

# Reliable sources

Cost pressures mean that only a small proportion of the UK building stock is protected by sprinkler systems. **Craig English** and **Sam Bennett** show how probabilistic design techniques can be used to assess the benefits of sprinklers

**S**prinkler systems are arguably the most effective means of protecting buildings and their contents from fire. This, however, is not their only benefit: in attacking fires at source, sprinklers also provide significant life-safety and environmental benefits. Yet, despite these benefits, sprinklers are rarely provided in new buildings unless explicitly requested by fire safety guidance documents.

In theory, if a sprinkler system works there should be little or no need for passive fire protection measures. However, historical concerns regarding the reliability of sprinkler systems means only minimal reductions

in other fire safety measures are granted when they are used. Unfortunately, the cost savings afforded by reductions in other measures rarely equal the costs of providing a life-safety sprinkler system; hence the vast majority of UK buildings tend to be constructed without them.

Risk-based modelling techniques can be used to generate further reductions in passive fire-safety measures, and in doing so could significantly change the way developers, clients, architects and building control authorities think about sprinkler systems. In this article Monte Carlo simulations are used as part of a probabilistic approach to justify bigger compartment

## Fire safety

### Jargon buster

#### Event tree analysis

Event trees are a graphical representation of a problem with frequencies of occurrence attached to various branches.

#### Eurocodes

These are European-wide standards for structural design developed by the European Committee for Standardisation. They have been adopted by British Standards and replace and supercede the BS Design Code.

#### Fire compartment

A fire compartment is an area within a building, which is completely surrounded with fire-resistant construction.

#### Fire load

The sum of thermal energies that are released when all combustible materials (building contents and construction elements) in a space ignite.

#### Monte Carlo methods

These methods are a class of computational algorithms that rely on repeated random sampling to compute their results.





sizes when sprinklers are used in schools, assembly and recreation buildings, and manufacturing spaces.

A probabilistic approach requires calculation of the likelihood of a fully developed compartment fire occurring. For a compartment with and without sprinklers, this can be done relatively easily using event trees. Event trees assume fires will develop via a series of discrete stages and that each different stage will produce a number of subsequent events, such as: ‘fire burns out of its own accord’; ‘fire spreads beyond one material item’; and so on. The event trees used in this analysis are illustrated in figures 1 and 2. This analysis technique is comparative, so it is hoped that any inaccuracies in these simple event trees will cancel out.

### Heating conditions

The heating conditions within the fire compartment then need to be determined. This stage is more difficult to quantify, due to uncertainties in fire load quantities and the rate at which ventilation enters the room when glazed elements fail. In the case of windows, for example, the proportion of glass that shatters will depend on numerous factors – such as the thickness and type of glass, the type of frame and the quality of workmanship. Uncertainties like these can be addressed using Monte Carlo simulations.

### “ A probabilistic approach requires calculation of the likelihood of a fully developed compartment fire occurring ”

The main benefit with Monte Carlo simulations is that the embedded calculations are based on physical theory and experimental measurement. This helps compensate for a lack of information about real fires in a manner that other risk methods cannot. Furthermore, assumptions made within the analysis are explicit – which means that the sensitivity of these assumptions can be measured. This is achieved by changing the values for each variable, re-running the same set of simulations, and then comparing the new results with those originally generated.

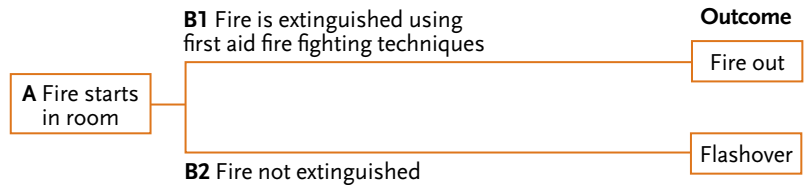


Figure 1: Illustration of fire development stages prior to flashover occurring in a non-sprinklered compartment

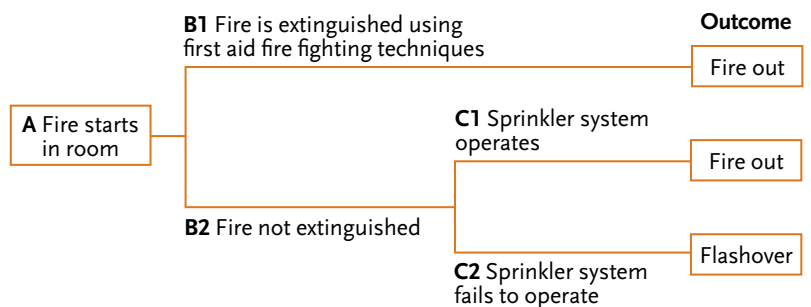


Figure 2: Illustration of fire development stages prior to flashover occurring in a sprinklered compartment

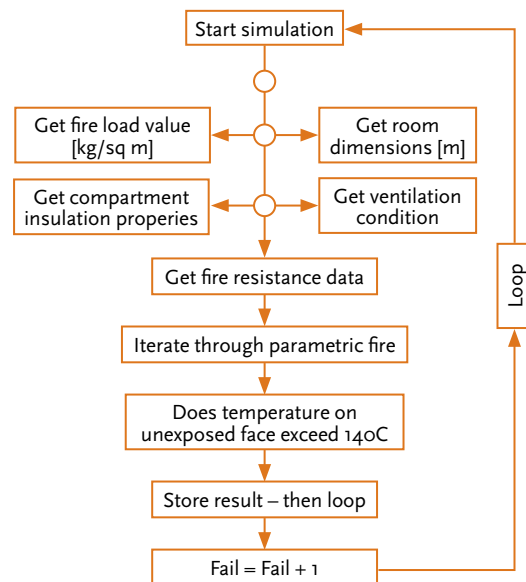


Figure 3: Illustration of Monte Carlo simulation process

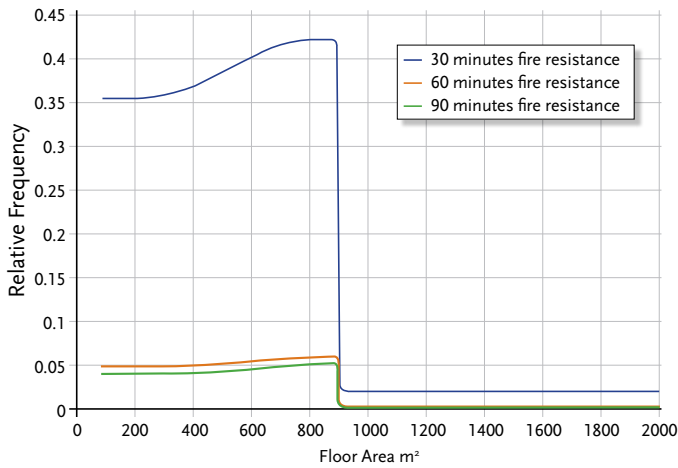


Figure 4: Schools – relative frequency of compartmentation failure

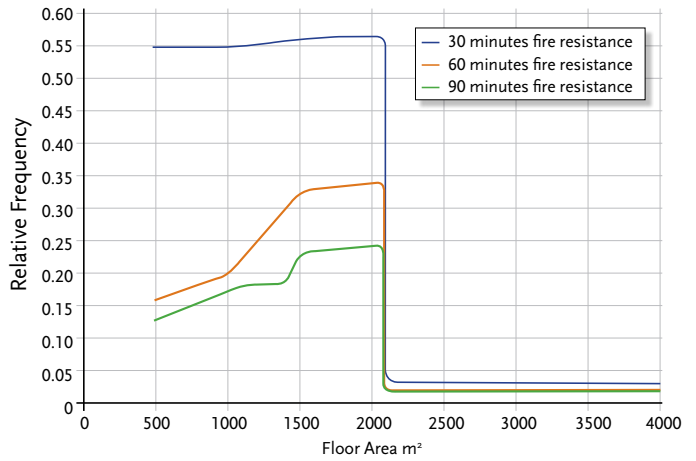


Figure 5: Assembly and recreation – relative frequency of compartmentation failure

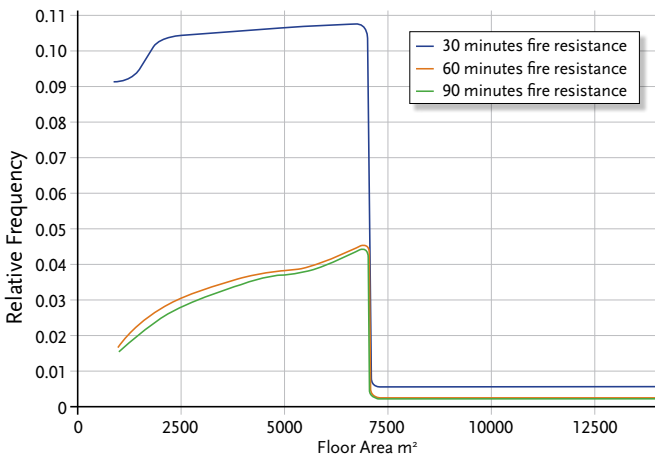


Figure 6: Manufacturing – relative frequency of compartmentation failure

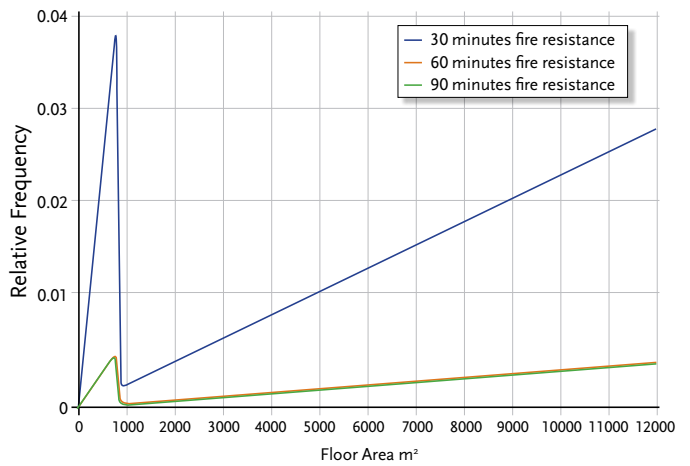


Figure 7: BB1000 – risk of compartmentation failure versus compartment size

**Updated guide from CIBSE**

A revised and updated CIBSE *Guide E*, on fire engineering, is available soon. Written by experienced fire engineers, it offers useful, practical advice on fire-safety engineering and covers the latest techniques. The new edition includes details on BS9999 and other recent developments. It also has two completely new chapters on performance-based design principles and the application of risk assessment to fire-engineering designs. The new edition of *Guide E* is due to be published in May. Call 020 8772 3618 or visit [www.cibse.org/bookshop](http://www.cibse.org/bookshop) for more.

> In these examples, the iterative parametric fire calculation in Eurocode 1-1-2 and the heat transfer calculations in Eurocode 3-1-2 were executed thousands of times using randomly selected values for fire load and ventilation. In the absence of statistical data, ventilation values have been assumed to increase linearly between the validated minimum and maximum opening values permitted in EC1. The simulation process is illustrated in figure 3.

**Compartments**

Fire-separating elements are considered to have sufficient fire resistance if, when subject to a controlled heating exposure [standard fire test], the temperature of the unexposed surface remains below an average temperature of 140°C [peak temperature of 180°C]. This laboratory type test is run for different time periods (30, 60, 90 and 120 minutes) depending upon the purpose of the fire-separating element and nature and size of the building in which it is to be placed.

Using the process outlined in figure 3, the frequency that a real fire (typical of that which may occur in the building) will heat the same fire-separating elements

beyond 140°C, can be measured. The data in figures 4, 5 and 6 show the relative frequency that a real fire will heat the unexposed surface of different sized, fire resisting compartments in different buildings beyond 140°C. A relative frequency of 1.0 means the compartment enclosure always fails. The break in the plots relates to the reduced risk of flashover when sprinklers are introduced.

As the floor area of the fire compartment increases, so will the frequency of fire starting. If this is factored into the analysis, the results given in figures 7, 8 and 9 are derived.

The graphs show that, for a school, the likelihood of a fire spreading from 800 sq m fire compartments, without sprinklers – but with a 60 or 90-minute fire-resistant enclosure, is the same as that for a 12,000 sq m compartment with sprinklers. It is noted that the design guide, *Building Bulletin 100: designing and managing against the risk of fire in schools*, calls for compartments with sprinklers to be no greater than 2,000 sq m.

Using the same approach, a 20,000 sq m compartment can be achieved in assembly and >

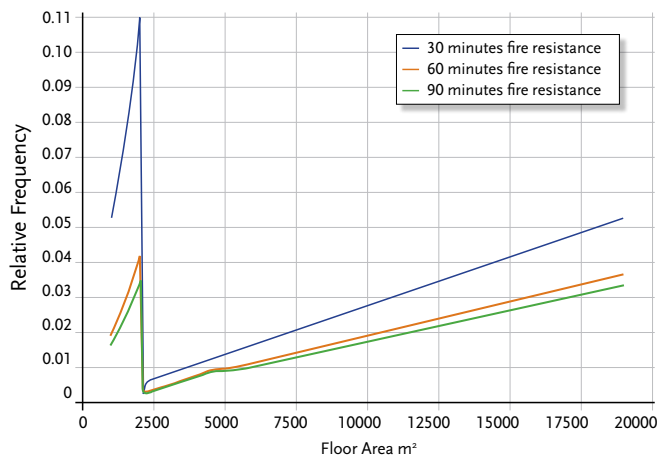


Figure 8: Assembly and recreation – risk of compartmentation failure versus compartment size

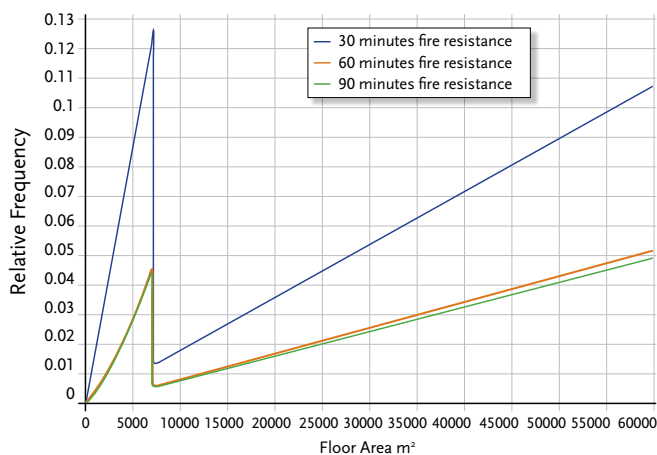


Figure 9: Manufacturing – risk of compartmentation failure versus compartment size

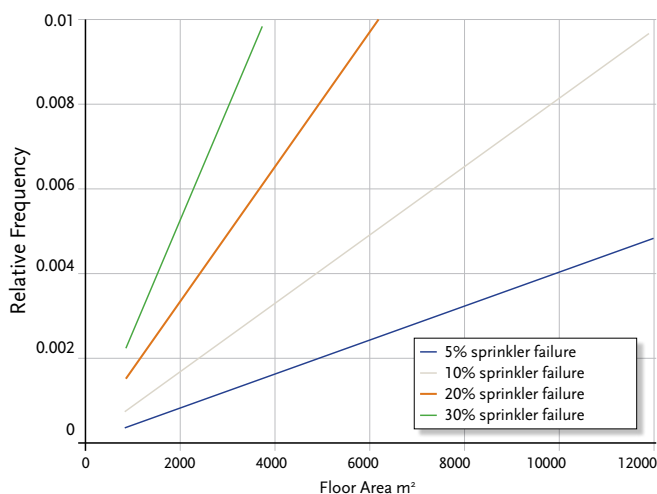


Figure 10: Risk of compartmentation failure versus sprinkler success rate – schools

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> recreation buildings with sprinklers. This is five times greater than the 4,000 sq m called for in Approved Document B. In manufacturing-type buildings, Approved Document B requests that compartments with sprinklers are restricted to a 14,000 sq m area, yet the graph indicates that a compartment size of 60,000 sq m could be reached before precise equivalency is attained.

The data in these figures assume that the sprinkler system will fail only five per cent of the time. Using Microsoft Excel, it's very simple to determine how the results will change when a higher sprinkler failure probability is used. The outputs in figure 10 show how the results generated for a school may change when the sprinkler system failure rate is increased to 0.1 [10 per cent], 0.2 [20 per cent] and 0.3 [30 per cent] for a 60-minute fire resisting enclosure. This means of accounting for reliability is one of the main benefits of using a probabilistic approach.

**Conclusions**

Current compartment sizes stem from the recommendations made in the *Fire Grading of Buildings Report* published in 1946. This publication does not thoroughly explain the thinking behind current area limits; however, it does state that 'a proper solution to the issue of compartment size limitation requires extensive statistical analysis and the data needed for such a study is not available at the current time'.

Sixty years on, robust statistical data still don't exist. However, the restriction this imposes on design is less severe. This is because computational, risk-based design approaches of the type described here can be used to generate statistical data via simulation.

Design techniques of this type are starting to gain widespread acceptance. For example, the BRE tool CRISP III, which uses a similar approach, was recently used to justify open-plan sprinklered apartments. In other studies, sprinklers have been used as a substitute for passive fire protection in low-rise steel-framed buildings and to derive new fire-resistance periods for UK buildings.

Probabilistic methodologies can be used to compare the performance of any fire engineered design. However, if used to promote the inclusion of sprinkler systems in buildings, by justifying significant reductions elsewhere, a sharp reduction in annual UK fire losses would most certainly result. ●

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