

1 THE PLACE OF FIRE SAFETY IN THE COMMUNITY

1.1 The nature of the fire hazard

The hazard of fire is the consequence of uncontrolled, exothermic chemical reactions, especially between organic materials and air. It is particularly associated with combustible materials and energy sources used by people in everyday life. Although fire threatens both life and property and its control occasions much expenditure, the hazard must be set against the benefit gained from these resources so that a balanced view can be obtained. Moreover, living standards are highly dependent on the use of buildings. The extra danger when fires occur in an enclosure, with the heat and smoke being trapped rather than moving relatively harmlessly upward, needs to be set against the intrinsic value of using buildings. It follows that one cannot, in general, eliminate fire hazard, although one can reduce it to an acceptably low level by suitable design procedures.

1.2 Interaction between fire hazard and other hazards

Fire takes its place alongside many other hazards in living. These include health hazards such as epidemics and sickness, industrial transportation and domestic accidents, as well as natural hazards such as earthquakes, floods, hurricanes, and so on. The fire hazard can of course be reduced by a severe restriction in the use of energy and combustible materials, but this could bring in its wake suffering and cost in excess of any alleviation of the fire problem. It could even give rise to conditions that prompt other hazards, particularly health hazards. There is a tendency for people who specialize in fire safety to look at the fire problem in isolation. One must be careful not to lose perspective in so doing, for example, with regard to the benefits that might ensue using a material or process that might incidentally impose an increased fire hazard.

This point is illustrated diagrammatically in Figure 1.1 (Rasbash, 1974). Risks are associated with the act of living. Some risks have to be taken, while others are taken voluntarily. Risks are taken to obtain a benefit, of which perhaps a notional measure might be denoted by A . Amongst the risks, there are those with fire, which may inflict a penalty of “detriment” of fire damage and hurt because of fire occurrence. These may be assigned a notional value of f_d (“d” for detriment). The fire danger requires a fire safety programme that inflicts a cost of f_c (“c” for cost). In the same way, other hazard scenarios inflict detriment h_d , and safety programme costs of h_c . The

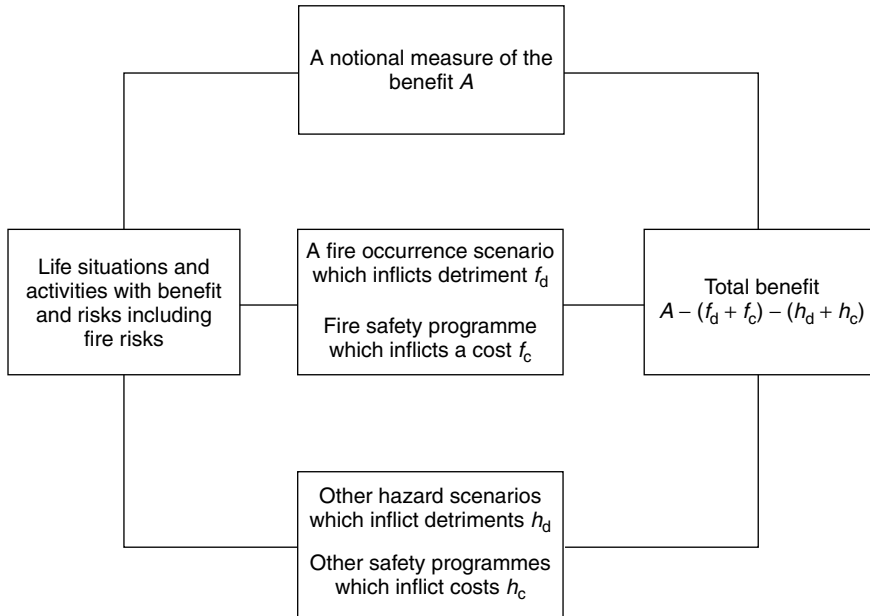


Figure 1.1. Fire safety in the community

object of any rational programme toward controlling fire safety should be to maximize the total benefit: $[A - (f_d + f_c) - (h_d + h_c)]$.

Two examples serve to illustrate this point. Insulation in houses saves energy and would thus increase A . Insulation, particularly on the inside surfaces of a room, is also known to increase the rate of fire spread even if the insulation is not combustible. The introduction of such insulation would therefore serve to increase f_d . Would $[A - f_d]$ be increased by the introduction of insulation? Many effective insulating materials are in themselves highly flammable. This tends to rule out their use on interior walls. It is normal in these circumstances to introduce a noncombustible layer on the inside wall with extra cost f_c . In this case, the relevant benefit is the change in value of $[A - (f_d + f_c)]$.

The provision of smoke stop doors is common in buildings, particularly in the United Kingdom. These of course occasion a certain cost that contributes to f_c . As long as they can be opened when necessary by people escaping a fire, such doors reduce the risk of death in the event of a fire and thus reduce f_d . But an extra cost that tends not to be brought into the equation is the inconvenience of having these doors scattered about buildings, particularly to those who have a physical handicap. There is a consequent reduction of the general benefit factor A , although in this case the reduction is difficult to quantify. This factor usually manifests itself by the doors being propped open much of the time, thus nullifying much of the reduction in f_d . Again, this can be overcome by having such doors held open and closed only following automatic detection of fire. This substantially increases the cost f_c .

1.3 Major fire hazard areas

Fires causing loss and damage can occur wherever human activity occurs. Perhaps the most frequent location for fires is within buildings. These include both domestic and nondomestic premises, and the latter can extend to a wide range of occupancy, such as factories of various

kinds, buildings where there are special risks to the public, including places of public assembly and places where people sleep, such as hotels and hospitals. Industrial occupancies extend beyond buildings to include mines, process plant housed in the open, offshore installations, agricultural crops, and forestry. Finally, there is a whole range of facilities for road, rail, marine, and air transport even extending in recent times to satellites and space modules. For most of these hazard areas, a considerable and costly fire occurrence background has built up over the years and has given rise to extensive requirements for fire safety. In the world of fire insurance, specific hazard areas are often called “risks.”

1.4 The total cost of fires

The total cost of a fire to a community may be represented by the sum ($f_d + f_c$) for all the fire risks in the community; this would include all buildings, plant, processes, means of transport, and so on. Many items contribute to the sum. With regard to f_d , the detriment produced by fires, we have, of course, the direct toll of life and injury and the actual financial losses caused by fire. There are indirect or consequential effects due to disruption of facilities, loss of trade, and employment. There is also public concern and anxiety, particularly following major disasters and the cost of any inconvenience caused. The cost of fire safety measures f_c includes costs aimed at preventing fires, controlling them when they occur, and mitigating their direct and indirect effects. They include the cost of services such as the fire brigade, fire insurance, and a substantial part of building control or other regulating procedures.

Information on the direct financial loss due to fires has been available in the United Kingdom since World War II. However, it was realized in the 1950s that this direct financial loss was only the tip of the iceberg since it is necessary to be concerned with the total cost of fire. An early exercise to deal with this matter was made by Fry (1964). He found that the direct fire loss in the United Kingdom when corrected for rising prices had remained relatively constant until 1957, although there were indications of an increase after that date. During the whole of the period covered, the direct financial fire loss represented about 0.2% of the gross national product. However, when some other costs of fire relevant to f_c were included, particularly incremental building costs and the costs of fire services and insurance, the total cost of fire to the nation was found to approach about 1% of the gross national product.

In an analysis for 1976, Rasbash (1978) added estimates of costs of indirect loss, fatalities, injuries, and inconvenience to f_d and of fire prevention to f_c . This increased the total value of ($f_d + f_c$) relative to the gross national product by 50%. The fire precaution costs were about twice as great as the cost of losses and hurt. This points to the necessity of being sufficiently discerning in fire safety design to ensure that the increase in the cost f_c brings about a comparable reduction of the expected detriment f_d . The estimated detriment in the Rasbash analysis did not include the cost of public anxiety, which is a major factor following the occurrence of fire and explosion disasters.

Since about 1980, Wilmot has collected data that provide a continuous overview of costs of fire precautions and fire detriment for a number of countries. These are summarized in Section 6.7.4.

1.5 Prescriptive and functional approach to fire safety

In the past, and indeed for the most part in the present as well, the provision of fire safety has been through enactments that have been prescriptive. This may be regarded as the traditional approach to fire safety. More recently, as test methods for performance of items of fire defense have become available, the entirely prescriptive approach to fire safety has become modified, in requiring that items of fire defense fulfill a performance standard. Moreover, there has been a

move in recent years from prescriptive to functional, that is, what is proposed can be shown to bring about sufficient safety from fire. This recognizes the multifaceted approach to fire safety and the demand for obtaining cost-effective fire safety. To achieve this it is necessary to specify not only the objective of the fire safety activity but also the degree of fire safety aimed for. There is a tendency for official legislation, at least in the United Kingdom, to be somewhat open ended in this matter. Thus, the Health and Safety legislation generally aims for the level of hazard to be “as low as reasonably practicable” (ALARP) while recognizing risk levels that are either negligible or intolerable. “Not reasonably practicable” may be defined as incurring costs in bringing about a reduction in risks that are seriously out of proportion to the benefits achieved by the reduction in risk (Royal Society, 1983). The relative value of f_c to f_d referred to in the previous section, would indicate that, at least for the United Kingdom as a whole, the level of fire safety reaches this standard. Building Regulations (England and Wales) now aim for some requirements to be for “appropriate levels of safety.” Nevertheless, insofar as the requirements are functional rather than prescriptive, the detailed way in which these aims are accomplished is left to the designer.

The difference between the prescriptive and the functional approach is that in the latter it is necessary to quantify the elements of fire safety, particularly how much “fire” can be expected, how much “safety” is being installed, and at how much cost. This helps ensure that money is spent on safety where it is most needed and the least costly regime of precautions capable of providing sufficient safety is put in place. It also helps to give flexibility to designers and to demonstrate that solutions to fire safety for a given risk are equitable and fair. This aspect will assume increasing importance as harmonization is sought on fire safety design between countries with different traditional approaches to fire safety. It has been the practice in the past to follow fire and explosion disasters by lurches of requirements for fire defense. A quantitative fire safety design procedure for complex plant and building hazards would be a major step in avoiding disasters in the first place. Currently, there is a move toward the functional approach to fire safety in buildings by defining the constituent elements to be expected of fire control and fire safety needs in buildings of a given hazard type and setting up performance standards for each of these elements (Bukowski and Tanaka, 1991). It is visualized that these performance standards would not require special expertise for supervision by a control authority.

There is a tendency, particularly in the reports of public inquiries following disasters, for a detailed range of prescriptive measures to be laid down to ensure the disaster “never happens again.” Much of this tends to become embodied in prescriptive requirements. However, this need not necessarily be the case. An example of a recommended scheme following a disaster, where the object was to give flexibility of design and management, is given in the Keane report into the inquiry into the Stardust disaster in Ireland (1982). This report indicated the way the hazard in public assembly buildings might be assessed and appropriate fire safety introduced to fit the hazard.

1.6 Purpose and outline of this book

The last few decades have seen the development of methodologies that will allow a designer to accomplish the change from a prescriptive approach to a functional approach to fire safety. It is the purpose of this book to provide a description of these methodologies. Part I deals with the structure of the fire problem and, in addition to this introductory chapter, contains in Chapter 2 a description of the fire safety system. This will outline the constituent and interdependent components of the system, particularly precautions for prevention, protection, and accommodation, concepts of fire safety design and management and the place of quantitative objectives in dealing with fire safety. The major input into fire safety are the lessons of disasters, lessons we continue to have to learn. Chapter 3 gives summaries of some recent fire and explosion disasters that have been studied in

detail and those lessons that are currently being absorbed into fire safety requirements. A range of prescriptive requirements for fire safety has been inherited from the past and will be outlined in Chapter 4. An appreciation of these is an important part of the functional approach to fire safety since usually the levels of safety they represent form a basis against which functional approaches to fire safety can be judged. Part II will be devoted to the data that are available for a quantitative functional approach to fire safety. Although Chapter 5 will outline recent physical experimental data, particularly on fire behavior and control, Part II will deal mainly with data from statistical sources on various aspects of fire safety. Part III – Methods of measuring fire safety – will describe the methods currently being developed to pursue the functional approach, particularly methods to quantify fire safety and measure it against objectives. This will feature deterministic, probabilistic, and stochastic methods as well as the use of logic diagrams in fire safety evaluation. The book does not discuss economic aspects. Topics such as cost-benefit analysis, consequential losses, value of human life, decision analysis, and application of Utility Theory, all in relation to fire, are discussed elsewhere (Ramachandran, 1998).

1.7 Definitions

It is desirable to set down the meaning of a number of terms that will be used frequently in this book.

First the word “fire.” Fires occur because sources of ignition come into contact with or develop within combustible materials. Most fires, of course, are wanted fires, since they are the most widespread way of making energy available for general use. As far as the context of this book is concerned, fires are mainly of interest where they extend beyond the point of origin to cause hurt, damage, expense, or nuisance. This would exclude wanted fires, unless they fall into the above category, and indeed those unwanted fires that do not extend beyond the point of origin to cause detriment in the above way. But the term is wider than those “fires that result in a call to the fire brigade,” which is often taken as a definition of the term “fire.”

The word “risk” has been defined as the potential for realization of unwanted negative consequences of an event or process (Rowe, 1977) or the chance of injury or harm (Cassell, 1974). Following this, “fire risk” may be stated as being the chance for injury or harm associated with the occurrence of fire, as defined above. It will be a major concern of this book to quantify the “chance” or “potential for realization” of the risk by characterizing the expected frequency of its occurrence against the severity of the consequences. The words “risk” and “hazard” are interchangeable in general usage. However, in recent years it has become accepted in the professional engineering world that the word “hazard” should cover descriptive definition of the dangerous situation and that the word “risk,” a quantification or estimation of the hazard. Thus the nomenclature of the Institution of Chemical Engineers (Jones, 1992) defines “hazard” as

“a physical situation with a potential for human injury, damage to property, damage to the environment or some combination of these.”

“Risk” is defined as

“the likelihood of a specified undesired event occurring within a specified period or in specified circumstances. Risk may be either a frequency (the number of specified events occurring in unit time) or a probability (the probability of a specified event following a prior event) depending on the circumstances.”

More briefly, a glossary of terms associated with fire (British Standard 4422, 1984) defines fire risk as the probability of a fire occurring and fire hazard as the consequences of the event if fire

occurs. It will be noted that there is a lack of coincidence between these two pairs of definitions. The latter pair also masks the fact that a fire, if it occurs, can have a whole gamut of possible effects ranging from a call to the fire brigade without damage to the destruction of a city. In this book, the assessment and quantification of fire risk will usually be visualized as the product of the frequency (F) with which fire occurs with each product of the probabilities (p_i) relevant to specific harmful effects (Ha_i) that may follow.

$$\text{Fire risk} = F(p_1 Ha_1 \dots p_i Ha_i \dots p_n Ha_n) \quad [1.1]$$

Equation [1.1] embraces both the above pairs of definitions for n harmful effects under consideration. It may not be possible to sum these harmful effects directly for two reasons. Firstly, they may not be expressible in similar terms, for example, number of deaths, direct loss due to damage, and public anxiety. Secondly, the specified harmful effects may overlap, for example, the chances that area damaged may exceed 100m^2 and 1000m^2 . Where the harmful effect is readily expressible as a mean value, particularly financial loss or areas damaged, then the fire risk can also be expressed as the product of frequency and the mean effect.

The above differentiation between hazard and risk will generally be followed in this book, but it will not be followed slavishly since, in the fire safety world, particularly the insurance world, there is an inherited tendency to use the words “risk” and “hazard” interchangeably and to use the word “risk” for a specific hazard area. The term “risk agent” is the name given to entities, particularly people, exposed to the risk.

The term “major hazard” has come into use to describe an activity, process, or a situation in which the consequences of an incident may be disastrous or catastrophic. The likelihood of such a disaster may be very small, although the public perception of the risk may be influenced by the catastrophic consequence. It is possibly as a counter to this that the professional engineering world has sought to discourage the use of the word “risk,” particularly in this situation, except as a quantitative statement of likelihood.

“Safety” is regarded in this book as the inverse, the complement or the antithesis of risk, that is, the lack of potential for unwanted negative consequences of an event, process, or activity. Assuming that air exists everywhere or cannot be rigorously excluded, there is a fire hazard and consequent risk wherever combustible material is present. There are thus very few situations indeed in which one can say that there is a complete absence of fire risk and that fire safety is complete. The quantification of safety will be approached through the quantification of fire risk associated with processes and activities. These may be said to be “fire safe” when a sufficiently low fire risk is associated with them. It should be noted that in this sense the word “safe” covers both a description of the harmful effects arising from the hazard and a quantification of freedom from these effects. For a given harmful effect Ha_1 , and assuming that F is substantially less than one per year, which is generally the case for frequency of fires in buildings attended by the fire brigade (Chapter 7), the safety for this harmful effect may be expressed as

$$\text{Safety}(Ha_1) = 1 - Fp_1 \quad [1.2]$$

This is the probability in a year that the harmful effect by fire will not occur.

An alternative definition of safety is

$$\text{Safety}(Ha_1) = 1/Fp_1 \quad [1.3]$$

This is the expected time interval between fires that brings about the harmful effect.

In the fire safety world, one frequently comes across the terms “fire prevention,” “fire protection,” “fire safety design,” and “fire safety management.” There is as yet no general consensus on the meaning of these terms, particularly the first two of them. Thus, the term “fire protection”

is often implied to cover all of the above terms. This is apparent in the activities of many organizations in this field known as Fire Protection Associations or Organizations. The term “fire prevention” is often used by Fire Services to cover all aspects of fire safety other than direct fire-fighting actions carried out by themselves. The British Standard Glossary of fire terms (British Standard 4422, 1984, Part 1) defines fire prevention as

“measures to prevent the outbreak of a fire and/or to limit its effects”

and fire protection as

“design features, systems, equipments, buildings or other structures to reduce dangers to persons and property by detecting, extinguishing or containing fires.”

It will be noted that the second part of the definition of fire prevention overlaps heavily with the definition of fire protection. The IChemE nomenclature (loc.cit) defines fire prevention as

“measures taken to prevent outbreaks of fire at a given location.”

and fire protection as

“design features, systems or equipment which are intended to reduce the damage from a fire at a given location.”

Specific meanings for these terms as used in this book, which are in line with the IChemE nomenclature, will emerge in Chapter 2, which will introduce the concept of fire safety as a system. The term “fire safety” itself is comparatively recent. It is used to cover all aspects of safety from fire. It is finding increasingly widespread use in this sense, although it is sometimes limited to safety of life only.

“Fire Safety Engineering” is a relatively new term used to describe the discipline concerned with the design and management of Fire Safety for situations in which hazards exist. Traditionally, the terms “Fire Protection Engineering” in the United States and “Fire Engineering” in the United Kingdom have been used. The term “Fire Safety Engineering” was adopted by the author, who found after inquiries that it was less confusing to lay people than “Fire Engineering.”

Symbols

A	A notional measure of benefit associated with risk situations
f_c	A fire safety programme that inflicts a cost
f_d	A fire occurrence scenario that inflicts a detriment
h_c	Safety programme other than fire, which inflict costs
h_d	Safety programme other than fire, which inflict detriments
F	Frequency with which fire occurs
p_1, p_i, p_n	Probabilities of specific harmful effects associated with fire
Ha_1, Ha_i, Ha_n	Harmful effects associated with fire

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