
1.1 Purpose

Accidental fires are a threat to human life (Figure 1.1), property and the environment. Fire engineering design can reduce these threats in a cost-effective way for the benefit of society.

Fire engineering design of buildings and other structures is a large, complex and rapidly expanding multi-disciplinary subject area which extends well beyond the scope of this Fire Engineering Design Guide.

This Guide introduces fire engineering design and provides basic strategies and design information supplemented by some worked examples. It is not a stand-alone document and should not be used without referring to supporting texts that are recommended at the end of each chapter. This will be a useful starting point for those who wish to become professional fire engineering designers through a combination of further education, design experience and fire investigation. In particular, this Design Guide provides introductory guidance to those wishing to carry out or review specific fire engi-



Figure 1.1: The worst fire disaster in New Zealand was the 1947 Ballantynes fire in Christchurch where 43 people died (photo courtesy of The National Library of New Zealand)

neering designs. The worked examples provided throughout the text are simple hand calculations and it is likely that more complex analysis will be required in real fire engineering design. Numbers used in the worked examples are selected to illustrate the calculation method and are not intended to be definitive or recommended for a particular purpose.

1.2 Performance-based Design

Performance-based fire engineering design is being adopted around the world as a rational means of providing efficient and effective fire safety in buildings. This development is being supported by the adoption of performance-based codes which specify the objectives and minimum performance requirements for fire safety, and allow those objectives to be met in a variety of ways, provided that safety can be demonstrated.

Traditional design for fire safety, which is still practised in many countries, relies on 'prescriptive' codes which specify how a building is to be built, with no statement of objectives and little or no opportunity to offer more rational alternative designs.

Most modern performance-based codes have a clear statement of objectives, and allow those objectives to be met either by compliance with a prescriptive 'acceptable solution', or by specific fire engineering design. New Zealand has had a performance-based building code since 1992. This Design Guide is based on the building control system in New Zealand (Buchanan, 1994) which is very similar in many other countries, for example Australia (ABCB, 2007), Sweden (SBHBP, 1994) and England & Wales (HMSO, 2000). In the USA, several regional building codes have been combined into a national code which is moving towards a performance-based approach (ICC, 2006).

1.3 Regulatory Environments

New Zealand

The Building Act was first passed into law in December 1991. This Act consolidated a wide range of previous legislation relating to building construction, established the Building Industry Authority and required that all new construction be in accordance with the Building Code.

The Act makes it clear that, with due regard to costs and benefits, the principal fire safety objectives are for the health and safety of the building occupants, protection of neighbouring property and facilitating rescue and fire fighting operations by the New Zealand Fire Service.

Protection of property, including the building structure and contents and tenants' property, are not included in the legislation. If design for property protection is considered necessary, the designer must establish any additional performance requirements beyond those required by the Act and the Building Code.

The New Zealand Building Code (NZBC), included in the Building Regulations, is a

performance-based code that specifies objectives and performance, permitting compliance to be achieved with an approved Compliance Document. The Compliance Documents contain at least a Verification Method (such as a structural design code) or an Acceptable Solution. There are no approved Verification Methods for fire safety, so an Acceptable Solution must be used. The Acceptable Solution is a prescriptive method of meeting the requirements of the Building Code. For many small or simple buildings, design in accordance with the Acceptable Solution will be satisfactory. Even in those cases where additional requirements are established or where specific fire engineering design is intended, it is likely that the Acceptable Solution will be used as a starting point.

The Building Act allows ‘alternative solutions’, such as specific fire engineering design, where the Building Consent Authority is satisfied on ‘reasonable grounds’ that the performance provisions of the Building Code can be met. Note that the provisions of the Building Code are generally non-quantitative, so designers will need to be guided by experience, training and engineering judgement (as defined in IFEG (ABCB, 2005)).

Chapter 18 gives a more detailed description of the regulatory framework in New Zealand.

Australia

Unlike New Zealand, Australia has a wide range of legislation, which varies considerably from State to State. The key element in each State or Territory is a form of building act which provides the enabling legislation for building regulation and control in that particular State or Territory. The legislation typically provides each State and Territory with control over:

- planning provisions;
- project approval procedures;
- adoption of the Building Code of Australia (BCA) and State Appendix into legislation;
- appeal mechanisms;
- registration of Building Practitioners; and
- preparation and distribution of Regulations.

The Government departments or authorities responsible for the administration of the building Acts also play a public and industry education role.

All states and territories have one or more Fire Brigade Acts which control the role, management and operations of the fire brigades in their State. Key roles defined by the Fire Brigade Acts around Australia include:

- fire fighting operations;
- building fire safety inspections;
- community fire safety;
- input to Government policy and fire safety administration; and

- building approvals process.

In Australia, the acceptable solutions are known as ‘Deemed-to-Satisfy’ provisions. They are the prescriptive provisions that are deemed to satisfy the performance requirements of the Building Code of Australia.

Chapter 17 gives a more detailed description of the regulatory framework in Australia.

1.4 Specific Fire Engineering Design

Specific fire engineering design can be used when:

- (a) the Compliance Documents are not applicable; or
- (b) the Compliance Documents require specific fire engineering design; or
- (c) the owner’s requirements go beyond those of a building code; or
- (d) additional benefits in cost or safety will result from specific design.

Quantifying performance

There are no simple methods available for quantifying building performance or safety in a possible fire. The performance requirements of a building code are generally qualitative, not quantitative. In the final analysis, the acceptance or not of performance requirements is a matter of opinion by those who are best equipped to make such a judgement.

Several aspects of fire engineering can be calculated with reasonable accuracy, but others can only be roughly estimated or require subjective judgement. There is no overall framework that allows a single figure to be placed on safety.

Methods for fire safety evaluations of buildings using risk assessment are under development. Fire design guidelines based on or including risk assessment have been produced in Australia (FCRC, 1996), Canada (Yung et al, 1997), Sweden (Frantzich et al, 1997) and USA (Fitzgerald, 1993). Other risk assessment methodologies are under development.

Owner’s requirements

At an early stage in the design process, it is essential to establish the performance requirements for the building. These will be established by the owner in consultation with the designer, the owner’s insurance company and any other relevant stakeholders. Each case should be assessed on the basis of the proposed use (and future uses) of the building and the likely impact on the building’s owner if a fire occurs.

The performance requirements must meet the minimum requirements of a building code, which in some cases will be the basis for more extensive protection. Any fire engineering design solution should be checked to ensure that the minimum requirements of a building code are met.

1.5 Design Considerations

Factors influencing the performance required from a specific fire engineering design include:

- building geometry and intended use;
- location of adjacent properties;
- probability of a fire occurring;
- fuel load and distribution;
- number, location and abilities of occupants;
- proximity and likely response of the fire service;
- available water supply; and
- building management practices that affect fire safety.

1.6 Compliance Schedule in New Zealand

The Building Act requires certain fire safety systems in buildings to be subjected to regular inspection, maintenance and reporting procedures. A Compliance Schedule is required for each new building, to be provided by the designer as part of the documentation package. The Compliance Schedule details the required maintenance of specific systems in the building including automatic sprinkler systems, fire doors, fire alarm systems, emergency lighting, escape route pressurisation systems, riser mains for the fire service, signs, means of escape from fire and fire hose reels.

Inspections and maintenance will generally cover complete installations, appropriate to the type of system and the consequences of system malfunction. The Compliance Schedule is valid for the first 12 months the building is occupied. After that time a certificate must be displayed in the building, called the Building Warrant of Fitness, to be renewed every 12 months. This is the responsibility of the building owner, who hires an Independent Qualified Person (IQP) to perform the inspections.

Fire safety depends on successful operation of active fire protection measures at any time in the life of a building, which may be 50 or 100 years or more. Provision must be made for regular maintenance, good housekeeping, and checking of all systems, both active and passive over the life of the building.

Certain active systems will be checked regularly within the Building Warrant of Fitness scheme, but some others such as passive systems and housekeeping matters are not covered. Special monitoring must be provided if the specific fire engineering design has placed limitations on the use of the building, such as restrictions on the type of furniture, storage height of goods, number of occupants or access through adjacent rooms for egress. The use of management procedures and the Compliance Schedule to overcome issues of design needs to be carefully thought through and not left to building management and those who have no knowledge of the requirements or implications of

not ensuring that they are adhered to.

The Building Act also deals with buildings deemed to be dangerous in respect of fire and egress, and suggests that the Building Consent Authority seek advice from the New Zealand Fire Service. The New Zealand Fire Service will also be assessing buildings under the Fire Safety and Evacuation of Building Regulations 2006, which will, to some extent, address passive systems and housekeeping matters.

In Australia, maintenance of fire protection systems has become a significant issue through use of Essential Services Legislation (see Section 17.8).

1.7 Insurance and Building Design

Insurance has a number of areas relevant to building design and construction:

- loss or damage to the project and lost profits during the construction and defects liability period;
- liability for loss, damage or interference with surrounding property;
- marine cargo covering the transportation of goods, plant and machinery from all around the world to the project site;
- professional liability of designers and certifiers or others rendering a professional opinion or service; and
- post-construction insurance of the building and contents, and loss of use or increased cost consequential upon damage.

The insurance market operates as a series of segments, each specialising in a class of insurance. For example, it is very likely that insurance for each of the above areas of risk will be provided by a quite different market segment or individual insurer. In most cases, each will be negotiated at different times. Negotiations will most likely be via an Insurance Broker whose function is to place the insurance with an underwriter or series of underwriters.

The loss, damage or liability areas involve insurance of the asset itself during construction and of the liability for harm suffered by other parties consequential to construction. These insurances need to be negotiated and in place prior to commencement of the contract. An important issue to insurers who offer such insurance cover are the fire protection arrangements during construction, e.g. floor-by-floor extension of riser mains, progressive enlightenment of sprinklers and fire prevention activities such as control of flammable liquids, 'hot work' and site tidiness along with separation from adjoining buildings.

Marine cargo covers are intrinsically linked with the conditions of purchase. These conditions will establish who is responsible for the goods and when this responsibility changes hands. Their relevance is primarily the building contractors concern, but in industrial projects where large items of machinery are being imported, cognisance of purchase agreements and marine cargo insurance are necessary to ensure an efficient

over all project programme.

The professional liability category is insurances taken out to defend and settle claims against an individual or firm for failure to fulfil an obligation or a legal duty, whether statutory or contractual. Such insurances are likely to be general and not specific to a particular building. The key issues to an insurance company offering this type of cover will be the competency of those individuals providing the service (including their 'quality system' practices) and the extent to which the services provided reflect conventional or innovative technology or design.

As a general rule, insurers are most comfortable when on familiar ground and may require additional information (and premium) if, for example, a first principles design is envisaged. To the extent that building failure can lead to personal injury or death, this risk exposure is considerably modified in New Zealand by the Accident Rehabilitation and Compensation Insurance Act, which substantially denies the right to sue for compensation for personal injury arising from accident.

Post-construction insurance will be purchased typically by both the owner and the tenant, close to the end of the contract. Handover from construction insurance to operating annual insurance needs to be seamless or at least with a time gap and generally occurs when partial or practical completion is reached. Sufficient notice needs to be given to the principal of impending practical completion so that they may arrange the operating insurances.

Only where the building is one of a group of existing buildings owned and insured collectively is there much likelihood of the designer being able to discuss fire protection arrangements with certainty with the insurer. Nevertheless, the insurance market across the board has a number of design preferences which apply to most buildings. By incorporating these features, the designer will ensure that the operating insurances will be able to be negotiated from a favourable basis. Important design preferences include:

- Automatic sprinkler protection of the whole building in accordance with NZS 4541 (Standards New Zealand, 2007) or similar Standards like NFPA or Factory Mutual Standards (where compliance is with NZS 4541 as amended by the New Zealand Building Code this may be of interest to insurers).
- Low combustibility walls and cladding systems (the use of insulated panel systems needs special consideration).
- Non-combustible roofs.
- Adequate water supplies to and around the site.
- Internal subdivision in fire resisting construction and fire doors on the openings, particularly in tall buildings.
- In large buildings (even with sprinklers), the size without subdivision by fire walls will be a factor because of the accumulated value of the buildings contents and impact on continued business operations.
- Fire sealing of openings for reticulation of services and gaps between floor slab

edges and outer facing walls.

Where possible, insurers should be consulted early in the design process to enable property protection requirements to be considered for incorporation into the overall design and to reduce the risk of costly retrofitting of protection measures.

The insurance market moves in cycles, typically five to seven year periods. During 'hard' markets, available capacity is low and pricing is high. Insurers are also more selective. In this situation good built-in protection can be beneficial in controlling price and obtaining capacity. In the 'soft' part of the market cycle insurers will not be so forthcoming with individual premium costings. Most buildings will outlive several insurance market cycles, hence the need for a mature, rather than minimalistic, view of the required fire safety.

1.8 Design Documentation

It is essential that fire engineering designs be well documented in a rational and consistent manner (Caldwell et al, 1999). Documentation should include the acceptance criteria that were agreed to by all the stakeholders involved in the design. Every design submittal should be a written report including:

- 1 The name and credentials of the person with overall responsibility for the fire safety design, including co-ordination between various trades.
- 2 The name and credentials of the person or persons doing the actual fire safety design.
- 3 A statement of design philosophy including at least:
 - (a) The performance requirements forming the basis of the design.
 - (b) The differences between the performance requirements and those of a building code.
 - (c) The overall strategy for meeting the performance requirements.
 - (d) An overview of the fire engineering analysis.
 - (e) A summary of the building design and fire protection features.
 - (f) Assumptions about the long-term life and use of the building.
- 4 A clear description of the fire scenarios considered, and why they were used.
- 5 Assumptions regarding performance of the fire service.
- 6 Calculations which provide sufficient information for the entire procedure to be followed clearly and precisely, with references for all equations and assumptions. References should only be to literature that has been peer reviewed. Copies of important references may be included as an appendix.
- 7 Full details of any computer input, and a summary of the output with graphs rather than numerical print-out. Actual print-out can be included in an appendix.
- 8 A statement of any inspection procedures necessary on site.

- 9 A schedule of the drawings and specification which form part of the fire design package, including applicable drawing numbers and dates.

The submittal should include adequate contract drawings showing the fire safety requirements. These may be separate fire engineering drawings or suitably marked architectural drawings. The drawings must be consistent with the written report and the specification.

The written specification for the contract must support the requirements shown on the drawings. There should be a separate fire section to provide overall information, including references to the drawings and cross reference to all other sections of the specification which have fire related material. Inspection procedures should be included.

A detailed methodology for presenting fire engineering designs and documentation is given in the International Fire Engineering Guidelines (IFEG) (ABCB, 2005), described in Section 18.6.

1.9 Peer Review

All fire engineering designs in New Zealand are subject to review. This may be an in-house review by the Building Consent Authority (for example, a City Council), or it may be a peer review by other consultants, especially if the approving authority does not have sufficient expertise. It is important that peer reviews be carried out in a professional manner, be well documented and consistent across the country (Caldwell et al, 1999). Essential documentation for fire review reports includes the following:

- 1 The name and credentials of the person carrying out the review.
- 2 The reviewer's association with the designer and any possible conflict of interest.
- 3 Confirmation of the design philosophy used by the designer.
- 4 A statement of the basis on which the design is accepted or rejected:
 - (a) The design is an 'acceptable solution' that meets the prescriptive requirements of a compliance document, or
 - (b) The design is an 'alternative solution' based on fire engineering principles, accepted on the basis of:
 - i. Evidence by analysis or otherwise that the design meets the performance requirements of a building code; or
 - ii. Evidence by analysis or otherwise that the design is equivalent to the prescribed acceptable solution; or
 - iii. Some other criteria.
- 5 A statement as to whether the whole design process has been checked, or just the design solution.
- 6 Expression of concerns about any of the steps in the design procedure, even if the design solution appears to be acceptable. For example, if computer modelling was inappropriately used, even if it had no effect on the final outcome.

- 7 Any additional analysis recommended.
- 8 Confirmation or modification of any inspection procedures necessary on site.
- 9 Confirmation of the schedule of dated drawings and specification which form part of the fire design package that was reviewed.

In Australia, the review is generally undertaken by the Certifying Building Surveyor, although, like other engineering disciplines, the surveyor may call upon or ask for further evidence of compliance from a peer reviewer.

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