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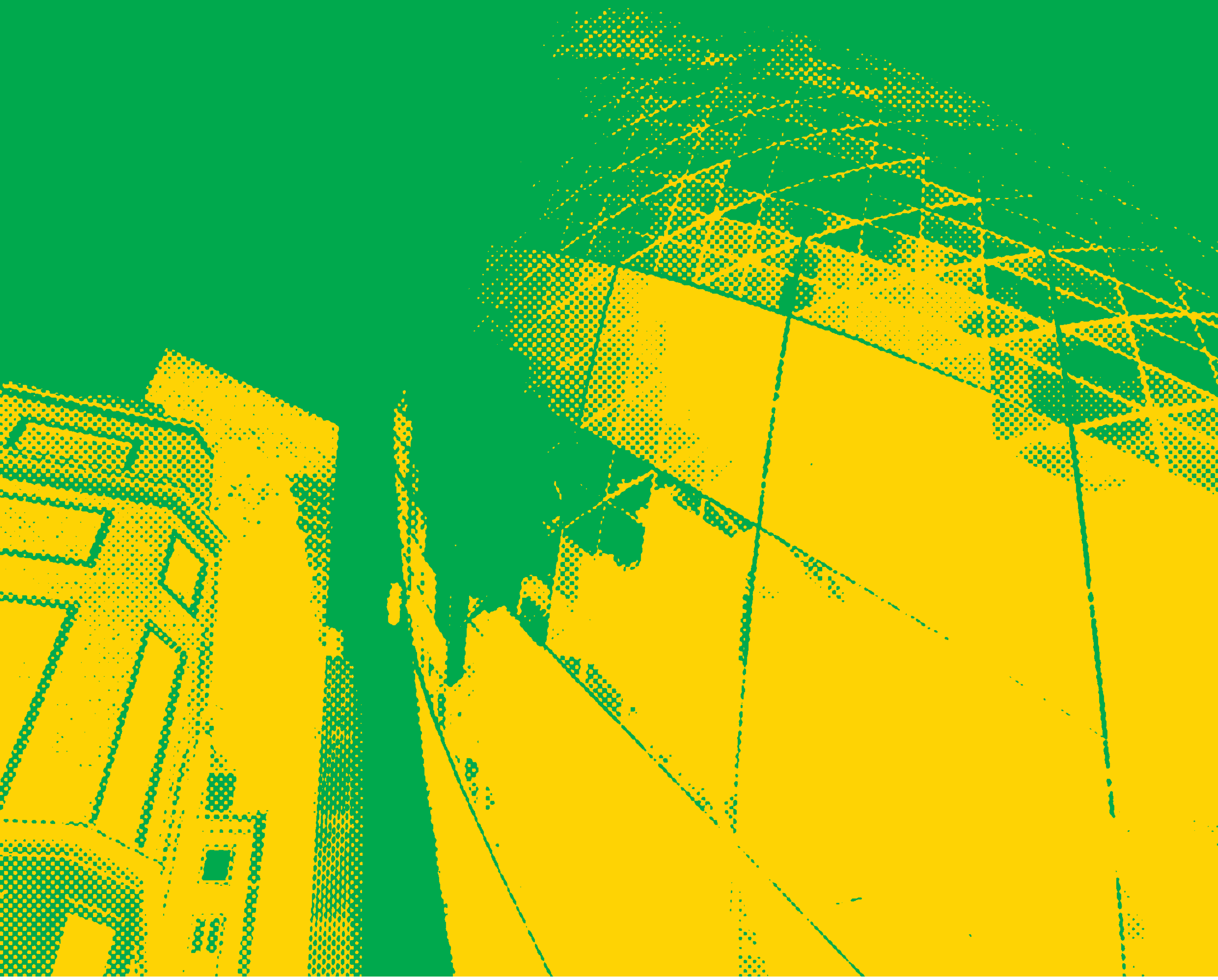
# Building, Design and Management

## Fire safety engineering
## A guide for insurers



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## IMPORTANT NOTICE



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## OVERVIEW

This revised document provides a simple guide on fire safety engineering for the commercial property insurer. It updates the 2002 version produced through ABI's Medium Term Research Strategy, and fulfils the request from RISCAuthority members for a simple guide on fire safety engineering.

## SUMMARY

Fire safety engineering (FSE) is a relatively new discipline applied to fire performance aspects of building design. It is of particular relevance to insurers and others involved in the specification of fire protection, as it is intended to offer an alternative to compliance with the traditional prescriptive Building Regulations.

Existing guidance and technical papers on fire safety engineering do not address the needs of insurers, nor do they explain the basis of requirements insurers may have.

This report gives guidance on fire safety engineering for insurers. In particular, it gives an overview of FSE (background, application, basis of calculation, typical design solutions), defines specific insurer requirements, actions, decisions, and implications (eg impact on retention and rating) and highlights risks and benefits to insurers.

## 1. INTRODUCTION

Fire safety engineering is a relatively new discipline applied to fire performance aspects of building design. It is of particular relevance to insurers and others involved in the specification of fire protection, as it is intended to offer an alternative to compliance with the traditional prescriptive Building Regulations.

Generally, FSE solutions are intended to meet the requirements under Building Regulations for life safety. Consequently, they are unlikely to meet insurer and client requirements for the protection of property (ie buildings and contents) or for the protection of businesses against loss or damage by fire to the means of production or earning of revenue.

Prescriptive requirements of the Building Regulations are well understood and tested. Innovative solutions to meet Building Regulations using FSE are likely to be met with circumspection by insurers and other specifiers unless they can be demonstrated to address fundamental requirements for both property protection and business interruption.

Existing guidance and technical papers on FSE do not acknowledge the role of insurers, nor do they explain the basis of requirements they may make. This guide:

- gives an overview of FSE (background, application, basis of calculation, typical design solutions);
- defines specific insurer requirements, actions, decisions, and implications (eg impact on retention and rating); and
- highlights risks and benefits to insurers.

## 2. BACKGROUND

### 2.1 Regulations and recommendations

Building design involving FSE has gained momentum following the release of a new edition of **Approved Document B** (**ADB**) in 1992 (ref. 1). The **ADB** contains practical guidance on meeting the Building Regulations relating to fire safety (ref. 2) and introduced the statement that 'fire safety engineering can provide an alternative approach to fire safety'.

FSE is approached in a similar manner to other engineering disciplines and is dependent on fire science and calculation methods. In 1997, the first British Standard Draft for Development on fire safety engineering was published, **DD 240** (ref. 3), which was later converted into a full British Standard, BS 7974: **Application of fire safety engineering principles to the design of buildings. Code of practice**, and published in 2001. This code provides the framework and describes the philosophy of FSE and also outlines the principles involved in the application of the philosophy to the fire safety engineering of particular buildings. It is supported by a series of seven Published Documents, PDs, that contain guidance and information on how to undertake detailed analysis of specific aspects. These PDs are a summary of the state of the art and it is intended they be updated as new theories, calculation methods and/or data become available.

Initially, required qualifications for those carrying out FSE lacked clarity. The practice of FSE requires detailed knowledge of fire science (hazards, events, modelling techniques) and a scientific approach. The Institution of Fire Engineers (IFE) Registrants Group has established an appropriate education/experience package necessary for qualification as a chartered fire engineer. With a suitable period allowed for uptake, all future fire safety engineers should be registered as chartered.

### 2.2 Application

Typical buildings where FSE is applied are shopping complexes, commercial buildings containing atria, entertainment venues, airports and stations. The common characteristics for these buildings tend to be:

- prestigious and of unique design;
- large open spaces; and
- occupied by large numbers of people.

Large buildings with few people, eg warehousing and industrial sites, are less commonly subject to FSE design.

While, in theory, FSE should be used for the design of a whole building, the practicalities of this usually mean that it is performed on limited design details, typically:

- travel distance (or other exit requirements in relation to the number of people);
- fire resistance of elements of the construction; and
- size of uncompartmented space.

Therefore, most parts of the completed building will be in accordance with **ADB** (ref. 4) and standards. Only the detail (eg travel distance) and its implications on the rest of the building will be considered.

Typical aims of FSE projects are to allow innovative building design features and cost-effective fire safety solutions. This is possible because the FSE approach permits fire safety solutions that a) depart or b) have no standard prescriptive recommendations given in **ADB** and supporting standards (eg BS 5588: **Fire precautions in the design, construction and use of buildings. Code of practice for**

**residential buildings** (ref. 5)). This permits novel materials, new design concepts or a new fire protection strategy without compromising the project by compliance with restrictive conventional fire safety requirements.

The basis for departure from prescriptive recommendations is by demonstrating that with a 'reasonable worst case fire scenario' the FSE design presents:

- minimal risk to life, ie a risk less than or equal to that under current **ADB** recommendations or a risk less than current statistics;
- acceptable risk to environment; and
- acceptable risk to property (building, contents and business continuity).

The environmental and property risks are rarely considered in a FSE design, due to a lack of regulatory requirements. However, conscientious risk-aware clients who consider these risks at the earliest stages of design see benefits in later years (fewer or smaller fire incidents, improved business resilience, and lower or less onerous insurance costs and terms).

### 2.3 Insurance risk

Insurer objectives for FSE design are addressed in the **FPA Design guide** (see Box 1) (ref. 6). Additional FSE design guides for specific types of premises detail series of recommendations. Property objectives are also proposed in BS 7974: 2001 (ref. 7) (see Box 2).

When assessing the risk to property/business by fire (or other perils) of a design solution, an insurer may consider all or any of the following:

- normal loss expectancy (NLE);
- estimated maximum loss (EML); and
- maximum foreseeable loss (MFL).

Precise definitions of these vary but are, in essence, as follows:

**NLE** will assume normal circumstances, all available means of protection, both public and private, are functioning as intended. Loss is expected to be due to a single fire, not multiple seats, nor a catastrophic event (ie possible but unlikely).

**EML** will assume poor circumstances, with some of the available private means of protection not functioning (eg fire doors and sprinklers). Loss is expected to be due to a single fire, not multiple seats, nor a catastrophic event. This case allows the 'what if' scenarios to be considered and evaluated, eg sprinklers operating or not.

**Box 1: Insurer objectives. Text taken from Approved Document B, fire safety, buildings other than dwellinghouses, incorporating insurer's requirements for property protection, Annex J (ref. 8)**

The principles of the recommendations contained within the **Design Guide** are:

**Reaction in the event of fire**

***Principle 1***

The building shall be constructed in such a manner that if a fire starts, the extent of fire and smoke damage will be minimised and confined as close to the source of fire outbreak as is practical/feasible.

***Principle 2***

With the exception of joinery products, the building shall be constructed from building materials/products that will not make a significant contribution to the early stages of a fire or contribute to the spread of fire.

***Principle 3***

Suitable measures will be taken for the prevention of premature structural collapse and excessive deflection.

***Principle 4***

Consideration should be given at the design stage regarding potential damage from firefighting water and to ensure as far as practical that the effect on the environment of the fire effluent will be minimised.

**Workmanship**

***Principle 5***

As minimum, all fire protection products shall be third party certified to an appropriate product or performance-based standard (attestation level 1 for CE marking)

***Principle 6***

All fire protection products/systems shall be installed by adequately trained specialist installers.

**Response to fire**

***Principle 7***

The building shall be fitted with an appropriate automatic fire alarm system.

***Principle 8***

The fire protection systems shall be regularly maintained so that they are able to perform their intended function throughout the life of the building.

**Fire prevention**

***Principle 9***

There shall be adequate provision to prevent an arson attack.

***Principle 10***

The building shall be so constructed that fire cannot spread into the premises from an adjoining building or other external fire source.

**Fire safety management**

***Principle 11***

The building owner shall ensure an adequate standard of the fire safety management throughout the life of the building.

***Principle 12***

Any fuel-burning appliance and services or electrical appliance and services shall be designed, constructed and installed in a manner that reduces their potential as an accidental source of ignition.

**Box 2: Property objectives (from BS 7974: 2001)**

**6.4.3.3 Loss prevention**

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

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

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

**6.4.3.4 Environmental protection**

As a conflagration involving several buildings or the release of quantities of hazardous materials may have a significant impact on the environment, consideration should be given to the limitation of:

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

**6.4.6.1.2.3 Loss prevention and environmental protection criteria**

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

*Note 1: Typical examples of objects contained in these groups are given in the table below.*

**Table: Property groups found in and around a building**

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

These objects have different degrees of susceptibility to fire damage caused by heat and smoke. For instance, a fire that results in an enclosure or a compartment flashover is likely to damage all the linings, fixtures and fittings, services and contents, so that they have to be replaced. Smoke spread to other areas of the building may result in damage to other linings, fixtures, fittings and contents.

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

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

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

a) selecting materials with resistance to fire;
b) providing fire protection systems;
c) contingency planning.

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

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

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

- number of specific valuable objects that it is acceptable to damage;
- maximum zone of direct fire damage;
- maximum zone of smoke and hot gas damage;
- maximum zone of water damage; and
- maximum time periods for recovery from the fire.

*Note 2: Zones are often described by their floor areas.*

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

**8.2.2.1 General**

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

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

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

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

a) low fuel loading;
b) large separations between fuel loads;
c) compartmentation;
d) the operation of active fire protection (eg sprinklers); or
e) active firefighting.

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

**MFL** will assume most adverse circumstances, with all available means of protection, both public and private, not functioning. Loss is expected to be due to a ‘worse case’ fire, not a catastrophic event. This case assumes the end of the fire event will be due to fire burn out.

The insurance and FSE evaluation methods are similar in that they both use fire scenarios. However, the FSE approach tends to assume that all circumstances are normal (ie NLE, except where there are life safety implications with a particular circumstance), while the insurance approach additionally investigates other worse scenarios (eg protection system failures).

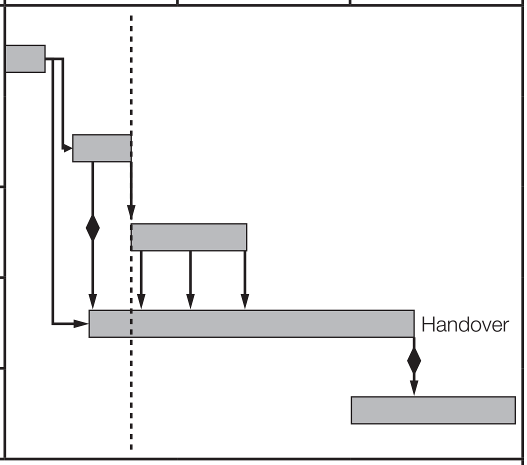
## 3. FSE DEFINED

### 3.1 Design, construction and management of buildings

The anticipated design life of most buildings is about 50 years. The type of construction and occupancy, of course, will have a great influence. For example, what we now consider as heritage buildings have stood in one form or another for hundreds of years and structures for events, such as the Millennium Dome in London, have a design life of just two years. This design life and the vision for a building are the fundamental starting points for clients in the design process.

**Figure 1: Phasing, activities, and personnel involved in building design, construction and use. Typical timeline for a traditional ‘new build and fit-out’ project**

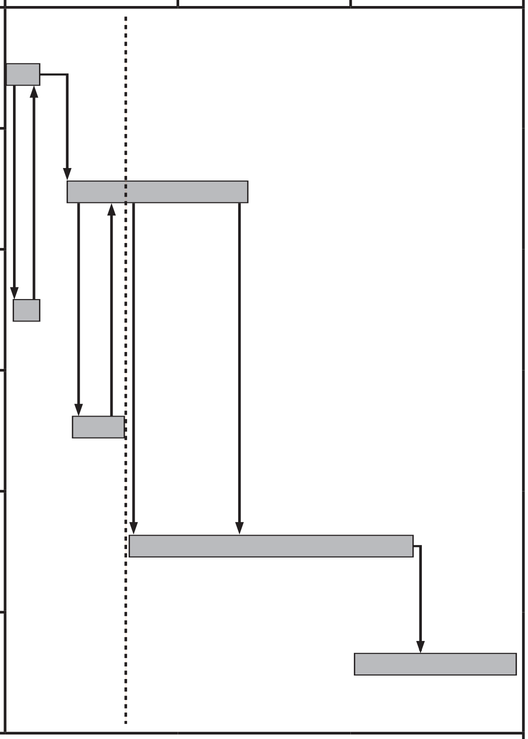
| ID | Stage | Task details | Key personnel | Year 1 | Year 2 | Year 3 |
|---|---|---|---|---|---|---|
| 1 | Feasibility and concept | Develop brief, site and master planning (shape, size, function, cost) | Client, project manager, architect, engineers | | | |
| 2 | Scheme | Establish plans (shape, size, layout, equipment position, cost) | | | | |
| 3 | Detailed | Engineer all aspects of design | Approvers | | | |
| 4 | Construction | Construct sub-structure, frame, claddings, finishings and services, drains and site work | Contractors | | | |
| 5 | ‘In use’ | Daily activities (works/facilities/ entertain, manage, maintain) | Tenants, public | | | |




**Key:** Engineers = all consulting engineers, eg fire safety, structural, mechanical, electrical
Approvers = building control, fire service, insurers

**Figure 2: Phasing of FSE activities during building design, construction and use. Typical timeline**

| ID | Task name | Task details | Year 1 | Year 2 | Year 3 |
|---|---|---|---|---|---|
| 1a | QDR | Develop – trial designs (escape, fire protection, compliance) –> based on key hazards and objectives | | | |
| 2a | QDR | Specify - trial design (escape, fire protection, compliance) –> based on hazards, objectives, plans (building, people) and agreed acceptance criteria, quantification methods and data | | | |
| 1b | Quantification | Calculate preliminary analysis (fire, people, damage, fire protection) | | | |
| 2b | Quantification | Calculate/model full analysis (fire, people, damage, fire protection –> involving assumptions, sensitivty studies, assessments, FSE report | | | |
| 3a | Fire safety manual | Compile – plans, assumptions, procedures (management, maintenance), FSE report | | | |
| 3b | Management | Manage, maintain | | | |



**Key:** QDR = the Qualitative Design Review is an on-going exchange of information between all personnel involved in the project.
By the end of the process all objectives, assumptions etc for the final building have been explicitly defined. Based on this information the FSE trial design is specified.

There are many types of design and build contracts, each with tasks and responsibilities arranged differently. However, they all proceed through the same stages (see Figure 1). Very early in the design process, Stage 1, details such as water supplies and points of access/exit are decided, along with associated budgets and costs. Plans, performance criteria and costs may be fairly fixed before the approving authorities and insurers are consulted (planning application in Stage 2). Hence, it is important for clients to be aware and have access to insurer requirements when they embark on a design/build project.

Detailed design and construction phase (Stages 3 and 4) will involve intensive effort to ensure conformity to design requirements/specifications. Linked with this are the health and safety at work requirements (ref. 9) – in particular, the health and safety manual that is developed for the construction phase (ref. 10).

Only after handover will the client's vision for a building and design life be realised and tested. The fire safety design will take into account the type and standard of management expected over the working life of the building.

### 3.2 FSE as a component of building design construction/management

FSE has three key components:

- QDR – qualitative design review;
- quantification – quantitative analysis; and
- fire safety manual – reporting and management.

Figure 2 shows how the FSE design activities link into the different project phases.

### 3.3 Qualitative design review (QDR)

The objective of the QDR is to assess the project and define the problem in qualitative terms (eg reasonable worst case scenario) suitable for detailed analysis and quantification. An important function of the QDR is to establish one or more fire protection schemes (trial designs) that are considered likely to satisfy the fire safety criteria. QDR requires the explicit definition of project details and assumptions for the final building by personnel involved. Generally, this is established through ongoing exchanges of information between key personnel, and recorded in the FSE report. On major projects, this will involve members of the design team, fire safety engineers, appropriate approval bodies, insurers and operational management.

Tasks carried out in the QDR are:

- review the architectural design;
- determine building, environment and occupant characteristics;
- establish the fire safety/protection objectives;
- establish an evacuation strategy;
- identify acceptance criteria;
- identify fire hazards and possible consequences;
- establish trial fire safety/protection designs;
- specify reasonable worst case fire scenario(s) for analysis;
- indicate appropriate methods of analysis; and
- report the results of the QDR.

### 3.4 Quantification

The analysis will evaluate the impact of a fire on people and property at different times in the development of a fire.

For the 'reasonable worst case fire scenario' the characteristic doses of heat and other potential hazards (eg toxic and corrosive smoke, loss of visibility) are determined for:

- fire growth and development;
- spread of combustion products;
- spread of fire from the enclosure of origin; and
- fire control (by active systems operation or fire service intervention).

The impact of the described fire doses are used to evaluate times to:

- fire detection;
- sprinkler operation;
- fire ventilation operation;
- structural failure; and
- fire service intervention.

Ultimately, the analysis determines if safe evacuation of occupants is possible and the extent of areas that will be damaged by the fire incident (location and degree of damage).

#### 3.4.1 Quantification methods

The quantitative analysis can take different forms according to the problem. Quantification methods (calculations and fire models) are based on physical, chemical, thermodynamic and human behavioural relationships, derived from scientific theories and empirical calculations. Some of the calculations are outlined in BS 7974: 2001.

Fire models that are frequently used are of two types: zone and field.

**Zone models** take a few minutes to run on a personal computer. They are set up to give dose and impact calculation (eg ceiling temperatures and time to sprinkler operations). Zone models calculate average temperature in a fire enclosure and the average velocity of air entering and leaving the enclosure. They divide a fire enclosure into two zones separated by a horizontal plane. The influence of the fire plume as a heat/mass (including entrained air) pump into the upper zone is calculated. Some assumptions are made (eg simple geometry, ideal gas, turbulence, heat and mass capacity of contents). Examples of zone models include Hazard1, Cfast and Fastlite.

**Field models** precisely define the dose and use post-processing to calculate the impact on a target. A single trial design can take several days to calculate. As processor speed increases and the model/user interface improves, the use of these models for design is expected to increase. Field or CFD models predict the two- and three-dimensional distribution of velocity and temperature in a building from a known fire source. They are complex, involved computer models, that sub-divide the building into blocks. In each block, they calculate the fundamental conservation equations (mass, energy, and momentum) and the unknowns of viscous stress components in fluid flow, by solving the Navier-Stokes equation. Sub-processes that form part of field models are turbulence modelling, radiation and soot modelling and combustion modelling. Examples of field models include FDS, Jasmine, Sofie, Flow-3D, Fluent, Phoenics and Smartfire.

**Detector response models** predict primarily the time to activation of an initialling device. While most of these models predict the response of a thermal detector, sprinkler, or fusible link to a fire-induced flow, a few calculate the response of a smoke detector. Typically, these models utilise the zonal approach to calculate smoke and heat transport, but utilise sub-models to determine the response of the thermal elements in the detectors to the heat and flow field (ref. 11).

**Egress models** predict the time of occupants of a structure to evacuate. A number of egress models are linked to zone models, which will determine the time to the onset of untenable conditions in a building, but there are also stand-alone versions available. Egress models are often used in performance-based design analysis for alternative design code compliance and for determining where congestion areas will develop during egress. The number of egress models increase every year due to the fact that improved computer resources allow egress models to be created for more complex geometries involving the movement of larger groups of people (ref. 11).

**Fire endurance models** simulate the response of building structural elements to fire exposure. Some of these models are stand-alone, while others are incorporated into zone or field models. The concept is the same as that of the field models where the structural object is divided into smaller volumes, and the equations for thermal heat transfer and mechanical behaviour for solids are solved to determine when the structure will fail. Typically, the material properties are required input for the model as well as the boundary conditions (ie, the fire exposure) for the structural element (ref. 11).

**Miscellaneous models** are models that are not appropriate for one of the previous categories or have features that fulfil more than one of the other categories. Many of these models are computer programs that contain many sub-models and, therefore, can be used for several of the categories listed above. These are suites of programs that have several separate models which each address an individual aspect of fire and are contained in one computer package. Others are programs which model unique aspects of fires such as radiation or risk (ref. 11).

In addition to the above approaches, **probabilistic models** are also used. These are similar to those used for offshore assessment of risk. They aim to detail all possible events and outcomes from a fire incident. By assigning probabilities to each event, an overall risk can be found for each outcome. Acceptance of the risk will depend on the client/approvers/insurers approach to risk. Each person has his or her own level of acceptable risk. In the UK, the number of deaths that occur each year per building has been used to generate a risk to life figure of 1.5 x $10^{-6}$ for buildings other than dwellings. Societal acceptance of multiple deaths is much lower and hence the probability for this event is also lower.

The available input data are limited. At present, these studies are best applied to show the relative risks of different trial designs. An example of a probabilistic model is Firecam.

### 3.4.2 Sensitivity analysis, engineering judgement, safety factors

There are inevitably many uncertainties in FSE calculations. 'For example, it is possible to calculate with a high degree of accuracy the minimum time (ie the flow time) required for people to travel to and pass through a particular exit. However, it is known that people tend to leave a building by the routes with which they are familiar and it is often difficult to determine how many people will use each of the available exits.' (ref. 3).

Uncertainties may be due to:

- choice and definition of the reasonable worst case scenario(s);
- appropriateness of the quantification model; and
- input data, assumptions and other chosen parameters.

For these uncertainties FSE has four types of approaches:

- conservative inputs;
- sensitivity analysis;
- safety factors; and
- engineering judgement.

**Conservative inputs.** An appropriate conservative approach is taken at the quantification stage, eg by selecting a fire growth rate that is faster than would normally be expected.

**Sensitivity analysis.** An investigation into the criticality of individual parameters is made. This requires establishing the primary sources of uncertainty. By testing a range of values for the input parameter of concern and investigating the response/consequences of the output parameters, an indication of the sensitivity of results is gained. This approach gives a guide to the level of accuracy required of the input data. An example would be if the response time of the sprinkler was changed from quick response to slow response, does this effect the outcome significantly?

**Safety factors.** If a single system or assumption is shown to be critical to the overall level of safety achieved, a degree of redundancy in the design should be provided (eg duplication of supply).

**Engineering judgement.** FSE will require engineering judgements for the specification of the chosen scenarios, models and data. Most appropriate judgements will require a full understanding of their basis and limitations. These will be made explicit in the reporting and presentation of the final design, in case of future changes/developments.

**Box 3: Format of FSE report (text taken from BS 7974: 2001)**

The FSE report should contain the following information:

**a) objectives of the study;**

**b) description of the building;**

**c) results of the QDR:**

1) membership of the QDR team;

2) fire safety objectives;

3) results of the hazard analysis;

4) trial fire safety designs;

5) acceptance criteria;

6) fire scenarios for analysis;

**d) analysis:**

1) assumptions;

2) engineering judgements;

3) calculation methods;

4) validation of methodologies;

5) sensitivity analyses;

**e) comparison of the results of the analysis with the acceptance criteria;**

**f) conclusions**

1) fire protection requirements;

2) management requirements;

3) any limitations on use;

**g) references:**

1) drawings;

2) design documentation;

3) technical literature.

### 3.5 Fire safety manual

Essential to the continuation of the building and risk as intended will be compliance to specifications made in the fire safety manual. The fire safety manual should have been created by the project manager of the QDR and updated throughout detailed design and construction phases. It should be kept on the premises concerned, for the benefit of those managing the premises.

This fire safety manual should reflect the general management and operational procedures of the organisation concerned. It should be a definitive document that includes sufficient information for maintenance staff, whether in-house, contracted, or specialist equipment suppliers, concerning the safe undertaking of any building or engineering work. Because of the integrated nature of building and engineering work, the technical specifications of all aspects of the building should be included in the fire safety manual.

The manual should cover the following:

1. fire safety policy statement;
2. fire safety specification for the building;
3. safety management structure;
4. continuing control and audit procedures;
5. actions to be taken in a fire emergency;
6. fire drills;
7. housekeeping;
8. planned maintenance procedures;
9. staff training;
10. security;
11. contingency plans for damage control and salvage; and
12. record keeping.

More details of the fire safety manual are given in BS 9999: 2008: **Code of practice for fire safety in the design, management and use of buildings** Annex H (ref. 12).

Attached to the fire safety manual should be the FSE report. This report will form the basis of much of the content of the fire safety manual.

#### 3.5.1 FSE report

The results of a FSE study should be fully documented so that a third party can readily assess them. The report should set out clearly the basis of the design, the calculation methods used and any assumptions made during the study. The format of the report will depend on the nature and scope of the fire safety engineering study. It should contain all information that will be essential for the next stages of the design and life of the building (see Box 3).

#### 3.5.2 Commentary

Where property conservation is not a primary consideration, together with safety, then this should be clearly spelt out in the introduction/scope of any FSE report.

## 4. KEY CALCULATIONS

The starting point for the quantification is the 'reasonable worst case scenario'. This requires the definition of the fire, as well as building/people/property parameters.

### 4.1 Ignition

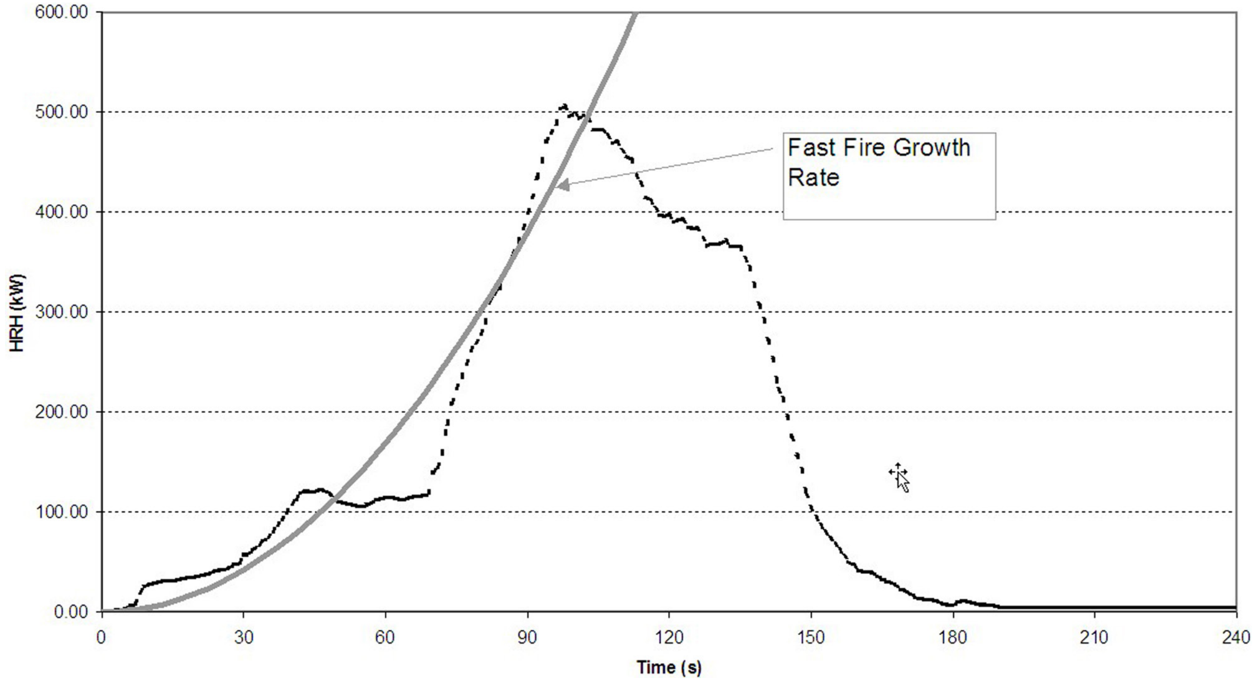
The type of ignition and initial fire growth will depend on the type of hazards within the building. A normal method of selecting these is to:

a) review previous fire events in the building of concern, ie review Home Office (ref. 13) and Fire Protection Association (ref. 14) statistics. For example, most department store fires are either malicious or under investigation (assumed malicious) in origin (ref. 15).

b) assess what fire start would represent the 'worst case'. For example, a malicious fire started with flammable liquid would lead to a very rapid fire start and development, resulting in, perhaps early detection and a large fire before intervention. A slow smouldering fire may be hard to detect and result in smoke logging of a complete building before an alarm is raised.

c) distinguish between regular fire events (for which simple reliable routine protection methods are installed, eg fire blankets for cooking ranges and drenchers for cardboard compactors) and events that could lead to escalating unacceptable consequences.

**Figure 3: Fire growth rate example – a Christmas tree. Calorimetry measurements for a wet Noble fire tree**




### 4.2 Fire growth

The rate of fire growth will initially depend on the characteristics of the items first involved in the fire and neighbouring combustibles, ie material and geometric arrangement, eg the growth rate of tightly packed timbers will be slow, but with loosely stacked boxes will be fast.

Fire growth rates can be found for single items, eg a chair, or small arrangements like stack of boxes, by burning them under a laboratory calorimeter. The categories of growth rate are slow, medium, fast and ultra fast. For example, a recently felled Christmas tree has a fast growth rate (see Figure 3) (ref. 16).

For whole rooms, fire safety engineers often refer to published data and surveys. These account for fire spread in typical rooms with an extensive range of items, some very combustible and others less so. BS 7974: 2001 (ref. 7). classifies room types or occupancies, see Table 1.

**Table 1: Design fire growth rates**

| Building use | Fire growth rate |
|---|---|
| Dwelling | Medium |
| Office | Medium |
| Shop | Fast |
| Hotel reception | Medium |
| Hotel bedroom | Medium |
| Picture gallery | Slow |
| Industrial storage or plant room | Ultra fast |

#### 4.2.1 Commentary

The fire growth rates are 'average' values used for design. They do not represent all risks. For instance, in a recent experimental test of an office fire, faster than expected growth rates were found following window failure (ref. 17).

Selection of the most appropriate fire growth rate will require some engineering judgement, and knowledge about the particular risk. The client and insurer will be able to assist with this.

Factors that could increase the fire growth rate are:

- an increase in highly flammable combustibles, eg plastics;
- an increase in the intensity of the ignition source;
- an increase in the amount of exposed surfaces, eg loose hanging garments compared to piled or stacked garments; and
- an increase in ventilation, eg when windows break and rapidly oxygenate preheated combustibles in a room fire.

Factors that could decrease the fire growth rate are:

- counter to the above, ie a decrease in flammables, a decrease in exposed surfaces, a greater separation of combustibles and a decrease in ventilation;
- sprinkler operation (expected to control and suppress the fire); and
- fire service operations.

### 4.3 Heat release rate (HRR or Q)

The amount of heat released by a burning item, as above, is dependent on its characteristics and fire conditions.

A typical heat release rate (HRR or Q), for a single item, increases to a peak value and then decreases, (see Figure 3). The heat release for a room can be described as the summation of all the individual heat releases, as each item becomes involved. The proximity of items and room characteristics will influence the time to ignition and rate of burning of each item.

A fully developed fire burns quite steadily for a period of time, until the fuel becomes exhausted (see Figure 4). Figure 4 gives a hypothetical value for a group of Christmas trees, with an assumed ignition sequence and no room/fire effects that alter individual tree heat release rates. This fire could be described as fuel bed controlled.

Figure 4: Heat release rate of a fully developed fire example – hypothetical Christmas trees. Hypothetical, cumulative HRR for a sequence of Noble fir tree ignitions

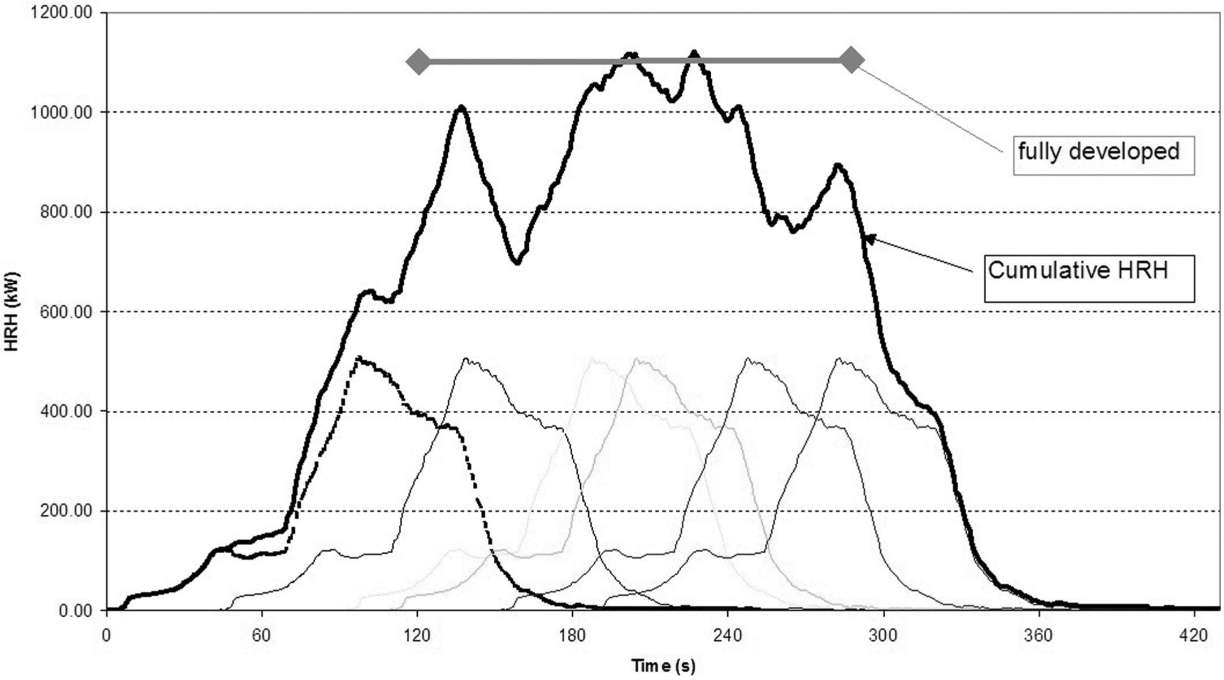



Table 2: Fire load density design values (text from PD 7974-1: 2003 (ref. 18))

| Occupancy | Fire load density (MJ/m²)(a) | | | |
|---|---|---|---|---|
| | Average | 80% fractile(b) | 90% fractile | 95% fractile |
| Dwelling | 780 | 870 | 920 | 970 |
| Hospital | 230 | 350 | 440 | 520 |
| Hospital storage | 2000 | 3000 | 3700 | 4400 |
| Hotel bedroom | 310 | 400 | 460 | 510 |
| Offices | 420 | 570 | 670 | 760 |
| Shops | 600 | 900 | 1100 | 1300 |
| Manufacturing | 300 | 470 | 590 | 720 |
| Manufacturing and storage | 1180 | 1800 | 2240 | 2690 |
| Libraries | 1500 | 2250 | 2550 | |
| Schools | 285 | 360 | 410 | 450 |

**Note 1:** *Limits*. The fire load densities given in this table assume perfect combustion, but in real fires, the heat of combustion is usually considered less.
**Note 2:** The values given in this table included only the variable fire loads (ie building contents). If significant quantities of combustible materials are used in the building construction, this should be added to the variable fire load to give the total fire load.

**(a)** Derived from surveys: see CIB W14 Workshop Report, 1983 (ref. 19).
**(b)** The 80% fractile is the value that is not exceeded in 80 % of the rooms or occupancies.
**(c)** Storage of combustible materials at less than 150 kg/m².

Flashover is a term used to describe when a whole room quickly becomes involved in the fire.

The available oxygen and thermal properties of the room (ie insulation) will affect the HRR or size of a fully developed fire contained within a room. The rate of air entering the room will be balanced by the rate of heat/smoke leaving the room and this will control the HRR of combustibles in the room.

The duration of a fire will depend on the above and the amount of combustibles, or fire load. The mass and type of combustibles can be found by survey to determine fire loads for particular rooms or occupancies. PD 7974-1: 2003: **Application of fire safety engineering principles to the design of buildings. Initiation and development of fire within the enclosure of origin (Sub-system 1)** (ref. 18) summarises the results of previous surveys, so that fire load density values are available to fire safety engineers for design purposes (see Table 2).

### 4.3.1 Fire load density commentary

The choice of fire load density for design purposes will depend on the characteristics of the individual occupancy and the criticality of the calculation. Generally the 80% fractile value will be used.

The fire load densities found in practice may be less than shown in Table 2, because they assume perfect combustion. Also, the values given in Table 2 include only the variable fire loads (ie building contents). If significant quantities of combustible materials are used in the building construction, this should be added to the variable fire load to give the total fire load.

#### 4.3.2 HRR as the starting point for quantification

For most calculation and models the HRR or fire size is the primary input. With a known HRR the following can be estimated or derived:

- flame height;
- flame temperature;
- flame velocity;
- room temperatures;
- time to detection;
- radiation onto targets (other combustibles, people and property);
- rate of smoke generation (and smoke extract requirements); and
- fire resistance periods.

### 4.4 Typical calculations

#### 4.4.1 Smoke filling and vent sizing

Smoke and smoke vent calculations are often performed to show that a smoke control system is adequate to ensure occupants can safely evacuate a building.

Account is taken of:

- building features (balconies, smoke reservoirs, smoke curtains etc);
- air flows (air conditioning, inlet and outlet vents and doors);
- fire type and size;
- smoke type and volume;
- people (evacuation strategies, vulnerability to smoke); and
- sprinkler operation.

##### 4.4.1.1 Commentary

Different fire types are specified for different buildings and occupancies. FSE uses either a steady state or growing fire.

The steady state fire is a typical fully developed fire size for the occupancy (ref. 20). In the early stages of a real fire it overpredicts the rate of smoke generation, and hence should result in 'safe' smoke control strategies at this early stage, during the period of evacuation.

The growing fire assesses the occupancy (as described above) and uses this as the basis for design. The accuracy of the method will depend on the accuracy of the chosen design fire. Fire safety engineers often use a conservative input for the growth rate to ensure 'safe' design.

Smoke calculations are often performed only for the period necessary for 'safe' evacuation (10 to 20 minutes). For both types of design fire, whether the real fire and design fire are identical at the later stages will depend on the particular occupancy and if fire protection measures have been successful. Fires are not generally extinguished in the first 10 to 20 minutes and will continue to generate smoke. Assessment of the extent of property damage due to the full fire event will require consideration of the later stages of a fire (ie the volume of smoke produced and potential paths for its distribution).

Smoke contamination of goods and furnishings can result in total loss and complete replacement.

Smoke damage of critical equipment can result in long periods of business shutdown.

#### 4.4.2 Structural fire resistance

Structural fire resistance calculations are often performed to show that the proposed level of protection (often less than specified in guides and codes) is adequate for the particular circumstances.

Account is taken of:

- building features (room size, wall construction or insulation, etc);
- openings (vents, doors and windows);
- fire type and size; and
- structural elements (material, period of stability required).

##### 4.4.2.1 Commentary

Often, it is the specification of the design fire that allows new fire resistance values to be calculated. This is performed by:

- determining the likely severity/duration of a fire (eg lower than normal HRR and fire load);
- taking account of successful operation of sprinklers (ie trade off);
- showing that the path of the fire is unlikely to reach an element (eg external flaming); and
- showing that the path of the fire is unlikely to substantially effect an element (eg installed or inherent passive fire protection).

If any of the above assumptions is incorrect at the time of the fire, the property damage is likely to be extensive.

Business interruption needs to be considered as higher values of fire resistance may still be required to ensure a rapid reinstatement of a facility and a return to business.

An insurer, for his or her loss calculations, will require consideration and determination of consequences when above assumptions are not valid.

#### 4.4.3 Non-standard sprinkler installations

Non-standard sprinkler installations are designed where sprinkler protection is a requirement but existing systems are not perceived to be adequate for fire control, or where building or goods arrangements prevent a standard system from being installed.

Account is taken of:

- building features (room/volume size, walls, obstructions, hidden voids, ceiling height etc);
- fire type and size; and
- sprinkler type (response, delivery, arrangement).

##### 4.4.3.1 Commentary

Often, it is the specification of the design fire and its interaction with the building that allows new sprinkler protection systems to be justified. This is performed by:

**Table 3: Insurer input into building projects and operational buildings**

| | Client activity | Insurer advice |
|---|---|---|
| **Feasibility and concept** | • list essential features/equipment<br>• development of fire safety strategy<br>• features/activities that will limit:<br>  • business interruption<br>  • property loss<br>• significance of risk limiting features/activities | • brief clients on:<br>  • risk of business interruption -> effective protection eg duplicate electrical supplies, continuity plans<br>  • risk of fire damage -> property protection<br>• supply advice documents<br>• preliminary EML considerations, accounting for hazards, risks, business interruption and redundancy |
| **QDR and quantify** | • design/risk decisions to be based on realistic 'reasonable worst case scenarios'<br>• fire protection specification (sprinklers, active, passive)<br>• engineering judgements (what if?, 'departures from normal', eg LPC Design Guide, compensating features) | • property point of view of statistically common fire problems and extent of damage - fire loss statistics, reports, research and fire models<br>• standards, recommendations, guides<br>• event trees – to address the significance of 'what if?' questions |
| **Scheme** | • definition of full performance specifications for all building features/equipment, regarding:<br>  • means of escape<br>  • fire protection<br>  • compliance (or not) with recommendations to the regulations, standards, insurer requirements | • provide clients with definitions of business and property protection performance objectives, either:<br>  • general as per LPC Design Guide, or<br>  • on-site advice such as acceptable extent and period of fire damage<br>• provide clients with guides/standards for business and property protection, eg LPC Design Guide, LPC Sprinkler Rules, Loss Prevention reports |
| **Detailed** | • assurance of conformance with performance specification and value for money | • recommend:<br>  • approved products<br>  • ad-hoc approval for non-standard features/ equipment/activities, checking consultants<br>• assess design business/property risks/protection |
| **Construction** | • assurance of conformance with design | • site visits:<br>  • risk assessment of features/equipment/activities<br>  • specific client advice |
| **Fire safety manual** | • a useable fire safety manual (log book) contains all necessary information | • advise clients on fire safety manual content |
| **'In use'** | • successful building with no unexpected fire related problems | • recommendations and inspection:<br>  • fire safety manual<br>  • maintenance<br>  • 'change' (hazard, activity, protection) |

- determining the likely time to activation of the first sprinkler (eg a tall ceiling can result in slow response);
- assuming subsequent sprinklers will operate successfully if required; and
- showing that the amount of delivered water matches standard specifications.

The role of sprinkler systems is sometimes misunderstood. Sprinklers are generally installed to prevent a catastrophic event, eg full building involvement in a fire, at any time during the life of a building. For this reason, sprinkler systems are required to protect all, not selected parts of a building, so that building protection can be maintained, not just in the normal operation of a building but also, while combustibles are relocated, during redecoration or refurbishment.

Sprinkler systems, designed and maintained to the **LPC Sprinkler Rules** (ref. 21), follow a well rehearsed practice and have proven reliability. The introduction of variations or more sophistication to standard sprinkler systems requires greater knowledge about the particular system, by all those who will encounter it in its relatively long dormant life. This could lead to errors and system failures. Insurers will consider the value of non-standard systems cautiously for this reason.

### 4.5 Cases of concern to insurers

#### 4.5.1 Non-standard sprinkler protection in atria

Sprinkler systems that rely on sophisticated detection systems (eg smoke, infra-red, UV zoning) and actuators, may be more prone to false activation and unwanted water delivery, leading to water damage losses. False alarm rates for smoke detection systems can be as high as nine in every ten alarms. This may be acceptable in some situations, but when an alarm leads to water delivery, the proven reliability of the detection method is paramount.

#### 4.5.2 Ductwork from catering establishments

Relatively small fires in ductwork can cause unexpectedly high losses. These fires can be hard to locate and can result in smoke and further fires at locations quite distant from the original fire incident. Hence, the period required for firefighting and ensuring the building is safe to re-enter can be relatively long, leading to long downtimes for production facility or long periods of business interruption in, for example, an airport.

#### 4.5.3 Refurbishment activities (eg hot work)

Unexpected fires that start in buildings considered as low risk in normal operation, eg offices, can result in large fires and losses, as the buildings and management are unprepared for fire incidents. The fires may be started in hidden areas, eg floor voids, or in areas where normal protection methods have been disabled because of the type of refurbishment work being performed. Additionally, the building may contain materials with little or no resistance to fire and smoke damage, as no such requirement would normally be necessary.

#### 4.5.4 Unique equipment

Many businesses are highly dependent on one or two specialised pieces of equipment (eg electronic facilities, production equipment) for the functioning of the business. Equally, some building facilities or decorative features, eg escalators, marble facades, may be so unique that replacement and/or reinstatement may require a couple of years or may not be possible at all. Fires that damage such equipment or features can lead to unacceptable periods of business interruption.

#### 4.5.5 Large retail stores/warehouses

Fires starting in large stores that contain a relatively high fire load, if not extinguished or controlled in the early stages, can quickly become massive fires. Such fires are almost impossible for the fire service to fight and hence complete loss of building and loss of the local business is likely.

#### 4.5.6 Tunnels

Tunnels are constructed to solve logistical or environmental difficulties and many communities become dependent on them. Health and safety is of paramount importance in the construction phases of tunnel designs, but during its service life the ability of a tunnel plus services to withstand fire are not always fully addressed. This can result in protracted closures and downtime following a fire. Reinstatement of a tunnel, after a fire incident, could be relatively quick if at the design stage consideration is given to both life safety and property protection objectives so that 'reasonable worst case scenarios' could be selected on this basis.

## 5. INSURER PARTICIPATION

### 5.1 Design stage – assistance

Insurers can offer advice to clients at all stages of the design process, in advance of in-life management of a building risk. In particular, insurers can assist clients and fire safety engineers with the development of:

- property protection objectives (QDR) where this is not just limiting damage to certain parts of a building but also minimising the impact on a business due to avoidable interruptions post fire;
- property protection acceptance criteria (QDR) – specification of percentages of damage (number of rooms) that would be deemed acceptable, and high value areas (due to content or use) where extensive damage would be unacceptable;
- reasonable worst case fire scenario, from a property point of view – hazards and loss events that are known to be common for the particular occupancy or client, fire size (amount and type of combustibles that should be considered in a quantification exercise), system failures and consequences that should be considered and time periods required for assessing the extent of loss from a fire event;
- specification, checking and approval of active and passive fire protection;
- specification, checking and approval of fire safety manuals; and
- engineering judgements (what ifs? departures from normal, eg **LPC Design Guide**, compensating features).

Table 3 shows the contributions an insurer can make at each stage of the design process. Insurers are able to offer assistance in these areas as they are supported by experts and have access to:

- fire loss statistics;
- fire loss event reports;
- fire research;
- fire models;
- standards;
- recommendations;
- hazard/event scenarios of concern for loss; and
- checking consultants (design, fire protection systems – with acceptable credentials).

### 5.2 Insurer evaluation of loss

An insurer will consider all aspects affecting a potential fire loss. Factors include building, location, material, people, activity, and management.

In the first instance, an insurer will not consider a fire safety engineered designed building as a complete solution. Only after proven application of insurer requirements for both property protection and business interruption will benefits of fire safety engineered designs be fully recognised by insurers.

NML, EML and MFL will be determined following consideration of building, the fire safety manual and the FSE report. In particular, an insurer will

1) look for designs whose initial objectives set out to minimise property and business losses;
2) assess design and management activities followed; and
3) evaluate short- and long-term financial implications. Fire safety engineers should be aware that some building types might be deemed uninsurable due to an unacceptable level of risk (eg some large composite panel buildings).

When applying FSE to building design, early consultation with an insurer can assist the client in ensuring the final design is acceptable to an insurer.

## 6. CONCLUSIONS

- Fire safety engineered buildings tend to be prestigious and thus large, well controlled risks. Hence, a reduced number of fire incidents is anticipated. However, the problems of a large fire event remain a possibility.
- The lack of numbers of fire safety engineered buildings, and hence experience, makes estimation of loss difficult. Greater use of engineered and hazard/consequence calculations will be required.
- Fire safety engineering is a highly specialised discipline. It is the application of scientific/engineering facts to design. It requires extensive knowledge, data and fire modelling competency. In addition, the professional qualification 'chartered status' and the ability to understand the criteria of the FSE study (ie life safety and property conservation objectives) are essential.
- Early participation by insurers at the design stage when applying fire safety engineering to building design will assist the client by ensuring that the final design is acceptable to an insurer.
- Quantification of FSE should consider the full period of a possible fire event, from ignition to fire extinguishment, salvage and clean up, for designs where property conservation is to be considered.
- Conformance to the fire safety manual and 'in use' management procedures (eg for 'change of use') will be essential for the continuous acceptance by insurers of fire safety engineered buildings.
- An emphasis on simple and reliable fire protection solutions will be viewed favourably by insurers.
- Fire safety engineers need to be made aware that some building types or fire safety engineered designs may result in a building that is deemed uninsurable by insurers.

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Fire Protection Association
London Road, Moreton in Marsh
Gloucestershire GL56 0RH, UK
Tel: +44 (0)1608 812500 Fax: +44 (0)1608 812501
Email: administrator@riscauthority.co.uk
Website: www.riscauthority.co.uk



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