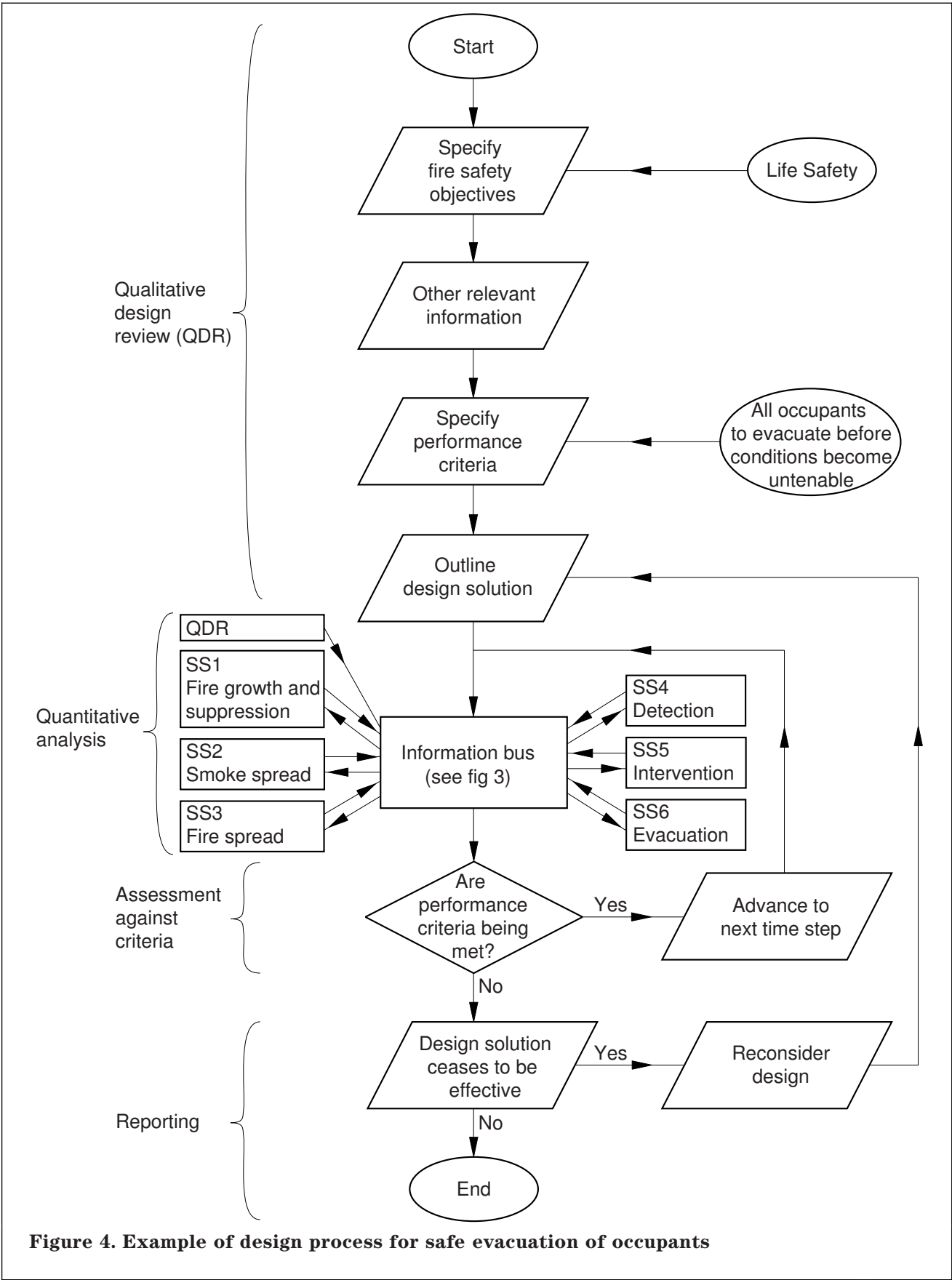


Figure 4. Example of design process for safe evacuation of occupants

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

- 1) deterministic studies; or
- 2) probabilistic risk assessment.

In practice, the analysis may combine 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. Some methodologies are outlined in the sub-systems. 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.

4.4 Assessment against criteria

Following the quantitative analysis, the results should be compared with the acceptance criteria identified during the QDR. Three 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 quantitative analysis should be repeated until a satisfactory fire safety strategy has been found.

In a deterministic study, the objective is to show that, on the basis of the initial assumptions (usually 'reasonable worst case'), a defined set of conditions will not occur. In a probabilistic study, the criterion set is 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. 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 design offers at least the same level of safety as compliance with 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 provision of the prescriptive code, as a particular provision may have more than one objective. Once this has been done, alternative designs may be developed that address the specific underlying objectives. The engineer should demonstrate that the solution proposed will be at least as effective and reliable as the conventional approach.

There are inevitably many uncertainties in fire engineering calculations. It may, therefore, 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 are generally conservative.

4.5 Reporting and presentation

Most designs produced in accordance with the provisions of this Draft for Development will be subject to review and approval. It is therefore essential that the findings of the fire engineering study and any assumptions made should be presented in a form that can be clearly and easily understood by a third party. Clause 8 provides guidance on the presentation of the results of the fire engineering study. This Draft for Development does not recommend a fixed format for the report but does make recommendations concerning the minimum information that it should include, e.g. the findings of the QDR, assumptions, references, engineering judgements, methodologies employed, sensitivity analyses and comparison of results with acceptance criteria.

4.6 Additional information

Annex A provides general guidance on the factors which influence the performance and evaluation of a range of fire protection measures. Annex B provides selected statistical data that may be incorporated into a probabilistic risk assessment study. It is not possible to provide guidance on all aspects of fire engineering design in this Draft for Development and annex C provides a bibliography of publications that may be used as a source of additional design information; this list is not exhaustive.

5 Qualitative design review

5.1 General

The purpose of the QDR is to:

- a) review the architectural design;
- b) perform a characterization study of the building, environment and occupants;
- c) establish the fire safety objectives;
- d) establish an evacuation strategy;
- e) identify acceptance criteria;
- f) identify fire hazards and possible consequences;
- g) establish trial fire safety designs;
- h) specify fire scenarios for analysis;
- i) indicate appropriate methods of analysis;
- j) prepare a fire safety manual;
- k) output results of QDR.

The QDR is of primary importance when establishing fire safety in buildings. Detailed information required for the QDR is given in clauses 11 to 16.

5.2 Personnel involved in the QDR

For large and complex projects, it is recommended that the QDR be carried out by a study team comprising one or more fire safety engineers, other members of the design team and a member of operational management. It may also be appropriate to include representatives of approval bodies or insurers. For smaller projects, the QDR may be carried out by a smaller study group, but the same basic process should be followed.

The QDR allows the team to think of the ways in which a fire hazard might arise and to establish 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 systematically, to ensure that no relevant item is omitted.

The QDR is essentially a qualitative process that draws upon the experience and knowledge of the team members. However, it is often 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 QDR cannot be completed until a full architectural design is available. However, a preliminary study at the outline design stage may obviate the need for significant changes to the architectural design at a later stage. The QDR is likely to involve a series of iterations on the design process, moving from broad concept to greater detail. The QDR should be substantially completed before the working drawing stage is reached, so as to avoid late design changes.

The findings of the QDR are recorded and the main findings are clearly documented for reference by the design team or a third party (see clause 8).

6 Quantitative analysis

6.1 General

Following the QDR, a quantitative analysis should be carried out to verify the effectiveness of the proposed fire safety solutions. A convenient method is to split the analysis into a number of parts, referred to as sub-systems in this Draft for Development (see clauses 11 to 16). Each sub-system may be used in isolation for analysing a particular aspect of design or they may be used together for an overall fire engineering evaluation of a building.

The analysis associated with each sub-system is described in detail in clauses 11 to 16. The various aspects of the analysis (or, in effect, each sub-system) may be quantitative by means of either:

- a) deterministic design procedures; or
- b) probabilistic design procedures.

6.2 Deterministic design procedures

6.2.1 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.

6.2.2 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 clauses 11 to 16).

6.2.3 Fire scenarios

The interaction of fire, buildings and people can give rise to a very complex system. Therefore, in order to evaluate fire safety in large complex buildings by deterministic calculations, some conservative simplifications need to be made. In theory, several factors may contribute to the fire scenarios; but in practice, the contribution of many of these factors is insignificant. By carefully selecting when and where to apply calculations, and then adopting the appropriate calculation technique, an equally safe solution can be reached more easily. Guidance on the selection of significant scenarios and initial assumptions is given in 9.9.

When considering scenarios in isolation, it is usual to choose the worst credible conditions for assigning values to the variables. However, when considering several scenarios, it should be recognized that the use of a series of unlikely events would lead to an over-conservative design. On the other hand, the use of average values for the variables would be perceived as leading to a non-conservative design.

A successful analysis relies upon qualitative rationalization of the problem, in the context of the particular fire safety requirements, during the QDR. Attention can then be focused on the quantitative interpretation of the design and, in particular, on the uncertainties that the quantification may involve.

6.2.4 Limits of application

Often the experimental work used to develop empirical relationships is carried out in scaled-down facilities in research establishments. It is important to appreciate that the application of the 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. Justification should be given for any extrapolation of test data.

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 accurate. Normally, well formulated models provide conservative predictions within their range of application. In situations where there is any doubt as to the validity of a model, the fire safety engineer should establish from the literature how the experimental work was carried out and justify the solution, for example by a sensitivity analysis.

6.3 Probabilistic design procedures

Subclauses 6.4 to 6.6 illustrate how some of the techniques of probabilistic risk assessment (PRA) can be applied to fire safety engineering problems. A detailed description of the procedures and techniques involved in PRA is beyond the scope of this guide. Various text books are available on this topic (see annex C).

Many factors can influence the development of a fire within a building and the escape of occupants, and these vary according to the circumstances at the time of the fire (e.g. whether first-aid firefighting has been attempted or whether fire doors are propped open). In a PRA study the objective is to estimate the likelihood of a particular unwanted event. This can be achieved by the use of statistical data regarding the frequency of fire starts and the reliability of fire protection systems (see annex B), combined with a deterministic evaluation of the consequences of the 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 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.

Using the procedures presented in this Draft for Development, it is also possible to estimate the extent of property damage that could result from a fire and its products. This information can then be used to estimate potential financial losses and enable a cost-benefit study to be carried out on additional fire protection measures. However, such financial calculations fall outside the scope of this Draft for Development.

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

Although many factors can contribute to the development and consequences of a fire, in practice some of these factors will be insignificant. By carefully selecting when and where to apply calculations, and then adopting the appropriate calculation technique, a pragmatic solution can be developed.

The PRA 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 amount of calculation required.

6.4 Data required for probabilistic design

6.4.1 General

The acquisition of reliable data is one of the most important tasks in performing any risk assessment. Where data are lacking, it is possible to make reasonable worst-case assumptions regarding occupancy, fire load, etc. However, the use of reliable statistical data will help to ensure a realistic risk assessment.

The information required for a PRA can be classified into four groups:

- a) deterministic data;
- b) fire statistics;
- c) building data;
- d) system reliability data.

6.4.2 Deterministic data

Deterministic information regarding the development and possible consequences of fire can be evaluated by means of the deterministic procedures detailed in clause 6.2 and the sub-systems (see clauses 11 to 16).

6.4.3 Fire statistics

The likelihood of a fire occurring within a particular type of building should be established on the basis of statistical data from buildings of similar use and location. Where no specific data on the numbers of fires are available for the appropriate type of building, the values given in tables B.1, B.2 and B.3 may be used.

6.4.4 Building data

Surveys are available to quantify key items of the PRA such as fractile fire loads and occupancy levels. These are described in clause 10. The continued development of a fire and the potential consequences depend upon a number of factors such as:

- a) the availability of combustibles and the fractile fire load;
- b) the imposed structural loads;
- c) the number of occupants present at any given time.

6.4.5 System reliability data

All fire protection systems can fail for reasons such as lack of maintenance, random mechanical failures or inability to cope with an unusually severe fire. Data regarding the reliability of each type of system should be obtained.

Examples of data on the reliability of systems are given in table B.9.

6.5 Techniques of probabilistic risk assessment

6.5.1 General

The basic purpose of PRA is to analyse a system comprising the building and its contents, occupants and fire control systems, with the intention of determining:

- a) what fire and human behaviour scenarios can occur;
- b) the frequency of each scenario;

- c) the effects and consequences of the selected scenarios;
- d) the total risk associated with fire and occupancy;
- e) the extra measures required to reduce the unacceptable risks.

Items a), c) and e) should be considered in detail during the QDR.

6.5.2 Combining probabilities

The methodology can be illustrated by considering the risk of structural failure in a fire, as follows.

From statistical data the following should be established:

- a) the probability of the critical fire load being present, P_i ;
- b) the probability of the fire starting, P_f ;
- c) the probability of the critical fire load being burnt, P_c .

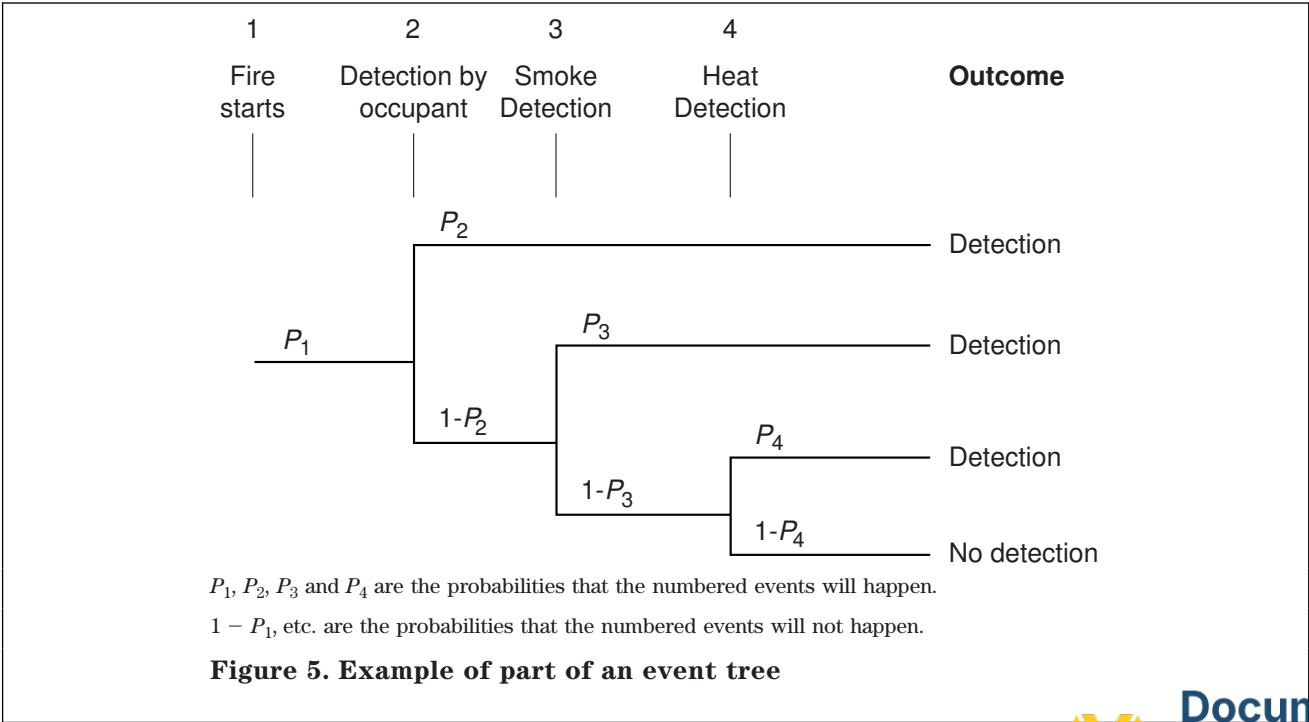
If sprinklers are installed, P_c should be modified accordingly.

The probability of a fire which will lead to structural failure, P_f , should then be calculated as follows:

$$P_f = P_i \times P_f \times P_c$$

6.5.3 Event trees

Event trees (see figure 5) are logic diagrams that can be used to illustrate the sequence of factors involved in ignition, fire development and fire control. Event trees are generally more suitable than fault trees (see 6.5.4) for use in PRA.



6.5.4 Fault trees

6.5.4.1 General

Fault trees are logic diagrams that illustrate the ways in which a system can fail so that a particular unwanted event, known as a 'top event', (e.g. structural collapse) occurs. Given the unwanted event as a starting point, it is necessary to work backwards through the tree to establish the combination of events (fire start, sprinkler failure, detector failure etc.) that would give rise to it. The events in the tree are connected at node points, termed logic gates, that show which combination of events could cause a particular unwanted outcome. These logic gates are of two types, as described in 6.5.4.2 and 6.5.4.3.

6.5.4.2 AND gates

AND gates are those in which all the component events need to occur to cause the specific event. If, in figure 6, P_1 is the probability of ignition and P_2 is the probability that no self-termination will occur, then:

probability of established fire = $P_1 \times P_2$

6.5.4.3 OR gates

OR gates are those in which only one of the component events need occur to cause the specific event. If, in figure 7, P_1 is the probability of manual suppression being effective and P_2 is the probability of sprinklers activating, then:

probability that fire will be suppressed = $P_1 + P_2$

6.6 Risk analysis

6.6.1 General

The risk analysis considers the probability of a fire starting and heat and smoke spreading to produce hazardous and damaging conditions in an occupied space. It is based on statistical data or, if these are not available, on the probability and potential consequences of a range of possible deterministic fire scenarios. The criteria for hazardous and damaging conditions are given in 9.6.3.

The overall risk associated with a particular building design is the sum of the risks for all the potential fires of interest within that building.

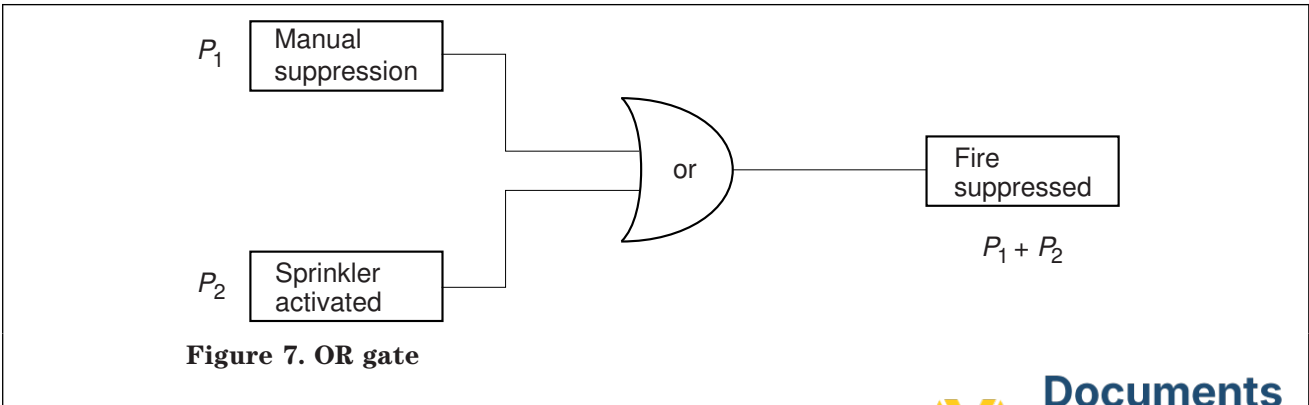
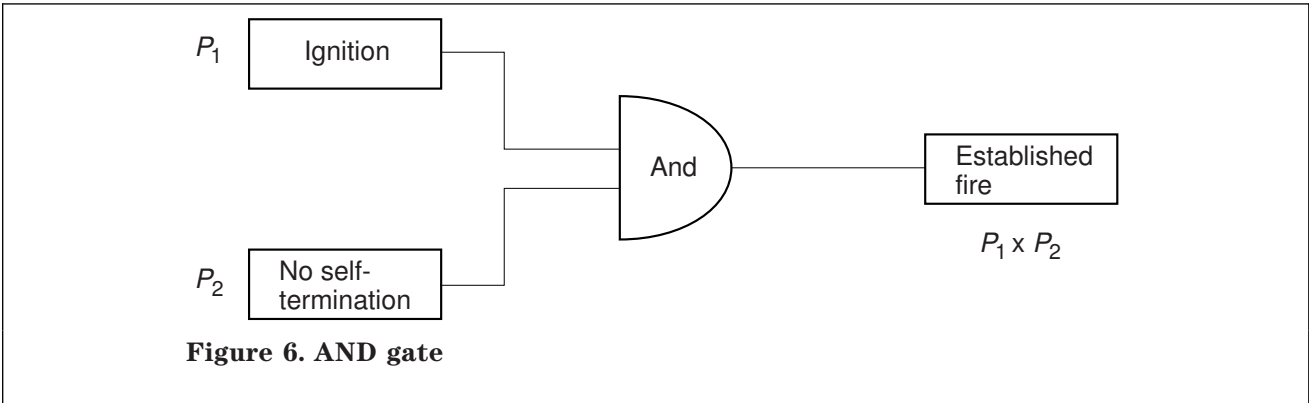
6.6.2 Life risk analysis

The basic steps in a life risk analysis are shown in figure 8.

The probable number of casualties (including fatalities) for a given fire scenario is given by the following equation:

$$N_{cas} = N_{INIT} - N_{EXIT}$$
 where

- N_{cas} is the number of casualties for the assumed occupancy;
- N_{INIT} is the initial number of occupants expected to be in the threatened area;
- N_{EXIT} is the number of occupants able to escape to safety in ASET.



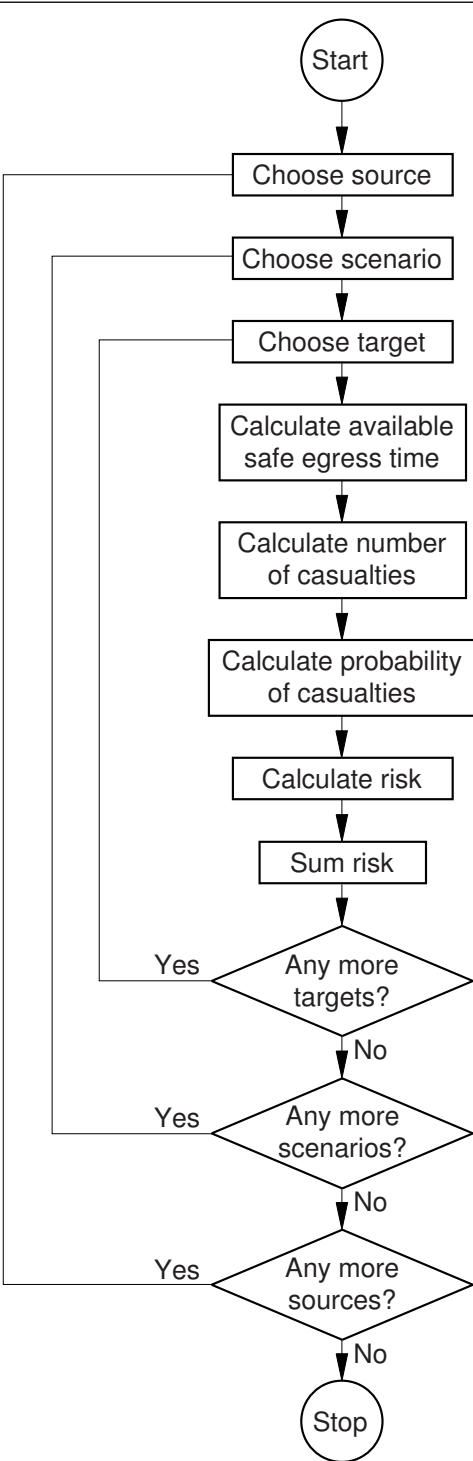


Figure 8. Steps in life risk analysis

The risk to life is given by the following equation:

$$P_d = P_{\text{esc}} \times P_i \times P_{\text{scen}} \quad (2)$$

where

- P_d is the risk to life from the scenario;
- P_{esc} is the probability that the escape time will exceed ASET;
- P_i is the probability of fire starting;
- P_{scen} is the probability of the specified fire scenario developing after ignition.

P_{esc} is a function of the number of occupants present at the time of the fire, the pre-movement time and the travel speed.

There is generally more than one way in which a fire at a specified location can hazard the occupants. The characteristic risk associated with a particular fire location (source) is, therefore, the sum of the risks over all fire scenarios and all potentially threatened (target) locations.

The total risk associated with a particular building is the sum of the risks for all the potential fire sources within that building.

To produce a definitive measure of the risk to life it would be necessary to consider every combination of fire source, fire scenario and target location within the building. However, the computational effort required increases with the number of sources, scenarios and targets considered. The QDR team (see 9.9) therefore need to simplify the problem before a comprehensive PRA can be carried out.

6.6.3 Property and environment risk analysis

The basic steps in a property and environmental risk analysis are similar to those given in 6.6.2 (see figure 8).

The objects or 'targets' for the damage risk assessment may be individual objects of value, e.g. a computer, structural components or ground water. Normally, objects are not moved from an area under attack by fire. They may be individually protected from a fire by, for instance, an enclosed cabinet, or groups of objects may be protected by compartments or active protection methods.

The probability of an object being damaged by fire is a function of the independent probability of the following:

- a) a fire starting in a particular place;
- b) a specified fire scenario developing after ignition;
- c) damage occurring from the scenario;
- d) available protection being sufficient.

6.6.4 Common mode failures

The failure of one part of the system can adversely affect the efficiency of another fire protection measure. For example, an open fire door will not only be an ineffective barrier to fire spread but may also lead to failure of a gaseous extinguishing system due to loss of extinguishing agent. Particular care should be taken by the QDR team and those responsible for the PRA to ensure that any such common mode failures are identified and accounted for in the analysis.

7 Assessment against criteria

7.1 General

The results from the analysis of the sub-system should be compared with the acceptance criteria identified during the QDR. Three types of approach can be considered:

- a) deterministic;
- b) probabilistic;
- c) comparative.

If the quantified assessment shows 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.

7.2 Deterministic criteria

7.2.1 General

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.

7.2.2 Life safety

7.2.2.1 General

The aim of the assessment for life safety is to demonstrate that all persons can leave a threatened part of a building in reasonable safety without assistance. In a deterministic study, it is necessary to define the onset of hazardous conditions and the time required for people to escape from the area.

The study should 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 threats are significant and require quantification.

7.2.2.2 Tenability conditions

Information on the tenability criteria for exposure to toxic gases, smoke obscuration and heat is given in tables 2, 3 and 4 (see 9.6.2.2).

Usually, it is loss of visibility due to the spread of smoke that constitutes the initial threat to life and consequently determines the ASET. In some circumstances, the operation of an extinguishing system may spread smoke downwards, adversely affecting visibility in the very early stages of a fire. 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.

Essentially, when designing for life safety, the aim is to ensure that:

$$[ASET] > \Delta t_{\text{esc}} \quad (3)$$

where

$$\Delta t_{\text{esc}} = \Delta t_a + \Delta t_{\text{evac}}$$

and

$[ASET]$ is the ASET;

Δt_{esc} is the time (in s) taken from ignition for all occupants to evacuate to a place of safety;

Δt_{evac} is the time (in s) taken from alarm for all occupants to evacuate to a place of safety;

Δt_a is the time (in s) from ignition to alarm.

The inhalation of smoke and toxic gases can impair movement but does not always cause total incapacitation which would prevent escape. In principle, it would be possible to take account of the effect of 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 conditions become untenable, after which movement ceases.

7.2.2.3 Structural failure

Failure of structural elements before the evacuation is complete can present a threat to life. 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 7.6).

7.2.3 Loss prevention and environmental protection

7.2.3.1 General

The aim of the assessment for loss prevention and environmental protection is to demonstrate that the objectives and criteria set for the building scheme are met. For example, the calculated projected floor area of fire damage should be equal to or, preferably, less than the specified limits for damage to property.

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 distribution of heat and smoke can be related to damage in and around the building (this includes damage to the building, contents and environment).

When exposed to heat, radiative and convective, objects can suffer irreversible damage and can even combust. As the temperature and time of exposure increases, the damage is likely to increase. Smoke released from fires contains gases, liquids and small particulate matter. This smoke travels away from the fire in convective flow, contaminating the building, contents and environment. Hot firebrands 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:

- low fuel loading;
- large separations between fuel loads;
- compartmentation;
- the operation of active fire protection (e.g. sprinklers);
- active firefighting.

While limiting the extent of the fire, firefighting media can cause damage to property. The quantity of media discharged and their effect on the building, contents and environment can be predicted by deterministic evaluation.

7.2.3.2 Damage to property

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 heat and smoke damage should not exceed these defined limits.

7.2.3.3 Environmental damage

The extent of acceptable contamination of the air, land and water is normally specified for the building scheme. Deterministic calculation can predict the mass release of substances and their distribution at locations of interest. Calculated contamination values should not exceed the specified environmental limits (see 9.6.2.3).

7.2.3.4 Structural damage

The degree of structural damage can be predicted by deterministic calculation. As well as the obvious property loss associated with structural damage, other aspects should be considered, such as the cost of building restoration, recovery time, and the possible release of large quantities of material into the environment.

7.3 Probabilistic (risk) criteria

In a probabilistic study, criteria are set such that the probability of a given event is acceptably low. The risk criteria are usually expressed in terms of the annual probability of the unwanted event.

7.4 Comparative criteria

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 which conforms to more prescriptive codes. For instance, in a large exhibition hall, travel distances may be extended, increasing the 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 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, the intent of that code needs to be clearly understood. During the QDR, the team should consider the intentions of each recommendation, as a particular provision may have more than one objective. Alternative design solutions may then be developed to address the specific underlying objectives. The engineer should demonstrate that the solution proposed will be at least as effective and reliable as the conventional approach.

7.5 Safety factors and uncertainty

In developing the solution to a fire safety engineering problem, as with any engineering design, there are many sources of uncertainty. These may include uncertainties associated with:

- a) the choice and definition of the scenario(s);
- b) the formulation of an appropriate conceptual model for a chosen scenario;
- c) the formulation of the associated computational model;
- 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 then combined to establish an overall level of uncertainty. This overall level may then provide the basis for the choice of safety factor to be used.

Unfortunately, it is not yet possible to quantify levels of uncertainty for all stages of the design process, nor is there yet a generally accepted methodology for combining them. These problems are being addressed, as noted in DD 240 : Part 2; but until further progress has been made, 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 basis and limitations of chosen scenarios, models and data, and should be made explicit in the reporting and presentation of the final design. As a contribution to this process, DD 240 : Part 2 contains the result of a review of the equations cited in this Part of DD 240 and provides a measure of the confidence which can be placed in each equation and an assessment of its limits of applicability. It is therefore important that the guidance given in DD 240 : Part 2 is considered before the levels of uncertainty and any safety factors are decided.

7.6 Sensitivity analysis

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

- 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.

An indication of the sensitivity of results to such uncertainties can 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 study 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 6.3).

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 may have been assumed that an enclosure remains an enclosure, and that the possibility of an open door may be ignored. However, by considering an alternative scenario in which it is assumed that the door is open, the effect of confinement can be assessed. An example of a sensitivity analysis is given in annex A of DD 240 : Part 2.

8 Reporting and presentation

8.1 General

When checking that a design conforms to traditional codes and guidance documents, it is relatively straightforward to establish whether the various provisions of these have been correctly implemented. This Draft for Development, however, provides for a flexible approach to design, using performance-related objectives rather than prescriptive solutions. When this approach is adopted, an approvals body cannot simply assess the proposed design against a set of well-defined recommendations. The results of a fire engineering study should therefore be fully documented so that they can be readily assessed by a third party. The report should set out clearly the basis of the design, the calculation methods used and any assumptions made during the study.

8.2 Contents of the report

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

- a) objectives of the study;
- b) description of the building;
- c) membership of the QDR team;
- d) results of the QDR:
 - 1) fire safety objectives;
 - 2) results of the hazard analysis;
 - 3) basis for selecting fire and human behaviour scenarios for analysis;
 - 4) acceptance criteria;
 - 5) trial design;
 - 6) influence of fire-safety management;
- e) analysis of results:
 - 1) assumptions;
 - 2) engineering judgements;
 - 3) calculation methods;
 - 4) validation of methodologies;
 - 5) sensitivity analyses;
- f) comparison of the results of the analysis with the acceptance criteria;
- g) fire protection installations;
- h) management requirements;
- i) conclusions:
 - 1) fire protection requirements;
 - 2) any limitations on use of the building;
- j) references:
 - 1) drawings;
 - 2) design documentation;
 - 3) technical literature.

For clarity, it is desirable that the main body of text provides an overview of the study and that calculations, computer outputs, detailed analysis, etc., are included in appendices. It is also important that the report draws a clear distinction between life safety, property protection and environmental protection, so that building owner, manager and regulating authority clearly understand the purpose of proposed measures.

9 Procedure for the QDR

9.1 General

The procedure for the QDR is to:

- a) review the architectural design;
- b) perform a building, environment and occupant characterization study;
- c) establish the fire safety objectives;
- d) establish an evacuation strategy;
- e) identify acceptance criteria;
- f) identify fire hazards and possible consequences;
- g) establish trial fire safety designs;
- h) specify fire scenarios for analysis;
- i) indicate appropriate methods of analysis;
- j) output the results of the QDR.

9.2 Review of the architectural design

At the first stage in the QDR, the architect/designer should describe the project by reference to schematic drawings, models etc., and highlight any architectural or client requirements that may be significant in the development of a fire safety strategy.

All the relevant information about the building, its use and its anticipated contents, should be provided. The team should be provided with information on building location, internal layout, contents, combustible materials, ventilation, and management regimes. It is important that the team also establish at this stage the number of people likely to be present at any time, their distribution within the building and their general characteristics, such as mobility.

Information on any proposed passive and active fire safety systems should also be provided to the QDR team at this stage.

Table 1 provides a checklist of items that may need to be considered when reviewing the architectural design. The list is not exhaustive, but is a guide to the range of factors to be considered in a full study.

Table 1. Checklist for review of architectural design

Area of review	Items to be considered
Building design	Location relative to other buildings or site boundary Nature of construction Normal circulation routes Provision for dispersal of people from vicinity of building Escape routes Access for fire appliances Firefighting access within the building Fixed firefighting appliances Fire brigade response time Compartmentation (fire and smoke spread routes) Number of storeys above and/or below ground level General dimensions Geometry and interconnections of spaces Design constraints Expected degree of continuing fire safety management Any other factor that may influence the fire safety design
Occupants	Number Distribution Mobility State of wakefulness Responsiveness Familiarity with the building Social group Any other factor that may influence the fire safety design
Enclosure	Potential ignition sources Combustible contents Fire load density Wall lining Ceiling linings Floor coverings Ambient noise levels Ventilation systems Possible fire and smoke spread routes Escape routes Proposed fire protection systems Any other factor that may influence the fire safety design

9.3 Building, environment and occupant characterization

The second stage of the QDR is to extract the necessary information from the review of the architectural design for transfer into the information bus (shown in figure 3). The relevant information falls into three categories, as follows.

- a) *Building characterization* includes 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 will influence fire safety design through their effect on structural loads, smoke ventilation systems and the nature of external flame envelopes issuing from the windows of the building.
- c) *Occupant characterization* includes the type of occupancy, the building population and its distribution, the likelihood of the fire alarm being raised manually, and the type of fire detection and alarm system.

Guidance on assembling this data is given in clause 10.

9.4 Fire safety objectives

9.4.1 General

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

The objectives and criteria should be established with interested parties during the QDR. The procedures presented in this guide may be used either to develop a complete fire safety strategy or simply 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 objectives that usually need to be addressed in carrying out a fire-engineering study are presented in 9.4.2 to 9.4.5. The list is not exhaustive, and not all items may be appropriate to a particular study.

9.4.2 Limiting the probability of outbreak of fire

The potential for ignition of combustible materials should be minimized as far as is reasonably practicable.

9.4.3 Life safety

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 be to ensure that:

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

The objectives concerning evacuation, in item a), and collapse, in item c), are generally covered by legislation.

9.4.4 Loss prevention

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

- a) the structure and fabric of the building;
- b) the building contents;
- c) the ongoing viability of the business;
- d) the corporate image.

Statutory requirements are generally intended to protect life and to prevent conflagration; however, in a particular scheme it may also be desirable to reduce the potential for large financial loss. 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.

9.4.5 Environmental protection

A conflagration involving several buildings or the release of quantities of hazardous materials can have a significant impact on the environment.

Consideration should therefore be given to limiting:

- a) the effects of fire on adjacent buildings or facilities;
- b) the release of hazardous materials into the environment.

9.5 Evacuation strategy

9.5.1 General

The purpose of an evacuation strategy is to ensure that, in the event of fire, the occupants are able to leave the building (where appropriate) without being exposed to untenable conditions.

9.5.2 Strategies

Basic evacuation strategies include:

- a) total evacuation of the occupants, by either simultaneous or phased procedures;
- b) evacuation of the occupants to a place of safety within the building, where people can remain and from where, if necessary, they can subsequently complete the evacuation in safety, as part of a managed system;

- c) the occupants remaining in place, when their location is such that evacuation could not normally be contemplated for functional reasons, provided that the design ensures that the location remains a place of safety throughout.

The evacuation strategy should not rely on direct assistance to the occupants, except for special cases such as the evacuation of the infirm. The choice of evacuation strategy should be carefully matched to the nature of the building and its occupants. Some strategies are not applicable to certain types of building. For example, in hospitals or premises providing residential care, appropriate evacuation strategies might include those where occupants are evacuated to a place of safety within the building or are afforded protection while remaining in situ. Similarly, it may not be appropriate to adopt a strategy of total evacuation from an air traffic control tower. In buildings such as hospitals, where progressive horizontal evacuation or phased evacuation is adopted, some of the occupants may remain in the building for an extended period while firefighting operations take place elsewhere in the building.

9.5.3 Evacuation process

The time necessary for evacuation of the occupants to a place of safety depends on a number of factors relating to the occupants and the building. It is useful to consider the sequence of events within the evacuation process. Evacuation time is the sum of two discrete times, namely the time taken for occupants to become aware of the need for evacuation and the time actually to travel to the place of safety.

9.6 Acceptance criteria

9.6.1 General

Whatever measures are taken to reduce the consequences of fire, the possibility of death or injury cannot be totally eliminated. There is no such thing as zero risk. It is, therefore, important to establish the criteria against which the adequacy of a design can be judged. The following types of criterion can be used:

- a) deterministic (including, when appropriate, safety factors);
- b) probabilistic (risk-based);
- c) comparative;
- d) financial.

9.6.2 Deterministic criteria

9.6.2.1 General

For 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 the calculation methods; and/or
- b) the consequences of failure of the design.

If the reliability of input data or calculation methods is in doubt, a conservative approach should be adopted.

9.6.2.2 Life safety

Table 2 shows limits for asphyxiant (narcotic) gases and irritants, and can be used as a simple design guide. For detailed methods for the analysis of hazards from toxic products, heat and smoke in fires, see [3] and [4]. Beyond these limits, 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.

When mixtures of toxic products are present, as in all fires, then the effects of different products are approximately additive. The accumulated dose for each toxic gas can be expressed in terms of the exposure dose, which is the product of concentration and exposure time.

For asphyxiant gases the exposure dose is the most important criterion. Table 2 shows maximum tolerable exposure doses, for design purposes, for individual asphyxiant gases. If these are exceeded, incapacitation (loss of consciousness) can occur. The peak concentration of hydrogen cyanide should not exceed 0.01 %, averaged over any period of 30 s. The level of oxygen depletion should not exceed 9 % (equivalent to the presence of 12 % oxygen), averaged over any period of 30 s.

In order to estimate the effects of mixtures of asphyxiant gases, the exposure dose for each gas accumulated over a period of time during a fire is expressed as a fraction of the maximum tolerable exposure dose for that gas (the fractional incapacitating dose (FID) above which incapacitation becomes increasingly likely). The incapacitating doses for each gas are then summed, and the maximum tolerable exposure for the mixture (FID) is reached when the fraction reaches unity. The time during the fire when this limit is reached represents the time limit (from ignition) for tolerable exposure to asphyxiant fire products. For survival, the maximum tolerable exposure dose of an asphyxiant mixture (above which death becomes increasingly likely) is approximately twice that for incapacitation.

For irritant products, the most important consideration is the concentration at which pain to the eyes, nose throat and lungs is likely seriously to impede or prevent escape. When exposure is prolonged and the concentrations of irritants are high, the accumulated exposure dose of irritants can cause incapacitation or death due to lung inflammation, usually some hours after exposure. Maximum tolerable concentrations for individual gases are shown in table 2. At higher concentrations,

Table 2. Maximum tolerable exposure doses and concentrations for individual combustion products for 5-minute and 30-minute exposures.

Fire product	5-minute exposure		30-minute exposure	
	Exposure dose (concentration × time) %-min	Peak concentration %	Exposure dose (concentration × time) %-min	Peak concentration %
<i>Asphyxiants</i>				
CO	1.5	1	1.5	1
CO ₂	25	6	150	6
Low O ₂	45 (depletion)	9 (depletion)	360 (depletion)	9 (depletion)
HCN	0.05	0.01	0.225	0.01
<i>Irritants</i>				
HCl	—	0.02	—	0.02
HBr	—	0.02	—	0.02
HF	—	0.012	—	0.012
SO ₂	—	0.003	—	0.003
NO ₂	—	0.008	—	0.003
Acrolein	—	0.0002	—	0.0002

NOTE 1. Acrolein in this context is used as an indication of the presence of organic irritants. As a guide, the tenability limit for acrolein and other organic irritants is unlikely to be exceeded if the smoke optical density is less than 0.5/m.

NOTE 2. Mixtures of asphyxiant gases should be considered as approximately additive. The tenability limit for incapacitation from asphyxiation is reached when the fraction of an incapacitating dose (FID) is equal to one; i.e. $FID = 1$, where $FID = (\text{exposure dose for CO})/1.5 + (\text{exposure dose for CO}_2)/25 + (\text{exposure dose for O}_2 \text{ depletion})/45 + (\text{exposure dose for HCN})/0.05$.

NOTE 3. Mixtures of irritants should also be considered additive. The tenability limit for incapacitation from irritants is reached when the fractional irritant concentration (FIC) is equal to one; i.e. $FIC = 1$, where $FIC = (\text{HCl concentration})/0.02 + (\text{HBr concentration})/0.02 + (\text{HF concentration})/0.012 + (\text{SO}_2 \text{ concentration})/0.003 + (\text{NO}_2 \text{ concentration})/0.008 + (\text{acrolein concentration})/0.0002$.

escape is likely to be impaired. The effects of mixtures should be considered as additive, and can be estimated by summing the fractions of the maximum tolerable concentration of each gas present to find the fractional irritant concentration (FIC). The maximum tolerable exposure for the mixture is reached when the sum of the fractions reaches unity. Provided that an FIC of 1 is not exceeded, it is unlikely that serious post-exposure effects from lung inflammation will occur.

For fires involving mixed fuels such as the contents of an office, shop or dwelling, most or all the irritant gases in table 2 are likely to be present at various concentrations. As a design guide, it is suggested that the maximum tolerable concentrations for mixed irritants are unlikely to be breached if the smoke optical density does not exceed 0.2/m (extinction coefficient 0.5). This was found by Jin [5] to be the optical density of irritant smoke at which people behaved as if they were in darkness. For flaming fires involving only organic irritants, it is unlikely that limiting conditions would be encountered in smoke with an optical density of less than 0.5/m (extinction coefficient 1.15).

Taking into account all toxic products (asphyxiants and irritants), for preliminary design purposes it is considered that limiting conditions are unlikely to be breached for up to 30 min in situations where the smoke optical density does not exceed 0.1/m (extinction coefficient 0.25).

The tenability limits for smoke obscuration are given in table 3. It is considered that the minimum visibility acceptable for escape from a small room is 5 m (0.2 optical density/m), which, for irritant smoke, is that at which people behave as if in darkness. In large rooms, people need to see much further in order to orient themselves and find exits. People are also reluctant to enter heavily smoke-logged escape routes. In a study of numerous building fires, Wood [6] and Bryan [7] found that the average smoke density at which people turned back rather than continue through smoke was 0.33 optical density/m (3 m visibility). For these reasons, and to avoid toxicity problems, the minimum visibility in large spaces should not be less than 10 m (0.1 optical density/m).

NOTE. Fire effluent from mixed fuels contains a mixture of toxic gases including asphyxiants such as carbon monoxide (CO), hydrogen cyanide (HCN), carbon dioxide (CO₂) and depleted oxygen (O₂), and irritants such as acrolein and hydrogen chloride (HCl). Guidance on tenability limits for mixtures of these gases, smoke and heat is given in tables 2 to 4. Since CO and irritant smoke are major products from all fires, it is unlikely that the tenability limits for mixed toxic products will be exceeded provided that the smoke optical density does not exceed 0.1/m and the CO does not exceed one fifth of the tenability limits given in table 2. If these limits for smoke density and CO are exceeded, then either the design should be changed or a more detailed toxic hazard analysis should be carried out.

Table 3. Tenability limits for smoke obscuration ¹⁾		
Location	Visibility m	Optical smoke density m ⁻¹
Small room	5	0.2
Other rooms or spaces	10	0.1
¹⁾ Derived from <i>Toxicity assessment of combustion products</i> , by D.A.Purser [3].		

The limit for exposure to radiant heat should be taken as 2.5 .kW/m². Radiant heat at this level causes intense skin pain followed by burns within a few seconds, but lower fluxes can be tolerated for more than 5 min. For very short exposures, such as the time required to pass the open doorway of an enclosure containing a fire, a flux of 10 kW/m² may be tolerable. For fluxes greater than 2.4 W/m², the tolerance time for heat radiation is given by:

$$t_m = \frac{90}{q^{1.333}}$$

(4)

where

- t_m

is the time (in s) to incapacitation due to skin pain;
- q

is the radiant heat flux (in W/m²)

Table 4 gives tolerance times for different fluxes.

Table 4. Tenability limits for heat ¹⁾			
Type of heat exposure	Radiant heat flux kW/m ²	Temperature °C, at < 10 % H ₂ O (V/V) (unless stated)	Tolerance time min (or s where stated)
Radiation	< 2.5	—	> 5
	2.5	—	30 s
Convection	10	—	4 s
	—	< 60, saturated air	> 30
	—	180	1
	—	160	2
	—	140	4
	—	120	7
	—	100	12
	—	—	—

¹⁾ Derived from *Toxicity assessment of combustion products*, by D.A.Purser [3].

Exposure to convected heat causes severe pain to naked skin, and burns, and incapacitation can occur after a time which depends upon the temperature according to the following relationship:

$$t_m = 179 \exp(-T/36.6^\circ) \quad (5)$$

where

t_m is the time (in min) to incapacitation due to skin pain (for periods of up to 1 h);

T is the temperature (in $^\circ\text{C}$).

For air saturated with water vapour the tenability limit is 60°C , which is the highest temperature at which saturated air can be breathed. Table 4 gives tolerance times for different temperatures.

Conducted heat is important only when skin is in contact with hot surfaces, such as door handles. A 1-second contact with metal at 60°C can cause burns.

9.6.2.3 Loss prevention and environmental protection

Property in and around a building that can be fire damaged can be grouped into three areas: building, contents and the environment. Examples of objects in these groups are given in table 5. These objects have different degrees of susceptibility to fire damage caused by heat and smoke. For instance, a fire that results in flashover within an enclosure or compartment is likely to damage all the linings, fixtures and fittings, services and contents, so that they need to be replaced. Structural elements may sustain some damage, but may not need replacing. Smoke spread to other areas of the building may result in damage to other linings, fixtures, fittings and contents.

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

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

- selecting materials with resistance to fire;
- providing specific protection;
- contingency planning.

Special consideration should be given to design, protection and planning with regard to objects, events and layouts that escalate fire damage.

In order to set the limits for property loss and environmental damage, it is necessary to carry out a risk assessment. During this risk assessment, attention should be paid to the value of the property in and around the building and to the effects of fire.

Limits specified for damage to property and business should include:

- the number of specific valuable objects to which damage (to a certain degree) is acceptable;
- the maximum zone of direct fire damage;
- the maximum zone of smoke and hot gas damage;
- the maximum zone of water damage;
- the maximum periods for recovery from the fire.

Zones are often described by their floor areas.

Group	Sub-group	Examples
Building	Sub-structure	Foundations, slabs
	Super-structure	Frame, floors, roof, staircases, external walls, internal walls and partitions, windows, doors
		Carpets, tiles, wall paper, decorative panels, plaster, coving, blinds, curtains
	Fixtures and fittings	Furniture, shelving, cupboards, desks
	Services, supply and distribution	Electrical, heating, water and waste, communications
Contents	Electrical appliances	Lamps, computers
	Records	Books, accounts, video, tapes, disks
	Production equipment	Machinery
	Raw materials	Timber, plastic, chemicals, food
	Finished product	Toys
	Unique objects	Oil paintings
Environment		Water, soil, air, neighbouring buildings

9.6.3 Probabilistic criteria

The object of a probabilistic risk assessment (PRA) is usually to show that the likelihood of a given event occurring (e.g. injury, death, large loss of life, large property loss and environmental damage) is acceptably small.

Based upon a simplification of the figures presented in 1984 by Rasbash [8], who analysed UK fire statistics, the risk of individual and multiple deaths is:

- a) individual risk (per individual per year):
 - 1) at home: 1.5×10^{-5} ;
 - 2) elsewhere: 1.5×10^{-6} ;
- b) risk of more than 10 deaths: 5×10^{-7} per building per year;
- c) risk of more than 100 deaths: 5×10^{-8} per building per year.

Recent statistical data show that the number of deaths is decreasing but that the number of injuries is increasing. The most recent Home Office statistics indicate approximately 20 injuries for every death due to fire in the home, and 40 injuries for every death elsewhere.

These figures represent the current UK experience, although other data may be relevant in establishing design criteria for life safety, as suggested, for example, in *The Tolerability of Risk from Nuclear Power Stations* [9].

Society is far less tolerant of incidents, however infrequent, that can give rise to many casualties (e.g. bus accidents) than of more frequent incidents which, individually, involve fewer casualties (e.g. car accidents).

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

Fires of all sizes cause damage. Fires can range from a small fire in a waste-paper bin, with insignificant losses, to a large conflagration engulfing a row of buildings, with very large losses. In the UK, fire loss information is collected for losses greater than £50,000.

The average probability of a fire involving large loss occurring in an occupied building within the UK is 0.0004 per building per year¹⁾. This probability covers all occupancies²⁾ except dwellings. The probability of any fire occurring is 0.02 per building per year.

The proportion of loss attributed to direct damage and to business interruption in a 5-year period is 83 % and 17 % respectively.

9.6.4 Comparative criteria

In many projects codes of practice and other guidance are followed and fire engineering techniques unnecessary (or are used only to justify limited departures from the codes). The QDR team may therefore simply define the acceptance criteria in terms of compliance with an existing code. 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 compliance with the well established codes. This approach generally involves deterministic and/or probabilistic techniques and requires less extensive analysis than a full study. The objective of a comparative study is simply 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 codes and guides allow alternative means of compliance. Examples can be found for fire resistance, compartment sizes and building separation. In a comparative study, such alternatives may be applicable without the need for detailed analysis.

9.6.5 Financial criteria

The procedures described in this guide may be used to estimate the probability and extent of smoke damage 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.

9.7 Identification of fire hazards

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

- a) general layout;
- b) potential ignition sources;
- c) nature of the activities;
- d) anticipated occupancy;
- e) materials of construction;
- f) combustible contents;
- g) any unusual factors.

This list is not exhaustive, and the QDR team should attempt to identify all significant fire hazards. In evaluating the significance of a fire hazard, the QDR team should take particular account of the influence of each hazardous event on the achievement of the fire safety objectives.

¹⁾ This figure is based on statistics published in *Fire Prevention*, January 1996. These statistics may underestimate the number of fires, because some are unreported.

²⁾ A breakdown of the occupancies can be found in the Home Office and LPC statistics published in *Fire Prevention*, January 1996.

When identifying hazards, the QDR team should consider the possible consequences of failures in the fire protection systems and management procedures, e.g. fire doors left open or failure of the smoke detection system. In a probabilistic risk assessment (PRA), the likelihood and consequences of such failures are generally quantified; however, in a deterministic study, the team should decide upon a credible scenario for detailed analysis. Where a comprehensive fire safety management plan is implemented, and is subject to third-party review (see 10.5), the benefits of this should be taken into account when assessing the likely efficiency of the evacuation process or the reliability of the fire protection systems.

9.8 Trial fire safety designs

It is often necessary to amend the architectural design or provide additional fire protection measures to achieve an acceptable level of safety. To enable the quantitative analysis to be carried out, the QDR team should establish one or more trial fire safety designs (fire protection strategies).

There are no established rules for the specification of alternative fire protection strategies. The members of the QDR team should use their knowledge and expertise to make sensible judgements on the suitability of various alternatives. Whilst under- or over-specifications should be identified in the quantification process that follows the QDR, this can be time consuming and it is clearly desirable that the QDR team identify cost-effective strategies that are likely to satisfy the fire safety objectives and criteria.

There are factors other than fire safety that determine whether a particular design is acceptable. These factors may rule out some of the proposed fire safety designs, simplifying the subsequent quantification.

The alternative design strategies should be compared in terms of cost and practicality.

Table 6 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 system that should be considered and to the basic information required to enable a quantified study to be carried out.

9.9 Fire scenarios for analysis

9.9.1 General

The number of possible fire scenarios in a complex building can become very large and often neither the data nor the resources are available to attempt to quantify them all. The detailed analysis and quantification should therefore be limited to the most significant fire scenarios.

Table 6. Checklist for development of trial design

Fire protection system	Examples of information to be provided by QDR
Automatic suppression	Extinguishing medium Delivery rate Nozzle spacing
Detection	Detector types Locations Zoning Response characteristics
Subdivision	Fire resistance Location Boundaries
Automatic systems	Dampers Shutters Magnetic door catches Fans Vents
Smoke ventilation	System type, extraction/pressurization Extract rate/pressurization level
Alarm and warning systems	Sounder or public address Zoning
Evacuation strategy	Phased, simultaneous, staged or progressive horizontal Management procedures
Escape routes	Exit widths Travel distances Stairways Protected lifts 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
Fire safety management	Management plan Staff availability Staff training Third-party audit of procedures Maintenance schedules

For the purposes of analysis, the characterization of a fire scenario should involve a description of the initiation, growth and extinction of fire, together with the likely routes of smoke and fire spread and the effect of any fire suppression measures. The possible consequences of each fire scenario should also be considered.