Fire Safety Engineering : Role in Performance-Based Codes

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ABSTRACT

Fire safety engineering provides one of the major ways of obtaining the benefits of performance-based codes and conversely, performance-based codes allow the much wider application of fire safety engineering and greater involvement in the design process.

However, the practice of fire safety engineering is hindered by the lack of agreed principles and methodologies. This is reflected in the reluctance of some approval authorities to accept fire engineered designs and the difficulties encountered in accrediting fire engineers. Various organisations have written or are writing documents to provide a basis for fire safety engineering assessments. The most comprehensive published document is the Fire Engineering Guidelines' which has been prepared by the Australian Fire Code Reform Centre. It provides guidance for both design engineers and those approving the designs for compliance with the performance-based codes.

This paper discusses the current situation with respect to the benefits of performance-based codes, the use of fire safety engineering to meet the objectives of such regulations and guidelines for fire safety engineering.

1. INTRODUCTION

The construction of buildings is becoming an international activity as multinational companies proliferate and national construction companies seek export and off-shore opportunities, particularly in the Asian Region. Likewise, countries with growing economies, which require rapid increases in the built environment, are looking internationally for the technology and expertise which more mature economies possess.

A paramount consideration, re-inforced by several tragic fires in multi-storey buildings in Asian countries in recent years, is the fire safety of the buildings constructed. In many cases, national building codes are either not suitable for modern multi-storey buildings or non existent. Furthermore, many of the buildings are designed and constructed by foreign companies, using foreign codes and building practices. The need or ability to comply with local regulations thus becomes an issue. With large complexes and unusual buildings, compliance with any prescriptive code is difficult or impossible and the buildings have to be 'fire engineered' to provide safety for occupants.

All of those problems lead to confusion, unnecessary expense, delays in construction and, in some cases, buildings of reduced safety. One solution would be to have a universal building code but, of course, this is impracticable and would not take into account legitimate local variations in requirements and building practice. Another, more practical approach, is the adoption of performance-based codes by individual countries and the application of fire safety engineering to meet the objectives of the codes. There is greater chance for compatible objectives for national codes (than prescriptive requirements) and fire engineering could readily cope with the differences.

This paper discusses progress with the introduction of performance-based codes around the world and fire safety engineering and its application to performance-based codes. In addition, the impediments to the wider use and acceptance of fire safety engineering are discussed and some comments made on future directions.

2. PERFORMANCE-BASED CODES

The primary aim of such codes is to provide a set of statements which provide rational goals for those designing fire safety for buildings. These goals are variously expressed as 'objective', `performance requirements', 'functional requirements', etc. which may or may not be quantified.

2.1 Advantages and Disadvantages

Performance-based codes are perceived to have many advantages in that they:

(a) Are less conservative and more cost-effective

(b) Yield cost savings by designing for a particular building
(c) Have greater flexibility
(d) Allow the use of new technology and materials
(e) Are suitable for large or unusual buildings
(f) Provide explicit objectives and performance requirements.

However, there are a number of disadvantages, viz:

(a) Increased design costs and time
(b) Greater expertise required by designers and fire engineers
(c) Greater expertise needed for those approving designs
(d) Less certainty of approval and greater time for approval
(e) The need for new tools, methodologies and a fire engineered approach to maximise the benefits.
(f) More care required in permitting changed usage of buildings.

Those disadvantages can be obviated by the inclusion of a prescriptive path in the performance-based code for those buildings where the benefits do not outweigh the cost of designing to the objectives or performance requirements.

2.2 The World Situation

The United Kingdom[1] was the first country to revise its prescriptive regulations. The Building Regulations 1985 comprised 23 pages of 'Functional Requirements' as opposed to 307 pages of prescriptions. Most of these prescriptions were included in appended 'Approved Documents' which indicate the minimum standards to demonstrate compliance. However, the opportunities for performance based design has been limited by the lack of performance requirements and verification methods.

New Zealand[2] introduced performance-based regulations in 1991 with the prescriptive requirements as 'Acceptable Solutions'. Again, the opportunities offered by this change have not been utilised to the extent expected, despite a heavy emphasis being placed on educational activities to support the change.

Sweden[3] revised its code in 1994 to a performance-based format which includes design criteria in each section. At the same time, the responsibility for proving compliance was transferred to the building owner from the fire service. This is said to have increased the opportunities for university educated fire safety engineering practitioners in the private sector.

Australia[4] published its national performance-based code in October 1996 and it is anticipated that it will be adopted progressively by the individual state governments from July 1 1997. The format is based very closely on the New Zealand code . The Building Solutions include the previous Prescriptive Requirements, with only minor modifications, as Deemed-to- satisfy Provisions'.

Canada[5] has developed a step-wise approach to the development and introduction of a performance-based code. The first step in the process, in 1998, will be a set of Objectives which reflect the intent of the present prescription requirements. The second step, in 2001, will be a restructure to embrace Regulatory Objectives, Functional Requirements and at least one 'Satisfactory Solution' in the form of an (existing) prescriptive requirement. It is expected that additional Satisfactory Solutions, reflecting new technology and products, will be added over a period of time.

Japan[6] is also considering how it can achieve the transformation to a performance-based code. Studies are being made of the present codes and the associated standards. This has lead to the recognition of a framework comprising Objectives, Functional Requirements, various standards and tools and design codes. It is expected that this framework will form the basis for future code change.

The USA[7] appears to be some distance from a national or even regional performance-based code because of the involvement of some 50 states and several private code-writing organisations. Recently, the three major organisations, BOCA, ICBO and SBCCI, agreed to develop a common (prescriptive) code by the year 2000 and it is thought that this will allow the ultimate development of a performance-based option for use along with the prescriptive code. In the meantime, two organisations, the National Fire Protection Association (NFPA) and the Society of Fire Protection Engineers (SFPE), have promoted the development of the performance-based approach through their publications and seminars[8]. The SPFE has been particularly active in fostering a 'conceptual model' for a performance-based building regulatory system and convened an International Focus Group which provided an impetus for further development.[9]

2.3 The Performance-Based Building Code of Australia

Prior to the publication of the performance-based BCA (BCA96[10]), the Australia code (BCA90[11]) was essentially prescriptive although, with amendments, about fifth of the BCA90 clauses were considered to be performance-based. BCA96 includes the existing BCA90 technical requirements, with a `performance hierarchy' built around them.

This performance hierarchy consists of four levels:

(a) The Objectives. These set out an interpretation of what the community expects from buildings. They are primarily expressed in general terms, and usually refer to the need to safeguard people and protect adjoining buildings or other property.

(b) The Functional Statements. These set out, in general terms, how a building could be expected to satisfy the objectives (or community expectations).

(c) The Performance Requirements. These outline a suitable level of performance which must be met by building materials, components, design factors, and construction methods in order for a building to meet the relevant functional statements and, in turn, the relevant objectives.

(d) Building Solutions which set out the means of achieving compliance with the performance requirements. The BCA96 provides for two pathways which can be followed to develop Building Solutions. These are:
   (i) Deemed-to-satisfy Provisions. These include examples. of materials, components, design factors, and construction methods which, if used, will result in compliance with the performance requirements of the BCA96. The deemed-to-satisfy provisions are, with minor variations, the prescriptive provisions from the BCA90.
   (ii) Alternative Solutions. An approval authority may still issue an approval if it differs in whole or in part from deemed-to-satisfy provisions described in the BCA if it can be demonstrated that they comply with the relevant performance requirement.

The four-tier performance hierarchy provides many opportunities for the use of Fire Safety Engineering. Indeed, because methods for carrying out a comparison with a 'Deemed-to-satisfy Solution' are not specified, Fire Safety Engineering assessments will be the prime means (other than Deemed-to-satisfy Solutions) for demonstrating compliance with the performance-based Code.

3. FIRE SAFETY ENGINEERING

Fire Safety Engineering is defined[12] by ISO/TC92/SC4 as:

"The application of engineering principles, rules and expert judgement based on a scientific appreciation of the fire phenomena, of the effects of fire, and of the reaction and behaviour of people, in order to:

(a) save life, protect property and preserve the environment and heritage.
(b) quantify the hazards and risk of fire and its effects.
(c) evaluate analytically the optimum protective and preventative measures necessary to limit, within prescribed levels, the consequences of fire."

This indicates that fire safety engineering uses information and expertise from a number of disciplines besides engineering, e.g. chemistry, physics, fluid dynamics and psychology.

The discipline of fire safety engineering has grown in terms of its capabilities, sophistication and breath of application as the underpinning science, methodologies and tools have developed over the last three decades. However, there is still much further research [13,14] needed for a fully quantified fire safety engineering approach to building design. In the meantime, a conservative approach coupled with the use of expert or engineering judgement is required. Engineering judgement is defined[12] as:

"The process exercised by a professional who is qualified by way of education, experience and recognised skills to complement, supplement, accept or reject elements of a quantitative analysis."
Unfortunately, the availability of recognised or accepted fire safety engineers to provide this expert judgement is limited in many countries. This lack is one of the factors limiting the acceptance of fire safety engineering and buildings which have been fire-engineered.

3.1 Fire Safety Systems

The prescriptive codes are essentially comprised of a multitude of requirements which attempt to specify all the different components of the system which provides fire safety for a building. However, the contribution of each requirement to the level of safety provided by the system is not known and the interactions between the components are not generally known or taken into account. These inherent deficiencies lead to lack of flexibility, conservative outcomes and unnecessary cost burdens.

Fire safety engineering has the ability to consider the system as a whole by focussing on the objectives whether they be life safety, property loss, business interruption, environmental damage or heritage preservation. Furthermore, given that a fire safety system can be broken into sub-systems and sub-system components, fire safety engineering can quantify the inter-relationships, interdependencies and the consequences with respect to the overall objective(s). The way in which the Fire Safety System is split into subsystems may vary according to the demands of the assessment and various ways have been put forward.[10,15-18]

The assessment can be done at various levels ie, the component, subsystem or system level, using a deterministic and/or a probabilistic approach. Assessments of individual components are generally simplistic and akin to the `equivalence' variations which have traditionally been used to meet prescriptive regulations. Consideration of one or two subsystems, such as 'smoke development and management' and 'occupant avoidance', their interaction and consequent effect on life safety is the most common type of assessment carried out.

To date most assessments are done using deterministic tools and do not take into account the probability of events occurring and do not quantify the actual level of safety (or expected risk to life) which a particular design will deliver. The ultimate aim is to have validated methodologies which are risk-based, integrate deterministic tools and address the fire safety system as a whole. The Australian Fire Engineering Guidelines[18] provides for assessment at different levels and both deterministic and probabilistic methodologies.

3.2 Application of Fire Safety Engineering

As indicated above, fire safety engineering is the most appropriate way of carrying out assessments to the objectives of a performance-based code. Indeed, it might be argued that it is the only legitimate approach because it considers the whole system and utilises basic fire science, the behaviour of people and the many methodologies and tools which have been developed on the basis of these disciplines.

However, fire safety engineering has many other uses:

(a) Identifying those Deemed-to-satisfy Solutions and fire safety systems which have the greatest impact on life safety and/or are the most cost-effective.
(b) Justifying alternatives to individual Deemed-to-satisfy Solutions.
(c) Developing 'rules' for the trade-off of various fire safety measures.
(d) Assisting in the transition from prescriptive to performance-based codes by analysis of the performance implicit in the prescriptive requirements.
(e) Developing quantified Performance Requirements.
(f) Developing more soundly based Deemed-to-satisfy Solutions.
(g) Assisting in the management of fire safety for a building during its life time, taking into account changes of building use.
(h) Identifying research and data needed for the attainment of better performance-based codes.
(i) Assisting in the development of issues beyond the scope of Building Codes, e.g. cost-effectiveness and insurance underwriting.

3.3 Advantages and Disadvantages

The fire safety engineering approach to building design has many advantages over the prescriptive approach, many of which result from the applications of fire safety engineering listed above:

(a) The ability to quantify Objectives and Performance Requirements in terms of life safety, cost effectiveness etc.
(b) The provision of less conservative and more flexible designs, unconstrained by prescriptive requirements.
(c) The ability to design for large, complex or unusual buildings which are not amenable to prescriptive provisions.
(d) The facilitation of the use of new technology, materials and building design.
(e) The provision of a more disciplined and structured approach for designers.
(f) The facilitation of a universal approach to design irrespective of national regulations and practices.

Many of the advantages of fire safety engineering are shared with performance based codes and this demonstrates the synergy that is available by the use of fire safety engineering and performance-based codes together.

Of course, there are some disadvantages to using fire safety engineering:

(a) The lack of agreed principles, methodologies and tools to exploit the benefits of fire safety engineering to the full.
(b) The absence of accreditation processes for practitioners to ensure high professional standards and to engender confidence in and credibility for the professional.
(c) The lack of education available on the principles and practice of fire safety engineering.
(d) The increased cost and time involved in carrying a fire safety engineering design compared with the cost and time of following the provisions of a prescriptive code.
(e) The difficulties and time involved in gaining approval from regulatory authorities for fire engineered designs.

Again, some of these disadvantages are shared by performance-based codes and will be ameliorated by the development of better and more sophisticated codes. The next section discusses activities which are currently being undertaken to reduce some of the problems listed above.

4. GUIDELINES AND STANDARDS FOR FIRE SAFETY ENGINEERING

Most countries that have introduced performance-based codes, have found the need to produce guidance for designers and approval authorities, especially with regard to the methodologies which might be used for fire safety engineering of building fire safety systems. In addition, various international organisations, with a particular interest in fire safety, have recognised the potential for fire safety engineering and the need for guidance to foster its development.

In the United Kingdom,[1] the guidance documents (Approved Documents) that were published to support the performance-based code, are essentially the previous prescriptive requirements together with some performance requirements and a few verification methods. However, it was recognised that greater guidance was necessary to support a fire engineered approach to satisfying the objectives of the code. This realisation has resulted in development of a 'Draft Code of Practice for the Application of Fire Engineering Principles to Fire Safety in Buildings' published by the British Standards Institution[17]. This document uses subsystems of the fire safety system for analysis and design which are based on the Draft National Building Fire Safety Systems Code (NBFSSC) developed in Australia[6] in 1991.

New Zealand has published[19] the New Zealand Fire Engineering Design Guide' for engineering calculations for performance-based designs. However, it does not provide comprehensive guidance nor a systematic methodology for fire safety engineering.

Sweden is said[8] to be developing a guidance document similar to the U.K. Code of Practice and the New Zealand Design Guide.

Australia has published[18] (in March 1996) a "Fire Engineering Guidelines" document well in advance of the publication of its performance-base code, BCA96. This document, prepared by the Australian Fire Code Reform Centre (FCRC), provides a benchmark for good Fire Engineering Design. It is recognised by the Australian Building Codes Board, the organisation responsible for BCA96, those bodies involved in the approval process, viz. The Australasian Fire Authorities Council and the Australian Institute of Building Surveyors, as well as the Institution of Engineers, Australia which accredits fire safety engineers.

The Canadian objective-based code is some time away but it is envisaged[5] that supporting documents will include a methodology for evaluating alternative solutions for the performance objectives.

There appear to be no design guidelines, comparable with those discussed above, being produced in Japan or the USA. This reflects the status of the development of performance-based codes discussed above. However, the American SPFE intends[9] to develop an 'Engineering Guide'.

Of the international organisations involved in fire safety engineering, the International Organisation for Standardisation Committee ISO/TC92/SC4, "Fire Safety Engineering", has the most extensive range of activities related to the development of guidance for fire safety engineering and its application to building codes. The committee is developing a series of Technical Reports[12] to produce a scientifically based fully developed engineering package that can be applied in a cost effective way to the design and management of buildings.

The International Council for Building Research Studies and documentation (CIB) has promoted fire science and engineering for many years and currently[20] has many international experts involved in four projects designed to underpin fire safety engineering:

(a) Engineering Evaluation of Building Fire Safety.
(b Assessment and Verification of Computer Codes for Predicting Fire Development and Smoke Movement.
(c) Assessment and Verification of Computer Codes for Predicting Thermal Performance of Structures.
(d) Interlaboratory Calibration of Fire Growth Measurements.

5. FUTURE DIRECTIONS

As indicated in the discussion in the sections above, there remains much to do in the development of performance-based codes and fire safety engineering. Many of these activities are common to the needs of both the codes and the engineering discipline because of the synergy between the two.

For performance-based codes there should be:

(a) Further development of Objectives, Functional Statements and Performance Requirements along with new Design Solutions and Verification methods. These should reflect the need for consideration of the fire safety system as a whole and the interactions and inter-relationships of the sub-systems.

(b) Opportunities to foster compatibility between national codes, especially with regard to the objectives, to allow for international design and the universal use of fire safety engineering.

(c) Greater use of fire safety engineering, not only for assessing designs to code Objectives and Performance Requirements, but also, in the development of Alternative Solutions and improved Deemed-to-satisfy Solutions.

For Fire Safety Engineering there should be:

(a) The development of more sophisticated methodologies, recognised internationally and their integration with architectural design methodologies.

(b) Development and verification of more tools and associated data bases to lessen the need for expert judgement which currently `fills the gaps'.

(c) The production of design standards to enable the wider application of the fire engineered approach by practitioners in general.

(d) The upgrading of existing and writing of new `Guidelines' documents with a view to fostering international compatibility of fire safety engineering assessments.

(e) More widespread accreditation of practitioners.

However, despite the deficiencies indicated above, performance-based codes, complemented by fire safety engineering, provides the way ahead, not just for better building design, but for the amelioration of all the consequences of fire.

In the short term, fire safety engineering will only be used for the design of a small percentage of buildings, say 5-10%, with prescriptive requirements, albeit improved by the application of fire safety engineering studies, providing for the remainder. However, in the long term these prescriptive requirements will be replaced by fire-engineered design standards so that all buildings will be designed using fire engineering principles.

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