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Fire Safety Engineering of Assembly Buildings
Étude de la protection contre l'incendie pour des lieux de réunion
Brandschutzprojektierung für Versammlungsbauten

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SUMMARY
Assembly buildings are becoming larger and are often used for several disparate activities. Existing codes of practice for fire safety in buildings may not have caught up with leading-edge developments. Design from first principles using fire safety engineering methods is then necessary and it is the purpose of this paper to describe a proposed UK method and illustrate its application to a hypothetical assembly building.

RÉSUMÉ
Les lieux de rassemblement deviennent toujours plus grands et sont utilisés pour des buts fort dissemblables. Les normes existantes de protection contre l'incendie n'ont probablement pas toujours suivi les plus récents développements, il est donc indispensable que les considérations techniques se réfèrent aux principes élémentaires de la protection contre le feu. L'article présente une proposition britannique relative à cette protection à l'aide de l'exemple d'une salle de réunion hypothétique.

ZUSAMMENFASSUNG
Versammlungsbauten werden immer grösser und für mehrere ungleichartige Zwecke geplant. Die bestehenden Brandschutznormen haben vielleicht nicht mit den allerneuesten Entwicklungen Schritt gehalten. In solchen Fällen ist eine ingenieurmässige Betrachtung ausgehend von Grundprinzipien des Brandschutzes notwendig. Der Beitrag erläutert einen britischen Vorschlag zur Methodik am Beispiel eines hypothetischen Versammlungsbaus.

INTRODUCTION

Over the past two decades there has been a welcome move in the United Kingdom from comprehensive prescriptive building regulations to brief functional regulations supported by non-mandatory detailed technical guidance. This combination of regulations and guidance has served the country well - the UK has a good record for safety of life in fires in buildings. It is however accepted that buildings are becoming more complex and larger, placing more people at risk from fire than before: This is particularly true of large public assembly buildings.

Present technical guidance (such as the Approved Document B which applies to new buildings and alterations to existing buildings in England and Wales, and the supporting series of BS 5588 Fire Precautions in Buildings codes) does not, except in a few instances, provide a basis for calculations of fire safety to be made based explicitly on engineering principles. It is, for instance, very difficult to assess the effect on life safety of changing active or passive fire precautions since the basic principles and calculation methods for trade-off have not been written down.

A methodology based on sound engineering principles and employing calculation tools is needed to facilitate the design of those buildings for which existing technical guidance is inappropriate. This methodology is called fire safety engineering.

There is at present no internationally agreed definition of fire safety engineering. Here it is assumed to have the following widest meaning.

> 'The application of engineering principles, rules and judgement based on a scientific appreciation of the phenomenon of fire and its effects to:
>
> - save life, protect property and preserve the environment
> - quantify the hazards and risk of fire and its effects and
> - evaluate analytically the optimum protective and preventative measures necessary to limit within prescribed levels the consequences of fire.

Fire safety engineering has many benefits. It can:

- facilitate different ways of designing buildings having comparable safety levels
- facilitate more economic design of complex buildings while retaining safety levels
- overcome the restraints on design imposed by prescriptive regulations/codes
- identify topics of fire research which have a major bearing on life safety
- enable drafters of regulations and codes to improve the consistency of information, and justify the removal of out-dated traditional measures.

It was clear that a Fire Safety Engineering (FSE) methodology was needed which took account of many factors including: characteristics of the building including fire safety installations; characteristics of the occupants; intervention by the fire brigade; environmental conditions; and fire safety management.

Time-based calculation methods would be needed for determining:

- rate of heat release
- smoke production, toxicity and smoke spread
- fire severity and fire spread
- locations of occupants during evacuation

In 1989 a format and list of contents for a comprehensive Code of Practice on the application of fire engineering principles to fire safety of buildings was placed before the British Standards Institution (BSI). It was intended that the proposed code would cover general principles, life safety considerations, property safety considerations, mitigation of socially unacceptable events, and reduction in economic loss. Towards the end of 1990 a small group of fire safety engineers (which included the author) was formed to undertake a 3 year contract, administered by BSI and funded by the Department of Trade and Industry (DTI), of narrower scope which would culminate in a Code of Practice giving a framework, a methodology and a set of principles for the fire safety engineering design of new and existing buildings. A draft of the code was submitted to BSI in January 1994 for discussion. It guides on deterministic and probabilistic methods[1].

The basic procedure is to make a qualitative design review followed by a systems analysis. The qualitative design review (QDR) is needed because the interaction of fire, building and occupants gives rise to a large number of possible fire scenarios bearing in mind that fire can occur in any room in a building and can travel along many different routes. The review requires that the building designer (eg architect) explains to the fire safety engineer the concept and details of building usage, activities within rooms, location of circulation spaces in normal use, and the emergency evacuation strategy, if any. As part of this review it may become clear to the experienced fire safety engineer that there are several fire hazards which give rise to life-threatening conditions which require in-depth consideration if they cannot be removed by, for instance, the addition of a fire barrier or an automatic fire suppression system. The engineer can then focus his attention on the areas of the building likely to affect the life threat scenario(s) identified.

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 objectives. 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 is recognised that tools for computation and data for quantification will not always be available and the application of engineering judgement within the QDR will then be important.

The next stage is to make the detailed analysis. The draft code uses a sub-systems (SS) approach which is illustrated in Figure 1. Six sub-systems can be used ranging from SS1 'Initiation and development of fire' to SS6 'Evacuation'. Output data from one sub-system are the input data for other sub-systems and this is shown in the Figure. Before the sub-systems can be used data must be compiled which characterises the occupants, the fire safety systems and those parts of the building which influence the fire scenarios identified in the QDR.

Not all six sub-systems necessarily have to be used in a fire safety engineering assessment. For example if the objective is only to establish that occupants will not be overcome by smoke, SS1 is used to provide the rate of heat release data. SS2 takes these data and, using air entrainment factors, calculates at appropriate time intervals which areas of the room or building are contaminated by smoke. The locations of occupants in the building at different time intervals is calculated in SS6 and the outputs of SS2 and SS6 are compared to see if any occupants are in areas contaminated by smoke. If they are, the design is altered and, if appropriate, the sub-systems analysis is repeated. Further information on the draft BSI Code of Practice is available[2,3].

HYPOTHETICAL EXAMPLE OF FSE METHOD

A large diameter shallow light-weight dome is to be built in an urban area for holding temporary exhibitions, pop concerts, boxing tournaments and other sporting events. Simplified cross-sections are shown in Figure 2. The author emphasises that the design is purely hypothetical and has been conceived solely to provide a basis for this study.

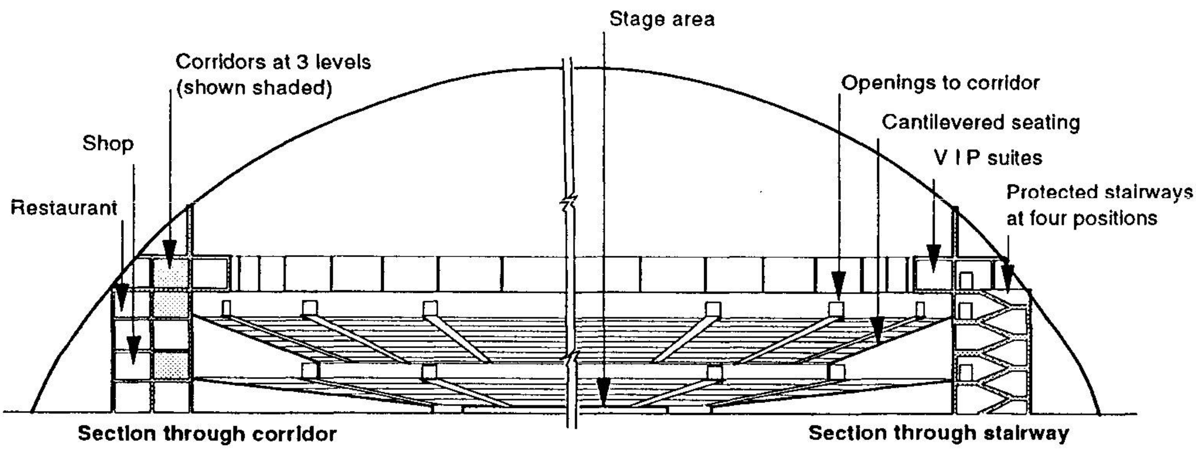

Figure 2. Typical sections through assembly building

A fire safety engineer (hereafter called the engineer) is appointed late in the design stage when the building control officer discovers that roof vents are not to be provided and he wishes to obtain an independent expert view to be sure that evacuation can be completed before the building becomes smoke logged. The engineer's brief becomes wider and involves making an assessment of the fire safety features in all of the building. The fire safety engineering study begins. First the objectives are agreed: safety of occupants and professional firefighters is of paramount importance; the developer is not concerned about property damage; and damage to the environment by contaminated fire fighting water is unlikely to be a problem.

The qualitative design review is commenced. The engineer obtains from the building designer a 3-dimensional visualisation of the building and a knowledge of how the building is intended to work in normal use and when fire occurs. This is the point when characterisation of the building and occupants is required and the following data are collected.

The framework is unprotected steel with floors of composite steel/concrete construction. The roof comprises a tubular steel geodetic space frame clad with sandwich panels having facings of sheet steel and a core of rigid polyurethane foam for energy conservation. Four large capacity stairways are provided for normal entry and egress and these are intended to be used for escape if fire occurs. Firefighting facilities are confined to hydrants outside the building and hose reels and portable fire extinguishers within. The building is not sprinklered and there are no roof vents. Audience seating is of upholstered moulded plastics which is supported by ramped unprotected steel framing. The upper framework for the seating is cantilevered. The flooring immediately underneath the seating is also composite steel/concrete. At the top of the audience seating there is a wall which extends from ground level to roof level with openings at sixteen positions around the circumference where people can move from the seating into the outer part of the building. There are sixteen equi-spaced aisles oriented radially, and three and six circumferential aisles in the upper and lower seating areas respectively. Above the audience seating there are some VIP suites which are fully glazed along their fronts. Conditioned air is blown from above the VIP suites downwards and towards the centre of the building. There are three circumferential corridors giving access to and from the audience seating and the VIP suites, one at each level. These corridors connect with the four staircases but with no intervening fire doors. The corridors serving the two ramped seating areas also contain a number of units such as snack bars, licensed bars, small shops, restaurants and toilets.

The QDR is continued. The engineer undertakes a fire hazard analysis to locate areas in the building where a life threatening fire might occur. First he identifies the worst fire that might arise if it occurred in the centre of the building. Using the methodology in SS1 he determines that the highest fire load density is associated with exhibition usage and it is assumed that initially fire is confined to an exhibition stand nominally 3.5 m square which, using plausibly pessimistic data, corresponds to a 20 MW fire.

The engineer agrees with the building control and fire authority that the smoke can be allowed to descend to the level of the top of the VIP suites, Figure 3(a), with safety if evacuation of all occupants into the protected corridors is complete by that time.

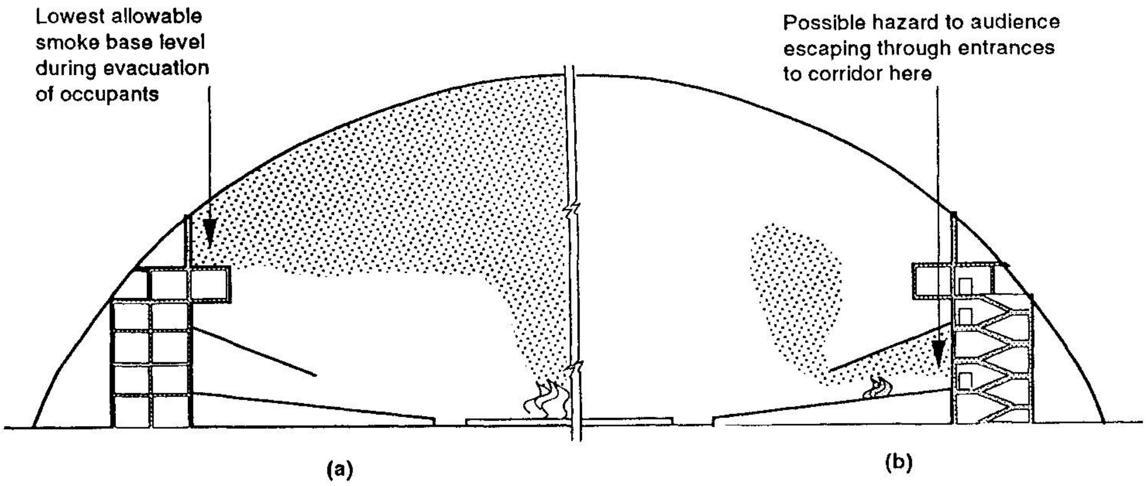

Figure 3. Possible life–threat scenarios

SS2 is now used. The smoke fill time is calculated using an appropriate model (eg the axi-symmetric plume mass flow model given in the BRE micro-computer package ASKFRS). The model assumes that the smoke is contained within a rectangular volume and this means that the volume of the dome above the top of the VIP suites - the smoke reservoir in this case - has to be represented by a rectangular shape of the same volume. The input to the model is the length, width, height and depth of the smoke reservoir, and the smoke layer temperature which corresponds to the 20 MW heat release rate. The output is, say, a 10 minute smoke fill time. This is compared with the evacuation time of, say, 7 minutes derived from sub-system 6 or derived independently by the architect. The 3 minute safety factor is agreed by all to be adequate since the smoke fill calculation assumes that the fire is producing a constant 20 MW whereas detection of the fire and commencement of evacuation would have occurred in the preceeding fire growth period. Thus the 20 MW design fire is a worst case scenario.

The fire authority reminds the design team that it has a responsibility to provide a search and rescue service in addition to fire-fighting and wishes to know the fire conditions on arrival at the site. The engineer agrees with the fire authority the likely time taken from fire detection to time to gain access within the building. The parameters listed in SS5 are relevant here. The smoke level at the agreed time is calculated and found to be acceptable to the fire authority. During this debate the method of fire detection is reviewed and it is agreed that flame detection should be explored because of possible delay in smoke detection caused by deflection of the smoke plume by the conditioned air blown from above the VIP suites.

The engineer and the fire authority raise the problem of smoke clearance after a fire and the client agrees to install a small number of vents at the centre of the roof.

As part of the QDR the engineer notices that fire in the lower-level audience seating could cause the nearest exit doorways to be blocked by smoke, Figure 3(b). The likelihood of this happening depends on the ignitability, rate of heat release and smoke production of the upholstered plastics tip-up seats. He suggests two alternatives. One is to determine the rate of heat release of one or two burning seats in a test using a full size furniture calorimeter prior to a smoke fill calculation. The other is to increase the time for evacuation by improving the resistance to fire of the seating: the engineer proposes using a higher performance standard such that the seats satisfy the criteria for ignition source 0 (which represents a smouldering cigarette) in BS 5852: Part 1: 1979 and ignition source 5 (which represents some burning newspapers) in BS 5852: Part 2: 1982. The costs for the second option are found to be acceptable.

A further scenario is presented by a large shop with a fully glazed front which opens onto one of the protected circumferential corridors, Figure 2. The hazard is a fire in the shop which becomes well developed so that, when the glazing fails, a considerable volume of hot smoke will suddenly flow into the corridor presenting a hazard to people there. From SS1 it can be deduced that the rate of heat release of a fire in a shop can be represented by a fast 't-squared' fire. These data can be used as an input to the appropriate equation (the equation for smoke flow from an opening) in SS2 which takes account of the air entrained in the plume as it emerges from the shop and rotates through 90°. Having entered the corridor the smoke loses heat to the surroundings, becomes less bouyant and increases in depth the further it travels. The length of the circumferential corridor is large and it is therefore essential to allow for heat loss from the smoke using information on the thermal properties of the enclosing surfaces. It may be necessary to create smoke reservoirs within the corridor using smoke screens to retain buoyancy. However, the engineer suggests that the problem can be circumvented (and the need for the smoke fill calculation thereby avoided) by the use of a vertical-drop shutter on the shop front. The shutter is designed so that it descends to a height of 2 metres above floor level on actuation from a smoke detector, and only closes fully when the temperature of the fusible link used to actuate the shutter exceeds the life tenability temperature of, say, 120°C. Such a shutter enables people from within the shop to escape with safety and yet provide a barrier to massive invasion of the corridor with smoke.

The engineer may identify a number of other features which need improvement such as the provision of appropriate levels of fire resistance in those rooms used to store materials. Recommendations given within parts of the BS 5588 codes on fire precautions in buildings are also applicable to a number of matters.

At the end of the study a report is prepared which contains information given under the headings in the Appendix.

CONCLUSIONS

This paper has described the approach followed in the development of the draft British Standard Code of Practice on fire safety engineering. A hypothetical assembly building has been used to show a few of the ways in which the code can be applied to an assembly building.

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APPENDIX. THE CONTENTS OF THE FSE REPORT

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

- objectives and scope of the study;
- description of the building and its fire safety installations
- description and characteristics of the occupants
- results of the qualitative design review (QDR) including: membership of the QDR team; fire safety objectives; results of the hazard analysis; basis for selecting fire scenarios for analysis; acceptance criteria; trial designs; and influence of fire-safety management;
- results of the systems analysis including: description of models used and relevant limitations; the input and output data for each sub-system; and the analysis of data including information on uncertainty of input data and calculated data.
- comparison of sub-systems output and tenability criteria
- conclusions
- references
- appendices for details

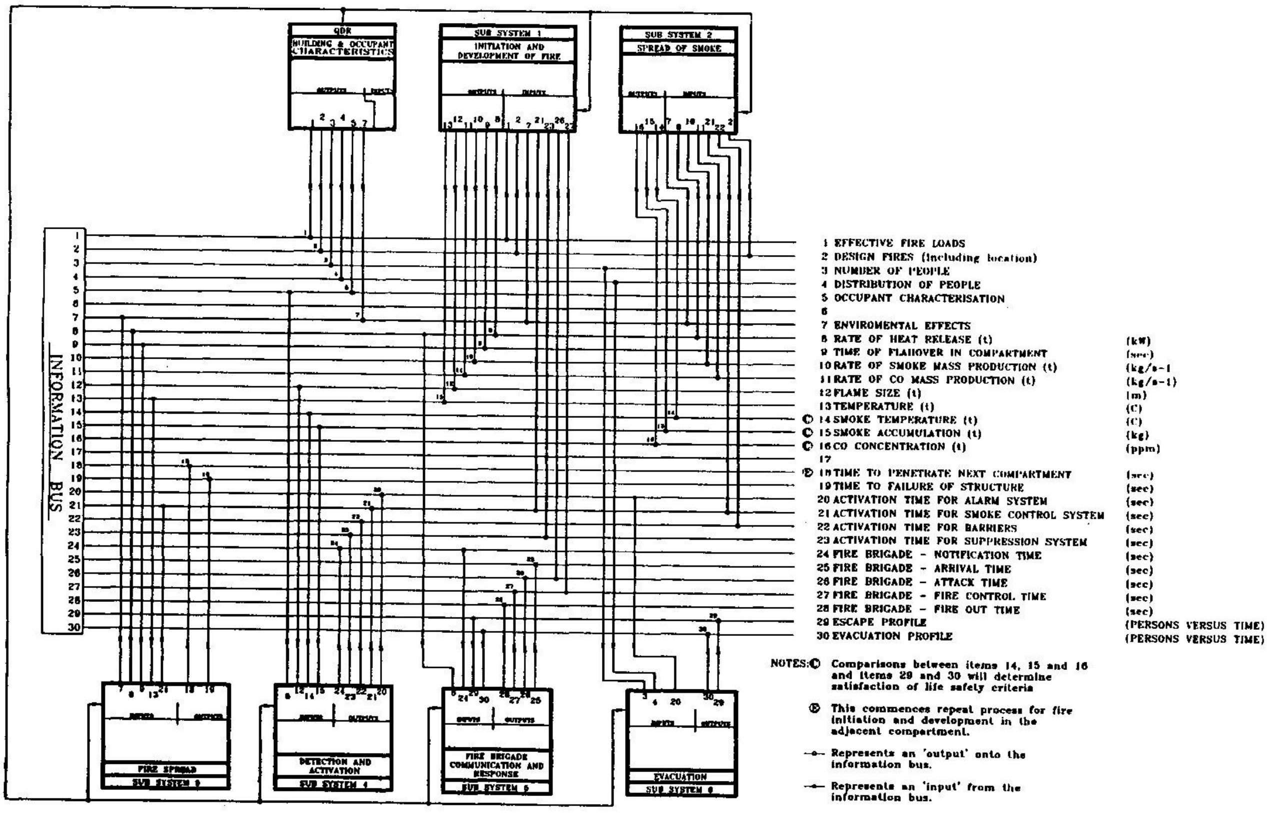

Figure 1. The sub-systems and their independence