FIRE SAFETY ENGINEERING

Fire safety engineering - *the UK approach*

The draft code of practice for fire safety engineering has been greeted with considerable interest by the fire community. Here Gordon Cooke, one of its authors, outlines its underlying principles

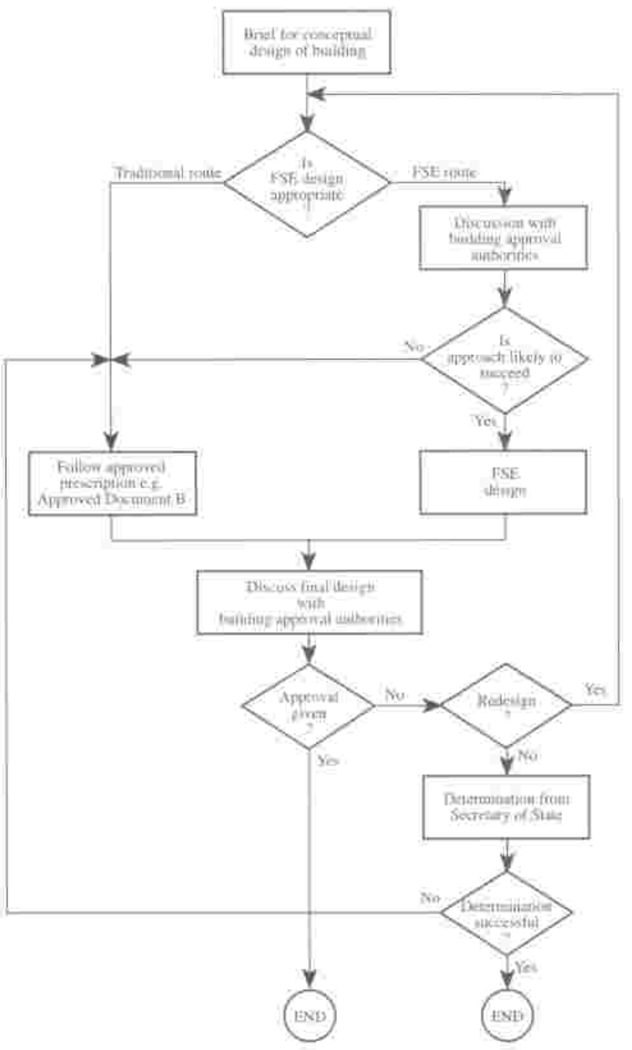

Figure 1 Routes to building approval in England and Wales

IN THIS article Fire Safety Engineering (FSE) is assumed to have the following meaning:

> The application of engineering principles, rules and expert judgement based on a knowledge of human behaviour and a scientific understanding of the phenomena of fire and its effects to:
>
> - save life, protect property and preserve the environment and heritage;
> - quantify the hazards and risks of fire and its effects; and
> - evaluate analytically the optimum protective and preventative measures necessary to limit within prescribed levels the consequences of fire.

The challenge

The effects of fire in or near buildings are mitigated by fire precautions required by national regulations and codes of practice. Over the past two decades building regulations in some European countries, including the United Kingdom, have moved from comprehensive prescriptive regulations to functional regulations supported by detailed technical guidance which, although less prescriptive, still constrains design options. It is generally accepted that prescriptive guidance is ill-suited to today's large, less compartmented and more complex buildings which accommodate many people.

While the present combination of regulations and guidance has served well, and will continue to be appropriate for simple buildings, there is a pressing need for a framework for FSE. This should include performance-based principles, acceptance criteria and calculation tools which permit the use of time-based calculations to address the important relationship between the time required for escape and the time available for escape.

It is anticipated that the next decade will see a major move to more performance-based codes using risk-based quantification design processes. The government has a commitment to deregulate in the field of building legislation and allow building designers more freedom to satisfy the functional requirements for fire safety in buildings using a fire safety engineering approach.

This has led the DoE Construction Sponsorship Directorate to identify, with the assistance of the Fire Research Station, the research[1] needed to enable FSE to be applied to the design of buildings in the UK. The importance of FSE and the need for further research has also been recognised in Europe and has led the European Group of Official Laboratories for Fire Testing (EGOLF) to prepare a report on research needed[2]. A brief review of FSE activities in several international organisations, the European Union (EU) and some countries is given elsewhere[3].

Meanwhile the fire safety design of buildings in the UK will comprise a mixture of FSE and prescriptive methods.

Using the FSE approach is daunting and exciting due to the many imponderables. Will the fire be accidental or malicious? Where will it occur? What will be the item first ignited? Will doors be open or closed? What will be the rate of fire growth? Will the fire reach flashover? Will the sprinklers operate and will they control the fire? How soon will occupants be aware of the fire and how rational will be their escape behaviour? Will the life risk be caused by toxicity, smoke obscuration or heat? Some of these questions cannot be resolved by calculation but can be accounted for by use of appropriate statistics, if available. It is the paucity of such statistics which is a current limiting factor. All members of the design and legislation enforcement team need to be educated in risk-based design methods.

A methodology based on sound engineering principles, which employs calculation tools and expert judgement, is needed - this is called fire safety engineering.

Existing guidance

Two alternative routes - traditional or FSE - can be used to seek Building Regulation approval (see Figure 1).

Whilst the existing guidance (the Approved Documents and the supporting British Standards) is intended to represent just one way in which the functional regulations may be met, it is often used as if it is the only way. The main advantage of this approach is the knowledge that if the guidance is followed the designer can feel confident that building approval will be granted. The designer and the building control and fire authorities are familiar with the approach - and history has shown that the implicit level of safety is acceptable.

However, the approach, through its piecemeal nature, does not encourage the designer to get an overview of the whole fire safety design process: it does not generally permit trade-off of active and passive fire defence measures, and does not require the designer to think about objectives, hazards, fire and people behaviour, and acceptance criteria which are fundamental in risk assessment studies made by engineers in other fields. The risk assessment approach has been accepted within the UK by the safety authorities responsible for off-shore oil and gas installations, and special risks associated with industrial, nuclear and transportation projects.

Benefits of FSE

Fire safety engineering can have many benefits. It can:

- form the basis of design for fire safety of construction projects, including buildings which, by virtue of their complexity, cannot be designed easily using present technical guidance;
- facilitate fire investigations through improved understanding of events in a fire;
- provide the designer with a disciplined approach to fire safety design;
- allow safety levels for alternative building designs to be compared;
- enable regulations and codes to be improved and justify the amendment or removal of outdated traditional measures;
- provide a basis for 'trade-offs' between active and passive fire precautions;
- overcome the restraints on design imposed by prescriptive regulations/codes and allow innovation for construction products and building design;
- enable the basis of deciding insurance premiums to be rationalised;
- assist the management of fire safety for the building during its whole life cycle, including construction and changes of use.

Development of the BSI document

Work begun in 1991 by a small group of fire engineers (which included the author), and funded by the Department of Trade and Industry, has resulted in a draft British Standard code of practice *The application of fire safety engineering principles to fire safety in buildings*[1]. This draft has been considered by BSI Committee FSH/24 and its five sub-committees. It seems likely, at the time of writing this article, that it will be a Draft for Development, but here it is referred to as the Standard.

In preparing the Standard it was recognised that existing prescriptive technical guidance

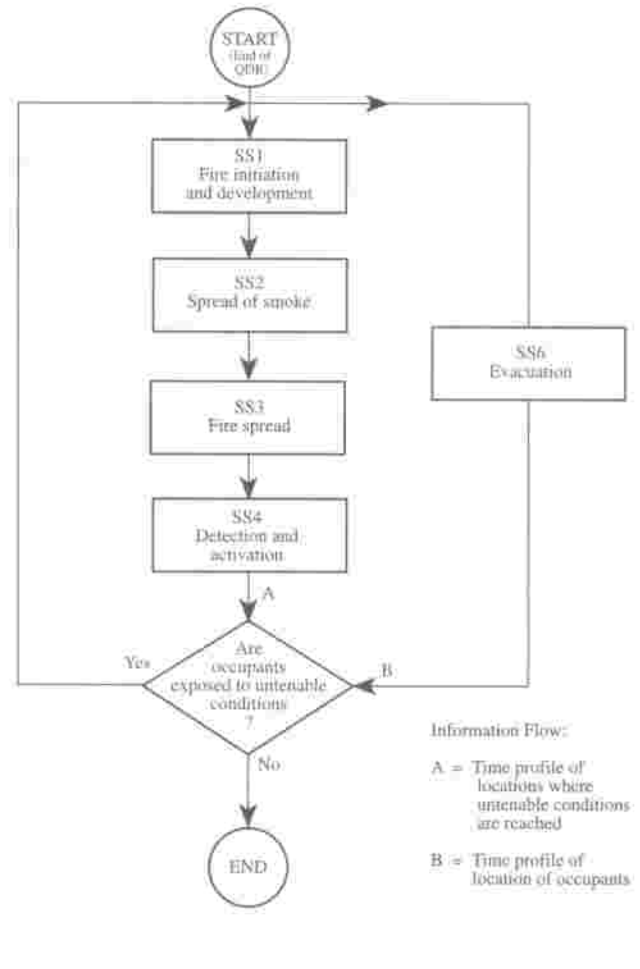

Figure 3 Systems analysis for life safety

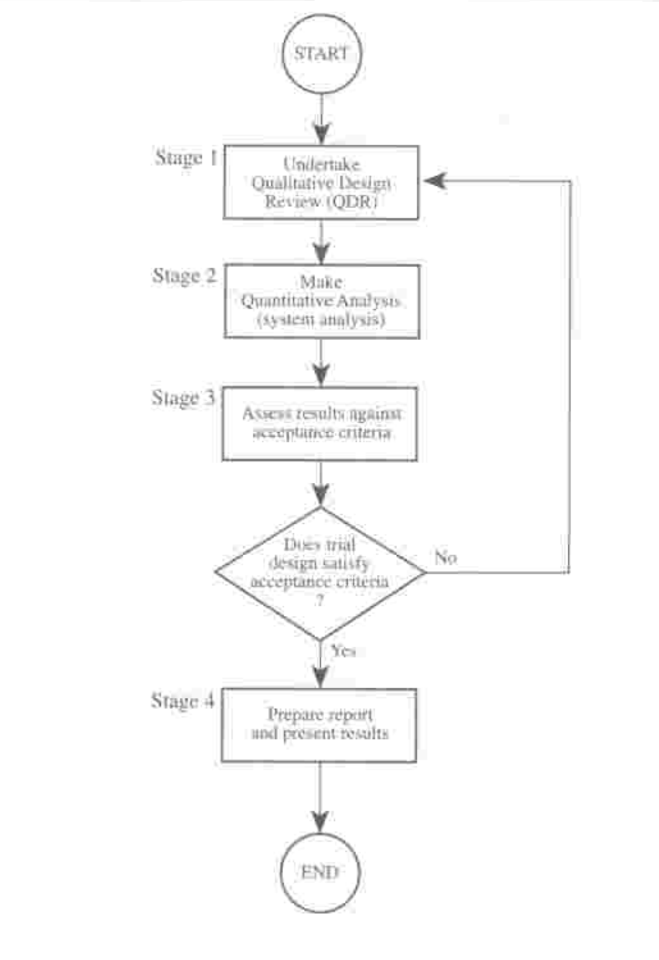

Figure 2 Procedure for basic design review and systems analysis

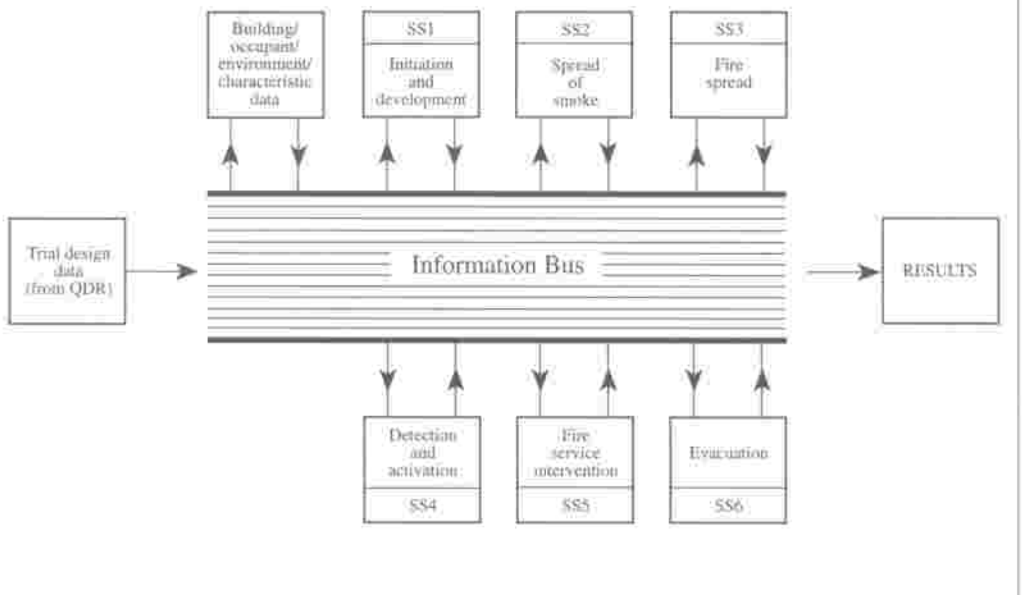

Figure 4 Concept of Sub-Systems and Information Bus

accompanying the functional regulations would continue to be used for the majority of buildings and that FSE would be used mainly for large, complex buildings where the benefits were sufficient to justify the cost of the FSE study.

The Standard is principally aimed at fire engineers who, if suitably qualified and experienced, should be able to undertake the required analytical work. It is also important that members of the design, construction and building approval team should be able to examine, understand and challenge the underlying assumptions and the bases of sensitivity analyses so that the fire safety design can be assessed.

The Quantitative Design Review

The FSE design procedure is in four stages, as shown in Figure 2. The Qualitative Design Review (QDR) is the first stage. The objective of the QDR is to review the architectural design, identify potential fire hazards and define the problem in qualitative terms suitable for detailed analysis and quantification.

Another important function of the QDR is to establish one or more fire protection schemes (trial designs) that are considered likely to satisfy the fire safety criteria. On major projects the QDR should be carried out by a group that includes members of the design team and one or more fire safety engineers. It may also be desirable for a representative of the appropriate approvals body and operational management to be involved in the QDR.

The purpose of adopting a team approach is to ensure that all aspects of the design can be considered in the context of the fire safety objectives and criteria. It is recognised that tools for computation and data for quantification will not always be available and in such cases the application of engineering judgement during the QDR can play an important part.

Some of the steps in the QDR are listed below together with an indication of the nature of some of the information collected/activities performed.

❑ Review the architectural design

The fire safety engineer obtains from the building designer information on: the relation of the building to other buildings or the site boundary; fire service access; how the building functions in normal use and when fire occurs; construction and geometry of the building/rooms and escape routes; installed fire safety systems; contents; occupants; management regimes; etc.

❑ Perform a building, occupant and environmental characterisation study

Assumptions may have to be made about environmental conditions (such as wind speed and direction, temperature, and internal air movement) as they may affect the response of, for example, heat detectors and natural smoke ventilation systems. Some occupant parameters may need to be characterised, such as familiarity, mobility, number, distribution and pre-movement times (interval between warning and first movement towards an exit).

❑ Establish the fire safety objectives

Is the primary objective safety of life or protection of property, environment or heritage? If the answer is life safety, is it the occupants of the building, firefighters or people near the building who need to be kept safe?

❑ Establish evacuation strategy

This may involve: total evacuation by simultaneous or phased procedures; evacuation to a place of safety within the building and, if necessary, complete evacuation as part of a managed system; or remaining in a place of safety where evacuation would not normally be contemplated, eg an operating theatre.

❑ Identify fire hazards and possible consequences

Each space and its contents are considered to determine potential and probable ignition sources and the likelihood of rapid development of fire, as well as the paths of fire effluent and the possible locations of people at risk. A short-list of important sites of fires and fire scenarios is prepared for quantitative analysis later.

❑ Establish trial fire safety design

❑ Specify scenarios for analysis

Characterisation of initiation, growth and extinction must be attempted as well as possible failures in protection systems and management procedures. Judgement is needed to avoid including scenarios which have a very low probability of occurrence.

❑ Indicate appropriate methods of analysis

❑ Prepare a fire safety manual when acceptable design is achieved

This should reflect the general management and operational procedures of the organisation concerned and include: fire safety policy statement; fire safety specification for the building; safety management structure; continuing control and audit procedures; action to be taken in a fire emergency; fire drills; housekeeping; planned maintenance procedures; staff training; security; contingency plans for salvage and damage control; and record keeping.

The systems analysis (stages 2 and 3)

The QDR is followed by a quantified analysis (stage 2) using one or more of six sub-systems (SSs):

SS1 - initiation and development of fire in enclosure of origin;

SS2 - spread of smoke and toxic gases within and beyond the enclosure of origin;

SS3 - fire spread beyond the enclosure of origin;

SS4 - detection and activation;

SS5 - fire service intervention; and

SS6 - evacuation.

The sub-systems are intended to give the general principles and appropriate procedures, and provide guidance on the type of calculations that may be carried out.

The sub-systems require input data for the calculations and these come from the trial design data, characterisation data, and outputs of other sub-systems. The proposed procedures outlined in the sub-systems are based on physical, chemical, thermo-dynamic relationships derived from scientific, theoretical and empirical relationships, and human behavioural relationships.

Several techniques are available for evaluating the development and effects of fire, and the nature and use of these techniques are given in the Standard.

The procedure for a systems life safety analysis is shown in Figure 3. The procedure begins at time equals zero when ignition is assumed to occur. The calculation methods in SSs 1, 2 and 3 enable predictions to be made, at repeated time steps, of the locations of smoke and heat in the building.

If active systems such as sprinklers and smoke vents are installed their time of activation is calculated in SS4 with their effect considered in SS1, SS2 and SS3 as appropriate. SS5 does not feature in a life safety analysis as the design should not be dependent on fire brigade resources.

SS6 is used to predict, at repeated time steps, the locations of all the occupants in the building. Finally the locations of fire effluent and location of occupants are continuously compared as time proceeds to see if occupants are subjected to untenable conditions.

Figure 3 represents the author's simplification of sub-system interaction: for instance, it does not show any interaction of fire and people which takes place in practice such as changes in the escape route occupants choose to travel along because of threat of fire near an alternative, more direct, escape route.

A concept called the 'information bus' has been developed to help visualise the flow of information in and out of the sub-systems and their interactions. This is illustrated, again simplified, in Figure 4. Basic input data is put on the information bus (the outcome of the QDR); these data are taken for input to each 'processor' (sub-system) which is plugged into the information bus.

These sub-systems can begin work on the data, and any other data that may subsequently be output from other sub-systems to the information bus.

The information bus ensures that the same data are being used by all sub-systems and that there is no duplication of data. All sub-systems are running against a common time base, and by taking a complete set of data off the information bus at any point in time a complete snapshot of the situation is obtained.

On completion of the systems analysis the results are compared in (stage 3) against the acceptance criteria. Finally a report is prepared (stage 4) ❑

FSE worked example

AS PART of the consultation process following the publication of the BSI fire safety engineering draft code (BS 94/340340 DC[1]), the Home Office commissioned a worked example[2], with commentary[3]. An innovative building design was chosen for the worked example. It contained an atrium and shop sales floors that were large and linked by the atrium. The hypothetical building, TEDS (The Example Department Store), used in this study was based on a department store located in outer London. This store provided the basic structural design, the architect's vision and the client's preferred layout, *writes Dr Louise Jackman.*

The aim of this study was to rigorously test all aspects of the draft code by carrying out a fire safety assessment on a planned building. Procedures defined in the draft code were followed and appraised. Five key steps took place; these were: (i) a clear definition of the objectives of the department store design from the viewpoint of all potentially interested parties; (ii) a hazard assessment of the department store; (iii) selection of the appropriate fire protection measures; (iv) a test of the design by calculating the impact of potential fire scenarios; and (v) reporting the fire safety engineering undertaken.

The study attempted to use the entire content of the draft code in a coherent exercise. Many difficulties were encountered in this process, so solutions had to be found. For example, when it came to step (iv), test of the design by calculation, the task became enormously complicated. All the equations given in the draft code were used, together with additional ones found to be necessary[4]. In excess of 350 variables were required and were linked together with an information bus. The values of some of these variables continuously change as time progresses.

To make the calculations manageable a unique spreadsheet was set up. It allowed the changing characteristics of a design fire and evolution of smoke and fire gases to be found at consecutive time steps. The impact of the developing fire scenario on the building, occupants and property for the period of the fire could readily be assessed.

Possible failures of the design and poor assumptions were also tested in the spreadsheet by selecting different input values. The calculations were repeated with slower response sprinklers and with sprinklers turned off. The slower response sprinklers resulted in a greater production of smoke and heat but still met the design objectives. However, without sprinklers, smoke layer radiation was found to make the store untenable before the occupants had started to leave the building ❑

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Dr Louise A. Jackman carried out the worked example with Tim Hodges, both of LPC Technical Development, and subsequently has been participating in the BSI redrafting process.

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