Department
of Health

Firecode – fire safety in the NHS
Health Technical Memorandum 05-03: Operational provisions

Part J: Guidance on fire engineering of healthcare premises

ISBN 978-0-11-322808-9

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Document Purpose	Best Practice Guidance		
ROCR Ref:		**Gateway Ref:**	9070
Title	Firecode HTM 05-03: Part J - Fire engineering in healthcare premises		
Author	Department of Health - Estates & Facilities Division		
Publication Date	Jan 2008		
Target Audience	Directors of Estates & Facilities; Trusts Fire Safety Managers; Trust Fire Safety Advisers		
Circulation List	GPs, Voluntary Organisations/NDPBs		
Description	This is a new document providing guidance and a basic understanding of fire engineering principles for healthcare premises		
Cross Ref	N/A		
Superseded Docs	N/A		
Action Required	N/A		
Timing	**N/A**		
Contact Details	Paul Roberts Estates & Facilities Division Quarry House, Quarry Hill Leeds LS2 7UE 0113 254 6881		
For Recipient's Use			

Firecode – Fire safety in the NHS
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Part J: Guidance on fire engineering of healthcare premises

London: The Stationery Office

Published by TSO (The Stationery Office) and available from:

Online
www.tsoshop.co.uk

Mail, Telephone, Fax & E-mail
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TSO@Blackwell and other Accredited Agents
(see Yellow Pages)
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ISBN 978-0-11-322808-9

First published 2008

Printed in the United Kingdom for The Stationery Office

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Executive summary

Preamble

This Health Technical Memorandum provides guidance on the fire engineering of healthcare premises. It supports Health Technical Memorandum 05-02 – 'Guidance in support of functional provisions for healthcare premises', Health Technical Memorandum 86 – 'Fire risk assessment in hospitals' and 'Fire risk assessment in Nucleus hospitals' (the latter two are soon to be replaced by Health Technical Memorandum 05-03 Part K – 'Fire risk assessments in complex healthcare premises').

It has been prepared in consultation with the Department of Health National Fire Policy Advisory Group (NFPAG).

The guidance in this Health Technical Memorandum is consistent with the guidance in BS 7974: 2001 'Code on the application of fire-safety engineering principles to the design of buildings'.

Fire engineering

This Health Technical Memorandum is a best practice guide that recognises the special requirements of fire precautions in the design of healthcare premises and should allow the current statutory regulations to be applied sensibly within a framework of understanding.

Fire engineering can be used during the design of fire precautions in new healthcare buildings and major extensions to, or the upgrading of fire safety in, existing healthcare buildings.

Fire safety is not solely about the physical fire precautions provided. This guidance document recognises the interaction between physical fire precautions, the dependency of the patient, the fire hazards within healthcare premises, management policies, and the availability of sufficient and adequately trained staff in achieving an acceptable level of fire safety within healthcare premises.

The primary remit of NHS organisations with regard to fire safety is the safety of patients, visitors and staff. For all premises under their control, NHS organisations will need to select and effectively implement a series of measures to achieve an acceptable level of fire safety, taking into account:

- the guidance in this Health Technical Memorandum;
- the relevant guidance contained in other parts of Firecode;
- all relevant legislation and statutes;
- the advice and approval of local building control and fire authorities.

Who should use this document?

This guidance document will be of particular value to directors of estates and facilities in NHS trusts, healthcare fire advisers, practising fire-safety engineers, building control officials, fire-prevention officers and all those with a responsibility for fire safety.

Acknowledgements

Building Research Establishment
Health Facilities Scotland
Health Estates Northern Ireland
Welsh Health Estates
National Association of Healthcare Fire Officers
Health Facilities Management Association
Fire Safety Development Group
National Fire Policy Advisory Group

Contents

1 Introduction and scope

General application

1.1 This Health Technical Memorandum provides guidance on the application of fire-safety engineering principles to the fire safety of healthcare premises.

1.2 It may be used as a source of reference in the design of:

a. new healthcare buildings;

b. new extensions to existing healthcare buildings;

c. alterations to existing healthcare buildings;

d. the change of use of an existing building into a healthcare building;

e. those parts of an existing healthcare building that are used as means of escape from a new extension.

1.3 As the use of engineering in support of performance-based regulation develops and becomes more complex, it is important to constantly develop and re-evaluate the knowledge base that underpins the design. Fire-safety systems differ from nearly every other engineering system in a building; any faults or failures in design, implementation or maintenance may only become apparent during the emergency for which they are required.

1.4 The topics covered in this guide do not form an exhaustive list. Basic descriptions for a number of key topics encountered in fire-safety engineering are provided, and aspects that should be considered by both designer, enforcer and other responsible persons (for example trust fire adviser) are highlighted.

1.5 This guidance document mainly addresses the fire-safety objective of the life safety of occupants (as do the provisions of Health Technical Memorandum 05-02 – 'Guidance in support of functional provisions for healthcare premises').

Note

Health Technical Memorandum 05-02 (and its predecessors) provides guidance on the methods that ensure the protection of property and the continuous provision of patient care. It is important that any fire engineering analysis also considers the potential impacts of any alternative fire strategy on these other fire-safety objectives, particularly the protection of property and the continuing provision of care (for example dialysis).

Who is this guidance for?

1.6 This guidance document provides an introduction to the subject of fire-safety engineering for both the novice and those currently involved in its practice. It attempts to explain the topics involved and the interconnected nature of the component parts in producing safe and cost-effective design.

1.7 This Health Technical Memorandum will be of particular value to directors of estates and facilities in NHS trusts, healthcare fire advisers, practising fire-safety engineers, building control officials, fire-prevention officers and all those with a responsibility for fire safety.

1.8 It is intended to be a reference for those who are new to, or occasionally encounter different aspects of, fire-safety engineering. Experienced practitioners may also find it useful as a short-cut to finding information in more detailed references. It is not intended to be a one-stop shop that will give all the information needed to solve fire-engineering problems during the design of a healthcare building.

Scope of Health Technical Memorandum 05-03: Part J

1.9 The central purpose of this document is to provide guidance on the application of fire-safety engineering as an alternative way to achieve the fire safety expected in healthcare premises.

1.10 This Health Technical Memorandum may be used as guidance on fire engineering in all parts and all types of healthcare buildings, including departments or areas providing ancillary services that are planned as an integral part of a healthcare building. However, in less complex healthcare buildings it may be simpler and more appropriate to apply the prescriptive guidance in Health Technical Memorandum 05-02.

1.11 This document therefore builds on the guidance in Health Technical Memorandum 05-02 and, where appropriate, on the requirements of Approved Document B of the Building Regulations.

Alternative solutions

1.12 The range of NHS premises providing patient care is extensive, and the guidance in this document may not be appropriate for all types of building. However, it is expected that NHS clients, designers, and building control and fire authorities will exercise a degree of judgement based on a full understanding of the problem, taking into account such things as:

- the type of care being provided;
- the mobility of the patients;
- the planned staffing levels;
- the age of the patients;
- the size of the premises.

1.13 A fire-safety engineering approach that takes into account the total fire-safety package can provide an alternative approach to fire safety. If such an approach is used, the responsibility is placed upon those promoting the alternative approach to demonstrate that it achieves the functional requirements and fire-safety objectives of this document.

Status of this guidance

1.14 This Health Technical Memorandum is best practice guidance prepared in consultation with the Department of Health's National Fire Policy Advisory Group (NFPAG) and has no statutory force. It is guidance that recognises the problems special to healthcare, and should allow the current statutory regulations to be applied sensibly within a framework of understanding.

1.15 When using this document, it is important to recognise that it is not possible to make comprehensive recommendations covering all eventualities, and it should always be borne in mind that the purpose of healthcare premises is to provide medical treatment and/or nursing care. The complex nature of healthcare buildings will sometimes require a more flexible approach to ensure that the correct balance is achieved between fire safety and the requirements for treatment and nursing care. This should be done on the basis of professional judgement and an understanding of the nature of the problems. However, care should be taken to ensure that the safety of patients, visitors and staff is not compromised.

1.16 In the design of healthcare buildings, no reliance is placed on external rescue by the fire-and-rescue services or manipulative types of escape appliance such as chutes or portable ladders. This document has been prepared on the basis that in an emergency the occupants of any part of a healthcare building should be able to move, or be moved, to a place of relative safety with assistance from staff only.

1.17 As fire safety is not solely dependent on the physical fire precautions provided, this document also considers the fire-safety implications of:

a. the dependency of the patient;

b. fire hazards within the healthcare premises;

c. management policies; and

d. availability of sufficient and adequately trained staff.

1.18 To further assist with these considerations, patient occupancy categories have been defined to assist designers in ensuring that the appropriate degree of fire-safety measures are incorporated into the building.

1.19 For the purposes of this document, occupants are classified as:

a. independent (including patients);

b. dependent; or

c. very high dependency.

Note

(b) and (c) refer to patients only.

This classification is based on a broad consideration of occupants' anticipated mobility and/or dependence. The categories differentiate between the anticipated dependence of various occupants, either during an evacuation or as a consequence of the treatment they are receiving.

Independent

1.20 Patients will be defined as being independent if their mobility is not impaired in any way and they are able to physically leave the premises without staff assistance, or if they experience some mobility impairment and rely on another person to offer minimal assistance. This would include being sufficiently able to negotiate stairs unaided or with minimal assistance, as well as being able to comprehend the emergency wayfinding signage around the facility.

Dependent

1.21 Unless classed as "independent" or "very high dependency", all patients are classed as dependent.

Very high dependency

1.22 Those patients whose clinical treatment and/or condition creates a high dependency on staff are classed as "very high dependency" patients. This will include those in critical care areas, operating theatres and areas where evacuation would prove potentially life-threatening.

Use by competent persons

1.23 The guidance in this document has been prepared on the understanding that it will be used by competent persons. For the purposes of this document, a competent person is defined as **"someone who has sufficient technical training and actual experience or technical and other qualities, both to understand fully the dangers involved and to undertake properly the measures referred to in this document"**.

Consultation

1.24 Because of the complex and changing nature of healthcare and the often conflicting requirements between fire safety and nursing care, it is essential that early consultation takes place between the design team, the client, the trust fire safety adviser and all relevant enforcing authorities. Depending on the nature of the scheme, it may also be advantageous to involve the client's insurers in the consultation process. Where a fire-engineered approach is adopted, this early discussion is paramount to ensure that all parties have a full understanding of the implications.

1.25 It is not possible to provide absolute safety from fire. The guidance in this document should reduce the risk to patients, visitors and staff as far as is reasonably practicable.

2 Glossary of terms

For the purposes of this document the following terms are defined:

Approval authority: organisation responsible for approving the fire-safety aspects of a building.

Auto-suppression: mechanical methods of fire suppression which are activated automatically – such systems may include water sprinklers and CO_2 flooding systems.

Available safe egress time (ASET): calculated time available between ignition of a fire and the time at which tenability criteria are exceeded in a specified space in a building.

Calorific value: total amount of heat released when a unit quantity of a fuel (measured at 25°C and atmospheric pressure) is oxidised during its complete combustion in oxygen under specified test conditions (although, in a fire, only a proportion of this energy will be released).

Circulation space: the communication routes both within the department/management unit and giving access to other parts of the hospital, and to all necessary fire escape exits.

Compartment: a building or part of a building, comprising one or more rooms, spaces or storeys, constructed to prevent the spread of fire to or from another part of the same building, or an adjoining building.

Designer: any person (including a client, contractor or other person referred to in the Construction, Design and Management Regulations 2007) who in the course or furtherance of a business either prepares or modifies a design, or arranges for or instructs someone under their control to do so. The design relates to a structure, or to a product, a mechanical or electrical system intended for a particular structure.

Design fire: hypothetical fire that is agreed as representative of actual severe fires likely to occur in a particular fire scenario.

Deterministic study: methodology based on physical relationships derived from scientific theories and empirical results, which for a given set of initial conditions will always produce the same outcome.

Enclosure: space defined by boundary elements (on all sides).

Equivalency: equivalency is to demonstrate that a building, as designed, presents no greater risk to occupants than a similar type of building designed in accordance with well-established codes.

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

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

Exit: doorway or other suitable opening giving access towards a place of safety.

Fire hazard: a set of conditions in the operation of a product or system with the potential for initiating a fire.

Fire hazard room: a room or other area that, because of its function and/or contents, presents a greater hazard of fire occurring and developing than elsewhere.

Fire load: quantity of heat that could be released by the complete combustion of all the combustible materials in a volume, including the facing of all boundary surfaces.

Fire load density: fire load divided by the floor area.

Fire resistance: the ability of an element of building construction, component or structure to fulfil, for a stated period of time, the required load-bearing capacity, fire integrity and/or thermal insulation and/or other expected duty in a standard fire-resistance test.

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

Fire-safety engineer: person suitably qualified and experienced in fire-safety engineering.

Fire-safety engineering: application of scientific and engineering principles to the protection of people, property and the environment from fire.

Fire-safety manual: document providing all necessary information for the effective management of fire safety in the building.

Fire scenario: set of circumstances, chosen as an example, which defines the development of fire and the spread of combustion products throughout a building or part of a building.

Flashover: sudden transition from a localised fire to the ignition of all exposed flammable surfaces within an enclosure.

Healthcare building: for the purposes of this document, a healthcare building is considered to be a hospital, treatment centre, health centre, clinic, surgery, walk-in centre, or other building where patients receive treatment or are provided with medical care by a clinician.

Hospital street: a special type of compartment which connects final exits, stairway enclosures and department entrances and serves as a fire-fighting bridgehead and a safe evacuation route for occupants to parts of the building unaffected by the fire.

Management: person or persons in overall control of the premises whilst people are present, exercising this responsibility either in their own right, for example as the owner, or by delegation (of statutory duty).

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

Patient access areas: those areas of the healthcare building to which patients have reasonable access either with or without supervision.

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

Place of safety: predetermined place in which persons are in no immediate danger from the effects of fire. The place of safety may be inside or outside the building depending upon the evacuation strategy.

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

Probabilistic risk assessment: methodology to determine statistically the probability and outcome of events.

Progressive horizontal evacuation: evacuation of patients away from a fire into a fire-free compartment or subcompartment on the same level.

Refuge: a place of temporary safety within a building. This may be an adjoining compartment or subcompartment capable of holding all those threatened, without a significant change in level and from which there is potential for further escape should that become necessary.

Smouldering: combustion of a material without flame and light being visible.

Subcompartments: areas into which the building can be divided to reduce travel distance and which provide 30 minutes' resistance to fire.

Tenability criteria: maximum exposure to hazards from a fire that can be tolerated without causing incapacitation.

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

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

Trial fire-safety design: package of fire-safety measures that, in the context of the building, may meet the specified fire-safety objectives.

3 What is fire engineering?

3.1 The definition of fire-safety engineering presented by the Institution of Fire Engineers (IFE) is:

The application of scientific and engineering principles based on an understanding of the phenomena and effects of fire and of the behaviour of people to fire, to protect people, property and the environment from the destructive effects of fire.

Other organisations, such as the British Standards Institute (BSI) and International Standards Organization (ISO), have published similar definitions (see, for example, ISO TR 13387).

3.2 The principal objective of fire engineering is, when an accidental fire occurs, to provide an acceptable level of safety. Often this will involve the calculation or modelling of scenarios addressing all or part of the fire system.

3.3 One of the characteristics of this new subject is its diversity. A fire-safety engineer needs to consider:

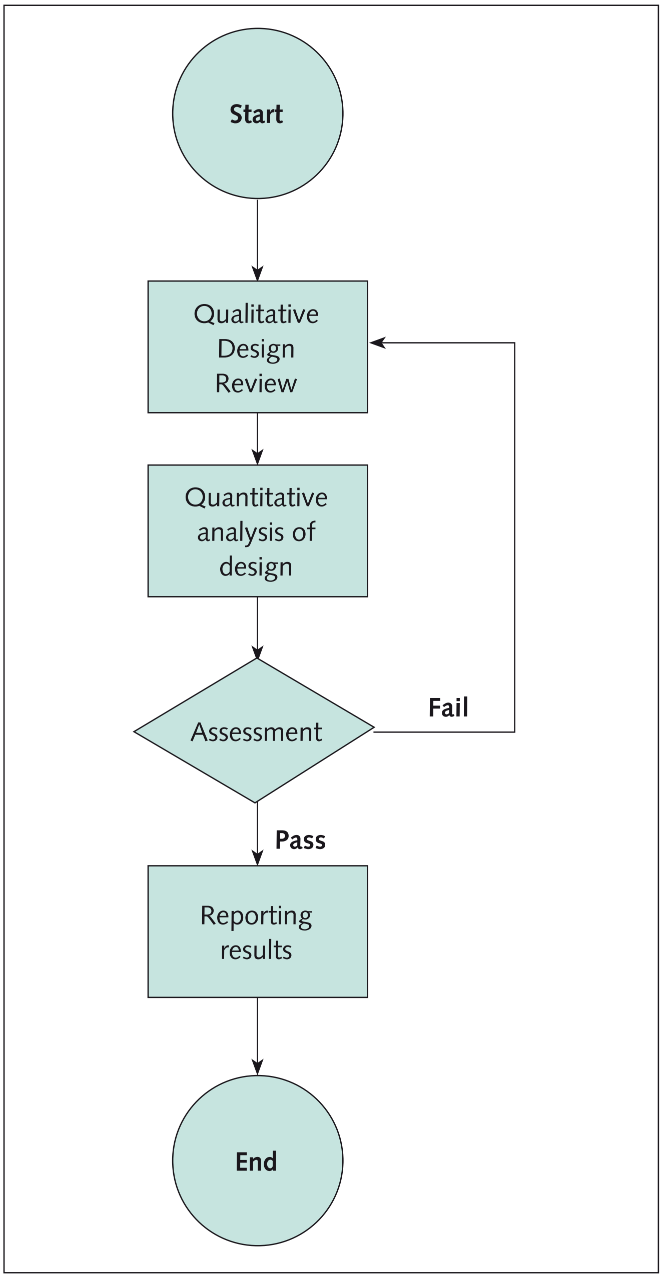
- chemistry (for example the behaviour of materials);
- physics (for example heat transfer, movement of smoke);
- civil, electrical and mechanical engineering (for example behaviour of technologies and systems);
- psychology (for example behaviour of people);
- procedures used by fire-fighters; and
- issues relating to management of large complex buildings.

Invariably there is always something new to learn or a distant memory that needs revision.

3.4 Often it is the interactions between different topics that cause difficulties in practical situations. Solutions to problems of a healthcare building's day-to-day use (ventilation, structure, security etc) may conflict with requirements for fire safety.

3.5 Fire-safety engineering must be undertaken using a systematic approach to avoid potentially life-threatening omissions in the analysis. Following BS 7974: 2001, the flow diagram in Figure 1 outlines a suggested approach to the design process.

Figure 1



3.6 At the design stage, particularly at the qualitative design review stage (see paragraphs 3.7–3.9), the interaction of all the healthcare building systems should be considered as well as the detailed performance of the fire-protection systems. This either brings into the process people who only occasionally encounter fire-safety engineering, or exposes a fire-safety engineer to a topic that is not often encountered. For these individuals, this guidance document will answer the following:

- What is fire engineering about?
- Is there anything special to look out for?
- Is it important to me as a designer or enforcer?
- Where can I find out more?

Qualitative design review (QDR)

3.7 The fire-safety design process begins with the qualitative design review (QDR). During this stage, the scope and objectives of the fire-safety design are defined, and performance criteria are established. For a detailed quantitative assessment, one or more potential designs will be considered. If the proposed design(s) are unsatisfactory according to the performance criteria chosen, the QDR must be repeated and new or modified designs will need to be considered.

3.8 For large projects, the QDR should be performed by a group of people, including members of the design team, one or more fire-safety engineers, and others as appropriate (such as building control officers, representatives of the fire-and-rescue service, the trust fire adviser and insurers). Professionally qualified staff should check and sign off the design.

3.9 The results of the QDR should be included in the final design report that is to be submitted for approval. If an initial design does not meet the performance criteria, a new design will be required.

Assessment of designs

3.10 The assessment of a fire-safety engineering design (that is, one that follows the procedures given in BS 7974) requires the results of a quantified analysis to be compared with the original design criteria determined during the QDR. BS 7974 gives three methods of assessing a design:

- **comparative criteria**, where a design is shown to have a comparable level of safety to some other method (for example Approved Document B of the Building Regulations);
- **deterministic criteria**, where a specific set of safety conditions are shown to have been achieved (for example smoke layer is never below a specified height);
- **probabilistic criteria**, where the probability of an event occurring is shown to be less than the given frequency.

3.11 Failure of a design to meet the assessment criteria will require the design to be modified and the QDR and qualitative analysis cycle to be repeated until a successful design has been determined.

3.12 The assessment method and criteria should be agreed before the quantitative design stage.

Reporting and presentation

3.13 The fire-safety design process should be subject to review and approval and be reported in such a way that a third party can readily understand the procedures and assumptions.

3.14 BS 7974 states that the following should be included:

- objectives of the study;
- building description;
- results of the qualitative design review;
- quantified analysis;
- comparison with acceptance criteria;
- fire-safety strategy;
- management requirements;
- conclusions;
- references;
- qualifications and experience of the fire-safety engineer(s).

Assumptions and engineering judgments should be clearly identified.

3.15 Sufficient detail should be included so that the quantified analysis can be repeated or reviewed by a third party. A sensitivity or uncertainty analysis should be performed to estimate the confidence limits for the key output variables that provide the comparison against the acceptance criteria (see paragraphs A139–A143 in Appendix A for further explanation).

3.16 Table 1 summarises the advantages and disadvantages of fire-safety engineering (BS 7974:2001).

Table 1 Summary of advantages and disadvantages of fire-safety engineering

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

4 Fire engineering in healthcare premises

4.1 Fire engineering is used to address a wide range of fire-safety issues, but it is mainly applied when:

- the design of a healthcare facility is complex or innovative;
- existing codes of practice restrict design flexibility;
- issues beyond life safety need to be considered; and
- the Firecode-compliant solution is unnecessarily costly.

4.2 With regard to healthcare, these situations tend to arise in:

- new hospitals that include:
  - non-standard layouts,
  - large developments, or
  - atria;
- non-standard healthcare buildings such as:
  - university hospitals,
  - ambulatory care and diagnostic centres,
  - treatment centres;
- existing hospitals where compliance with the guidance in Firecode is not possible or overly costly, such as:
  - high-rise hospitals;
  - hospitals on restricted sites;
  - healthcare premises for older people or for people with mental health problems.

4.3 Health Technical Memorandum 05-02 states that:

A fire-safety engineering approach that takes into account the total fire-safety package can provide an alternative approach to fire safety.

4.4 Equivalency is a helpful concept in judging the adequacy of alternative fire solutions.

5 Issues to consider for fire engineering

5.1 The following paragraphs identify some of the issues to be considered during the design of a healthcare project involving fire engineering.

Note

For an explanation of some of the concepts mentioned in this chapter, see Appendix A.

The fire engineering process

5.2 The fire engineering process involves a qualitative design review (QDR) – an assessment of the design and the presentation of sufficient detail to undertake a quantitative analysis. More information can be found in paragraphs 3.7–3.16.

Design fire

5.3 The determination of design fires is a critical part of the role of the QDR team in a fire-safety engineering design.

5.4 Steady-state fires may be assumed to encompass all fires up to the size of the design fire for an indefinite time.

5.5 Transient fires with a realistic growth phase are required for a reasonable calculation of time to detection and values of available safe egress time (ASET). (ASET is the maximum time that occupants have to move to a place of safety; see paragraphs A30–A35 in Appendix A.)

Fire growth

Heat release rate (HRR)

5.6 The size of a fire is commonly expressed in terms of the heat release rate (HRR). The fire growth rate is the rate at which the HRR increases. The HRR and area are key components of the characterisation of the design fire for a particular scenario, and most subsequent calculations will be dependent on these values.

5.7 In addition to specifying the correct HRR, it is important to specify the correct fire area. A large heat release over a small area is representative of a jet fire such as that from a broken gas pipe. Conversely, a small heat release over a large area will be more like a grassland fire. This can be checked by calculating the HRR per unit area (Q/A), where Q is the total HRR of the fire (kW) and A is the area of the fire (m^2). Q/A should normally be in the range 250–2000 kW m^{-2} for most materials found in buildings. Outside this range, most of the generally used equations for plume entrainment and flame height will be invalid.

5.8 Using incorrect values of Q/A will give incorrect temperatures and rates of entrainment in the fire plume.

Laws of thermodynamics

5.9 Calculations showing excessively high temperatures (above the adiabatic flame temperature, for example >2000°C) or temperatures below ambient would be the result of some fundamental error. Sudden jumps from low to high temperature remote from an obvious source of energy are also suspect.

$k\rho c$ (kay-row-see)

5.10 The properties k (thermal conductivity), ρ (density) and c (specific heat capacity) relate to the transmission of heat through materials (to other areas/compartments) and the ease of ignition (how quickly an object's surface temperature will rise). Low $k\rho c$ in a compartment's wall will increase the rate at which it heats up in a fire (this is often the case in many highly insulated energy-efficient healthcare buildings).

Fuel properties: (ΔH_{vap}, ΔH_c, stoichiometric ratio)

5.11 ΔH_c (heat of combustion) and ΔH_{vap} (heat of vaporisation) are required by calculations to estimate the heat release rate of a fire.

5.12 For some materials these properties may change with time during a fire, as more volatile components will tend to be burnt in the early stages of the fire.

5.13 Effective values of H_c and H_{vap} can be measured in the cone calorimeter. If there is insufficient air, as defined by the stoichiometric ratio, the fire will be vitiated. The heat release rate will be less than a free-burning fire, but the toxic hazard may be greater.

t-squared fire-growth curves

5.14 Fire-growth curves must be representative of the appropriate fire load and fire protection measures.

Fire severity

5.15 The correct choice of plume expression is important in the design of smoke-control systems to calculate the total amount of smoke and hot gases that needs to be exhausted.

5.16 The entrainment rate (important in determination of severity of vitiated fires) depends on the height of plume rise, the heat release rate of the fire, the fire area or perimeter and any deflection from vertical.

Smoke properties

5.17 Methods used to predict the properties of smoke produced in a fire require varying degrees of simplification.

- Do the proposed methods appear accurate?
- What are acceptable levels of smoke obscuration or concentration for different buildings?

5.18 In those areas of a hospital where dependent and/or very high dependency patients are present, there should be no obscuration or concentration at head height.

5.19 In other areas of healthcare premises, such as atria, the smoke layer may be above people's heads yet still present a hazard due to heat radiation.

Note

The presence of a smoke layer above dependent or very high dependency patients may also be unacceptable due to the anxiety caused by their inability to self-rescue.

Vitiated (ventilation-controlled) fires

5.20 The amount of air (oxygen) required for complete combustion depends on the stoichiometric ratio of the fuel.

5.21 The specification of the correct heat release (and rate) is crucial to the fire-safety design and will be dependent on availability of air as well as fuel properties.

Flashover

5.22 Flashover is a natural part of fire growth in a compartment where there is sufficient fuel and ventilation. This cannot be prevented by specific design features, other than by limiting the amount of fuel or by using a suppression system.

5.23 Action can be taken to delay the effect by:

- increasing the distance between potential fuel items;
- limiting the supply of air to the compartment (however, this may create a vitiated fire and conditions that could lead to a backdraught).

Backdraught

5.24 Backdraught is a concern for those (usually fire-fighters) entering and searching a well-sealed healthcare building (for example basements or unfenestrated buildings) in which a fire is suspected.

5.25 Ventilation techniques used by fire-fighters, such as positive pressure ventilation (PPV), can reduce the risk of a backdraught. Suppression techniques such as offensive fog attack (see www.firetactics.com) may also be effective.

Fully developed compartment fires

5.26 A fully developed fire has the most significance for the impact of the fire on the structure, and for tenability conditions in the building.

Effects of suppression

5.27 Some suppression systems may have adverse side-effects. For example, (accidental) discharge of inert gas systems in a closed room can suffocate occupants, or the accidental discharge of a sprinkler system may have adverse effects on electrical systems.

5.28 Halons are environmentally unfriendly (production of halons is now banned by the Montreal Protocol).

Halon systems can only be specified if they use recycled gases.

5.29 Cooling of the hot smoke by a water spray may lead to a loss of buoyancy and mixing of the smoky layer with clear air beneath, thus causing poor visibility in escape routes.

Compartment fire modelling

5.30 Strange or unexpected results from models require an adequate explanation from the user. For example, the prediction of the "trench effect" in the King's Cross fire investigation was supported by small- and large-scale experiments.

Cone calorimetry

5.31 Cone calorimetry is used to produce data on materials such as heat of combustion. Significant data (for example materials possessing notably high heats of combustion) may indicate a need for design review.

Cables

5.32 Where cables pass between compartments and through cavity barriers, adequate fire-stopping must be used.

5.33 The contribution of cables to a fire in a fire-safety-engineered building may be significant, and therefore the materials they are made of need to be considered.

Smoke spread and control

Buoyancy

5.34 If gas temperatures are low, other air movement (for example wind) may disturb a smoke layer and the (ideally) clear layer below may become contaminated.

ASET

5.35 ASET (available safe egress time) and RSET (required safe egress time) are not single deterministic values, but will have probability distributions associated with them. Analysis must consider the safety factor, not simply the principle that ASET should be greater than RSET.

5.36 Either ASET or RSET must account for the time delay between ignition and the fire first being detected.

Ceiling jets

5.37 Characterisation of the ceiling jet is essential for calculating the operation times of detectors and sprinklers.

Spill plumes

5.38 Spill plumes occur in atria, shopping malls and other geometrically complex buildings.

5.39 The identification of, and calculation for, spill plumes is essential for the estimation of ASET and sizing of extracts in smoke and heat exhaust ventilation systems (SHEVS; see paragraphs A56–A57 in Appendix A).

5.40 Where the geometry is complex, calculations may need to be done by computational fluid dynamics (CFD) simulations and perhaps verified using hot-smoke tests.

Stack effect

5.41 The presence of the stack effect and location of the neutral pressure plane is an important consideration in the design of smoke-control systems in tall hospital buildings.

Effects of wind

5.42 Wind will significantly affect the performance of natural (buoyancy-driven) smoke ventilation systems.

5.43 The wind pressure coefficient may be found by calculation, measurement on the completed building or by using a wind tunnel model.

5.44 Air flows also depend on the conditions inside the building (which will change as a consequence of these external air flows).

5.45 Greatest natural extraction will occur at vents, across which the greatest drop in pressure (interior–exterior) exists. If the difference in pressure is close to zero, flows may change direction as the system as a whole (interior–exterior) reaches equilibrium.

Heat losses to structure

5.46 Heat losses to the structure will reduce the temperature of hot gas layers, and hence their volume and buoyancy.

Smoke reservoirs

5.47 The volume of a smoke reservoir and the smoke extraction rate must provide an adequate ASET.

5.48 The smoke extract rate should also prevent the build-up of smoke from overflowing the reservoir.

5.49 If the reservoir is too large, the smoke may cool by losing heat to the structure. The smoke may lose buoyancy and fall to lower levels where people could be endangered.

5.50 Materials used within the smoke reservoir (including automatic smoke curtains) should be able to tolerate the predicted smoke-layer temperatures.

5.51 Sprinklers may need to be installed in the smoke reservoir if:

- the layer temperature is high enough to endanger occupants due to thermal radiation from the smoke layer (typically >200°C);
- there are sufficient combustibles under the reservoir to give a significant threat of excessive fire spread.

5.52 Screens and curtains should channel the smoke so that it does not present a hazard to occupants on floors between the levels of the fire and the reservoir.

5.53 Mechanical extract systems relying on a secondary power source (for example a generator) will have a limited duration of operation, restricting the ASET that can be achieved.

Smoke curtains

5.54 The operation of the curtains should be fail-safe or otherwise highly reliable.

5.55 The curtain material should tolerate the design temperatures of the smoke layer (typically >200°C except in the case of channelling screens where the temperature may be 600°C or higher).

5.56 Operation of the curtains should not endanger building occupants.

Smoke venting

5.57 A ventilation system cannot be designed in isolation from other parts of a building's fire-protection system. Design fire selection is critical. Fire resistance of the ductwork should be considered.

5.58 In the UK, fusible links tend to be regarded as a last-chance backup when primary opening devices have failed.

SHEVS

5.59 The design of a SHEVS involves more than simply determining the correct fan capacities: the interaction of the system with the overall fire-safety strategy needs to be considered.

5.60 In complex or unorthodox cases, or where safety factors appear marginal, verification of the design calculations using third-party review and/or hot-smoke tests may be required.

Replacement air (or make-up air or inlet air)

5.61 A smoke extraction system will not function correctly without an adequate supply of replacement air.

5.62 The provision of, and routes for, replacement (make-up) air should be confirmed.

5.63 If the occupants of the building are expected to use the route for replacement air, the velocity of airflow should be less than 3 m/s.

Pressurisation

5.64 Consider the effect of:

- stack effect (see paragraph 5.41);
- wind (see paragraphs 5.42–5.45);
- fire pressure.

5.65 A pressurisation system relies on the presence of building leakage paths.

Depressurisation

5.66 In atria, depressurisation provides replacement air for a ventilation system through areas of a building that need to be kept free of smoke for the safety of the occupants and fire-fighters. This is achieved by ensuring the neutral plane is above the highest level to be protected.

5.67 Fire strategies that use CFD analysis, using for example FDS or JASMINE, to demonstrate the effectiveness of depressurisation should be subject to independent third-party review.

Hot-smoke tests

5.68 A hot-smoke test may be desirable when:

- there is doubt in the validity of assumptions used in the design of the smoke-control systems;
- the final installation is found to differ from the proposal used to gain approval;

- conditional approval has been granted subject to proof of performance of the smoke-control system.

Structural fire protection

Fire resistance: stability, integrity and insulation

5.69 There is no direct relationship between performance in a standard test and the duration of a real fire. Fire-resistance time is **not** the length of time that a structure will survive in a real fire – fire-resistance time is simply used to compare the performance of different designs.

5.70 The failure mechanisms of elements of structure should be considered. In particular, consideration should be given to the failure mode and any trigger points and/or performance limits. In terms of robustness, is the failure likely to be catastrophic (that is, immediate, complete and without warning) or progressive?

Fire severity

5.71 Fire severity must be compared with the fire resistance of the structure (in terms of time, temperature or load-bearing capacity) and an adequate safety margin must be demonstrated.

5.72 Attempts to express severity in terms of equivalent exposure to a standard fire (so that the fire resistance can be taken directly from fire test results) may not be valid for some structures.

Time–temperature curves

5.73 In most situations, fire-resistance time is not related to the time available for escape.

5.74 Standard curves take no account of fire load density, compartment size or ventilation.

5.75 Time–temperature curves are a feature of standard test methods and do not necessarily provide data that can be used in a performance-based design.

Parametric time–temperature curves

5.76 Parametric curves have only been validated for compartments of moderate size (~100 m^2 floor area, 4 m ceiling height), a limited range of ventilation conditions, and fire loads of predominantly cellulosic fuels (rather than polymeric).

Fire load

5.77 Fire load is a key parameter in determining the duration of a fire and, hence, its severity.

5.78 Fire load alone does not determine the HRR; the nature of the material (for example thin wall linings, solid blocks) will also be important.

Time-equivalent exposure

5.79 Time-equivalent formulae are empirical, but the limitations are not well-documented.

5.80 Determining equivalence on the basis of equal areas under the time–temperature curves for a real fire ($0 < t <$ infinity) and standard curve ($0 < t < t_{equiv}$) does not adequately reflect the heat transfer mechanism (radiation: proportional to $T4$).

Note

Fire severity is calculated based on T (temperature), but radiation is proportional to T to the power of 4; therefore this model will underpredict the effect of radiation at high temperature.

5.81 Time-equivalent formulae may not be applicable to fire scenarios other than assumed in the original empirical derivation (for example non-cellulosic fuels, larger rooms, different types of fire protection, different levels of glazing/ventilation or different types of structural member).

5.82 Time-equivalent formulae are not intended for unprotected steel or timber structures.

Structural modelling

5.83 Most models have a similar theoretical basis; however, differences arise due to the way in which material properties are modelled and the data is used.

5.84 In thermal models, some boundary conditions (for example surface emissivity for heat re-radiation) tend to be adjusted empirically to improve the fit with experimental measurements.

5.85 Thermal analysis of concrete structures may have significant errors if there is an inadequate treatment of moisture within the concrete.

5.86 Structural analyses are very sensitive to the temperature of the structure; therefore, it is essential that the thermal model predictions are accurate to begin with.

5.87 Some of the simplifications adopted by structural models are inadequate when modelling concrete structures.

Flames from windows

5.88 The equations for the height and projection of external flames have been derived empirically and are only approximate due to the large scatter in the data.

5.89 The empirical equations break down if:

- there are substantial heat losses to the façade;
- external winds deflect the flame and reduce its length;
- flames merge from more than one floor;
- the burning rate is greater than expected (for example, the fuel has a large surface area or the fuel is non-cellulosic with a higher volatility).

Radiation from windows

5.90 Calculation methods include a number of caveats to reduce the number of trivial calculations.

5.91 There may be a temptation to exploit these to gain approval for some designs, particularly where there are small windows or doors on a wall close to a boundary.

5.92 There is a high probability of glass (non-fire-resistant) breaking under flame impingement or relatively low-temperature thermal shock; therefore, most radiation is likely be direct from the window space.

Detection/suppression

Smoke detection

5.93 Optical beam detectors can be used in large spaces (for example atria).

5.94 Response will vary with different fuel sources that have different smoke properties. CFD simulation may be required to determine the optimum detector locations.

Heat detection

5.95 Response time is characterised by the response time index (RTI). A lower value means a faster response, but may make the detector more prone to unwanted activations.

Radiation detectors

5.96 The sensor must be matched to hazard and normal environment.

Response time index (RTI)

5.97 The device does not react as soon as the hot gas temperature equals the nominal operating temperature.

5.98 Factors such as heat conduction to the sprinkler pipes, sprinkler orientation, airflow deflection and the latent heat of fusion for solder links may introduce delays in the sprinkler activation time.

Detector location

5.99 When a fire starts, the HRR is usually small and the normal air movement in the building will dominate the initial movement of smoke and hot gases. If a fire is detected during this phase, there is less risk of fire growth.

5.100 In the case of complex geometries, or where there is complex pre-fire air flow, the use of CFD models to examine the response of detectors may be useful.

Sprinklers

5.101 Extensive prescriptive rules exist for the design of sprinkler pipework and associated water supplies.

5.102 The addition of sprinklers can often lead to a relaxation of other (prescriptive) requirements. For example, fire-resistance times and building separation distances may be reduced (see also Health Technical Memorandum 05-02 paragraphs 6.94–6.109; and Approved Document B of the Building Regulations, Section 13.17).

Other suppression systems

5.103 Where a specific fire risk and fuel can be identified, a compatible extinguishing system can be selected.

5.104 Where gaseous flooding suppression systems are specified, a room integrity test will demonstrate that the system will work efficiently as designed without leaking gas to other rooms or the outside.

Fire-and-rescue service intervention

Arrival time

5.105 With regard to the standards of cover recommended by the Home Office, arrival times range from 5 to 20 minutes depending on the risk category for the building. Integrated risk management planning and intolerance to unwanted fire signals (UwFS; see Health Technical Memorandum 05-03 Part H – 'Reducing unwanted fire signals') may have a significant impact on the weight and timing of the initial fire-and-rescue service response.

5.106 Advice should be sought from the local fire-and-rescue service regarding the initial level of attendance for a healthcare building.

5.107 It is important to provide sufficient hard-standing and fire hydrants close to the building, for a reasonable number of appliances.

Set-up time

5.108 Fire-fighting usually starts after evacuation is complete.

5.109 Consultation with the fire-and-rescue service is required to establish the setup time for a particular fire scenario.

Positive pressure ventilation (PPV)

5.110 This is a fire-fighting tactic. Fans are carried on fire appliances.

5.111 Fire-fighters need to be able to identify windows and doors in the building that can be used as exhaust vents. These will vary with fire location and entry point.

5.112 The technique should not be used where it might push smoke so that it affects escape routes or occupants elsewhere in the building.

Fire-fighting shafts, lifts and corridors

5.113 Fire-fighting lifts require independent power supplies and controls that provide the fire-fighters with full control of the lift and doors, overriding the normal call points on each floor.

5.114 Fire-fighting lifts should not be used for general evacuation, as they should be waiting on the ground floor for use by fire-fighters on arrival. However, they may be used for the evacuation of disabled people.

5.115 Annual testing may be required by the fire authority.

Human factors

Required safe egress time (RSET)

5.116 When comparing RSET with ASET, it is important to be clear which parts of the building are being considered.

Pre-movement time

5.117 Pre-movement time depends on many different factors (for example type of warning given, people's activity at that time, their familiarity with the healthcare building and its systems, their behavioural roles and responsibilities etc). It can be a significant portion of the total evacuation time; therefore it should not be neglected.

Speed of movement (effects of person type and crowd density)

5.118 Walking speed is only one component of travel time, and travel time is only one component of the total evacuation time.

5.119 For dependent or very high dependency patients, the speed of walking may be very low (for example elderly patients) and/or they may be fully dependent on the assistance of staff for evacuation. Very high dependency patients may be unable to move (for example those in operating theatres).

Movement through doors

5.120 It should not be assumed that all doorways will receive just the right amount of traffic so that the last people to exit via each door do so simultaneously (optimising the evacuation time).

5.121 In the absence of a more detailed analysis, the widest door should be assumed to be unusable as the consequence of a fire in order to maximise the estimated time it will take for people to evacuate.

Movement on stairs

5.122 Stairs should not be considered as horizontal corridors, with their length adjusted to give the correct time to move from one end to the other, since this will only work for low crowd densities. It will not give the correct number of people who can occupy the stair, nor will it give the correct speed–density relationship.

5.123 Without the assistance of staff, stairs will be unpassable for many dependent and very high dependency patients.

Movement through smoke

5.124 For some healthcare buildings, a design approach that treats any encounter with smoke as a failure of the system may be too cautious.

5.125 On the other hand, it would be too optimistic to expect people to be able to anticipate and avoid the movement of smoke.

5.126 People do not have the same FED uptake rates (see paragraph A122 in Appendix A); young children and older people are more susceptible than fit adults.

Tenability limits

5.127 There are no standard values for tenability limits for particular combustion products.

5.128 If the smoke layer is stratified above a clear layer, the layer interface height should also be one of the tenability criteria. Some safety margin should be allowed; that is, the limit should not be set at head-height or below.

5.129 Layer height is not sufficient to cause loss of tenability; one of the other limits relating to smoke properties must also be exceeded.

Exit choice

5.130 Staff should have a good knowledge of the layout of their department. However, other people will not necessarily choose their nearest exit.

5.131 People will not choose exits on the basis of their width; that is, the number of people using each exit will not be optimised to minimise the total evacuation time.

5.132 As it is hard to quantify the probability of choosing any given exit, sensitivity studies should be performed.

Panic: a myth

5.133 The concept of panic can sometimes be used to argue that people will evacuate more quickly than predicted or will not evacuate at all. Most evidence does not support either of these arguments; therefore, panic should not be “invoked” as a reason to enable people to move more quickly or for people to behave irrationally.

Effect of dependent and very high dependency patients and those with disabilities

5.134 Special fire-safety precautions may be required to handle the needs of dependent and very high dependency patients, and disabled people.

Egress modelling

5.135 Human behaviour is the most complex and difficult aspect to simulate; yet it is crucial for achieving accurate results.

5.136 Not all aspects of behaviour are fully understood or quantified yet; therefore, sensitivity analysis is important.

5.137 Validation of the behavioural aspects of existing models is currently rather poor.

Risk assessment

Sensitivity analysis

5.138 Sensitivity analysis is essential to test the robustness of the conclusions of fire engineering analysis, unless it is shown that all the values and methods used in the analysis err sufficiently on the side of safety.

Elementary methods

5.139 Elementary methods can enable routine risk management on a day-to-day basis (for example to check that good practice is being maintained).

5.140 Presence of a risk assessment, however crude, can be taken as evidence of a safety culture, and may be sufficient for legal purposes.

Points schemes

5.141 Methods do not seem to have been calibrated beyond “they appear to work”. Scoring methods may not be readily translatable to other risk assessment approaches.

5.142 Subjectivity enters into the process when the user of the scheme must assign numerical values to various parameters. Some schemes help the user by restricting his input to “yes/no” answers to the list of questions. However, other parameters (for example “quality of staff”) may be much more difficult to quantify.

Statistical methods

5.143 Fire statistics may form a biased sample (from the population of all fires occurring) owing to the way the statistics are collected (that is, fire-and-rescue service reports on fires attended). For instance, in the UK it is estimated that the fire-and-rescue service only attends about 15% of fires.

Safety factors

5.144 Are safety margins adequate? The safety margin is intended to make the resultant fire strategy robust against credible unknown variations. The appropriate level of a safety margin depends on many factors including:

- the nature of the fire-safety solution (from a minor variation from Firecode to a highly unorthodox strategy);
- the method of analysis;
- the input data for the analysis; and
- acceptance criteria.

5.145 Many methods of analysis, input data and acceptance criteria include an implicit safety margin (see paragraphs 5.152–5.154 on worst-case scenarios). The extent of this implicit safety margin varies from method to method and from data to data. Therefore it is not possible to prescribe a safety margin – the appropriateness of any explicit safety margin proposed in fire-safety engineering analysis should be judged on a case-by-case basis.

Logic trees

5.146 Despite the claim that event trees are comprehensive and examine all possible outcomes, in practice this may only be achieved if the number of events (and hence branches of the tree) is strictly limited.

5.147 Due to uncertainties in all the input parameters, the accuracy of absolute risk estimates is only about an order of magnitude.

Monte Carlo simulation

5.148 Monte Carlo simulation models input data in the form of probability distributions, such as those for fire load. The simulation approach makes the underlying assumptions (for example the value of fire load) more explicit, ensuring consistent results from different users because they both use the same probability distribution rather than selecting different values from it.

5.149 This approach includes complex interactions between the components of the model, which can make it impossible to predict the behaviour of the system. This means that it is also virtually impossible to validate the model for the whole system – only the sub-models for the components (for example fire growth, smoke movement, evacuation etc).

5.150 Due to uncertainties in all the input parameters, the accuracy of absolute risk estimates is only about an order of magnitude.

5.151 Assessment using the quantification of relative risk is better.

Worst-case scenario

5.152 Assumptions that might be conservative for one aspect of the fire system might not be conservative at all for other aspects.

5.153 A large, rapidly-growing fire is not necessarily the most hazardous: an undetected smouldering fire in a closed room could kill a sleeping occupant.

5.154 The worst case may not be defined by a big fire with all fire-safety systems working as designed. If a component of the system (for example detection, suppression, smoke control) fails, the consequences might be severe enough to outweigh the smaller probability of this scenario occurring.

Appendix A – Fire engineering concepts

A1 The following paragraphs outline the more common terms used in fire engineering to assist with understanding the concept.

Fire growth

A2 The development of a fire is the primary determinant of the outcome of a fire scenario. ("Fire scenario" in this context means the interactions of all subsystems.)

A3 In order to grow, a fire needs a supply of the following three elements:

- fuel;
- oxygen; and
- heat.

This known as the "fire triangle".

A4 Most healthcare buildings have a plentiful supply of combustible contents; and oxygen is present in the air and as a medical gas.

A5 Sources of heat sufficient to cause ignition are usually kept well away from any combustible materials, and thus unwanted fires are fairly rare.

A6 If a fire does start, the heat released by the combustion of the fuel is generally more than enough to sustain the fire and enable it to grow larger. As the fire gets larger, it produces more heat, and so it gets larger still.

A7 The size of a fire is commonly expressed in terms of the heat release rate (HRR; also referred to as rate of heat release (RHR)), which is measured in kilowatts (kW) or megawatts (MW).

A8 The fire growth rate is the rate at which the HRR increases. This rate of increase is not usually a constant, but depends on the size of the fire. A convenient approximation for the growth phase is often given by the so-called *t*-squared fire, where the HRR is proportional to the square of the time after ignition. Other forms of "design fire" may use a steady-state fire size or an HRR taken from experimental measurements.

A9 Small-scale measurements from a cone calorimeter may be extrapolated to predict the HRR of full-scale fires, although this has pitfalls.

A10 Most of a fire's heat is taken away by convection in the fire plume; the remainder (typically 30% of the total) is heat radiation from the flames.

A11 The smoke produced by a fire is also carried away by the fire plume and diluted by the air that is entrained as the plume rises. However, a buoyant smoke layer does develop below the ceiling.

A12 A fire will not keep growing indefinitely – eventually it will run out of fuel or oxygen. The first way it can run out of fuel is after the item first ignited has been consumed. Whether the fire is able to spread beyond the first item depends on:

- the proximity of neighbouring items; and
- the size the fire has reached on the first item.

A13 An important mechanism for heat transfer is radiation from the hot smoke layer beneath the ceiling. This radiation may be sufficiently intense to cause near-simultaneous ignition of all fuel surfaces within the compartment – a process termed "flashover". The heat release rate then increases very rapidly.

A14 A fully involved compartment fire may arise as a consequence of either flashover, or the slower spread of fire from item to item. In these cases, the fire size will ultimately be restricted by the availability of oxygen.

A15 The initial amount of air within a compartment will only be sufficient for the combustion of a small quantity of fuel. However, openings in the compartment walls (such as doors and windows) will allow smoke to flow out and fresh air to flow in at a rate that is determined primarily by the size of the openings. If the oxygen supply is sufficiently restricted, the fire is "vitiated". Combustion will be less efficient, producing lower yields of end-products (mainly carbon dioxide and water) and more smoke and intermediate products (such as carbon monoxide).

A16 In extreme cases, the temperature in the fire compartment may be sufficient for significant fuel vaporisation to take place, but not enough oxygen for the combustion. If the oxygen supply is suddenly increased (for example a door opens or a window breaks), the fuel vapours may burn very rapidly when the inflow of air mixes with them, a phenomenon termed "backdraught".

A17 The fire may be controlled or extinguished by various suppression measures, which either remove the heat or cut off the oxygen supply, or both. Alternatively, it will go out when it finally runs out of fuel.

Design fire

A18 The specification of a design fire will relate to the particular scenario being considered and will depend on:

- the type of combustible materials and their distribution;
- potential ignition sources; and
- ventilation conditions.

A19 A design fire will be characterised in terms of:

- HRR;
- fire area;
- production rates of products and smoke.

A20 While HRR data exist for many materials, in practice a fire scenario will include a mixture of materials. It may be difficult to assign heat release data with confidence, particularly where textiles and furnishings are fire-retarded to Health Technical Memorandum 05-03 Part C – 'Textiles and furnishings'. Statistical analysis of fires and the use of experimental fires under calorimeters may be required to support the selection of a particular design fire.

A21 Design fires may have a constant HRR (steady-state) or a time-varying HRR (transient).

A22 Most fire-safety engineering calculations follow from the specification of the design fire and are strongly dependent on it. The determination of design fires is a critical part of the role of the QDR team in a fire-safety engineering design.

Smoke spread and control

A23 With regard to fires in healthcare buildings, smoke will usually move from the location immediately surrounding the fire to other parts of the building, creating a threat to the occupants.

A24 The time taken between the ignition of the fire and the onset of life-threatening conditions is the maximum time that occupants have to move to a place of safety (that is, the ASET).

A25 There is a range of methods, of varying complexity, available to calculate smoke movement. These include:

- buoyancy of smoke/fire gases;
- turbulent mixing and entrainment (dilution);
- stack effect;
- ventilation systems in the building and consequent air movement;
- effect of wind;
- thermal radiation.

A26 They provide information about:

- mass flow rate of smoke;
- temperature of smoke;
- velocity of smoke and hot gases;
- volume of smoke;
- optical density of smoke;
- concentration of toxic gases.

A27 From these, the onset of hazardous conditions at different locations in the building can be identified.

A28 Features can be introduced into a healthcare building to remove and to control the spread of smoke. These may be in the form of barriers and screens to contain the smoke in reservoirs, exhaust systems to remove the smoke, and pressurisation systems to prevent smoke entering sections of the building. These methods are collectively known as smoke-control systems.

A29 A smoke-control system will have a major impact on ASET for the overall design of the building, and must be considered at an early stage of design. Novel building concepts may require novel smoke-control systems, and it is essential that these can be shown to provide an adequate ASET. This may often be demonstrated using calculation methods (computer simulations) or hot-smoke tests.

Available safe egress time (ASET) and required safe egress time (RSET)

Available safe egress time (ASET)

A30 The available safe egress time (ASET) is the time between the start of the fire and the onset of conditions that create a hazard to the occupants.

A31 The concept of ASET was originally intended for an effectively closed compartment containing a fire. The concept has been broadened to include rooms not containing a fire; in these cases, calculations must account for the rate of smoke flow between rooms as well as the filling time for each room.

A32 ASET is used in comparison with the required safe egress time (RSET), which is the time for occupants to escape. The inequality should be ASET > RSET.

A33 ASET depends on the fire scenario chosen.

A34 There has been considerable discussion about whether ASET should be measured from ignition or from the time when the fire is first detected. However, if ASET is measured from ignition (as defined in BS 7974), the RSET must also be measured from ignition; that is, it must include a component for the time required to detect the fire.

A35 Various fire simulation models calculate ASET using either zone or CFD approaches (for example CFAST, JASMINE etc).

Required safe egress time (RSET)

A36 RSET is the time required, after a fire has started, for the last person to reach a place of safety. It includes the time for:

- the fire to be detected;
- the alarm to be raised;
- people to recognise the alarm for what it is;
- people to respond to the alarm; and
- people to evacuate.

A37 RSET depends on the fire scenario chosen. When comparing RSET with ASET, it is important to be clear which parts of the building are being considered. For progressive horizontal evacuation (PHE), for example, there may be one value of RSET for evacuation from one subcompartment to an adjacent subcompartment, and another value of RSET for evacuation from one compartment to an adjacent compartment.

A38 Numerous evacuation models predict the movement of people (for example CRISP, Simulex, EXODUS, EVACNET, EXIT89, EvacSim etc).

Spill plumes

A39 The rising plume of hot gases over a fire is not the only place where smoke can be diluted. Long "line" plumes can develop where smoke spills from under a balcony (like an inverted waterfall) or past the top edge of an open window.

A40 Spill plumes are likely to occur in atria, shopping malls and other geometrically complex buildings. Air may be entrained on one or two sides depending on whether the rising plume is attaching to a vertical surface.

A41 A spill plume significantly affects dilution of smoke and thereby sizing of extract systems. The plume width may be controlled by the use of channelling screens.

Smoke reservoirs

A42 A smoke reservoir is a volume at high level in a building (often an atrium in healthcare premises) designed to trap and hold smoke. It is intended to prevent the spread of smoke to other parts of the building beyond the reservoir.

A43 The smoke may be extracted from the reservoir at a rate matching the supply rate in order to provide an indefinitely long ASET, or the time taken to fill the reservoir may provide an adequate ASET.

A44 The reservoir may be formed by the building structure at ceiling level; this can be enhanced by fixed or automatic smoke curtains. Fixed smoke curtains may be glazed, depending on compatibility with expected smoke temperatures.

Smoke curtains

A45 When designing a SHEVS (see paragraphs A56–A57), consideration should be given to including features such as channelling screens or to blocking openings that would not be feasible for the normal day-to-day use of the building. One solution is to provide curtains that are activated by the smoke-control system. These curtains must be designed to operate reliably and safely (occupants should not be in danger of being struck by an operating curtain). They should also be able to withstand the anticipated smoke temperatures.

A46 Free-hanging curtains can be deflected (and not provide an effective seal) due to the buoyant pressures of the hot gases contained to one side of the barrier or by air movement caused by the extraction system.

Smoke venting

A47 Smoke can be removed from a healthcare building by either natural or mechanical ventilation. Natural ventilation uses openings in the roof or side of the building for smoke to leave using its own buoyancy.

A48 Several mechanisms are available to open vents. These include servos activated by the smoke detection system, or fusible links.

A49 Mechanical systems use fans and (usually) a network of ducts to extract the smoke. Some fans may be directly mounted on the roof.

A50 The smoke is usually extracted from a smoke reservoir (see paragraphs A42–A44). However, extraction using slit vents across openings is also used.

A51 Effects of wind on natural ventilation systems should be considered. Smoke escaping from ventilation outlets should not be able to re-enter the building or affect other buildings.

A52 Provision of replacement (make-up) air should be considered.

A53 Fans and ductwork may need to operate at high temperatures.

A54 Excessive localised extraction can draw air from low level through the smoke layer, creating a “plug-hole” effect and reducing the efficiency of the extraction system. This is a particular problem if the smoke layer is shallow.

A55 A ventilation system cannot be designed in isolation without considering other elements of a healthcare building’s fire-protection systems. Design fire selection is critical.

Smoke and heat exhaust ventilation systems (SHEVS)

A56 Smoke and heat exhaust ventilation systems (SHEVS) are designed to provide control of smoke from a given design fire. They are usually employed in large building spaces (for example shopping malls and exhibition halls) where there is no internal compartmentation and where travel distances are long. However, the principles can be applied to other building spaces where smoke control is required.

A57 The principles of SHEVS are simple: hot buoyant gases from a fire rise to form a stable layer in a reservoir below the ceiling such that a clear layer of sufficient height may be present for long enough to achieve the safe evacuation of occupants and/or rapid fire-fighter access to the fire with good visibility. Smoke extraction from the layer may be by natural buoyancy or fans.

Replacement air

A58 When a smoke extraction system (either natural or powered) in a healthcare building is running, the mass of smoke extracted must be replaced by an equivalent mass of replacement or make-up air (otherwise the smoke-control system would attempt to create a vacuum in the building). Restricting the flow of replacement air will make a smoke-control system less efficient.

A59 Replacement air will usually enter the building at low level where high air velocities may cause a number of problems. If the replacement air is drawn through an escape route, high velocities may impede the egress of occupants.

A60 In naturally ventilated systems, where there is not a large enough inlet area at low level, it may be possible to use open vents in an adjacent reservoir to provide sufficient replacement air.

A61 Air inlets should not be located so that they feed directly into the extraction system, causing a short-circuit. They should be remote from the exhaust of the smoke extraction system so that smoke is not recycled through the building.

A62 Doors that open automatically, as part of the SHEVS, should be sequenced so that they are fully open by the time the extract fans are running at full capacity.

Structural fire protection

A63 Structural fire protection is applied to a structure to achieve a certain degree of fire resistance. This is an important facet of any fire-safety design, particularly in hospitals, and is needed to prevent the spread of fire and to prevent structural collapse. This is of increasing significance as a fire continues to grow to full room involvement and beyond.

A64 Fire resistance is important in the protection of property, whether this is the healthcare building itself or its contents.

A65 Fire resistance also has an impact on life safety, particularly in large or tall buildings or where the occupants either cannot move, or only slowly, or may be asleep. In these cases it must provide sufficient time for evacuation or for people to remain in place while the fire is attacked by suppression systems or the fire-and-rescue service.

A66 It is also necessary to protect the members of the fire-and-rescue service, who may remain in the healthcare building well after all the other occupants have left. Additionally, fire resistance is important in the protection of property, whether this is the building itself or its contents.

A67 Prevention of fire spread within a healthcare building is accomplished by subdividing the building interior into compartments. The compartment boundaries (walls, floors or ceilings) need to inhibit the spread of fire (and smoke, although the tests in BS 476 do not examine this directly) to adjoining compartments, at least for a time, and thus slow down the spread of fire.

A68 Fire spread to nearby buildings could arise as a result of flame contact or radiation heat transfer, either through windows or other openings, or through openings that arise from structural collapse. The boundary walls therefore need to remain intact for a suitable period (for example, for a large hospital building using PHE, the fire resistance of the structure should exceed the fire severity), and any windows need to be limited in size or be fire-resisting (including insulation) to reduce radiant heat to adjacent buildings. Prevention of collapse requires load-bearing elements of the structure to retain stability for the duration of the fire.

A69 Fire resistance is most commonly expressed in terms of time. In furnace tests, the fire-resistance time is the duration for which the structural element retains its stability/insulation/integrity, in the test according to the pass/fail criteria. However, in furnace tests it is important to note that:

- the heating regime may be very different to that experienced in a real fire; and
- furnaces can only test elements of a structure, not its entirety.

A70 Various calculation methods may therefore be employed to predict fire resistance depending on the failure mode of the type of element of structure. It is important to realise that the time rating from a fire-resistance test is a comparative measure, but is not the survival time in a real fire.

A71 All calculation methods start with a definition or calculation of the heating regime. This enables calculation of the heat transfer from the compartment atmosphere to the structure. The temperature (distribution) within the structure can therefore be evaluated, and this is then used as input to structural stability calculations, or directly to estimate the insulation-resistance criteria. Note that calculations to predict loss of integrity (for example the opening of small fissures, through which hot fire gases can pass and ignite material on the other side of the barrier) are currently not possible.

A72 The fire severity is defined in various ways, as a measure of the destructive potential of the fire. However, the commonest and most convenient way is to express it in terms of time – that is, an equivalent exposure to the heating regime of a furnace test, which causes a similar level of damage. It is then possible to compare fire resistance and severity in terms of a common unit (time), with the design objective being that the resistance exceeds the severity by an appropriate safety margin.

A73 It is recognised that both the severity and the resistance are random variables, and therefore that there will always be some probability of failure (that is, untimely collapse). The design objective is therefore to keep this acceptably small.

A74 Fire severity depends on the temperature reached by the fire within the compartment and also the duration of the fire. Both of these quantities in turn depend on the amount of fuel available (the “fire load”), its physical disposition (for example, whether in thin wall linings or solid blocks of material) and on the amount of ventilation available. (Note: The area of openings providing ventilation may vary during a fire.)

Fire resistance: stability, integrity and insulation

A75 The term “fire resistance” can either be synonymous with passive fire protection (that is, construction materials and coatings which enable the building to withstand the fire) or relate to a period of time for which an element of construction (beam, column, floor, wall etc) will survive in a standard fire test. There are three performance criteria:

- **stability** (avoidance of structural collapse or unacceptable deformation);
- **integrity** (avoidance of cracks and fissures);
- **insulation** (restriction on temperature of unexposed face).

A76 The corresponding terms in the Eurocodes are load-bearing function (R), integrity (E) and insulation (I).

A77 Fire-resistance time is to the first failure criterion, although other failure modes may occur soon afterwards. The "standard fire curve" is not a good model for a real fire; the latter may have a faster growth rate and higher peak temperature, but a finite duration.

A78 Localised heating may occur in real fires, but not in standard fire tests where furnace temperatures are considered to be uniform. The performance of the structure as a whole may be quite different from that of individual components, due to redistribution of loads.

Fire severity

A79 Fire severity is a measure of the destructive impact of a fire, or a measure of the forces or temperature that could cause collapse or other failure as a result of a fire.

A80 Severity may depend on the total amount of heat transferred to the structure or the peak temperature attained. Severity may be expressed in terms of:

- time (equivalent exposure to a standard fire curve in a furnace);
- temperature (maximum reached by key part of structure); or
- minimum load-bearing capacity.

A81 Real fires have very different time-temperature curves to the standard curve; therefore, expressing severity in terms of equivalent exposure may be difficult. It may be necessary to perform calculations from first principles.

Detection/suppression

A82 Fire detection and alarm systems are key features of a healthcare building's fire protection strategy.

A83 For life safety, detection and warning must be early enough to enable complete evacuation of the danger area before conditions become untenable. Detectors may also be used to activate other fire protection measures (for example smoke curtains, vents or suppression systems).

A84 For property protection, early detection/alarm allows fire-fighting to start as soon as possible and the fire to be extinguished while it is still small.

A85 Life safety may be enhanced by providing additional information to the staff and/or occupants (for example, telling them where the fire is) so that they can choose appropriate actions and/or pick an exit that avoids the hazard. Informative warnings also lead to more rapid reactions by the occupants. PHE also relies on knowing in which building area the fire is.

A86 When designing a detection system, the type and location of the detectors depends on many factors, including the expected fire type, building use and characteristics of the building that will affect how the smoke will move around. The sensitivity of detectors is a compromise between achieving a rapid response and avoiding too many false alarms.

A87 Types of detectors include:

- UV (ultraviolet light: approximately between 170 and 290 nm);
- IR (infrared light: approximately between 650 and 850 nm: thermal radiation);
- flame flicker (optical light intensity variations);
- ionisation (detects numbers of particles; in smoke; most are smaller than 0.1 µm);
- optical (visible smoke particles, larger than 0.1 µm. Single-point detectors detect the light back-scattered from the smoke; beam detectors measure light attenuation);
- heat detectors (high temperature: approximately between 70 and 100ºC);
- rate-of-rise heat detectors (rapid increases in temperature);
- line (or aspirated) detectors for smoke particles or specific gases, which draw in smoke at a number of sampling points that feed into a common analyser.

A88 Some systems may also rely on manual alarms.

A89 The number of detectors required, and their locations, will be a compromise between the need to detect the fire as quickly as possible, and practicality and cost.

A90 Most suppression systems use water, which is widely available, cheap and has a number of desirable properties such as a high specific heat capacity and high latent heat of vaporisation.

A91 Sprinklers are the commonest water-based systems. Due to the complexity of the extinguishing mechanisms of water (gas cooling and cooling/wetting of the fuel surface are the main ones), only the most rudimentary calculation methods are available to estimate sprinkler effectiveness. However, much practical experience has been gained over the last century, and there are many types of sprinkler system that have been developed for different types of hazard.

A92 Water-mist systems are similar to sprinklers, but the droplets produced are much smaller. These extinguish fires by gas cooling, oxygen depletion, dilution of flammable vapours and wetting/cooling of the fuel surface. They can be used in some applications where sprinklers are less effective (for example hydrocarbon pool fires) but generally need to be used in a closed compartment.

A93 Water is not an ideal extinguishing medium in all circumstances. For hydrocarbon pool fires (for example in a basement car park or ambulance garage), fire-fighting foams are preferred. These spread over the fuel surface and effectively suffocate the fire. Halon systems usually flood a compartment with a gas that has flame-extinguishing properties (due to chemical reactions). They are effective, but further production is banned under the Montreal Protocol for stratospheric ozone protection.

A94 Other gaseous flooding systems include carbon dioxide and inert gases; these work by diluting the concentration of oxygen.

A95 Halon replacements are being developed, which operate in a similar fashion to halons, but without the ozone-damaging side-effects. Some halon replacements may have other side-effects such as the generation of hydrogen fluoride – a highly corrosive acid gas.

Smoke detection

A96 Smoke detectors usually work by sensing the presence of airborne particulates, but they may also work by chemical means (for example carbon monoxide detectors). The presence of other particulates (for example dust, water droplets from condensed steam) can lead to false alarms.

A97 Ionisation detectors respond with a change in electrical current through an ionisation chamber in the presence of smoke particles. This is proportional to the number and size of the particles. They are best used to detect flaming fires.

A98 Optical detectors may measure the attenuation of a light beam that is interrupted by smoke or light which has been scattered by smoke particles in a chamber. They are best used to detect smouldering-type fires.

A99 The sensor unit may be located at the detection point in an integrated unit (which may include a sounder) or remotely in an aspirated system where air is drawn through pipes from the sensing point(s) to a detector unit.

A100 Optical and ionisation detectors respond differently to smoke from different fuel sources. It may not be possible to predict the response of a detector to the properties of smoke measured in tests, such as the cone calorimeter, because the detector may respond to properties measured under different conditions (for example wavelength of light source).

Sprinklers

A101 Automatic sprinklers and the rules for their installation have been available since the 1880s and are now widely used in commercial applications and, increasingly, in residential premises. A sprinkler system is a system of pipework to distribute water to spray heads in the event of a fire. In an automatic system, the spray heads include a temperature sensor, usually a glass bulb or fusible metal link, which will allow the flow of water if a critical temperature is exceeded.

A102 The most common systems are “wet” (the pipework contains water under pressure up to the sprinkler head); however, “dry” systems are used where the water in the pipework could freeze.

A103 Deluge systems do not have automatic heads but activate a supply of water to open heads in response to a detector system. There are also pre-action systems where the pipework is dry until activation of a detector system, but the release of water is controlled by automatic heads.

A104 In addition to providing a system to control or extinguish, automatic sprinklers also detect the fire.

A105 Cooling of the hot smoke by a water spray may lead to a loss of buoyancy and mixing of the smoky layer with clear air beneath, thus causing poor visibility in escape routes.

Fire-and-rescue service intervention

A106 The design of a healthcare building should not assume that fire-and-rescue service intervention will contribute to the evacuation of occupants. Rescue by the fire-and-rescue service should be seen as an additional safety factor and not as an accepted part of the building evacuation. However, the first concern of the service is to ensure that all occupants have reached a place of safety before the main attack on the fire is made.

A107 The time taken for the fire-and-rescue service to begin activity to control and extinguish the fire depends on:

- the time of notification (related to detection time);
- the time taken to arrive at the scene of the fire; and
- the time to assemble the required resources.

A108 As the fire-fighting activity proceeds, further resources may be required.

A109 Adding the times for fire-and-rescue-service activity to the overall time-line for a fire scenario can give the size (heat release rate) of the fire when fire-fighting activity begins. This will give an indication of the fire-fighting resources required and a means of examining the effect of different fire-protection measures (for example different detection systems) on the conditions that the fire-fighters will encounter.

A110 Times for fire-and-rescue-service actions are difficult to quantify, and calculation methods are not available. Qualitative judgement in consultation with the fire-and-rescue service is required.

A111 The time taken for the fire-and-rescue service to begin effective fire-fighting operations depends on the ease of access to the seat of the fire.

A112 There must be space outside the building for the deployment of fire appliances and other equipment. In some cases (for example tall buildings or deep basements), it may be necessary to provide protected routes within the building (fire-fighting shafts, lifts and corridors). These will enable fire-fighters to move through relatively smoke-free air until they get close to the fire.

A113 Fire-fighting tactics such as positive-pressure ventilation can be used to give fire-fighters a relatively smoke-free route to the fire. However, a possible drawback is that other regions of the building may become smoke-logged.

Human factors

A114 In any fire-safety engineering design, protection of the healthcare building's occupants (patients, staff, visitors etc) is of paramount importance. The design will be heavily influenced by the initial distributions of people, which in turn will depend on the intended use of the building. The total number of people depends on the building's size, but their distribution within the building depends on the intended use of the different rooms.

A115 The time of day or night may also have a dramatic impact on the population in entrance areas and out-patient departments.

A116 It is also important to consider not just numbers of people, but also other characteristics that will have an influence on how they behave, and hence the outcome of any fire scenario. People's behaviours may depend on many factors, for example a defined role within the building population, the influence of training, familiarity with the building, age, gender, and other factors such as disabilities, which may restrict the possible activities that may be attempted.

A117 People's behaviour is firstly of significance in responding to the initial fire cues. The information content of the cues is of greatest importance in determining people's reaction to them. An uninformative cue is likely to be ignored, until reinforced by a stronger cue. The person's current activity at the time of the first cue will also influence how likely they are to change this activity and respond to the cue.

A118 The response of staff is particularly important, as a person with a defined role or training should behave more positively. If the initial cue is ambiguous, the most common positive response is to seek more information. People in groups will decide what to do depending on their perceptions of others' reactions; without a manager or staff member providing an early lead, people may take much longer to respond than if they were alone.

A119 Once the existence of a fire has been recognised, people may undertake a wide range of possible behaviours. These depend on role, training and also people's perception of the developing fire situation (which may of course differ considerably from the truth). People may, for example, continue working, go to collect belongings, attempt to fight the fire, seek to warn others (role/training may dictate a search of the building; on the other hand, people may simply warn others they encounter), rejoin family groups, rescue/assist others, seek refuge or escape. As the perceived situation worsens, the range of viable options reduces.

A120 The speed of movement of independent people, in crowded situations as well as unimpeded, is well understood for most common situations. Empirical relationships have been derived for walking speed as a function of crowd density (people per square metre), flow rates in corridors or up/down stairs, and the rate at which queues of people pass through doorways or other similar constrictions as a function of their width.

A121 The exit choices made by different people mean that all doors are not used by the optimum number of people to minimise the evacuation time. Some research has also been carried out to define the capabilities of dependent and very high dependency patients and disabled people, who will often move slower and in some cases may find particular obstacles impassable. These relations enable the movement-time portion of the total evacuation time to be estimated with a fair degree of accuracy. However, this portion is often not the dominant component of the overall time it takes for evacuation.

A122 As people move or remain within the healthcare building, they may be exposed to smoke and the toxic products of combustion. Exposure is usually quantified in terms of a fractional effective dose (FED), which depends on the concentration of particular toxins within the cocktail of fire gases and the duration of exposure. When the FED for a particular person reaches unity, they are overcome by the smoke. In the case of some combustion products (for example irritants), the effect is almost instantaneous rather than cumulative; therefore, concentration is the key parameter.

A123 Tenability levels for different rooms may be expressed in a number of ways – either the time for a person's FED to reach unity (if they remain in the room for the duration) or the value of the concentration of a given product that is sufficient to effectively prevent escape. (See also paragraphs A36–A38 on RSET.)

Pre-movement time

A124 Evacuation time is conventionally split into two components:

- travel time; and
- pre-movement time.

Note

RSET also includes a time for the fire to be detected and an alarm raised.

A125 The pre-movement time incorporates:

- the time to recognise that:
  - – an alarm has been given; and
  - – some action needs to be taken, and
- a response time for all other activities performed prior to evacuation.

A126 The response component may encompass many different activities (for example investigation, recognition of the threat, gathering family members, collecting valuables, searching the building, ordering others to leave etc).

A127 A modelling short-cut involves representing all pre-movement activities by a single time delay before a person moves; different people will move at different times. However, the probability distribution for this delay is hard to quantify without considering the activity explicitly.

A128 Evacuation models predict the pre-movement phase (most use a distribution of delay times; examples include CRISP, EXODUS (in development), EvacSim etc).

Speed of movement (effects of person type and crowd density)

A129 Not everybody moves at the same speed. Young adults walk faster than older people or children, and men walk faster than women. In uncrowded conditions, people can walk unimpeded; however, as the crowd density increases, movement slows down and at some point effectively stops.

Effect of patient dependency and people with disabilities

A130 There are many types of patient dependency (or disability of other occupants) and different degrees of severity. There are also many adverse impacts that dependency/disabilities may impose on a person's ability to be aware of, react to and escape from a developing fire situation.

A131 Sensory disabilities may negate any benefits of early detection and alarm, or prevent recognition of deteriorating conditions. Mental disabilities may prevent appropriate responses to cues and conditions. Physical dependency/disabilities may affect speed of movement and prohibit certain routes being used unaided (for example wheelchairs on stairs, insufficient strength/dexterity to open a self-closing door, need for frequent stops to rest). Disabled people may not be accompanied by able-bodied people, who can give assistance.

A132 Many dependent patients are unable to move without the assistance of staff; therefore, the number of staff and fatigue may become important factors. Additional measures may be required to cope with the needs of very high dependency patients and disabled people.

Risk assessment

A133 The principal objective of fire engineering is, when an accidental fire occurs, to provide an environment that has an acceptable level of safety. Often this will involve calculation or modelling of scenarios affecting all or part of the fire system. Implicitly or explicitly, a form of risk assessment is involved. It is important to match the right method to the decision to be made.

A134 Implicit risk-assessment examples include the comparison of calculation results with threshold criteria, for example "smoke layer well above people's heads" or "area of fire spread restricted to less than x m^2". Often these are linked with worst-case scenarios (see paragraphs 5.152–5.154). The idea is that worst and lesser scenarios have minimal consequence, other more severe scenarios being assumed to have minimal probability.

A135 Explicit risk assessment uses the formula:

risk = probability × consequence.

A136 Every fire-safety decision should require a full risk analysis, until or unless it can be shown that a less comprehensive approach is adequate. The preferred approach to uncertainty is to quantify it rather than rely on conservative assumptions.

A137 No healthcare building can be completely safe; yet there is an unresolved question of what absolute level of risk should be deemed acceptable. A further problem is that acceptable risk varies with circumstances and public perception. There are two ways in which these problems may be addressed:

- assume that the risks associated with buildings constructed following prescriptive guidelines (for example Firecode) are "reasonable";
- use quantitative methods in comparative mode; that is, assume that systematic errors and biases cancel out when two similar buildings are compared.

(Absolute risks are not calculated, since the state-of-the-art is insufficient to do this without a large degree of uncertainty.)

A138 The Regulatory Reform (Fire Safety) Order 2005 requires all responsible persons in healthcare premises to undertake an assessment of fire risk in their building. This form of fire risk assessment is usually qualitative in nature; that is, it considers the presence of different factors that may lead to an increase or a reduction in fire risk (without actually quantifying the risk). See also Health Technical Memorandum 05-03 Part K – 'Fire risk assessments in complex healthcare premises'.

Note

The QDR process in BS 7974 is also a form of qualitative fire risk assessment.

Sensitivity analysis

A139 The outcome of a fire engineering calculation will frequently depend on many variables, all of which have some degree of uncertainty in their values. A sensitivity analysis involves comparing the outcomes of many calculations, where each pair of calculations differs only in the value of one of the variables.

A140 The range of values that should be tried for a given variable should depend on the level of uncertainty. If the outcome is not sensitive to the value of a given variable, it does not matter if that variable's value has large uncertainty. On the other hand, if the outcome is sensitive, measures must be taken to reduce the uncertainty (even if it is already small).

A141 The outcome may be a highly non-linear function of the variable values; therefore, just looking at two or three possible values for a variable may miss regions where the sensitivity is high.

A142 Sensitivity analysis is essential to test the robustness of a decision based on fire-engineering analysis.

Worst-case scenario

A143 In a deterministic study (as opposed to a full probabilistic risk assessment), initial assumptions about fire size and growth rate, numbers of building occupants etc, are usually sufficiently conservative so as to define a reasonable worst-case scenario. The consequences of this scenario can be calculated and compared with the assessment threshold criteria. A system designed to handle a worst-case scenario is assumed to perform acceptably in less severe scenarios; more severe scenarios are assumed to have minimal probability.

A144 The consequences of the scenarios are not known before they are calculated. Therefore, it may be necessary to define several worst-case candidates and evaluate each one in turn. Using extreme initial assumptions will be over-conservative (that is, very low probability of this scenario ever happening). On the other hand, using typical or average values will not be conservative enough.

A145 The scenarios must be self-consistent; for example, a limiting fire size in a sprinklered building would no longer be appropriate if the sprinklers were to fail. A sensitivity analysis will estimate the consequences of uncertainties in the scenario, variable values etc.

Appendix B – Fire strategy

Provision of information

B1 The information in this Appendix should be provided to assist the responsible persons to operate, maintain and use the building in reasonable safety and to assist the eventual owner, occupier and/or employer to meet their statutory duties under the Regulatory Reform (Fire Safety) Order 2005.

B2 This Appendix is only intended as a guide. For clarity, the guidance is given in terms of simple and complex buildings; however, the level of detail required will vary from building to building and should be considered on a case-by-case basis.

B3 A key concept of a fire strategy is the integrated fire-safety design of the building as a whole. This includes the combination of separate measures (for example automatic fire detection and compartmentation), which seek to complement each other's function.

B4 Where a fire strategy depends on a non-standard fire-protection system or product, there should be evidence of suitability of performance (for example correspondence with the manufacturer).

Simple buildings

B5 For most buildings, basic information on the location of fire protection measures may be all that is necessary. An as-built plan of the building should be provided showing:

a. escape routes;

b. compartmentation and separation (that is, location of fire-separating elements including cavity barriers in walk-in spaces);

c. fire doors, self-closing fire doors and other doors equipped with relevant hardware (for example panic locks);

d. locations of fire and/or smoke detector heads, alarm call-points, detection/alarm control boxes, alarm sounders, fire-safety signage, emergency lighting, fire extinguishers, dry or wet risers and other fire-fighting equipment, and location of hydrants outside the building;

e. any sprinkler system(s) including isolating valves and control equipment;

f. any smoke-control system(s) (or ventilation system with a smoke-control function) including mode of operation and control systems;

g. any high-risk areas (for example heating machinery);

h. specifications of any fire-safety equipment provided, in particular any routine maintenance schedules; and

j. any assumptions in the design of the fire-safety arrangements regarding the management of the building.

Complex buildings

B6 For more complex buildings, a more detailed record of the fire-safety strategy and procedures for operating and maintaining any fire protection measures of the building will be necessary. See also Health Technical Memorandum 05-01 – 'Managing healthcare fire safety' and BS 5588-12 (Annex A – 'Fire safety manual').

B7 These records should include:

a. the fire-safety strategy including all assumptions in the design of the fire-safety systems (such as fire load);

b. any risk assessments or risk analysis;

c. all assumptions in the design of the fire-safety arrangements regarding the management of the building;

d. escape routes, escape strategy (for example simultaneous or phased) and muster points;

e. details of all passive fire-safety measures, including compartmentation (that is, location of fire-separating elements), cavity barriers, fire doors, self-closing fire doors and other doors equipped with relevant hardware (for example electronic security locks), duct dampers and fire shutters;

f. fire-detector heads, smoke-detector heads, alarm call-points, detection/alarm control boxes, alarm sounders, emergency communications systems, CCTV, fire-safety signage, emergency lighting, fire extinguishers, dry or wet risers and other fire-fighting equipment, other interior facilities for the fire-and-rescue service, emergency control rooms, location of hydrants outside the building, and other exterior facilities for the fire-and-rescue service;

g. details of all active fire-safety measures, including:
   - – sprinkler system(s) design, including isolating valves and control equipment, and
   - – smoke-control system(s) (or HVAC systems with a smoke-control function) design, including mode of operation and control systems;

h. any high-risk areas (for example heating machinery) and particular hazards;

j. as-built plans of the building showing locations of the above;

k. specifications of any fire-safety equipment provided, including operational details, operator manuals, software, system zoning, and routine inspection, testing and maintenance schedules;

m. records of any acceptance or commissioning tests;

n. any other details appropriate for the specific building.

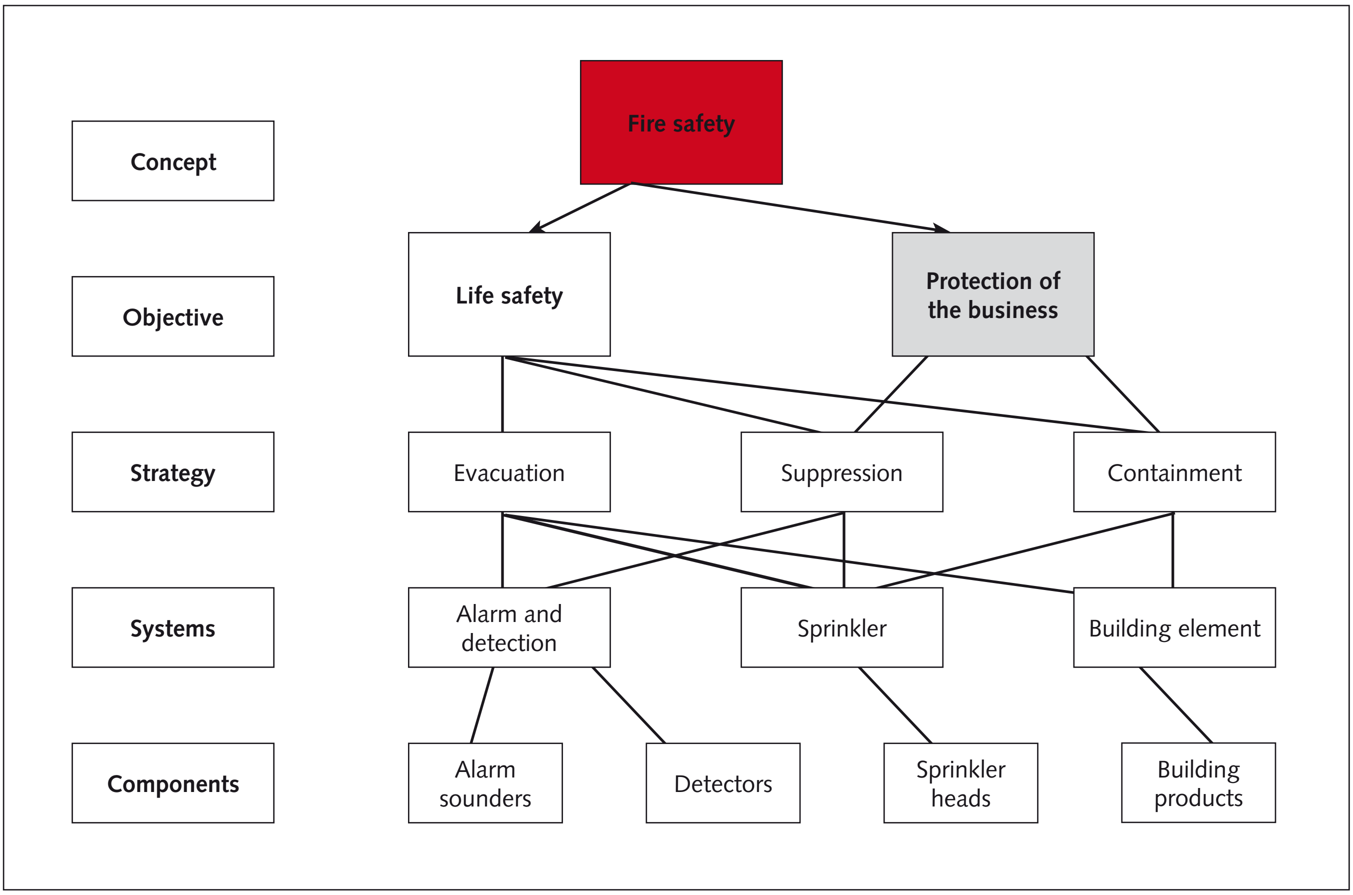
Fire strategies

B8 Fire safety in healthcare buildings can be considered on a number of levels:

- objectives;
- strategies;
- systems; and
- components.

(See Figure A1 for a fire safety paradigm.)

Figure A1 Fire safety paradigm



Objectives

B9 The two main objectives are:

- life safety; and
- financial protection (protection of the business).

B10 Other fire-safety objectives can include protection of the:

- environment;
- heritage;
- public image.

Strategies

B11 To achieve these objectives, one of many strategies could be used.

B12 Strategies usually consist of statements indicating the importance and/or role of the following with regard to meeting the objectives:

- prevention;
- evacuation;
- containment; and
- suppression.

Systems

B13 Systems that specify what overall precautions will be required to implement the strategy include:

- management policies;
- warning systems;
- compartmentation;
- sprinklers;
- smoke control.

Components

B14 Finally, each system should consist of components such as:

- procedures/drills;
- ability of fire doors to close and prevent spread of fire and smoke;
- adequacy of water supplies.

Example of the application for healthcare buildings

Objectives

B15 One of the main objectives may be to ensure that the risk of death or injury by fire to patients, visitors and staff is as low as reasonably practicable.

B16 From a financial perspective, the protection of high-value and essential medical equipment must be taken into account to prevent these being made inoperative due to the effects of smoke and hot gases.

Strategies

B17 The two main strategies in use can be described as:

- progressive horizontal evacuation (PHE); and
- defend in place (DIP).

B18 PHE requires that – wherever practicable – fires be prevented. However, if a fire does break out, it should be quickly detected so that staff can evacuate patients and suppress it. There should also be sufficient containment so that patients can be evacuated progressively further from the fire on the same level.

B19 DIP has similar requirements for prevention, but differs in that the fire should be suppressed automatically to minimise the need to evacuate patients. This will also cover financial considerations, particularly if smoke can be extracted or contained within the immediate fire area.

Systems

B20 For the PHE strategy, the main systems required for the evacuation aspect are detection, management and compartmentation.

B21 For the DIP strategy, there is usually a need for a sprinkler system for the suppression part. Clearly, the same system can perform different roles in different strategies and multiple roles in the same strategies.

Components

B22 The types of component required for systems common to both strategies are similar. However, their level of performance may vary considerably depending on their importance in the strategy. For example, rapid-fire detection is common to both strategies.

B23 For PHE, the role of staff in evacuation means that they can also have a wider role in the detection of the fire; therefore, a lower provision of automatic fire detection could be considered.

B24 For DIP, on the other hand, the greater emphasis on automatic suppression usually means a much higher cover by automatic fire detectors. This indicates the dependencies implicit in this paradigm but also the clarity and traceability from objective(s) to components.

Benefits of considering fire strategically

B25 Most prescriptive fire-safety guidance contains an implicit fire-safety strategy. The hierarchical approach can help the users of this guidance to understand the implicit fire strategies set out in prescriptive guidance. It can also be very helpful in considering alternative fire strategies and for integrating strategies to satisfy multiple fire-safety objectives, such as life safety and property protection.

Fire drawings

B26 To adequately assess the fire precautions at design stage, a set of fire drawings should be prepared using symbols based on BS 1635.

B27 To adequately assess the compliance with the requirements of this guidance, the drawings should show in sufficient detail the detection and alarm systems, the means of escape, the structural fire precautions, the portable and fixed fire-fighting equipment, smoke control/ventilation arrangements, and access and facilities for the fire-and-rescue service.

B28 A typical set of fire drawings would comprise:

a. a location plan;

b. a site plan;

c. a floor plan of each storey, prepared at a scale of not less than 1:200;

d. a floor plan of each department, prepared at a scale of not less than 1:100 and preferably at a scale of 1:50;

e. a set of elevations.

B29 During the construction of a project, variations to the structure and the layout frequently occur. These variations should not subvert the integrity of the agreed fire precautions. The variations should be recorded on the fire plans so that, on completion, an as-built set of drawings can be prepared; or on a list of products by name (so that fire-protection systems can be maintained as originally installed).

B30 The as-built drawings should be held by the trust so that any proposed future alterations can be checked against the fire drawings to ensure that fire safety is maintained in accordance with the recommendations in this document.

B31 This is an operational requirement and cannot be enforced through the current Building Regulations.

Appendix C – Examples where fire-safety engineering has been utilised in healthcare premises

Introduction

C1 This appendix provides some examples of the application of fire engineering. The description of these examples is by no means comprehensive, and important project-specific factors which may have had an influence over the demonstration of equivalency may not be described. The examples **should not be used as precedents**. The term "prescriptive guidance" should be taken to mean Firecode. The examples include:

- Application of BS 7974 to a care facility for older people: reduced fire resistance of compartmentation.
- Integration of an atrium in a teaching hospital.
- Structural fire engineering in a hospital.
- Integration of non-compliant design elements in a hospital.
- Atrium as centre of a district general hospital.
- Integration of a temporary structure in a high-rise hospital.

Note

The term "prescriptive guidance" should be taken to mean Firecode.

Application of BS 7974 to a care facility for older people: reduced fire resistance of compartmentation

C2 Older patients with mental health problems can present some of the most demanding challenges for fire-safety practitioners and operators. Standard guidance is based around a strategy that utilises a high degree of compartmentation. This has implications for the provision of doors, glazing, fire dampers, and fire-stopping of building services. These all have an effect on the cost, flexibility and use of the building.

C3 A two-storey, 48-bed extension was proposed, which was to provide care for older patients in a district general hospital. Beds would be provided on both the ground and first floors, with the roof providing a location for siting plant and other such equipment.

C4 Access is by a ground-floor entrance and an adjacent circulation stairway. Additional egress would be provided from the ground floor to the outside, and to the main hospital building via a first-floor bridge.

C5 The building is of steel frame construction with brick cladding. The floors are composite concrete slabs and the internal partitions are gypsum board on steel stud frames. There is glazing on all four walls. The building has a hipped roof that has been constructed using a steel portal frame.

C6 The fire-and-rescue service has access to three sides of the building. There are two hose reels sited in pertinent locations within the unit – one in the vicinity of the clothes store and the other adjacent to the day room.

C7 There is an anticipated maximum occupation of 108 persons. This is accounted for by having 24 patients per floor, an equal number of visitors, and six staff per floor. The distribution of persons is expected to be even. At night, there will be no visitors and only two members of staff per ward.

C8 The mobility status of the patients will generally be non-ambulant. Therefore, the patients will have a high dependency on external help to facilitate their evacuation. As a consequence, the fire strategy adopted must provide a high level of fire precautions.

C9 The objective of the assessment in this case was to assess whether a fire-engineered approach to fire safety would deliver a safer, more attractive or more cost-effective environment for the provision of care.

C10 A QDR team was assembled. This is key to the management and development of any fire-engineered strategy (see paragraphs 3.7–3.9).

A hospital QDR team may comprise the following key stakeholders:

- project manager;
- senior nursing manager (responsible for the type of occupants being provided for);
- hospital fire-safety adviser;
- project architect;
- fire-safety engineer;
- building control officer; and
- fire-and-rescue service safety officer.

C11 The QDR team then form a list of criteria to which any proposed fire-safety strategy must show equivalency. The value of this exercise is only truly realised by having all the relevant stakeholders present so that they can contribute to this process. The following objectives came from the QDR process for the DGH extension:

- Life-safety objectives:
  - the prevention of fire;
  - the occupants will be able to stay or be moved to a place of relative safety inside the building and ultimately, if necessary, leave to a place of reasonable safety outside the building;
  - fire-fighters are able to operate reasonably safely;
  - structural collapse will not endanger people (including fire-fighters).
- Loss-prevention objectives:
  - minimal disruption to the provision of healthcare;
  - minimal financial loss, hence drain on the provision of healthcare by the trust.

C12 In this example, the trust felt that loss-prevention objectives were important, but the life-safety objectives were far more challenging. Therefore, it was agreed by the QDR team to assess the design's loss-prevention performance once the life-safety objectives had been met.

C13 The QDR team developed two design-fire scenarios aimed to test the performance of the proposed fire strategies.

C14 One strategy proposed a fire in an unoccupied bed in a four-bedded bay on the first floor, at night, caused by smoking materials igniting waste before spreading to the bed. All patients are assumed to be asleep, in bed, and being cared for by two members of staff.

C15 The second strategy was a fire in the storeroom on the first floor, during the day, caused by deliberate ignition of textiles. Patients and staff are assumed to be distributed about the ward, with a number of visitors in the bed and day rooms.

C16 After review by the QDR team, the first fire scenario was deemed more challenging and therefore would be analysed against the acceptance criteria.

C17 The acceptance criteria against which the performance of any proposed strategy has to be assessed should be clearly defined by the QDR team. The criteria are often quantified (such as a clear layer height of 2.5 m or a maximum radiant heat flux of 2.5 kW m^{-2}).

C18 The trial designs were as follows:

- The QDR team decided that the design should comply with the compartmentation requirements of Health Technical Memorandum 81 – 'Fire precautions in new hospitals'. The basis for this decision was to provide patients with the facility for progressive horizontal evacuation. This resulted in a high specification of compartmentation, including:
  - 60-minute fire-resisting floors, staircases, lift enclosures, and one wall running right across the building on each floor; 30-minute fire resistance would have to be afforded to walls around each bedroom and each fire hazard room on each floor (approx 40 in total).
- Alternatively a sprinkler system designed to BS 5306-2:1990 could be installed throughout the unit and the level of compartmentation and subcompartmentation could be reduced. This could serve to further improve functionality and cost-effectiveness, and meet life-safety objectives.

C19 If the QDR team use Firecode as the benchmark of fire safety in healthcare, it has a reference point with which to compare any results from strategies developed by the QDR process. By producing a strategy that is, as a minimum, an equivalent to the prescriptive guidance, fire-engineered strategies often provide a level of protection above that of the prescriptive guidance.

C20 To aid calculation of the provisions required to mitigate the effects of fire, computational models were used by the fire-safety engineer to simulate a fire in the building under consideration. This shows how the fire would develop and spread based on the selected scenario. The same analysis can be done for the design following the prescriptive code, to show the engineered solution is at least equal if not superior to it. The calculation method used for predicting the fire hazards in the unit for the two protection strategies was a two-layer multi-compartment zone model.

C21 By utilising the techniques described and the application of engineering judgement, they were combined to equate the introduction of life-safety sprinklers to a reduction in compartmentation provision from 60 to 30 minutes.

C22 This solution is proposed under Firecode with the exception that the compartment line within the ward was reduced from 60 minutes to 30 minutes. This is considered effective with the activation of the sprinkler system, which will suppress fire growth.

C23 The alternative strategy, utilising automatic fire suppression, allowed for a reduction in compartmentation, and as a result a more flexible and user-friendly building was developed. This strategy also yielded a construction cost saving.

Integration of an atrium in a teaching hospital

C24 A three-storey block comprises conference and educational facilities on the lower levels, pathology and other laboratories on the upper level, and a central atrium. No patient care or treatment is envisaged, but there would be patient access in small numbers to many areas.

C25 The design process was at an advanced stage when the proposed atrium became an approvals issue. Interpretation of the prescriptive guidance would require the boundary of the atrium to have 120 minutes' fire resistance. To follow the prescriptive measures would have resulted in significant cost implications in the provision of fire-resistant glazing and also reduced functionality due to the inclusion of additional blockwork. Facing this option, there was also the distinct possibility that the concept of the atrium could be discarded altogether, significantly reducing the quality of the space.

C26 A fire strategy was produced to meet the fire-safety objectives whilst fulfilling the design objectives in terms of aesthetics and cost.

C27 Tools such as fire hazard modelling and cost-benefit analysis were used to justify and evaluate the desired strategy for the building. The alternative strategy to the prescriptive method used fire-resistant glazing around the atrium boundary to maintain light and open conditions for exhibitions, whilst it and other measures provided protection to the occupants in the event of a fire.

C28 An overall cost saving of £100,000 was achieved by tailoring the fire-safety specification to the building, on an individual basis. The alternative solution to the prescriptive guidance did not restrict the ultimate end-use of the atrium base for exhibitions and social functions.

Structural fire engineering in a hospital

C29 The hospital in this example is a state-of-the-art facility that is being procured through the Private Finance Initiative (PFI). The hospital has a high ratio of operating theatres to ward space. The building has a floor area of 12,000 m^2 and is spread over 11 floors. The layout also includes an underground basement car-park.

C30 On a strict interpretation of Health Technical Memorandum 81, the building originally required 120 minutes' fire resistance. Analysis based on the type of fire and temperatures that could be expected in the building was used to justify a reduction to 60 minutes' fire resistance.

C31 The client called for a strict control of vibrations, which required the use of a relatively deep composite slab. The composite slab uses Multideck 60, which supports a 150 mm deep composite slab in general areas and a 300 mm deep slab in the operating-theatre areas. This increased mass reduced the vibration sensitivity below the required perceptibility level. Importantly, this led to a significant inherent fire resistance for the building, which could be taken into account by considering the three-dimensional behaviour of the building in a fire.

C32 In order to assess the secondary effects, scoping calculations were conducted using the approach given in the Steel Construction Institute's SCI P288 and BRE's Digest 462. Whole-frame behaviour was also assessed using Vulcan – a finite element program developed at the University of Sheffield.

C33 The analyses demonstrated that in the event of a fire, secondary effects such as catenary action and tensile membrane action would dominate, leading to enhanced capacity in the floor slab. The key issue was that the slab would remain relatively cool and insulate the reinforcement. This leads to an alternative equilibrium in the fire condition to that assumed in the standard fire test.

C34 The analysis in combination with a qualitative risk assessment on the compartmentation requirements resulted in a solution where beams framing into columns were fire protected, but combinations of intermediate beams were unprotected.

Integration of non-compliant design elements in a hospital

C35 The proposed design of the hospital in this example included some aspects that were not compliant with the guidance in Firecode. The most pertinent issues that were resolved using a fire-engineered approach were:

- non-standard space planning;
- egress and compartmentation;
- fire-and-rescue service access;
- provision of an atrium.

C36 The benefits of fire engineering for this project included the clear definition of compartmentation specific to the design; enhanced handling of the entrance area included a reduced enclosure to allow a better use of space and the facilitation of innovative space planning. The key to achieving these benefits was to include fire engineering at the conceptual design stage so that changes could be made to the design without incurring a negative cost.

Atrium as the centre of a district general hospital

C37 The design proposed a two-storey atrium in a 533-bed Nucleus hospital. This proposed design would have contravened the guidance issued at the time in 'Firecode – Nucleus fire precautions recommendations'.

C38 The design team proposed three fire strategies to mitigate the effects of various fire scenarios that were possible in and around the atrium:

- the "sterile tube";
- powered smoke ventilation option (a);
- powered smoke ventilation option (b).

C39 The "sterile tube" strategy proposed that the atrium should not contain a significant amount of flammable materials. The sides of the atrium would also be impermeable and fire-resisting. This would mean that any windows within the boundary of the atrium would be fire-resisting and only operable by the fire-and-rescue service. It would also include rooms adjacent to the atrium to be fitted with sprinklers to assist fire-fighting.

C40 Powered smoke ventilation option (a) proposed that the atrium be fitted with a mechanical smoke-extraction system. The system would extract smoke produced from a fire entering the atrium at a sufficient rate so that the accumulated smoke layer would not descend below the lintels of the upper-storey windows. This would negate the need for fire-resistant glazing and allow windows in the atrium boundary to be opened by any occupant at any time.

C41 Restrictions on the fuel load permissible on the atrium floor would allow an acceptable fan size to be specified. The air-inlet area should be located on the ground floor and the air-inlet speed in escape doorways should not exceed 5 ms^{-1}. The fan capacity should not be less than 8.5 ms^{-1}, so there is enough capacity to cope with a fire in an adjacent room on the lower floor.

C42 Powered ventilation option (b) proposed that the atrium be fitted with a mechanical smoke-extraction system. The system would extract smoke at a sufficient rate so that the smoke layer was continually more than 3 m above the floor of the atrium and so that the smoke temperature was less than 200°C.

C43 The strategy allows for the smoke layer to deepen and descend past the upper-storey windows; these windows are required to be fitted with fire-resistant glazing and only be operable by the fire-and-rescue service. The glazing specified must be able to withstand a minimum of 200°C, the air-inlet area should be located on the ground floor, and the air-inlet speed in escape doorways should not exceed 5 ms^{-1}.

C44 In all the options, a high degree of quantification was provided in support of the strategies proposed. This allows for a full assessment of the methods used to determine the level of protection produced from adopting a particular fire strategy that differs from the prescribed method.

Integration of a temporary structure in a high-rise hospital

C45 The management of the hospital in this example wanted to extend the the site to include an endoscopy unit. The unit would be situated adjacent to the existing building on the seventh floor. The unit was to be a prefabricated construction sited on top of a temporary steel tower. The anticipated lifespan of the unit was one year, after which a more permanent solution would be found.

C46 The steel tower on which the prefabricated unit would be sited was to be built 450 mm away from the existing hospital structure. The base of the tower was located on split levels in the service yard of the hospital. The main concern was that a fire occurring in a room within the existing structure could break out through a window and impinge upon the steel tower supporting the prefabricated structure.

C47 Three strategies were developed based on a time-equivalent method to mitigate the hazard from a scenario where a fire starts in the existing clinic. The three options proposed were:

- Protect the exposed steel structure of the supporting tower.
- Fit wired Georgian glass to all windows – at all levels that overlook the exposed steel structure of the supporting tower.
- Provide an early warning of fire in the building so that a fast evacuation to the endoscopy unit can be made. No other protection would be afforded to the tower.

C48 Analysis of the steel structure showed it had an inherent fire resistance of less than 18 minutes. As a consequence, the structure was vulnerable to the effects of fire after a short period of time. The option to fit a proprietary fire-resistance system to enclose the exposed steel tower was deemed to be an expensive option for a temporary structure.

C49 After a survey of the rooms that were to have openings out onto the tower, the application of 6 mm thick-wired Georgian glass would provide 60 minutes' fire protection. This would afford the exposed steel structure the protection needed from direct flame impingement and, as a result, allow time for the occupants of the endoscopy unit to evacuate and the fire-and-rescue service to intervene.

C50 The final option considered the frequency of a fire in the year the structure came into existence. If the unit was fitted out with an extension of the existing fire alarm system and evacuation could be achieved in less than three minutes, the steel members of the tower could remain unprotected.

C51 The major drawback of this option was that there was still a significant risk of the structure collapsing. This could endanger persons at ground level and also hamper fire-fighting operations in the service yard at the base of the clinic.

C52 The option to fit the wired glass was viewed as the most appropriate, as it protected the steel and yet remained a cost-effective and future-proof option. It should be noted that temporary structures often stay in operation beyond the period of time for which they were originally commissioned.

C53 For all the options, a high degree of quantification was provided in support of the strategies proposed. This allows for a full assessment of the methods used to determine the level of protection produced from adopting a particular fire strategy that differs from the prescribed method.

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