FIRE ENGINEERING STRATEGIES

Eric W. MARCHANT

*Unit of Fire Safety Engineering, University of Edinburgh,
The King's Buildings Edinburgh, EH9 3JL
United Kingdom*

ABSTRACT

The use of fire engineering procedures for design of fire safety components to increase the standard of fire safety in historic buildings is no different to the use of such procedures in non-historic or new buildings. However, the need to apply components of fire technology to historic buildings has to be established properly by the results of appropriate risk assessment procedures.

The preservation of the character of the historic building is of paramount importance to the managers (owners) of the building and modified (reduced) standards of safety, when compared with new buildings, may be acceptable to the local authorities (government). It may be that some conventional fire engineering component solutions cannot be installed in an historic building. In such cases the fire engineering concepts of trade-off and equivalent safety may be used to ensure that the objective of necessary risk reduction is achieved.

In this paper some of the features that are characteristic of historic buildings are discussed; and the application of fire engineering procedures is described. It seems that the greatest skill needed by the fire engineer is the process of selection of the components of fire technology that can be installed sensitively in an historic building and that will enhance the standard of fire safety significantly(0).

INTRODUCTION

Buildings that are considered to be historic have some quality that reveals the problems and progress of society. Such buildings give the visitor the opportunity to visualise the lives and the environment of those people who preceded them [1]. Year by year some of this heritage disappears because of fire.

The preservation of old buildings may be considered because of their unique historical associations even though they serve no practical present day purpose. The justification for preservation is made less difficult if the building is capable of reasonably beneficial or profitable use. However, present-day use brings the necessity of satisfying present-day standards of safety for the occupants of, and visitors to the historic buildings [2]. In the general context of culture and education it is accepted that the preservation of historic buildings and monuments and their contents, libraries and records is of the utmost importance to the European Heritage. Therefore, to prevent, or minimise, the hazard (risk) of fire becomes essential. Historic buildings are varied in age, use, construction and condition but all share the

common threat of damage or destruction by fire [3]. This threat is omnipresent and its manifestation results in definitive destruction.

The number of buildings that could be defined as historical buildings could increase rapidly. The encapsulation of pieces of the architectural and cultural heritage within museums has been practised for centuries but the international growth of museums seems to be a characteristic of the 20th century and because of the role in society of these buildings it is likely that they will become historic [4]. Indeed, many museums have been deemed to be historic buildings in their own right. Therefore, the fire protection problems increase, for such buildings, beyond life safety and the protection of contents to the protection of the fabric of the building.

The threat of fire to historic buildings is now accepted as a serious problem but an almost equal threat is the impact of fire precaution measures to the architectural and historic integrity of the built heritage [5]. This problem did not exist before the preservation of older buildings became a socially valued goal but now spaces, materials and construc-

tional systems in historic buildings that do not comply with present-day standards cannot be modified or removed easily because of the inevitable destruction or the historical integrity of the building. Therefore, there is a set of potential conflicts between preservation goals (objectives) and the objective of fire safety improvement that is sufficient to generate a code-complying building [6]. Because of this proper emphasis on preservation, and reconstruction, the skilful integration of fire safety measures into the buildings of the past is of great importance so that the occupants, contents and fabric of the building can be protected from the fire threat [7].

In some of the guidance on fire protection for historic buildings there is an emphasis on those aspects of fire safety linked directly to life safety [8] but the consequences of fire will affect the contents, surfaces and fabric of the building and the economic viability of the particular building and its dependants.

The essential qualities of historic buildings seem to be their antiquity and uniqueness. The more valuable a building becomes when assessed for these qualities the more vulnerable it becomes from a fire safety point of view. Equally, as it becomes more valuable the introduction of any of the various fire safety systems needs to be carried out with increasing sensitivity bearing in mind the size shape, colour and location of the parts of the component of fire safety technology.

No building is static. Although the rate of physical change may be slow the system of which the building is a part is expected to perform adequately in a variety of changing patterns of environmental impact and usage, both in terms of space function and in numbers of people. The fire safety provisions need to be appropriate and adequate of any probable combinations of change .

The problems of fire safety in historic buildings are wider than those associated with life safety directly. A general description of the fire safety problems in historic buildings (9) discusses the contributions of contents and the fabric of the loss potential of an historic building and recommends a careful analysis of the whole situation of the building.

For an appropriate and adequate standard of fire

safety to be achieved the processes of survey; risk analysis, design of fire safety systems installation and valuation of systems needs to be completed.

FIRE RISK ANALYSIS

In the risk management approach four major steps can be identified in the process of risk analysis: hazard identification; risk estimation; risk evaluation; and risk reduction [10]. Depending upon the type of risk environment that is to be investigated each step in the process may rely upon intuition; subjective opinion; expert judgement; or statistical fact. In the process of analysis for fire risk it is most likely that each quality of analysis will be used, inherently or overtly. In fact much advice on fire safety provisions is given without direct reference to the rigour suggested by the four major steps.

Hazard Identification

The general method of hazard identification in buildings is by a survey of the specific building. Normal surveys will enable the identification of possible causes of ignition and the identification of possible those features of the building that are valuable and would be vulnerable to value reduction if involved in a fire. Equally, most, or at least some, of the vulnerable objects could be fuel for a fire. The collection of information on potential sources of ignition ; the amount of fuel available; and the nature of growth of a possible fire may enable an estimate of the probability of a fire being caused [11] especially when general statistical information about frequency of ignition and the size of the ensuing fire is available [12]. This type of survey is carried out on a building by building basis by consultants in the field [13] and it has been advocated to be carried out on a European basis [14]. In such surveys the whole of the fabric of the building will be recorded as will the size and spatial inter- relationships of all spaces in the building. Naturally, the fire safety features of the building would be recorded in the survey also.

The principal potential risk features of the building to be surveyed can be listed as: heating plant; electrical systems; concealed spaces; lightning protection; and, a safety feature, fire protection equip-

ment [15].

Risk Estimation

Risk estimation is characterised as an attempt to quantify the probability of a specific outcome from a specific cause. Although rough estimates can be made (from UK Fire Statistics) of the frequency of various sources of ignition [16] no doubt the ignition energy available could be estimated and then it may be practicable for the probability of ignition of the "first item" to be estimated also. However, a general knowledge (data base) on the ignition and burning characteristics of typical combustible contents in historic buildings is not available currently. Two views exist on the potential outcomes of ignition. Firstly, the danger of rapid fire spread from item to item within a room will be very low [17] and secondly, frequently it takes only a few minutes for a small fire to grow large [18]. Because of the wide range of views for a preliminary estimate for fire severity estimates it might be appropriate to assume that all of the available fuel in a space is available for combustion.

This is the assumption made in most codes and regulations that control fire safety in buildings. If this assumption is made then the worst possible consequences can be described. An estimate of rate of growth of the fire can be made from the survey information and then the minimum period of time can be estimated for safe evacuation of the occupants and for the rescue of valuable objects. These estimates could be modified usefully by reference to well documented case studies of fires in similar buildings [19] that is by the use of detailed experiential information.

In the estimation of risk the inherent and overt safety features of the building will be included therefore the outcome of the risk will be a value for residual risk.

This value could include information about the number of objects that could be damaged, and the area and volume of the building damaged. This information is essential for the next major step-risk evaluation.

Risk Evaluation

The first part of this process is to establish the level, or limit, of loss that managers of historic buildings are prepared to accept. This will be difficult but the classification of objects will be important with respect to their cultural value and money value. A classification of objects could be: irreplaceable; replaceable with difficulty; replaceable; and duplicates available. The fire protection standard for each class of object can be specified readily. A similar classification could be appropriate for the fabric of the building.

The fire risk evaluation will need to be carried out in three parts: life safety; contents safety; and building protection.

Life safety is usually the responsibility of government and control is exercised through legislation and the application of approved documentation. The requirements laid down in approved documentation contain descriptions of the acceptable standard. In most countries the standards for new buildings are applied to existing buildings when they are altered, extended or when the use of spaces in the building change significantly. As noted earlier the viability of preservation may depend on a change of use. In existing buildings generally and in historic buildings specifically the requirements for new buildings are unlikely to be met fully.

To help in the evaluation of fire safety in existing buildings a points scheme [20] has been established in the USA. This contains three simple tests of compliance. General fire safety; the standard expected for means of egress; and the standard expected for fire safety. In the scheme the risk factors are balanced against safety factors (components of fire safety) to give the scores for safety or residual risk. Therefore deficient components can be identified easily. However, the complexity of historic buildings is recognised in that the use of the scheme is not allowed for historic buildings but the use of the scheme would help to give a base from which to work. Advice on historic buildings specifically is limited to simple statements - approval for the use of the building by the code official when the building is judged, by the code official, to be safe. The approval is based on

a submission of professional and engineering plans and specifications bearing the seal of the designer (20). The collaborative approach to solving problems is important [21] as no codified guidance exists and any positive guidance that is developed cannot be specific because of the wide range of buildings that have historical merit.

The fire safety evaluation of historic buildings may be fully quantitative at some time in the future. Until then evaluation by comparison is perhaps the only way to make rational judgements. Before meaningful comparisons can be made the comparator or norm, needs to be established. So far it has been recommended that the owner should define the level of loss due to fire which is acceptable. The second standard of acceptability that can be established is the fire safety standard expected in the building by the codes and regulations controlling as if it was a new building. A comparison between the building, as surveyed, and the requirements of the codes will highlight the "Code problems" [22] or the deficiencies of the building. As it is most likely that the building cannot be made to comply with the requirements without reconstruction then some method needs to be defined which will allow the development of equivalent safety. Four approaches to equivalent safety have been described [22]. In the use of any of the four approaches the most important feature of the deficient component of fire safety is its fire safety purpose. The definition of purpose enables a clearer selection of other components of fire safety that can be improved to compensate for the identified deficiency.

1. The first approach is the procedural approach. Here the code describes the procedures for the evaluation process, does not prescribe solutions but may suggest alternatives for life safety components. This approach allows the architect and the local building code official freedom to reach a solution.

2. The second approach is the performance approach. This type of guidance document contains details of alternative life safety measures that may be acceptable depending upon, the usage of the building and level of hazard identified. This approach gives guidance for both architects and code officials

but does not determine solutions.

3. In the USA, as in other countries, some states have prescriptive Codes that include historic buildings. The immediate consequence is that the local official is relieved of liability but such codes lack the flexibility that is inherent in other types of guidance.

4. Fourthly, the points scheme component evaluation approach is regarded as a helpful tool [23]. If improvements in fire safety are needed an increased standard can be achieved by improving a group of components or a single component of fire safety. This approach is claimed to give architects a lot of guidance without constricting their choice of tactics, i.e. choice of alternative components. It is clear that the fourth approach is to be favored as it is at least objective and helps the architect to select a practicable set of improvements instead of specifying single component standards. Although the points scheme in the BOCA Code should not be applied to historic buildings it should be possible to devise a points scheme that is appropriate for historic buildings as such schemes do exist for hospitals, homes for the disabled and offices.

Each of the above approaches outlined are relevant to life safety only. After a package of improvement has been selected it should be reviewed for the contribution of the improvements to contents protection and the protection of the building.

Acceptable Risk

The acceptability of any group of improvements to be made to an historic building will rest with building code officials and in the UK and other countries, the local fire authority especially when reduced standards or solutions to problems that are unconventional are proposed.

Although the occupant may be aware of different standards the visitor is not likely to perceive differences in standards in ordinary circumstances. A knowledgeable visitor may choose to accept a lower than acceptable standard of fire safety because of the cultural and educational benefits gained during the short exposure to high threat. This may be acceptable to an individual but may not be tolerated by the local authorities or the visitor public if large numbers of

people are involved. Therefore, one of the limitations of operation of a building with deficiencies in the means of escape is to limit the number of visitors strictly. However, it seems to be normal to expect the standard of life safety in an historic building to be no same usage. If the standard some of the components of fire safety are not essential for life safety then they could be relaxed, that is a lower than normal standard could be acceptable [24].

The level of acceptable risk can be quantified for various types of building [25]. Target probabilities for the annual chance of death by fire is about 10^{-6} . In the same paper target failure probabilities for primary structural members in a building during fire exposure taking a 50 year building life time would be 10^{-4} for dwellings, and 10^{-7} for theaters. Such values as these are likely to be very useful as the gap reduces between this type of target and the design of fire safety components for adequate lifetime performance.

Values for general life safety have been developed for target probabilities for fire risk in buildings and for a population between 5 and 100 and for fatalities less than 5 people then the UK target annual probability for death would be about 10^{-6} . The development of this probabilistic approach to acceptable levels of safety is not complete but this approach will soon become a powerful tool which will contribute positively to fire risk assessment.

Risk Reduction

For improvements to the standard of life safety either the number of people exposed to a potential threat can be reduced or the life safety system can be improved by the improvement of the standard offered by the surveyed building or, perhaps, the installation of components of fire safety that did not exist in the building. (For example: emergency lighting systems). For the contents and fabric of the building, six approaches to the reduction of loss potential can be identified [26].

1. Avoid risk - Change the process in the building to eliminate risk; arrange for photographic duplicates to be made of

important paintings.

2. Reduce risk - Reduce quantity of material, objects exposed to fire risk; improve fire safety features.
3. Transfer risk - Arrange for others to accept potential loss.
4. Insure risk.
5. Hazard or risk protection - increase quantity and type of fire protection systems.
6. Any combination of 1-5.

Note: 1, 2 are preferred; 3, 4 less preferred; 5, 6 much less preferred options.

In commerce and industry it is reasonable to expect that the threat and potential losses can be reduced in a manner that is more dramatic than in an historic building. It seems that the preferred option for historic buildings could be a combination of 3 and 4 as little could be achieved to avoid or reduce the risk.

APPLICATION OF FIRE ENGINEERING

The most common application of quantitative or numerical techniques is to the design of components of fire safety. For example, warning systems, sprinkler systems, and smoke control systems. Some components cannot be calculated but can be organised rationally so that a positive contribution to fire safety is achieved. For example, the training of staff in fire safety matters and the arrangements for fire emer-

Diagram 1 : Stages of Fire Development

gency pre-planning [27]. The advantages of these activities can be quantified. For example, in trained hands the effectiveness of fire extinguishers is about 98% but in untrained hands a much lower value can be expected. The human and technological components of fire safety all have a special role as techniques of intervention in the fire threat sequence. The following list indicates the most effective location of the technique of intervention in the fire development sequence which is indicated in Diagram 1 [28]. If components before ignition were successful completely then there would be no need for any other technique to be installed.

Pre-fire: Stage (A)

- A1 Education and training of occupants and staff;
- A2 Surveillance of all areas especially valuable and vulnerable areas (manual or automatic);
- A3 Housekeeping (especially control of waste);
- A4 Salvage plan (post-fire contingency plan);
- A5 Hot work permit (control over workmen);
- A6 General maintenance of the building; and
- A7 Environmental monitoring (to sense unacceptable environmental changes).

Incipient Fire: Stage (B)

- B1 Monitor environmental temperature (especially temperatures above specified working temperatures but below ignition temperatures);
- B2 Detection of products of combustion (senses changes in chemical composition of atmosphere); and
- B3 Salvage (rescue of valuable objects).

Fire Growth: Stage C

- C1 Flame detection (provides very early fire detection but detectors need to be able to "see" the fire);
- C2 Smoke detection (commonplace but extremely important).
- C3 Heat detection (includes sprinklers);
- C4 Smoke control (all seven techniques, any technique could be useful);
- C5 Fire fighting (use of first aid fire fighting equipment);
- C6 Warning systems (selection of output dependent

on type of person(s) to be warned);

- C7 Information systems (signs, messages);
- C8 Escape systems (pathways and protected routes);
- C9 Emergency lighting (adequate and appropriate illumination essential);
- C10 Manual fire control (use of hose reels and attack by fire fighters); and
- C11 Passive fire control (non-combustible barriers limit spread of fire).

Fully developed fire: Stage D

- D1 Structural response (main, primary structural-members); and
- D2 Salvage in adjacent spaces (removal of valuable objects, protection of limited systems).

Each aspect of fire precautions has a unique contribution to make to overall fire safety in buildings. The A group of components are essential fire safety management. All other components (except salvage) have a hard engineering basis and the appropriate selection and installation of the systems' has a strong numerical element.

CONCLUDING REMARKS

Many components of fire safety engineering can now be engineered to produce a known performance with an acceptable level of reliability. The skill of the fire engineer will continue to be exercised in the selection of components to be installed or provided by rational, logical and systematic analysis of a real situation.

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