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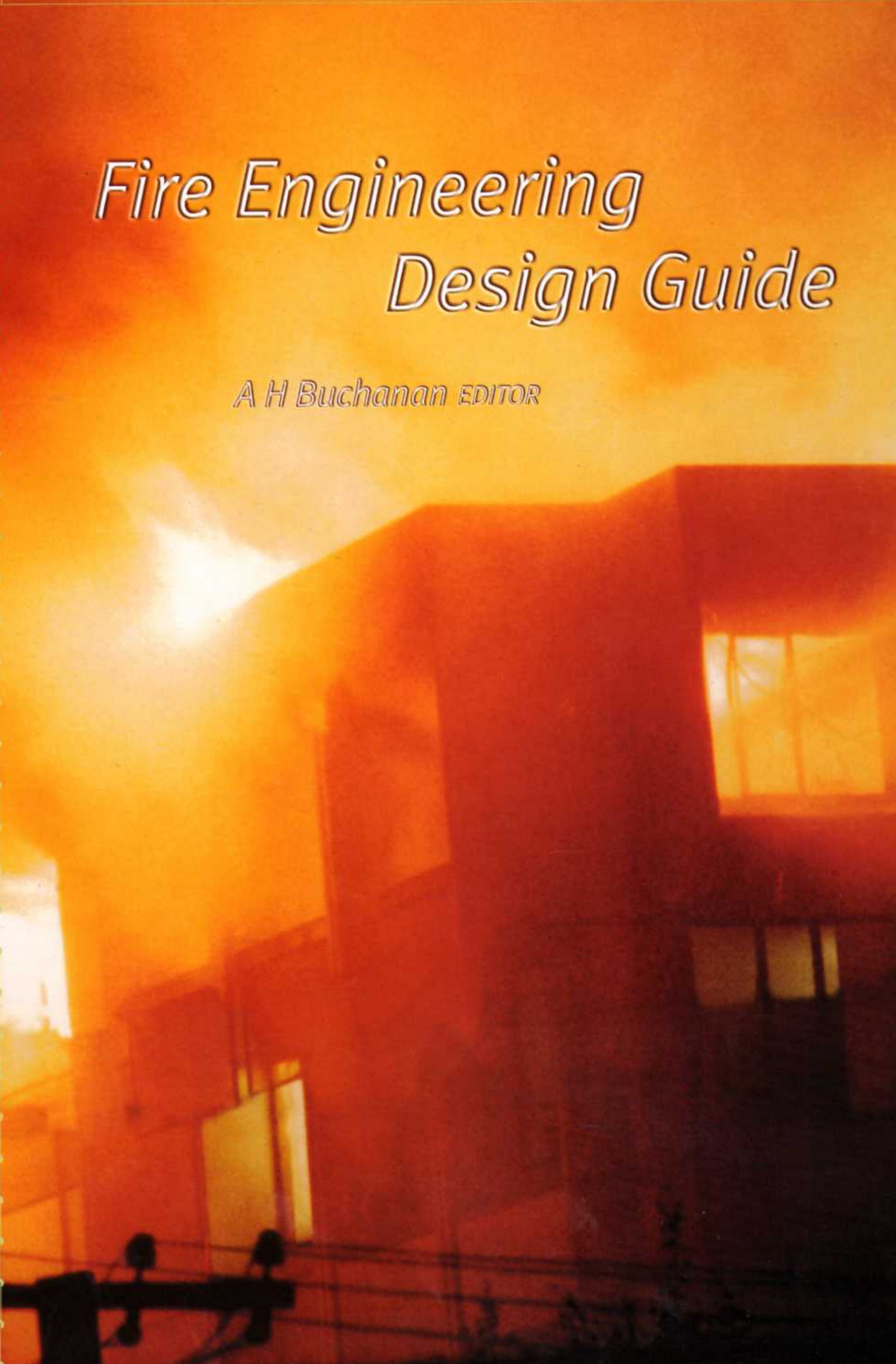
Fire Engineering Design Guide

A H Buchanan EDITOR



Fire Engineering Design Guide

A H Buchanan editor

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Preface

The purpose of this Design Guide is to provide an introduction to fire engineering. It will be useful for those wishing to carry out or review specific fire engineering designs to meet the requirements of the New Zealand Building Code or the Building Code of Australia.

The first edition of this Guide reported the findings of a study group formed by the Structural Engineering Society New Zealand, and the New Zealand Fire Protection Association in 1992, following the introduction of the Building Act in 1991. The Building Act consolidated a wide range of previous legislation relating to building construction, established the Building Industry Authority (BIA), and required all new construction to be in accordance with the New Zealand Building Code, in a performance-based framework.

The fire safety performance requirements of the Building Code can be met either by complying with the prescriptive provisions of the BIA Acceptable Solution, or by an "alternative solution" involving specific fire engineering design. This Guide provides a framework for carrying out specific fire engineering design when the Acceptable Solution is not applicable, the owner's requirements go beyond those of the Building Code, or when additional benefits in cost or safety are warranted.

The second edition of this Design Guide has been produced by members of the original study group, with help from several new contributors. It has been updated throughout with new material and recent references. New sections include:

- Documentation and peer reviews
- Domestic fire safety
- Design fires for computer modelling
- Updated tenability limits
- New fire detector technology
- Regulatory framework in Australia

Fire protection engineering is a vast and rapidly expanding discipline. It is hoped that this book will provide a useful introduction to the subject for all those involved in the design or assessment of fire safety in buildings, and for many others including students and fire fighters.

Andy Buchanan
University of Canterbury

March 2001

Australian Preface

I wish to welcome Australian readers to the Fire Engineering Design Guide.

While this Design Guide was written primarily for use in New Zealand, the second edition has been modified with the Australian design process and the Australian practitioner in mind.

Clearly a number of aspects of the building codes, legislation and regulations differ between Australia and New Zealand. However, there is a similarity between many of the Performance Requirements, and fire safety engineering in both countries is based on common fundamentals of fire science and engineering.

This Design Guide therefore provides a range of analytical methods, data and design approaches, which many Australian fire engineers and approval authorities may find useful. It also highlights the Australian performance requirements and refers to Australian standards and other documents to which design professionals in Australia and New Zealand may refer.

This Fire Engineering Design Guide does not replace the "Fire Engineering Guidelines" developed by the Fire Code Reform Centre for use in Australia. Rather it is complementary and offers Australian fire engineers an additional information resource in a rapidly expanding field of endeavour.

Peter Johnson

Arup Fire, Melbourne

March 2001

Acknowledgements

The first edition of this document was produced by a study group formed by the New Zealand Structural Engineering Society and the New Zealand Fire Protection Association in 1992. The second edition was produced with the help of many of the original authors and some new contributors in 2000, incorporating corrections and improvements.

The original study group and new contributors include the following:

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The text was assembled and edited by Andy Buchanan who wrote most of the material not referred to below. Major contributions were made by Cliff Barnett (Chapters 6,8 & 13), Stuart Bould (Chapter 9), Richard Brand (Chapter 10), Barry Brown (Chapter 15), Peter Byrne (Chapters 12 & 13), Paul Clements (Chapter 11), Charles Clifton (Chapter 5), Charley Fleischmann (Chapter 6 & 14), Russell Gregory (Chapter 9), Peter Johnson (Chapter 16) and Colleen Wade (Chapter 8). Committee members of the New Zealand Chapter of the Society of Fire Protection Engineers assisted with reviewing the second edition.

Final editing for publication was done by Charles Hendtlass of the Centre for Advanced Engineering, University of Canterbury. Graphics were done by Charles Hendtlass and Janine Griffin.

Financial assistance to this project was provided by the Centre for Advanced Engineering. The contributions of the employer organisations listed above are gratefully acknowledged.

Structural Engineering Society New Zealand

The New Zealand Structural Engineering Society (SESOC) promotes the science, art and practise of structural engineering, the advancement and dissemination of knowledge relating to structural engineering and provides a forum for structural engineering practitioners to communicate among themselves and the public. The Society is a technical group of the Institution of Professional Engineers New Zealand (IPENZ).

[www.sesoc.org.nz]

Fire Protection Association

The New Zealand Fire Protection Association (FPA) actively promotes fire prevention, fire detection and fire protection, encourages and provides training for the fire protection community, and is a forum for all activities which relate to the protection of life and property from fire.

Society of Fire Protection Engineers

The New Zealand Chapter of the Society of Fire Protection Engineers (SFPE)is a professional association for those with an interest in the development, application and promotion of scientific and engineering methods to reduce the risk and effects of unwanted fires. The Chapter is a Technical Group of the Institution of Professional Engineers New Zealand (IPENZ).

[www.sfpe.org.nz]

University of Canterbury

The Fire Engineering Programme at the University of Canterbury in Christchurch, New Zealand, carries out research into many aspects of fire science and fire safety in buildings, and offers Masters and Ph.D. degrees in related topics. The programme is partially supported by the New Zealand Fire Service.

[www.civil.canterbury.ac.nz]

CAE

The Centre for Advanced Engineering was established in May 1987 as a centre for the promotion and encouragement of innovation and excellence in engineering and technology, to commerorate the Centenary of the School of Engineering at the University of Canterbury. Through a range of projects, publications and symposia, CAE brings together selected groups of experts who provide specialist knowledge relevant to the engineering and related professions, industry, national and local government, and research institutions.

[www.caenz.com]

Society of Fire Safety

The Society of Fire Safety has been established to foster excellence in fire safety in Australia. As a learned society, the aims are to draw together individuals who are actively engaged in fire safety, to provide a national focus and leadership for the development, understanding, practice and application of fire safety engineering to achieve reductions of risk for life, property and environmental damage and the implementation of cost-effective fire safety codes and regulations.

The Society is national, with chapters throughout Australia. The Society is a Technical Society of the Institution of Engineers, Australia.

Contents

Chapter 1
Introduction

1.1 Purpose

The purpose of this Fire Engineering Design Guide is to provide introductory guidance to those wishing to carry out or review specific fire engineering designs to meet the requirements of the New Zealand Building Code and any additional requirements of the building owner.

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

This Guide is an introduction to fire engineering design which provides basic strategies and design information supplemented by some simple worked examples. 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 investigations.

This Guide has been expanded for greater application in Australia. While Australia has a different building code and regulatory system, many of the concepts, design methods and data in this Guide will be useful for Australian fire safety engineers.

The worst fire disaster in New Zealand was the 1947 Ballantynes fire in Christchurch where 43 people died

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 fire engineering design. New Zealand has had a performance-based building code since 1992. This book is based on the building control system in New Zealand (Buchanan, 1994) which is very similar in many other developed countries, for example Australia (ABCB, 1996), Sweden (SBBHP, 1994) and England (HMSO, 1985). In the USA, several regional building codes have been combined into a national code which is moving towards a performance based approach (IFCI, 2000).

1.3 Relevant documents

New Zealand

The Building Act 1991

The Building Act was 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.

Clause 6 of 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 rescue and fire fighting operations by the 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. See Chapter 15 for a more detailed description of the regulatory framework in New Zealand.

The Building Code

The Building Code is included in the Building Regulations 1992, issued in accordance with Part VI of the Building Act. The requirements for fire safety are reproduced in Appendix A.

The Building Code is a performance-based code that specifies objectives and performance, permitting compliance to be achieved with an approved 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. Otherwise, Section 34 of the Building Act 1991 allows "alternative solutions", such as specific fire engineering design, where the Territorial 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.

The Approved Documents

The Approved Documents published by the Building Industry Authority (BIA, 2000) include the Acceptable Solution, which 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.

Australia

Unlike New Zealand, Australia has a wide range of legislation which varies considerably from State to State. The performance requirements of the Building Code of Australia (BCA) are reproduced in Appendix B.

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, such as the Environment Planning and Assessment Act (1979), in NSW, typically provides each State and Territory with control over:

- Planning provisions;
- Project approval procedures;
- Adoption of the 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, such as the Building Control Commission (BCC) in Victoria, also play a public and industry education role. In the case of Victoria's BCC, they collect a levy on all buildings which is used for research of fire safety and other building matters, some through the Fire Code Reform Centre.

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. For example in Victoria, there are two fire brigades:

- Metropolitan Fire Brigades Board (MFFB), covering most of metropolitan Melbourne; and
- Country Fire Authority (CFA), covering the urban fringes of Melbourne and all rural areas of Victoria.

By contrast, in Western Australia the fire brigades form part of the Fire and Emergency Services Authority (FESA) which operates under a broader emergency services Act.

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.

See Chapter 16 for 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 Approved Documents are not applicable; or

(b) the Approved Documents specify specific fire engineering design; or

(c) the owner's requirements go beyond those of the Building Code; or

(d) additional benefits in cost or safety will result from specific design.

This document provides a framework for carrying out a specific fire engineering design, either as an extension to the Acceptable Solution or from first principles.

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.

Quantifying performance

There are no simple methods available for quantifying building performance or safety in a possible fire. The performance requirements of the Building Code are qualitative, not quantitative. In the final analysis, the acceptance or not of performance requirements is a matter of opinion by those 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 models 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 parties. 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 the 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 the 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 and location 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

Section 44 of 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 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.

Section 64 of the Building Act deals with buildings deemed to be dangerous in respect of fire and egress, and suggests that the Territorial Authority seek advice from the New Zealand Fire Service. The Fire Service will also be assessing buildings under the Fire Safety and Evacuation of Building Regulations 1992, which will, to some extent, address passive systems and housekeeping matters. This is covered in more detail in Chapter 15.

In Australia, maintenance of fire protection systems has become a significant issue through use of Essential Services Legislation (see Section 16.8).

1.7 Insurance and building design

Insurance has three main areas of relevance to building design and construction:

- damage and occurrences during the construction or demolition period;
- professional liability of designers and certifiers or others rendering a professional opinion or service;
- post-construction insurance of the building or 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 or negotiated with a quite different market segment or individual insurer. In most cases, each will be negotiated at different times.

The first of the above three areas involves insurance of the asset itself and of the liability for harm suffered by other parties consequential to construction. Typically this insurance will 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 enlivenment of sprinklers and fire prevention activities such as control of flammable liquids, "hot" work and site tidiness.

In the second category are insurances taken out to defend and settle claims bought by third parties against an individual or firm for failure to fulfil 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 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 personal injury arising from accident.

The third area of insurance will be purchased typically by both the owner and the tenant, close to the end of the contract and well beyond the design stage. Only where the building is another in a group of existing buildings owned and insured collectively is there much likelihood of the designer being able to discuss fire protection arrangements with the insurer.

Nevertheless, the insurance market 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 features include:

- automatic sprinkler protection of the whole building to the Australian or New Zealand Standards;
- low flammability wall linings;
- non-combustible roofs;
- in large or tall buildings, internal subdivision in fire resisting construction and fire doors on the openings;
- stopping-up of holes made for reticulation of services and gaps between floor slab edges and outer facing walls.

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). 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 the 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.

In Australia, the “Fire Engineering Guidelines”, produced by the Fire Code Reform Centre, provides a detailed methodology for presenting fire engineering designs and documentation (FCRC, 1996).

1.9 Peer review

All fire engineering designs are subject to review. This may be an in-house review by the Territorial Authority (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 the Approved Documents, or

b) The design is an “alternative solution” based on fire engineering principles, accepted on the basis of:

(i) An opinion that the design meets the performance requirements of the Building Code, or

(ii) An opinion 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.

Chapter 2
Fire Engineering Design Strategy

2.1 Introduction

This section outlines the major steps to be followed in the fire engineering design of a building. The Fire Engineering Guidelines in Australia (FCRC, 1996) has a similar structure.

The basic flow chart is shown in Figure 2.1. The design procedure is essentially a "trial and error" process to analyse the likely effects of a fire given the worst likely location and time of ignition. Knowledge of the fuel loads, the number and location of occupants and the fire protection features is essential for assessing whether the performance criteria are met.

The first two steps are to determine the geometry, construction and use of the building and to establish performance requirements. The following steps revolve around scenario analysis, considering all possible scenarios.

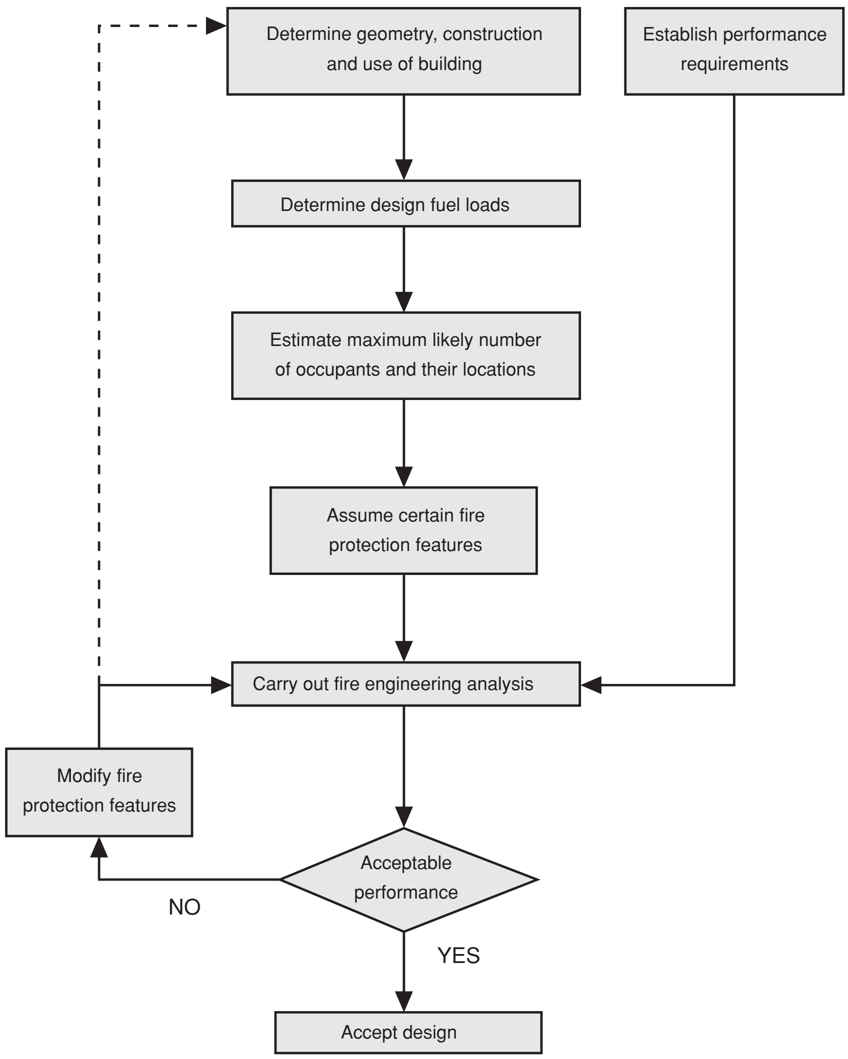


Figure 2.1: Overview of specific fire engineering design

Some parts of the analysis can be quantified with numbers, but much of the analysis requires subjective judgement as to the likely movement and consequences of a fire and the likely location and movement of people. If the performance criteria are not met, then either the building geometry or the fire protection features must be modified until satisfactory performance is achieved. This process must be repeated for all possible fire scenarios.

The more important boxes in the flow chart are described in more detail below.

2.2 Fire protection features

The principal fire protection features that can be provided or modified by the designer include those on the following list. This can be used as a checklist when establishing performance requirements or checking the scope of a design.

To prevent ignition:

- Control ignition sources (electrical, cooking, smoking materials, machines and equipment etc.)
- Control items of hazardous fuel

To control fire growth:

- Control fuel sources (good housekeeping)
- Specify suitable covering materials for walls and ceilings
- Provide hose reels, extinguishers
- Install sprinklers
- Check water supplies in the street for Fire Service use

To control smoke spread:

- Install smoke-stop doors and lobbies
- Ensure that doors are closed
- Seal penetrations
- Provide smoke reservoirs and vents
- Provide smoke detectors in ducts
- Provide automatic controls for the HVAC system
- Pressurize stairwells
- Limit quantities of smoke by using sprinklers

To limit fire spread within the fire building:

- Provide compartmentation
  - — fire resistance to walls and floors
  - — ensure that doors are closed
  - — control vertical shafts
  - — seal penetrations
  - — provide fire dampers in ducts
- Partition ceiling spaces and other concealed spaces
- Limit the size and geometry of external windows
- Control the fire by installing sprinklers

To prevent fire spread to other buildings:

- Limit the size of windows and type of glazing
- Provide adequate separation distances
- Ensure stability of external walls
- Maintain integrity of glazing using drenchers

To allow rapid egress:

- Provide detection and alarm systems
- Provide sufficient number of escape routes
- Make escape routes of sufficient width
- Limit the lengths of dead end paths, open paths
- Provide signs and emergency lighting
- Practice evacuation procedures
- Program the security system to release doors when the fire alarm activates
- Maintain good housekeeping in escape routes

To facilitate Fire Service operations:

- Provide alarms with direct connection to the Fire Service
- Provide indicator boards showing fire location
- Provide access for fire engines
- Provide fire resistant access within the building
- Provide for control of lifts
- Check water supplies in the street
- Ensure that fire hydrants are nearby
- Provide riser mains within the building
- Allow for water collection from hazardous substance fires

To prevent structural collapse:

- Provide the main structural members with adequate fire resistance
- Control the extent of the fire through compartmentation
- Control the fire with sprinklers

The 1988 fire in the First Interstate Bank, Los Angeles, illustrates the importance of containing the fire and providing structural stability

To minimise damage to the building and its contents:

- Control or extinguish the fire with sprinklers
- Control the extent of the fire and smoke through compartmentation

2.3 Acceptable performance

A building is considered to have acceptable performance if the designer considers that the performance requirements have been met to the approval of the owner and the Territorial Authority. The Certifying Building Surveyor provides this approval in Australia.

Determination of acceptable performance is a matter of judgement and opinion. The state of the art in fire engineering is not sufficiently developed to provide simple methods of quantifying the overall fire safety of a building. Quantitative risk assessment methods and large-scale fire tests may be used in special cases.

2.4 Performance requirements

The minimum performance requirements permitted by law are those specified by the New Zealand Building Code, shown in Appendix A, or the Building Code of Australia (BCA), shown in Appendix B. Additional performance requirements may be agreed upon by the owner and the designer, particularly with regard to protection of building contents and structure, as discussed in Chapter 1.

The performance requirements can be summarized as follows:

1. The design of the building and the activities within the building do not present an unreasonable probability of fire occurring; and
2. In the event of a fire, the following can be achieved with an acceptable degree of certainty, by extinguishment or active or passive control of the fire:
   (a) All occupants will have adequate time to move to a safe place without being overcome by the effects of the fire.
   (b) The Fire Service will have adequate time and suitable access to undertake rescue operations and to protect property.
   (c) The fire will not spread to adjacent household units or other property.
   (d) Significant quantities of hazardous substances will not be released to the environment.
   (e) The fire will not spread beyond the firecell of origin.
   (f) The contents of the building will not be damaged.
   (g) The building itself will not be significantly damaged.
   (h) Any damage to the building will be easily repairable.

Note that items 2(a) to (e) are summaries of the minimum performance required by the New Zealand Building Code. The remaining items will generally be additional requirements of the building owner.

In Australia, the BCA addresses items (a), (b), (c) and (e) only, with item (d) addressed by other legislation in some states.

2.5 Fire engineering analysis

For each room in turn, the designer must consider all the consequences of a fire occurring with the assumed fire protection features in place.

Procedure

1. Assume the worst or most likely location for first ignition.
2. Assume the worst likely arrangement of combustible materials during the projected life of the building.

3. Estimate the rate of fire development, temperature rise and smoke production.
4. Estimate the activation time for detection and suppression systems.
5. Throughout the development and burning phases, consider the likely movement of:

People	**Smoke, by**	**Fire, by**	
number	natural convection	conduction	— barriers
location	forced convection	convection	— openings
notification	mechanical plant		— penetrations
response			— concealed spaces
rate of movement			— gaps or weaknesses
safety of route		radiation	— across shafts
			— to other buildings

6. For life safety, continue the analysis until all occupants are deemed safe, with additional allowance for safety of firefighters.
7. For neighbouring property and public safety, continue the analysis for the full duration of the fire to ensure that external walls do not collapse and external openings do not increase in area, thereby allowing fire spread.
8. For the owner's property protection, continue the analysis for the full duration of the fire to ensure that damage is minimised.
9. For hazardous substance fires, ensure that excessive toxic products are not released.
10. Repeat the procedure with altered parameters.

The following assumptions are considered reasonable in the fire engineering analysis:

(a) If sprinklers are present, assume that they operate and limit the fire to a certain size. There is always a small probability that sprinklers will not control the size of the fire, especially after an earthquake. The designer should consider the consequences of this possibility within the overall context of the building's fire safety.

(b) Ignore the possible use of fire hose reels or portable extinguishers on fire growth because they will not always be used successfully (conservative assumption).

(c) Ignore the effect of Fire Service intervention on the initial fire growth because of uncertainty about time of arrival.

(d) Assume that the design fire load is less than the total fire load if the available Fire Service facilities with adequate water supplies can be relied upon to interrupt the growth and spread of the fire.

The analysis should be repeated for different times of day, different locations of ignition, different activities of the building, different arrangements of doors and windows etc. The analysis may be done by hand calculation or using fire growth computer models. In either case, detailed knowledge and experience of fire behaviour in buildings is essential. Large-scale fire tests may be used in special situations as part of the fire engineering analysis.

2.6 Fire during construction

The risk of fire is often greater during construction or alteration than during normal occupancy. At these times, the fuel loads will be very different, many additional potential ignition sources will be present and the occupants will be of a different type and in different places. Many fire protection systems will not be installed, or not in full operating condition.

A specific fire engineering design should include the possibility of fire occurring during construction or alteration. A British code of practice on the protection from fire of construction sites and buildings undergoing renovation is available (LPC 1993).

2.7 Fire following earthquake

The risk of an uncontrolled fire following a major earthquake is a serious threat to life and property, as evidenced by disasters in Tokyo, San Francisco, Napier, Kobe and other cities (Botting 1998). Earthquakes are largely unpredictable, and large fires following earthquakes are even less predictable. Historical records show that small fires are often initiated by earthquakes, and these sometimes grow into large destructive fires causing loss of life and severe damage to property. The concern is initially with fire damage in individual buildings, where the potential loss of life is much greater in tall buildings than in low-rise buildings. A subsequent concern is the possibility of a large urban conflagration. The factors which affect the likelihood of small fires growing into large ones include the amount of earthquake damage, the type and density of building construction, wind conditions, loss of water supplies, and fire fighting capabilities.

The probability of all active fire protection systems operating after a major earthquake is remote due to the likelihood of power failure, water supply failure, structural or non-structural damage. Control of fires in buildings after earthquakes is only possible if the buildings are designed with good earthquake resistance, good fire protection and good overlap between the two. Even if both are provided separately, the necessary coordination is often missing. Co-ordination between seismic design and fire design includes earthquake resistance of both active and passive fire protection systems, fire protection of items such as seismic gaps, and secure local and city water supplies. The New Zealand sprinkler code NZS4541:1996 specifies seismic restraints and an independent water supply for buildings in regions of moderate or high seismicity.

The probability of major loss in fire following earthquake can be reduced with:

- Provision of adequate earthquake resistance and adequate fire protection for all buildings.
- All active and passive fire protection systems to be provided with earthquake resistance.
- Earthquake resistant water supplies within cities and inside buildings.
- Seismic restraint of potential ignition items and liquid fuels.
- Reliability of stairs and escape routes for both earthquake loading and fire safety, especially in tall buildings.
- Earthquake resistant fire stations and communications facilities.
- Co-ordinated local government and Fire Service planning for hazard assessment of essential lifelines and emergency response.
- Avoiding electrical fires by ensuring that water supplies are restored before electricity is turned back on.

The risk of earthquakes in Australia is considerably reduced compared with New Zealand, but not insignificant, as evidenced by the Newcastle earthquake in 1989. Consideration of seismic requirements under the Building Code of Australia must be followed.

Debris in streets creates difficulty in access for firefighters after the Napier Earthquake, 1931 (photo courtesy of The National Library of New Zealand)

Chapter 3
Fire Behaviour

3.1 Introduction

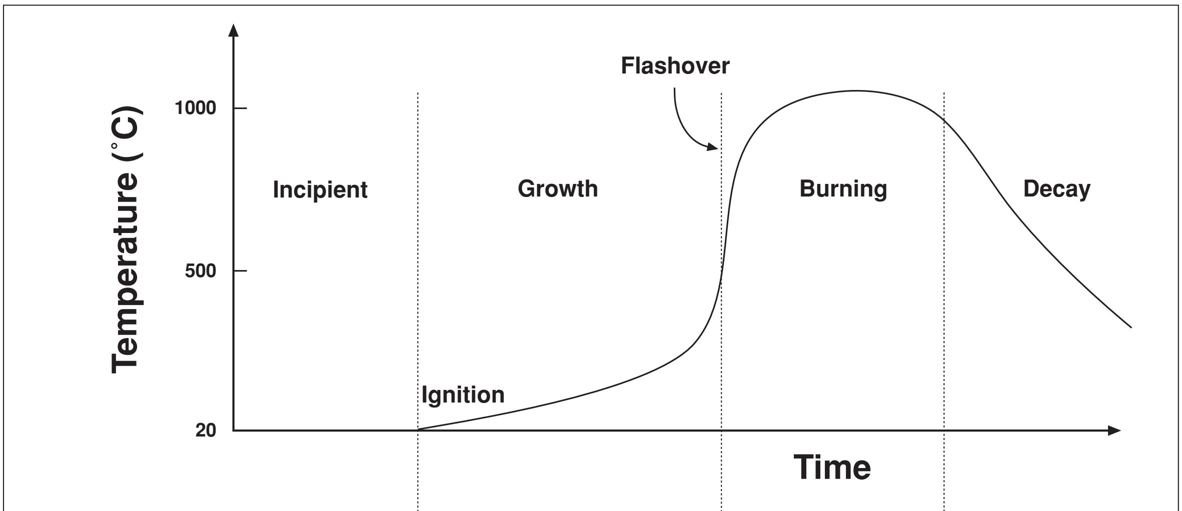
This chapter gives a brief overview of the main stages of fire development and subsequent decay as an introduction to the following chapters, which describe computer modelling of fires and the use of this information in design.

The science of fire development is a complex subject that is developing rapidly. Readers should consult texts such as Drysdale (1998), Quintiere (1998), Karlsson and Quintiere (2000), or the SFPE Handbook (1995) for more information.

The vast majority of fires follow a pattern of distinct stages, although the timescales, rates and magnitudes vary widely. Typical stages of development for fires where no fire fighting intervention takes place are shown in Figure 3.1. Each of the main stages of fire development are discussed below.

3.2 Fire initiation

Fire initiation includes ignition and the development of a self-sustaining combustion reaction. There are many possible sources of ignition both deliberate and accidental. The ignition source is commonly very small and has low energy, but if it affects combustible materials it is often sufficient to start a fire. There are many cases where ignition



Stage	Incipient	Growth	Burning	Decay
Fire behaviour	Heating of fuel	Fuel-controlled burning	Ventilation -controlled	Fuel-controlled burning
Human behaviour	Prevent fire	Extinguish by hand, escape	Death	
Detection	Smoke detectors	Smoke detectors Heat detectors	External smoke and flame	
Active control	—	Extinguish by sprinklers or Fire Service. Smoke control	Control by Fire Service	
Passive control	Control of materials	Flammability, surface spread of flame	Fire resistance, containment, prevent collapse	

Figure 3.1: Typical fire development curve

events have not started a significant fire because combustible materials were not close enough to ignite, or a small fire did not become self-sustaining and died out.

Ignition normally takes place in one of three ways:

- Pilot ignition where flaming is initiated in a flammable vapour/air mixture by a "pilot", such as a flame or an electrical spark.
- Spontaneous ignition (sometimes called auto-ignition) where flaming develops spontaneously due to a sufficiently high temperature within a flammable vapour/air mixture in the absence of a pilot flame or spark. The fuel for the flammable vapour/air mixture may be a gas, vapour from a flammable liquid or vapour produced by the pyrolysis of a solid fuel. Pyrolysis is the thermal decomposition of solid fuel into flammable vapours.
- Spontaneous combustion in bulk fuels. This is a less common means of fire initiation and is caused by self heating in bulk solids as a result of biological processes, chemical reactions or heating due to oxidation of drying oils, which can lead to smouldering combustion, normally starting deep within the mass of fuel.

3.3 Incipient stage

Ignition is always preceded by heating of potential fuel, often producing smoke. In many cases an incipient fire can be detected before ignition, by the occupants smelling smoke or by operation of a smoke detector. It is usually very easy to terminate the heating and prevent the fire from occurring if people are nearby. There will not be enough heat produced in this stage to operate a heat detector or a sprinkler system.

The duration of the incipient stage of a fire can be from a few milliseconds to several days depending on the initial fuel involved, ambient conditions, ignition source, etc. In the case of a flammable liquid spill the incipient phase is effectively nonexistent. If the ignition source is self-heating ignition, the incipient phase can last for hours or days. In some cases, the fire may never grow beyond the incipient stage, for example a cigarette which smoulders on a woollen fabric-covered chair, never igniting the flammable padding beneath the fabric. There are far too many variables to allow for reliable modelling of the incipient phase of a fire. When furniture is tested using the furniture calorimeter, a gas burner is used to simulate a wastepaper basket fire in order to eliminate the effects of the incipient stage.

A fire is considered to be in the incipient stage as long as the fire is small enough that the dominant form of heat transfer is not radiation. This equates to a fire that is about 20 kW or less, equating to a fire diameter of about 0.2 m. These values are "rule of thumb" rather than hard lines of demarcation. Below this threshold, the fire is of little threat to occupants outside the room of origin, and only threatens occupants within the room of origin if they are sleeping or incapable of self preservation. For computer-based fire modelling, the incipient stage is usually ignored and the growth stage is started from time zero. An obvious exception is when a smouldering fire scenario must be considered, such as in a sleeping occupancy.

3.4 Combustion

Smouldering combustion

A period of smouldering combustion can occur following ignition. Smouldering combustion normally results in slow fire development, which can continue for hours or days. Smouldering combustion may die out without progressing to flaming combustion. A smouldering fire may be more hazardous to life than a flaming fire due to the smoke and toxic fumes produced. Smouldering fires are also dangerous because they may not produce sufficient heat to activate sprinklers or heat detectors. Smouldering combustion only occurs in materials that form a stable char. A detailed description of smouldering fires is given by Ohlemiller (1995).

Flaming combustion

Smouldering combustion can develop into flaming combustion, which results in an increasing rate of fire development. Flaming combustion occurs where the fuel is a gas, a liquid which has evaporated, or a solid fuel which has pyrolysed to produce a flammable vapour.

To initiate flaming combustion of liquids and solids, external heating is required to heat the fuel, except in the case of flammable liquids that have flashpoints below the ambient temperature. Once flaming combustion has been initiated, sufficient heat is generally available from the flame to evaporate or pyrolyse the remaining fuel to sustain the combustion.

Combustion is an exothermic chemical reaction in which fuel is oxidised to produce flames, heat and combustion products. Most fuels in building fires have a chemical structure containing carbon, hydrogen and oxygen. Considering a simple hydrocarbon such as propane (C_3H_8), complete combustion producing carbon dioxide (CO_2) and water vapour (H_2O) can be represented as:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \qquad [3.1]$$

In all real fires there is incomplete combustion, producing carbon monoxide gas (CO) and some carbon (C), which appears as black smoke.

3.5 Fire growth stage

Knowledge of the growth stage of fire development prior to flashover is very important for fire engineering, as the initial risk to life safety is due to the heat and smoke produced during this stage.

The growth stage is considered to begin when the radiation feedback from the flame governs the burning rate. Assuming that the compartment is vented, the growth rate is primarily governed by the properties and orientation of the fuel. During the growth stage, the fire spreads across the fuel surfaces, increasing the burning area and the corresponding heat release rate. The heat release rate is assumed to be independent of the fire enclosure and governed mainly by the flame spread rate.

The fire growth stage follows the start of flaming combustion as the fire develops and spreads to adjacent fuel. Once flaming combustion is taking place, the fire will normally continue to develop unless it is remote from other fuel or fire control and extinguishment measures are applied. The fire will then develop at a rate governed by the geometry, combustibility and arrangement of the fuel until the fire size is limited by the surface area of the fuel or by a restricted air supply.

Black smoke deposits on walls show the depth of the hot smoke layer during the fire

During the growth stage, the conditions in a room can be approximated by the two-layer model shown in Figure 3.2. The air in the lower layer is close to ambient temperature, at least in the early stages. The plume above the fire carries smoke and hot gases into the upper layer along with a considerable volume of entrained air. Temperatures in the upper layer rise rapidly due to the heat of the combustion products carried up in the plume. When the plume reaches the ceiling, hot gases travel along the ceiling, moving radially away from the fire. This flow of hot gases is known as the "ceiling jet", which will trigger operation of heat detectors or sprinklers.

Automatic sprinkler systems are designed to operate well before flashover, while the fire is small enough to be controlled or extinguished with a moderate amount of water.

The duration of the growth stage may be only a few minutes or several hours. For a typical well-ventilated living room with plenty of soft furnishings, the time between ignition and flashover is often less than five minutes. Smouldering combustion may continue for an extended period and such a fire may grow rapidly when fresh air is introduced, sometimes leading to a smoke explosion or backdraft.

3.6 Flashover

As the fire continues to develop, the temperatures rise in the firecell and all the exposed surfaces are heated by radiation from the flames, hot surfaces and, especially, the upper layer of smoke and hot gases. Once the temperature in the upper layer reaches approximately 600˚C and the direct radiation at floor level reaches about 20 kW/m^2, all exposed combustible surfaces ignite rapidly and burn fiercely. This transition is known as flashover.

Flashover can be thought of as a transition from a small object oriented fire to full room involvement. This transition typically occurs over a short time span measured in seconds. Figure 3.3 is a plot of the heat release rate and upper layer temperature versus time for a compartment with wood cribs and wood-fibre-board wall linings. Flashover occurs in the cross-hatched region of the curve, where there is a rapid increase in both the heat release rate and the upper layer temperature. The increase in radiation from the upper layer not only ignites all of the combustibles in the room but also enhances the pyrolysis rate of all the burning objects.

Prior to flashover, fire growth is limited mainly by the pyrolysis rate of the fuels involved in the fire. After flashover, the maximum fire size within an enclosure is usually limited by the available ventilation, as more fuel is being pyrolysed than can be burnt using the available air supply.

It is not possible to survive a fire after flashover because of the high temperatures, high concentrations of carbon monoxide and smoke and the lack of oxygen.

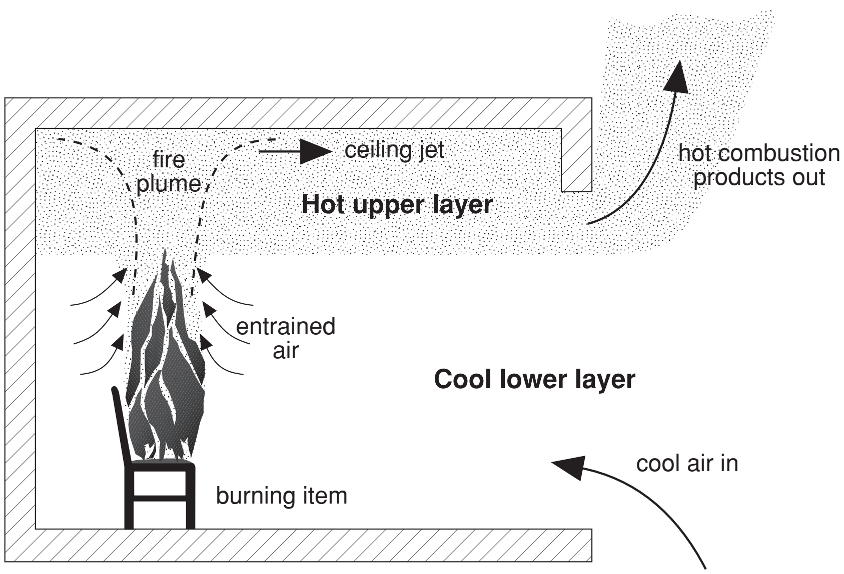


Figure 3.2: Two-zone model with fire plume

Flames projecting from the window indicate a ventilation-controlled, post-flashover fire

Flashover will not always occur. For example, in large firecells where temperatures will rise more slowly and never reach the high temperatures required for flashover, or in well-sealed firecells where the fire size and hence the upper layer temperatures are limited by the lack of oxygen supply to the fire.

3.7 Fully-developed fire

The fully-developed fire (the burning stage) is most important when considering property protection, structural stability and the possibility of fire spreading to other properties.

Once flashover has occurred, the fire is in the fully-developed stage (or burning stage), which is characterised by a very high heat release rate and high temperatures. During this stage the fire is usually ventilation controlled, the rate of burning being governed by the firecell openings. Typical gas flows through an opening in the fully-developed fire are shown in Figure 3.4.

In most fully-developed fires, ventilation control means that the rate of fuel pyrolysis is greater than can be burnt by the available air supply, resulting in flames burning from openings as the unburnt gases obtain access to outside air.

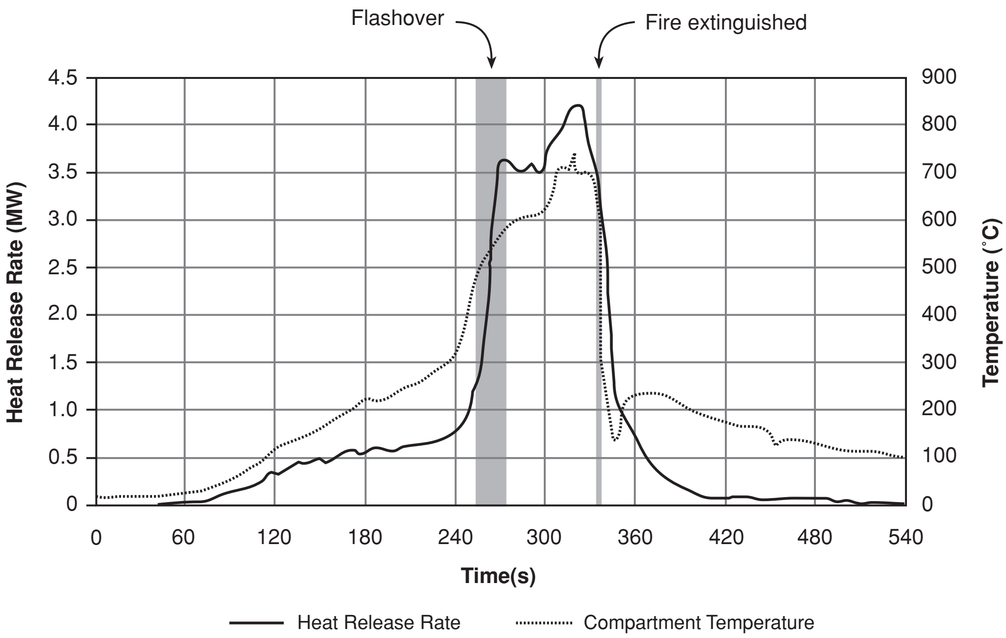


Figure 3.3 Heat release rate compared to upper layer temperature for a compartment fire

Exterior flames are indicative of a ventilation-controlled fire and do not normally occur in the growth stage. The duration of the fully-developed stage depends on the total amount of fuel and the available ventilation.

The nature and arrangement of the fuel and the thermal properties of the walls and ceiling also affect the growth and intensity of a fully-developed fire.

Figure 3.5 shows typical time-temperature curves for fully-developed wood crib fires in firecells with varying fire load and ventilation. It can be seen that low ventilation produces longer, cooler fires than high ventilation. The more fuel available, the longer the fire burns. These curves are only indicative. Some tests have shown very similar results, whereas others have produced quite different time-temperature curves.

The heat release rate in a post-flashover fire will not be the same as the heat release rate for the same fuel burning in the open air for two reasons:

Firstly, many burning objects actually release more fuel than can be consumed within the compartment, i.e. the fire is ventilation limited. When there is more fuel released from the burning object than can be consumed inside the confines of the compartment, the excess fuel will burn with visible flames outside the window or door opening. The excess fuel that is not consumed within the compartment is not easy to measure and has only been quantified in a few cases.

The burning rate inside a compartment is usually much greater than burning in the open air because of the additional radiant heat on the burning object from the hot gases hot lining materials. In the case of timber cribs, the mass loss rate from a crib burning in a compartment is enhanced by approximately 33% over the identical crib burned in the open. For pool fires, where the entire burning surface is seeing the radiating compartment environment, it has been shown that there can be as high as 100% increase over the open-air burning case. This compartment enhancement has been incorporated in the COMPF2 computer model for pool fires and timber cribs (Babrauskas 1979) but has not been explicitly incorporated into zone models and must be taken into account by the user.

At all stages of the fire development there is an energy balance. The energy released by combustion of the fuel in the room is equal to the sum of the energy conducted into the surrounding structure, the energy radiated through any openings and the energy carried away by convection of smoke, hot gases and combustion products through openings. The energy balance has been used in computer programs such as COMPF2 (Babrauskas, 1979; Feasey, 1999) to calculate the fire temperatures in post-flashover fires.

3.8 Decay stage

After a period of fully-developed burning, the fire intensity decreases as the fuel is consumed. Once the fuel supply diminishes to a point where it is unable to sustain the maximum burning rate, the fire is said to be in the decay stage. The transition to the decay stage is often defined as the time when 80% of the fuel has been consumed.

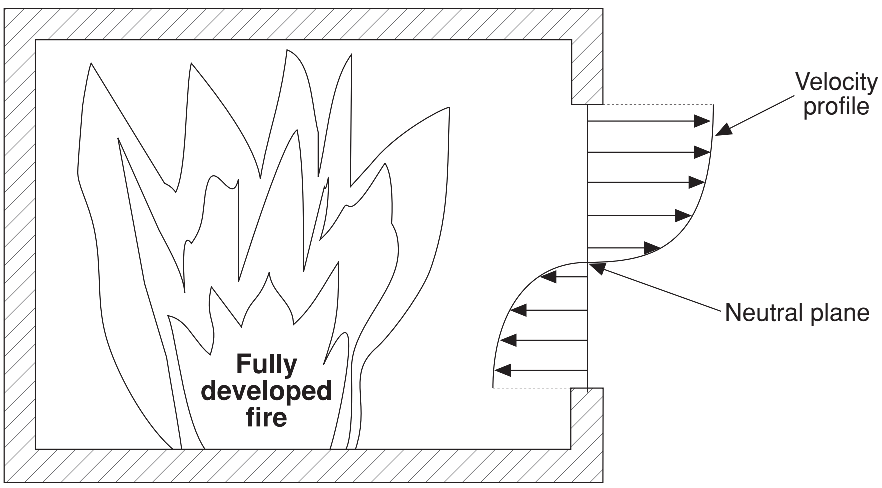


Figure 3.4: Gas flows through openings for a fully-developed fire

During the decay stage, the fire passes back from a ventilation-controlled fire to a fuel-controlled fire, with the burning rate governed by the fuel supply with more than sufficient air available for combustion of the remaining fuel. The fire continues to decay until the available fuel is consumed, and then goes out.

For fires that involve thermal plastics which melt and form pool fires, the expected decay stage would be quite short. However, for cellulosic fuels which form a char that will eventually be consumed the decay stage will be much longer. The decay stage is primarily of interest when determining the required fire resistance of structural elements and rarely an issue for addressing life safety.

3.9 Intervention

The stages of fire development described above ignore any fire fighting intervention by automatic or manual systems. Intervention with fire fighting water at any stage can control or extinguish the fire if sufficient cooling power is available.

The smaller the fire the less water is required. Hand held extinguishers or hose reels can extinguish a very small fire. Sprinklers are designed to extinguish a fire in the growth stage, but not after flashover.

The Fire Service can generally supply large volumes of water, which can extinguish a pre-flashover fire or a small fire after flashover. The Fire Service may be unable to initially extinguish some large fully-developed fires because of lack of sufficient cooling capacity and difficulty getting water on the seat of the fire. In these cases, they can reduce the rate of heat release by applying as much water as possible, thereby preventing the fire spreading until most of the combustible contents are consumed. The fire can then be extinguished in the decay stage.

Fire fighting water applied to exposed surfaces of adjacent buildings can reduce the probability of fire spread by radiant heat transfer.

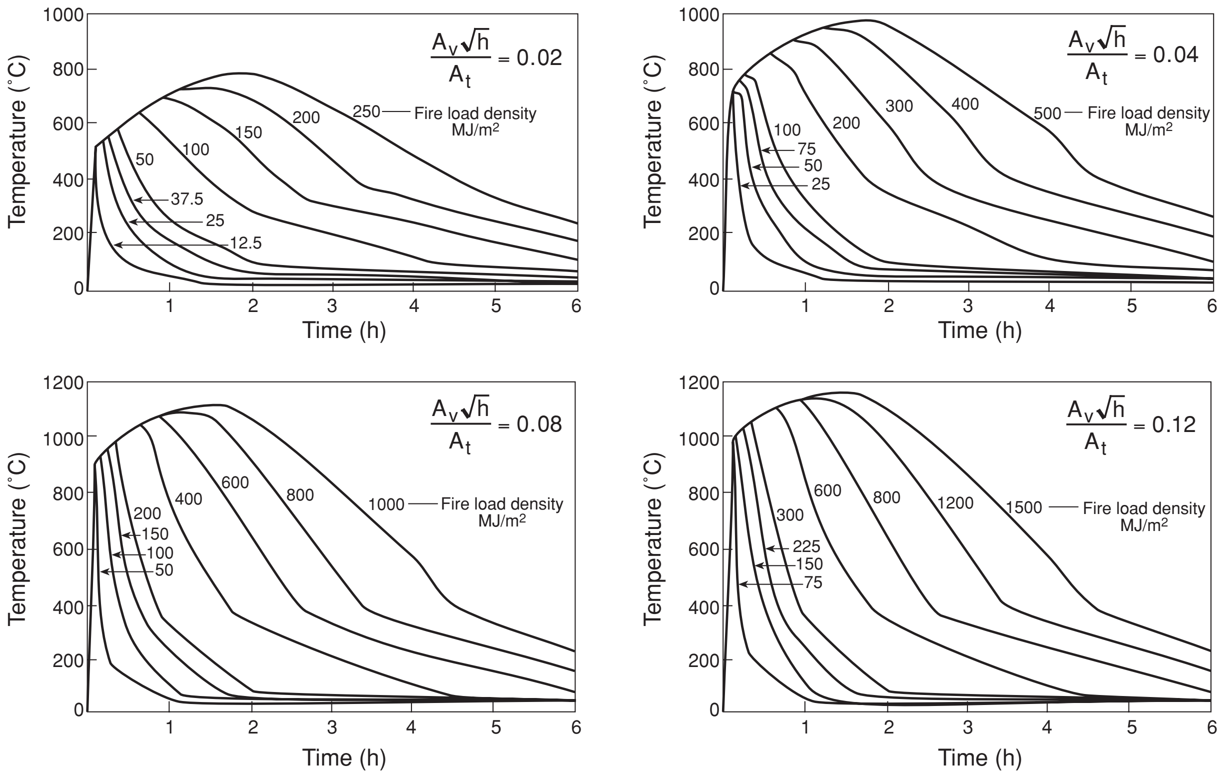


Figure 3.5: Time-temperature curves for various fuel loads and opening factors

Fuel load is MJ per square metre of bounding surface area

(Magnusson and Thelandersson, 1970)

Chapter 4
Pre-flashover Fires

4.1 Introduction

The objective of this chapter is to provide simple methods of quantifying the pre-flashover fire. For more detail, consult Drysdale (1998), Quintiere (2000) or the SFPE Handbook (SFPE, 1995).

Design for life safety requires the ability to predict the likely behaviour of a pre-flashover fire and the resulting production of heat and smoke. Pre-flashover fire growth can be predicted from experience in real fires and estimated using a computer fire growth model. A combination of these two methods will give the best results.

Computer models are described in Chapter 6. These can be used to predict such variables as the rate of burning, time to flashover, fire temperatures, detector response and production of smoke and toxic gases.

4.2 Calorific value of fuels

Fire loads should be determined using the nett calorific value of combustible materials at their natural moisture content. The nett calorific value h_a (MJ/kg) of a moist material is:

$$h_a = h_n (1 - 0.01 m_c) - 0.025 m_c \quad [4.1]$$

where h_n is the nett oven-dry calorific value (MJ/kg) as determined by ISO 1716 or similar

and m_c is the moisture content as a percentage by weight

$$m_c = (100 \text{ x } m_d)/(100 + m_d) \quad [4.2]$$

where m_d is the moisture content as a percentage of the dry weight (as usually quoted for wood products)

Values for calorific value h_n of some liquids, gases and solids are given in Table 4.1.

4.3 Design fires

Many assumptions are made in the modelling process. One of the most important is the design fire, which is required as input for nearly all fire growth computer programs (see Section 6.6).

Most fire growth models require the user to input a design fire as a specified heat release rate varying with time. The design fire is the heat release rate for the fuel assuming that it is free burning in the open air.

Modelling the actual growth rate of a fire is extremely difficult and is a current area of research. The fire growth rate is dependent on many factors which are not only a function of the burning object but are more stochastic in nature such as size and location of the ignition source, orientation of the object, and proximity to other objects, walls, or window openings. Notwithstanding these limitations, the engineer must rely on judgment when choosing a growth rate. It is true that most fires which will occur during the life of a building will be quite minor and are likely to go unreported. However, it is prudent to use the most likely worst case fire for design purposes.

Liquid fuels

Liquid fuels burning in the open, as pool fires, tend to burn at a constant rate once steady state conditions have been reached. The rate of burning is governed by the rate at which heat from the flames and combustion products is able to evaporate fuel on the surface of the pool, depending on the pool area. Typical burning rates for a range of liquid fuels are shown in Table 4.2 (derived from Babrauskas, 1995). These figures are for pools larger than about two metres in diameter, burning in the open.

Material	MJ/kg	Material	MJ/kg
Solids (dry)		Polyvinylchloride	16-17
		Ureaformaldehyde	14-15
		Ureaformaldehyde foam	12-15
Anthracite	31-36	Foam rubber	34-40
Asphalt	40-42	Rubber isoprene	44-45
Bitumen	41-43	Rubber tire	31-33
Cellulose	15-18	Silk	17-21
Charcoal	34-35	Straw	15-16
Clothes	17-21	Wood	17-20
Coal, Coke	28-34	Wool	21-26
Cork	26-31	Particle board (chipboard and hardboard)	17-18
Cotton	16-20		
Grain	16-18	**Liquids**	
Grease	40-42	Gasoline	43-44
Kitchen refuse	8-21	Diesel oil	40-42
Leather	18-20	Linseed oil	38-40
Linoleum	19-21	Methanol	19-20
Paper, Cardboard	13-21	Paraffin oil	40-42
Paraffin wax	46-47	Spirits	26-28
Plastics:		Tar	37-39
ABS	34-40	Benzene	40.1
Acrylic	27-29	Benzyl alcohol	26.9
Celluloid	17-20	Ethyl alcohol	26.9
Epoxy	33-34	Isopropyl alcohol	31.4
Melamine resin	16-19		
Phenolformaldehyde	27-30	**Gases**	
Polyester	30-31	Acetylene	48.2
Polyester, fibre-reinforced	20-22	Butane	45.7
Polyethylene	43-44	Carbon monoxide	10.1
Polystyrene	39-40	Hydrogen	119.7
Petroleum	40-42	Propane	45.8
Polyisocyanurate foam	22-26	Methane	50.0
Polycarbonate	28-30	Ethanol	26.8
Polypropylene	42-43		
Polytetrafluorethylene	5.0		
Polyurethane	22-24		
Polyurethane foam	23-28		

Table 4.1: Calorific values of combustible materials
(CIB 1986)

Solid fuels

Table 4.2 also includes burning rates of wood, based on a regression rate of 40 mm/hour on the exposed surfaces. This is a typical regression rate measured in standard fire resistance tests. Figures are given for a solid slab of wood and for wooden objects with a range of specific surface areas (m^2 of surface per m^2 of floor area). The three plastic materials have burning rates derived from Babrauskas (1995), for open air burning.

Burning objects

Design fire information for burning objects is available from several sources. Heat release rates for many items of furniture have been measured in furniture calorimeters and are available from Babrauskas (1988), Babrauskas and Grayson (1992), Nelson (1990) and others. For example, the heat release rate for selected items of furniture are shown in Figure 4.1.

Laboratory test of typical 2-seater sofa, less than 2 minutes after ignition (2 MW fire). In a real fire, the room would be full of hot, toxic smoke by this time.

	Density kg/m³	Regression rate mm/hr	Mass loss kg/hr	Surface burning rate kg/s per m² (surface)	Specific surface m² (surface) / m² (floor)	Total burning rate kg/s per m² (floor)	Nett calorific value MJ/kg	Heat release rate MW/m² (floor)
Liquids								
LPG (mostly C_3H_8)	585	609	356	0.099	1.0	0.099	46.0	4.55
LPG (mostly CH_4)	415	677	281	0.078	1.0	0.078	50.0	3.90
Petrol	740	268	198	0.055	1.0	0.055	43.7	2.40
Aviation fuel JP-5	810	240	194	0.054	1.0	0.054	43.0	2.32
Liquid hydrogen	70	874	61	0.017	1.0	0.017	120.0	2.04
Kerosene	820	171	140	0.039	1.0	0.039	43.2	1.68
Heavy fuel oil	970	130	126	0.035	1.0	0.035	39.7	1.39
Ethanol	794	68	54	0.015	1.0	0.015	26.8	0.40
Methanol	796	77	61	0.017	1.0	0.017	20.0	0.34
Wood								
Flat wood	550	40	—	0.0056	1.0	0.0056	16	0.09
1 m cube	550	40	—	0.0056	6.0	0.0323	16	0.53
100 mm in crib*	550	40	—	0.0056	14	0.078	16	1.24
Furniture	550	40	—	0.0056	20	0.11	16	1.8
25 mm in crib*	550	40	—	0.0056	47	0.26	16	4.2
Softboard	300	108	—	0.0090	1.0	0.0090	16	0.14
Plastics								
PMMA	—	—	—	0.054	1.0	0.054	24.0	1.34
Polyethylene	—	—	—	0.031	1.0	0.031	43.8	1.36
Polystyrene	—	—	—	0.035	1.0	0.035	39.9	1.40

* Cribs 1.0 m high. Spacing between sticks is two times the stick thickness (Yii, 2000)

Table 4.2: Rates of burning for some liquid and solid fuels

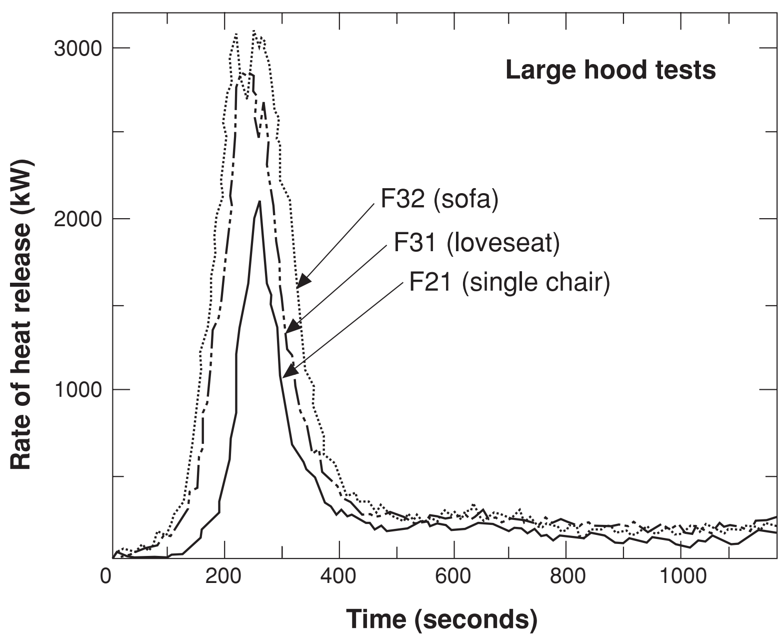


Figure 4.1: Heat release rate for items of furniture
(Babrauskas, 1995)

t^2 fires

There are several approaches to estimating the growth rate for a particular design fire. The most popular is the t^2 (t-squared) fire growth rate. Originally developed in the 1970s for predicting fire detector activation, the t^2 fire gained popularity when it was included in the appendix of NFPA-72E (now NFPA-72) with three categories for fire growth; slow, medium, and fast. These definitions are simply determined by the time required for the fire to reach 1.05 MW. A slow fire is defined as taking 600 seconds (10 minutes), a medium fire 300 seconds (5 minutes) and a fast fire less than 150 seconds to reach 1.05 MW (rounded to 1.00 MW in the calculations that follow).

The t^2 fire growth can be thought of in terms of a burning object with a constant heat release rate per unit area in which the fire is spreading in a circular pattern with a constant radial flame speed. Obviously more representative fuel geometries may or may not produce t^2 fire growth. However, the implicit assumption in many cases is that the t^2 approximation is close enough to make reasonable design decisions. Scaling by a growth constant can account for a wide range of fire growth rates, from very slow to very fast. The particular choice of growth constant depends on the type and arrangement of the fuel. It should be noted that the t^2 growth rate has sometimes been applied well beyond the scope of the original assumptions, in some cases for fires as large as 30 MW, and such applications have been questioned in the literature (Babrauskas 1996).

The heat release rate Q (MW) for a t^2 fire is given by:

$$Q = [t/k]^2 \qquad [4.3]$$

where t is the time (seconds) and k is the growth time (seconds)

To be dimensionally correct, k should have units $s/MW^{1/2}$, but for fire engineering purposes the numerical value of k is the time in seconds for the fire to reach a heat output of 1.055 MW. Heat release rates are shown in Figure 4.2 for the four different growth times given in Table 4.3.

An alternative formulation that gives identical results is to describe the heat release rate Q (MW) for a t^2 fire by:

$$Q = \alpha t^2 \qquad [4.4]$$

where a is the fire intensity coefficient (MW/s^2). Values of α are given in Table 4.3.

The term α and k are directly related by

$$\alpha = 1.055/k^2 \qquad [4.5]$$

The fire can be considered to grow according to the t^2 curve until either the fuel is consumed, or until the heat release rate reaches a peak value expected for that particular object, in which case the duration of constant burning at that rate can be calculated. The FORMULA package in FPEtool can be used to make these calculations. Some typical fire

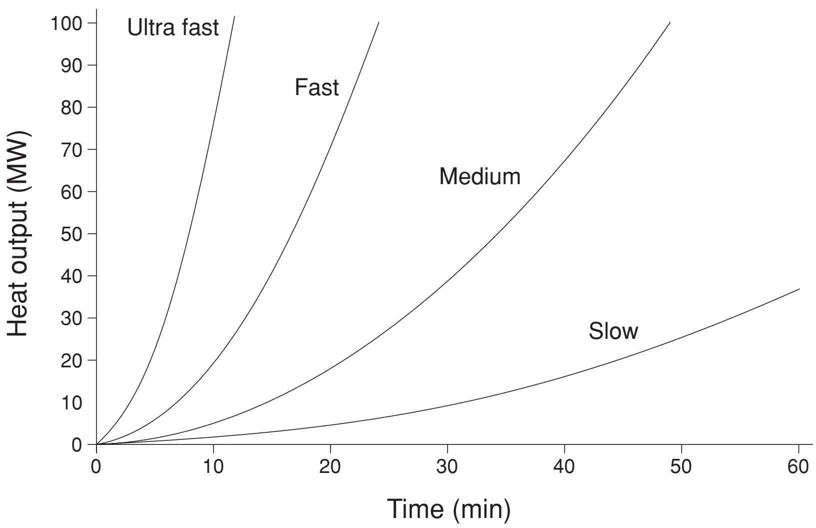


Figure 4.2: Heat release rates for t^2 fires

Fire growth rate	**Growth time k (s)**	**Fire intensity coefficient α (MW/s²)**	**Typical real fire**
Slow	600	.00293	Densely packed wood products
Medium	300	.0117	Solid wooden furniture such as desks Individual furniture items with small amounts of plastic
Fast	150	.0466	High stacked wood pallets Cartons on pallets Some upholstered furniture
Ultrafast	75	.1874	Upholstered furniture High stacked plastic materials Thin wood furniture such as wardrobes

Table 4.3: Typical growth times for design fires

growth rates and peak heat release rate values are given by Nelson (1990), and in Appendix C. This calculation assumes that the fire growth is not limited by the available ventilation, which may change if the burning object is in a room, as described in Section 4.4.

Calculations

Calculations for a t^2 fire are given, with reference to Figure 4.3.

Using equation 4.3 for a t^2 fire, the time t_1 (in seconds) to reach the peak heat release rate Q_p (MW) is given by:

$$t_1 = k\sqrt{Q_p} \qquad [4.6]$$

The energy released to time t_1 is given by:

$$E_1 = \frac{t_1 Q_p}{3} \qquad [4.7]$$

If the total energy E (MW) in the fuel has not been released at time t_1, the energy released in the steady burning phase E_2 (MW) is given by:

$$E_2 = E - E_1 \qquad [4.8]$$

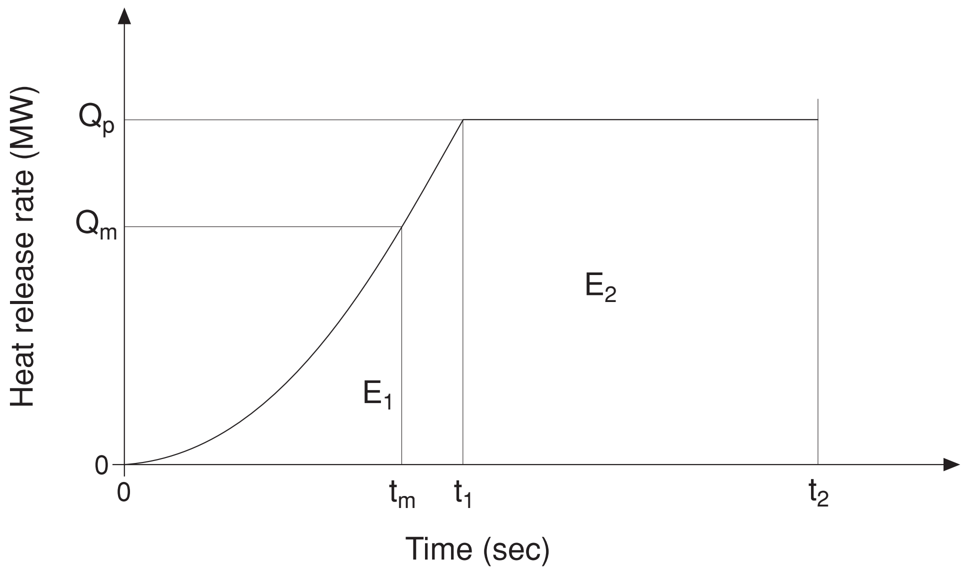


Figure 4.3: Calculation of heat release rate

and the duration of the steady burning phase is given by:

$$t_2 = t_1 - E_2/Q_p \quad [4.9]$$

If the fuel has insufficient energy to reach its peak heat release rate, all of the fuel will be consumed in time t_m (sec) where:

$$t_m = \left(3Ek^2\right)^{1/3} \quad [4.10]$$

and the burning rate at time t_m is given by:

$$Q_m = \left(t_m/k\right)^2 \quad [4.11]$$

Figure 4.4 shows three heat release rate curves for a fire in office furniture. The furniture weighs 160 kg with a calorific value of 20 MJ/kg, giving a total energy load of 3200 MJ. The peak heat release rate has been taken as 9 MW, being 2.0 MW/m^2 over an area of 4.5 m^2. The curves show the heat release rates for slow, moderate and fast fire growth. In each case the area under the curve is 3200 MJ. Calculations are shown below for the fast and slow fires.

Worked example

For fuel of known weight, calorific value and peak burning rate, calculate the heat release rate curve for all the fuel to burn in the open.

Assume a t^2 growth period followed by a steady phase, with no decay phase.

Mass of furniture	M = 160 kg	Calorific value	h_a = 20 MJ/kg
Total energy in fuel	$E = Mh_a$ = 3200 MJ	Peak burning rate	Q_p = 9.0 MW

Fast fire $k = 150$ sec/$MW^{1/2}$

Time to reach peak burning rate $t_1 = k\sqrt{Q_p} = 450\,\text{sec}$ (7.5 min)

Energy released when peak rate is reached $E_1 = \dfrac{t_1 Q_p}{3} = 1350\,\text{MJ}$

$E_1 < E$ so there is a steady state

Energy released in steady state $E_2 = E - E_1 = 1850$ MJ

Duration of steady state $t_s = \dfrac{E_2}{Q_p} = 206\,\text{sec}$ (3.4 min)

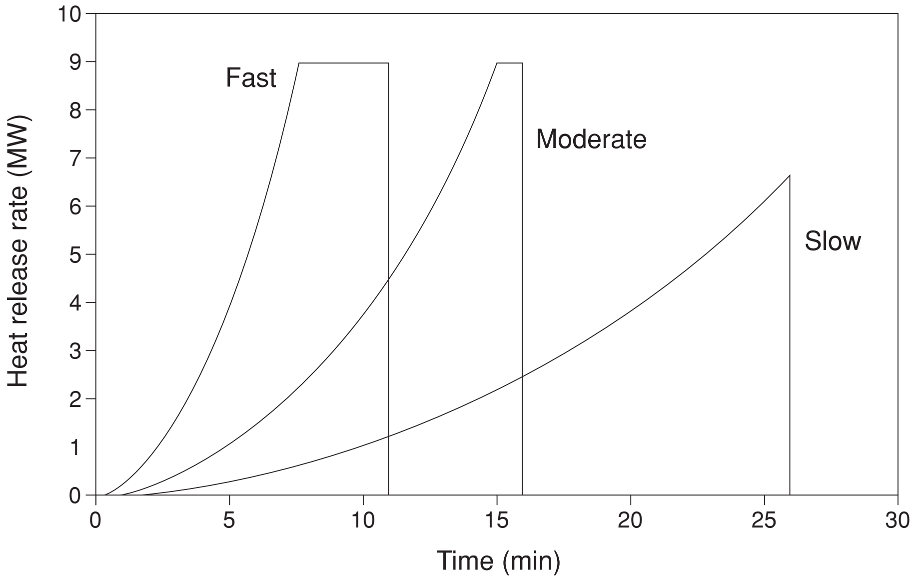


Figure 4.4: Heat release rates for a fire load of 3200 MJ

Slow fire $k = 600 \text{ sec/MW}^{1/2}$

Time to reach peak burning rate $t_1 = k\sqrt{Q_p} = 1800\,\text{sec} \quad (30\,\text{min})$

Energy released $E_1 = \dfrac{t_1 Q_p}{3} = 5400\,\text{MJ}$

$E_1 > E$ so the fire does not reach a steady state

Time for all fuel to be burned $t_m = \left(3Ek^2\right)^{1/3} = 1512\,\text{sec} \quad (25.2\,\text{min}))$

Burning rate when all fuel is burned $Q_m = \left(\dfrac{t_m}{k}\right)^2 = 6.3\,\text{MW}$

If design fires are available for individual fuel items in a room, they can be aggregated into one heat release rate curve by estimating the times of fire spread from one item to the next using the FREEBURN package in FPETOOL. Alternatively, an overall t^2 fire can be estimated by considering all of the fuel packages as one item, considering the rate of burning of each package and the expected rate of spread from one to the next.

4.4 Room fires

Fire growth computer models are used to calculate fire behaviour in a room (Karlsson and Quintiere, 2000). The input heat release rate, as described above, is the design fire that would occur if the fuel was burned in the open air with no limits on ventilation.

The actual heat release rate in the room, which can be calculated by the fire growth model, will follow the input curve if ventilation is not limiting, but will become less than that of the design fire if the window openings are not large enough to allow free burning. Hand calculations can be made for room fires, using equations 4.6 to 4.9. The value of Q_p should be the smaller of (a) the total peak heat release rate for all the fuel in the room, or (b) the ventilation controlled heat release rate as calculated in Chapter 5. For most rooms, the ventilation controlled heat release rate will govern.

As described in Chapter 6, fire growth models predict the temperature and depth of the hot layer, the volume of smoke produced and vented through various openings and the concentrations of gases and combustion products. Fire growth in rooms can be calculated using ASET for rooms with no openings or FIRE SIMULATOR for rooms with openings such as doors or windows. The more sophisticated computer fire growth models can calculate enhancement of the burning rate by radiation from the hot upper layer.

All of this information is very useful when calculating the time to response of active systems or the time available for escape of occupants.

4.5 Detector and sprinkler response

Activation time

The computer models described in Chapter 7 can be used to estimate the time of activation of heat-activated devices such as heat detectors and sprinklers.

Heat detector activation time can be used as part of egress calculations on the assumption that the detectors are connected to an alarm that will notify the occupants of the fire. The operation of automatic sprinkler systems will either extinguish a fire or limit its size. It is a conservative assumption to assume a constant burning rate after sprinkler operation.

Smoke detectors will generally activate considerably faster than heat-activated devices, and hence are of great benefit for improving life safety. However, smoke detector operation is more difficult to predict with fire growth models. Smoke detectors can be considered very sensitive heat-activated devices where a temperature rise of 4˚C or 5˚C at activation provides a good agreement with experiments in which the detectors were installed on ceilings 2.4 m high (Bukowski and Averill, 1998).

Figure 4.5 shows a comparison between typical response times of smoke detectors, heat detectors and sprinklers calculated using the SPRINKLER/DETECTOR RESPONSE module from FIREFORM in FPETOOL.

Life safety

Most fire fatalities occur in the pre-flashover stage of a fire. The principal life safety objective is to allow people to escape. Calculations of escape times, which are described in Chapter 8, require knowledge of the rate of fire growth and smoke production. These rates affect the time of detection of the fire and subsequent notification of occupants, and the time available for escape before conditions become untenable.

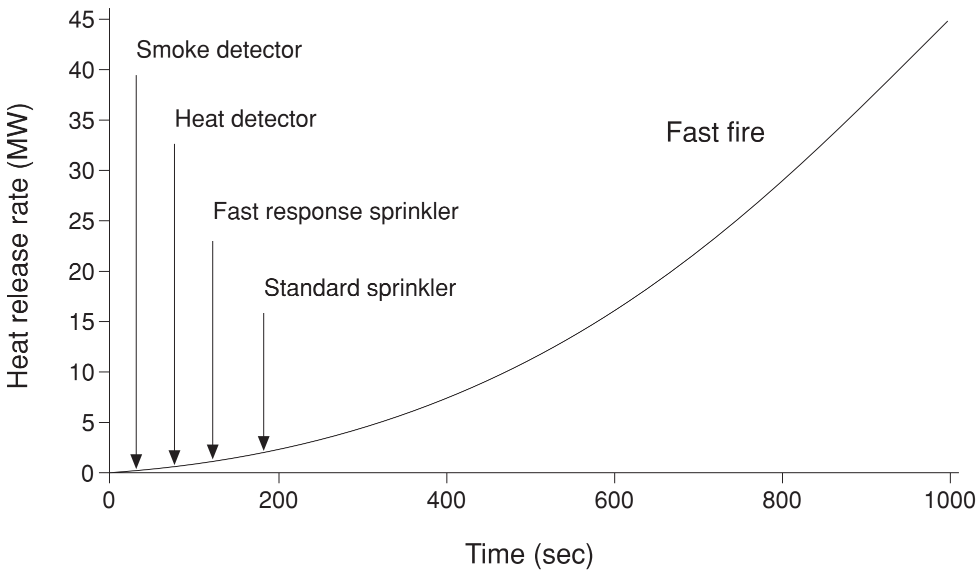


Figure 4.5: Example of typical detector activation times, shown on a heat release rate curve for a fast fire

Chapter 5
Post-flashover Fires

5.1 Introduction

The objective of design for a post-flashover fire is to contain the fire and prevent structural collapse, as necessary to meet the performance requirements.

In the post flashover phase of a fire all of the combustible objects in the compartment are burning and the heat release rate is limited either by the fuel surface area or the available air supply.

This chapter gives a method for assessing the expected severity of a post-flashover fire in a firecell, with known fire load and ventilation, and describes simple methods of assessing the fire resistance of elements of building construction.

5.2 Firecells and Fire Compartments

The New Zealand Building Code requires buildings to be divided into "firecells", surrounded by barriers that have resistance to the spread of fire. The Building Code of Australia uses the term "fire compartments".

If the firecell or fire compartment has no internal partitions, it is possible to calculate the expected severity of a fire occupying the whole firecell. For large open firecells with no partitions (floor area over about 100 m^2), the fire may move through the firecell as a migrating fire, not exposing all of the firecell to maximum temperatures at any one time. there are methods for estimating temperatures in migrating fires (Clifton, 1996), but it is generally conservative to consider the whole firecell as one space.

A firecell or fire compartment may consist of a number of rooms, separated by temporary or permanent walls. In this case, a fire in one room may be contained in that room or it may spread progressively to other rooms via concealed spaces, weaknesses in the walls or failure of the walls after sufficient fire exposure. If the walls have significant fire resistance, separate fire severity calculations considering each room may be necessary.

5.3 Fires

Fire loads

The design fire load is a value close to the maximum fire load expected in the life of the building. The design fire load is the sum of fixed and moveable fire loads.

When the fire load is determined from client-supplied information specific to a particular building, the design load should be that load which has less than 10% probability of being exceeded in 50 years or the life of the building (consistent with the definition of wind and earthquake loads for structural design).

When the fire load is determined from surveys representative of particular occupancies, the design fire load should be the 80 percentile value of surveyed loads.

The results of some surveyed fire loads in New Zealand are available from BRANZ (Narayanan 1994). In the Approved Documents, design values for hazard categories 1,2 and 3 (defined in Table 2.1) are given in Clause 2.2.1 as 400, 800 and 1200 MJ/m^2 floor area, respectively. For other occupancies or special situations, Appendix D of this guide gives moveable fire loads for many occupancies.

The total fire load stored in a firecell E (MJ) is the sum of all the energy available for release when the combustible materials are burned, given by:

$$E = \sum k_c M h_a \qquad [5.1]$$

where M is the mass of the fire load (kg)

h_a is the nett calorific value of the fuel (MJ/kg)

k_c is the proportion of the fire load available to burn in the time under consideration

The fire load energy density e_f (MJ/m^2 floor area) is:

$$e_f = E/A_f \qquad [5.2]$$

where A_f is the floor area of the firecell (m^2).

Fire duration and temperatures

Figure 3.5 shows typical temperature curves for post-flashover fires in firecells with varying fuel load and ventilation. These curves were derived from heat balance calculations based on observed rates of heat release of cellulosic fuels in small compartments. The curves shown in Figure 3.5 can also be used as the basis of more advanced fire engineering design methods by calculating the response of a structure to the expected time-temperature curve.

The COMPF2 computer program (Babrauskas 1995, 1979) is available for calculating the temperature and heat flux in post-flashover fires. This has recently been calibrated to a large number of experimental fires by Feasey (1999).

The fire severity t_e is not the same as the duration of the fire. For an estimate of the fire duration, use the time-temperature curves shown in Figure 3.5 or, alternatively, use the following approximate calculations.

For a ventilation controlled fire, the rate of burning is limited by the mass of air that can flow through the openings. This was observed Kawagoe (1958) when he was analysing the results of experimental post-flashover fires. His empirical relationship can also be derived by applying Bernoulli's equation to the post-flashover vent flows (Drysdale 1998), giving the mass flow rate of air into the compartment $\dot{m}_a$ (kg/s) as:

$$\dot{m}_a = 0.5 A_v \sqrt{h} \qquad [5.3]$$

where A_v (m^2) is the total area of the opening in the wall

h (m) is the height of the opening.

For several openings of different heights, the total area and the weighted average height should be used.

The heat release rate within the compartment is then estimated using the assumption that most fuels release a constant amount of energy per unit mass of air consumed, that is 3.0 MJ/kg of air. Thus the ventilation controlled heat release rate Q_v (MW) inside the compartment is:

$$Q_V = 1.5 A_V \sqrt{h} \qquad [5.4]$$

This does not include the additional heat released by combustion of unburned gases in flames outside the window openings, which cannot be readily calculated.

Kawagoe (1958) also derived an empirical relationship for the ventilation controlled burning rate $\dot{m}$ (kg/sec) of wood cribs, given by:

$$\dot{m} = 0.092 A_v \sqrt{h} \qquad [5.5]$$

where A_v is the total area of wall openings (m^2)

h is the weighted average height (m).

Equation 5.5 is often represented as $\dot{m} = 5.5 A_v \sqrt{h} \quad \text{kg/minute}$.

The corresponding heat release rate Q_v (MW) is given by:

$$Q_V = \dot{m} h_a \qquad [5.6]$$

where h_a is the calorific value of wood.

Post-flashover experimental room fire with large flames burning outside the opening

If h_a is taken as 16 MJ/kg, equation 5.6 becomes identical to equation 4.4.

The rate of burning may be less than Q_v if the fuel has insufficient surface area to achieve this rate of heat release, as calculated using Table 4.2.

If the mass M (kg) of the wood equivalent fuel load is known, the duration of the burning period t_b (sec) can be calculated from:

$$t_b = \frac{M}{\dot{m}} \quad [5.7]$$

Equation 5.7 gives an estimate of the duration of the fully-developed fire for fire spread calculations, whereas equation 5.9 is more appropriate for structural fire resistance. It should be noted that equation 5.7 only includes wall openings, whereas equation 5.9 also includes roof openings.

Thomas's flashover correlation

Thomas's flashover correlation can be checked to see if there is sufficient ventilation to permit a fire to develop a sufficient rate of heat release Q_{fo} (MW) necessary for flashover to occur, given by:

$$Q_{fo} = 0.0078\,A_t + 0.378\,A_v\sqrt{h} \quad [5.8]$$

where A_t is the total internal surface area of the firecell.

If Q_v is less than Q_{fo}, it is unlikely that flashover will occur (Walton and Thomas, 1995).

Worked example

For a firecell with a given geometry, fire load and window size, calculate the ventilation-controlled burning rate and duration of the burning. Check Thomas' flashover correlation to see if flashover is likely to occur.

Length of firecell	$L_f = 6$ m
Width of firecell	$W_f = 3$ m
Floor area	$A_f = L_f W_f = 6 \times 3 = 18$ m^2
Height of firecell	H = 2.5 m
Window height	h = 1.8 m

Window width	$w = 2.4$ m
Window area	$A_v = hw = 1.8 \times 2.4 = 4.32\ m^2$
Total internal surface area	$A_t = 2[A_f + H(L_f + W_f)] = 2[18 + 2.5(6 + 3)] = 81.0\ m^2$
Fire load energy density	$e_f = 1000\ MJ/m^2$
Total fire load	$E = e_f A_f = 18{,}000$ MJ
Calorific value of wood fuel	$h_a = 16$ MJ/kg
Mass of fuel	$M = E/h_a = 18{,}000/16 = 1125$ kg
Ventilation-controlled burning rate	$\dot{m} = 0.092\, A_V \sqrt{h} = 0.092 \times 4.32 \times \sqrt{1.8} = 0.533$ kg/s
Heat release rate	$Q_V = \dot{m}\, h_a = 0.533 \times 16 = 8.5$ MW
Duration of burning	$t_b = M/\dot{m} = 1125/0.533 = 2110$ s (35.2 min)
Thomas' Flashover Correlation	$Q_{fo} = 0.0078\, A_t + 0.378\, A_v \sqrt{h}$ $= 0.0078 \times 81 + 0.378 \times 4.32 \times \sqrt{1.8} = 2.8$ MW

Flashover will occur because $Q_v > Q_{fo}$

5.4 Fire severity

This document recommends calculation of fire severity using the rather crude "equivalent fire severity" concept. For more accurate assessment, actual time temperature curves can be predicted using a modified version of the Eurocode parametric fire equations (Buchanan, 2001). Note that the equivalent fire severity is not the same as the complete duration of the fire.

Equivalent time of fire exposure

The fire severity of a post-flashover fire (as used in this document) is the equivalent time of exposure to the standard fire that would produce the same maximum temperature in a protected structural steel member given a complete burnout of the firecell with no intervention. the time equivalent method was developed for structural steel members protected with insulating materials, where the steel temperature lags behind that of the fire. The method is also applicable to reinforced concrete members where the concrete insulates the reinforcing steel. It is considered applicable to heavy timber members, but with less accuracy. The method is not accurate for unprotected steel, where the steel temperatures closely follow the fire temperatures, so more detailed design methods should be used (Clifton and Feeny, 2000).

The recommended empirical expression (Eurocode 1996) for equivalent fire severity t_e (min) is:

$$t_e = e_f\, k_b\, w_f \qquad [5.9]$$

where e_f is the fire load (MJ/m^2 floor area)

k_b is a conversion factor given by Table 5.1

w_f is the ventilation factor, given below.

The values of k_b in Table 5.1 have been increased by a factor of 1.3 from those in the Eurocode, making them larger than in the First Edition of this book. Table 5.1 has been prepared for typical construction materials, based on Clifton (2000). The value of $k_b = 0.09$ is for firecells lined with fire-resisting plasterboard on the walls and ceiling, and should be used for calculations where the lining materials are not known. This is the value used in the 2000 revision of C/AS1, as shown in Table 5.2.

This calculated value of fire severity t_e can be used in the fire resistance calculations described later in this chapter when assessing the required fire resistance for materials or assemblies.

Ventilation factor

The ventilation factor w_f is given by:

$$w_f = \left(\frac{6.0}{H}\right)^{0.3}\left[0.62 + \frac{90(0.4-\alpha_v)^4}{1+b_v\alpha_h}\right] \quad > 0.5 \qquad [5.10]$$

where $\alpha_v = A_v/A_f \qquad 0.025 \le \alpha_v \le 0.25$

$\alpha_h = A_h/A_f \qquad \alpha_h \le 0.20$

$b_v = 12.5(1 + 10\alpha_v - \alpha_v^2)$

A_f is the floor area of the firecell (m^2)

A_v is the area of vertical window and door openings (m^2)

A_h is the area of horizontal openings in the roof (m^2) and

H is the height of the firecell (m).

$\sqrt{\lambda\rho c}$ ($J/m^2Ks^{0.5}$)	**Construction Materials**	k_b
400	Very light insulating materials	0.10
700	Plasterboard ceiling and walls, timber floor	0.09
1100	Lightweight concrete ceiling and floor, plasterboard walls	0.08
1700	Normal concrete ceiling and floor, plasterboard walls	0.065
2500	Thin sheet steel roof	0.045

λ = thermal conductivity W/m K ρ = density kg/m^3 c = specific heat J/kg K

Table 5.1: Conversion factor for different firecell lining materials

A_v/A_f	Fuel load 400 MJ/m^2					Fuel load 800 MJ/m^2					Fuel load 1200 MJ/m^2				
	A_h/A_f					A_h/A_f					A_h/A_f				
	0.00	0.05	0.10	0.15	0.20	0.00	0.05	0.10	0.15	0.20	0.00	0.05	0.10	0.15	0.20
0.05	90	60	50	40	40	180	120	100	80	80	240	180	140	140	120
0.06	80	50	50	40	40	160	110	90	80	80	240	160	140	120	110
0.07	70	50	40	40	40	150	100	80	80	70	220	160	140	120	110
0.08	70	50	40	40	30	140	90	80	70	70	220	140	120	110	100
0.09	60	40	40	30	30	140	90	80	70	70	200	140	110	110	100
0.10	60	40	40	30	30	120	80	70	70	70	180	140	110	100	100
0.11	60	40	30	30	30	110	80	70	70	60	160	120	110	100	100
0.12	50	40	30	30	30	100	70	70	60	60	160	110	100	100	90
0.13	50	40	30	30	30	100	70	70	60	60	160	110	100	90	90
0.14	50	30	30	30	30	90	70	60	60	60	140	100	100	90	90
0.15	40	30	30	30	30	80	70	60	60	60	120	100	90	90	90
0.16	40	30	30	30	30	80	70	60	60	60	110	100	90	90	90
0.17	40	30	30	30	30	80	60	60	60	60	110	90	90	90	90
0.18	40	30	30	30	30	70	60	60	60	60	110	90	90	90	80
0.19	30	30	30	30	30	70	60	60	60	60	110	90	90	80	80
0.20	30	30	30	30	30	70	60	60	60	60	100	90	80	80	80
0.25	30	30	30	30	30	60	60	60	60	50	90	80	80	80	80

Table 5.2: Values of equivalent fire severity t_e (minutes)
(from C/AS1,BIA 2000)

Tabulated values

Values of t_e from equation 5.9 have been tabulated in the Acceptable Solution C/AS1 (BIA, 2000). The table is reproduced as Table 5.2. This table is for a firecell ceiling height of 3.0 metres, k_b value of 0.09 and for fire load energy densities as shown (MJ/m^2 floor area). The values here have been rounded to the nearest ten minutes. The equation should be used for any significant departures from these values.

Rate of heat release

The average rate of heat release implied by the equivalent time of exposure is Q_e (MW) given by:

$$Q_e = E/60\,t_e \qquad [5.11]$$

This may be considerably different from the actual average or peak heat release rate in the real fire under consideration, but may be useful as a comparison between different fire scenarios.

Worked example

For a concrete firecell with a given geometry, window size and fire load, calculate the equivalent fire severity.

Length of firecell	$L_f = 5$ m	
Width of firecell	$W_f = 5$ m	
Floor area	$A_f = L_f\,W_f = 25\ m^2$	
Height of firecell	H = 3 m	
Fire load energy density	$e_f = 800\ MJ/m^2$	
Conversion factor	$k_b = 0.07\ min\ m^2/MJ$	
Window openings	Height h = 2.0 m	Width w = 3.0 m
Area of openings	$A_v = h\,w = 6\ m^2$	No ceiling openings ($A_h = 0$)
	$\alpha_v = \dfrac{A_v}{A_f} = 0.24$	$\alpha_h = \dfrac{A_h}{A_f} = 0$
	$b_v = 12.5(1 + 10\,\alpha_v - \alpha_v^2) = 41.8$	
Ventilation factor	$w_f = \left(\dfrac{6.0}{H}\right)^{0.3}\left[0.62 + \dfrac{90(0.4-\alpha_v)^4}{1 + b_v\,\alpha_h}\right] = 0.836$	
Average fire severity	$t_e = e_f\,k_b\,w_f = 46.8$ min	
Total fuel load	$E = A_f\,e_f = 20{,}000$ MJ	
Equivalent rate of heat release	$Q_e = \dfrac{E}{t_e}$	$Q_e = 427$ MJ/min = 7.1 MW

Single storey buildings

Most single storey buildings do not have fire-resisting roof construction so that the roofing materials collapse or burn away during the fire, at which point the fire becomes more like an open-air fire than a compartment fire.

The severity of an open air fire on surrounding structure is less than that of an enclosed compartment fire because most of the heat is vented directly to the atmosphere.

It is conservative to use the equivalent severity formula assuming that the roof remains in place for the duration of the fire. Provided that skylights are made of plastic or other material that will melt or burn early in the fire development, they should be considered to be horizontal roof vents when using Table 5.2 or equation 5.9.

If the calculated fire severity exceeds the likely fire resistance of the roof, it is more accurate to estimate the time of roof collapse and consider the fire to be an open-air fire from that time on, where the rate of burning is governed by the fuel itself rather than by the ventilation, in which case it is difficult to make meaningful calculations of fire severity. If the fuel is of known type and quantity, some indication of burning rate can be obtained using Table 5.2.

Worked example

Consider a warehouse 20 m x 40 m x 4 m high storing 30 tonnes of polyethylene plastic. The warehouse has full height openings 10 m long in one wall and the roof is 10% skylights.

Floor area $A_f = 20 \times 40 = 800 \text{ m}^2$

Height of roof $H = 4.0 \text{ m}$

Area of wall openings $A_v = 10 \times 4 = 40 \text{ m}^2$

Height of wall openings $h = 4.0 \text{ m}$

Area of roof openings $A_h = 80 \text{ m}^2$

$\alpha_v = 40/800 = 0.05$ $\quad \alpha_h = 80/800 = 0.10$

$b_v = 12.5(1 + 10\alpha_v + \alpha_v^2) = 18.7$

Ventilation factor $$w_f = \left(\frac{6}{H}\right)^{0.3}\left[0.62 + \frac{90(0.4 - \alpha_v)^4}{1 + b_v \alpha_h}\right] = 1.23 \text{ m}^{-0.3}$$

Mass of fuel $M = 30{,}000 \text{ kg}$

Calorific value of polyethylene $h_a = 44 \text{ MJ/kg}$

Total fuel load $E = h_a M = 44 \times 30{,}000 = 1.32 \times 10^6 \text{ MJ}$

Fuel load energy density $e_f = E/A_f = 1650 \text{ MJ/m}^2$

Conversion factor $k_b = 0.045$

Equivalent fire severity $t_e = e_f k_b w_f = 91 \text{ min}$

If the roof remained in place, the equivalent rate of heat release would be: $Q_e = E/60\,t_e = 242 \text{ MW}$

Assume that the roof is not fire-rated so that it would collapse after less than half an hour of fire exposure. Calculate the rate and duration of burning as an open air fire.

From Table 4.2 the heat release rate for a surface of polyethylene is $q_f = 1.36 \text{ MW / m}^2$. Assume that the exposed surface of polyethylene is the same as the floor area.

Heat release rate $Q = q_f \times A_f = 1.36 \times 800 = 1088 \text{ MW}$

For all of the fuel to burn at this rate, the duration of the burning period is: $t_b = E/Q = 1213 \text{ sec} = 20.2 \text{ min}$

To do this calculation more accurately, the equations in section 5.7 can be used to calculate the limiting steel temperature under dead load only and the corresponding time to reach the limiting temperature, hence roof collapse. An estimate can then be made of the amount of fuel remaining, hence the burning period of the open air fire. Boundary walls can conservatively be provided with a fire resistance rating equal to the sum of the two periods of fire exposure.

5.5 Fire resistance

Introduction

The objective of design for fire resistance is to ensure that all elements of building construction have sufficient fire resistance to prevent spread of fire and to prevent structural collapse in order to meet the specified performance requirements for the building.

Fire in a single story industrial building after penetration through the roof; the walls are preventing fire spread

Fire resistance is a measure of the ability of a building element to resist a fire. Fire resistance is most often quantified as the time for which the element is expected to meet certain criteria while exposed to a standard fire resistance test. The specified fire resistance is not necessarily the time for which an assembly can resist a realistic fire. Structural fire resistance can also be quantified using temperature or load bearing capacity of the structural element. Fire resistance of any building element depends on many factors, including the severity of the fire, the material, the geometry and support conditions of the element, restraint from the surrounding structure and the applied loads.

The *fire resistance rating* (FRR) or *fire resistance level* (FRL) is the fire resistance assigned to a building element on the basis of a test or some other approval system (England et al, 2000).

Fire resistance may be required to:

a) prevent the spread of fire into the "safe path" of egress routes until all occupants have escaped. The time required can be calculated as described in Chapter 8;
b) provide protection to fire fighters by preventing spread into egress routes and preventing collapse of any structure within the firecell, in accordance with Chapter 12;
c) prevent spread of fire to other firecells or to other rooms of the same firecell, as described in Chapter 7;
d) prevent collapse of any structural elements;
e) prevent spread of fire to neighbouring buildings by insulation failure or collapse of external walls;
f) provide for repair and reuse of the building after a fire.

Failure criteria

The three failure criteria for fire resistance testing are *stability*, *integrity* and *insulation*. To meet the *stability* criterion, a structural element must perform its load-bearing function and carry the applied loads for the duration of the test, without structural collapse. Many testing standards have a limitation on deflection or rate of deflection for load-bearing tests, so that a test can be stopped before actual failure of the test specimen which would damage the furnace.

The integrity and insulation criteria are intended to test the ability of a barrier to contain a fire in order to prevent fire spreading. To meet the *integrity* criterion, the test specimen must not develop any cracks or fissures that allow smoke or hot gases to pass through the assembly. To meet the *insulation* criterion, the temperature on the cold side of the test specimen must not exceed a specified limit, which is an average increase of 140˚C and a maximum increase of 180˚C at a single point. These temperatures represent a conservative indication of the conditions under which fire might spread to the other side of the barrier.

All fire rated construction elements must meet one or more of the three criteria as shown in Table 5.3, depending on their function. Note that fire resistant glazing need only meet the integrity criterion because it is not load bearing and it cannot meet the insulation criterion as glass has very little resistance to radiant transfer of heat.

The required fire resistance is often specified seperately for stability/integrity/insulation (in that order). For example, a typical load bearing wall may have a specified fire resistance rating of 60/60/60, which means that a one hour rating is required for stability, integrity and insulation. If the same wall was non-load bearing, the specified fire resistance rating would be -/60/60. A fire door with a glazed panel may have a specified rating of -/30/-, which means that this assembly requires an integrity rating of 30 minutes, with no requirement for stability or insulation.

	Stability	Integrity	Insulation
Partition		X	X
Load bearing wall	X	X	X
Floor/ceiling	X	X	X
Beam	X		
Column	X		
Fire resistant glazing		X	

Table 5.3: Failure criteria for elements of building construction

Standard test

When fire resistance is determined experimentally, it is with the use of a standard fire resistance test of a full size component. The test specification most often used in Australia and New Zealand is AS 1530 Part 4, which is similar to ISO 834, BS 476 Parts 20 to 22 and ASTM E119 (with different pressures and support conditions). In tests according to AS 1530 Part 4 or ISO 834, the specimen is exposed to a fire with temperature T (˚C) increasing according to:

$$T = 345 \log_{10} (8t + 1) + T_o \quad [5.12]$$

where t is the time (min)

T_o is the ambient temperature (˚C)

Failure is assessed according to three criteria:

Stability failure:	Loss of load capacity
Integrity failure:	Penetration by flame or hot gases
Insulation failure:	Average temperature rise of 140˚C or a local maximum of 180˚C on the unexposed face.

Not all of these criteria apply to all types of elements. The criteria applying to common elements are shown in Table 5.3. The same criteria apply to determination of fire resistance by calculation.

Design based on equivalent time

Design for fire resistance in this document is based on equivalent fire severity, calculated as an equivalent time of exposure to the standard fire for comparison with the results of standard fire tests or calculations based on such tests.

The design should be such that:

$$t_r \geq t_{ed} \quad [5.13]$$

where t_r is the fire resistance rating (min) described below

t_{ed} is the design fire severity (min) given by:

$$t_{ed} = k_s t_e \quad [5.14]$$

where t_e is the equivalent fire severity calculated as shown in section 5.4

k_s is 0.5 for sprinklered buildings, 1.0 for all others.

The value of k_s is the subject of continuing debate and further study. A value of $k_s = 0.5$ is incorporated into the New Zealand Acceptable Solution (BIA, 2000). A larger value of k_s should be considered for very tall multi-story buildings.

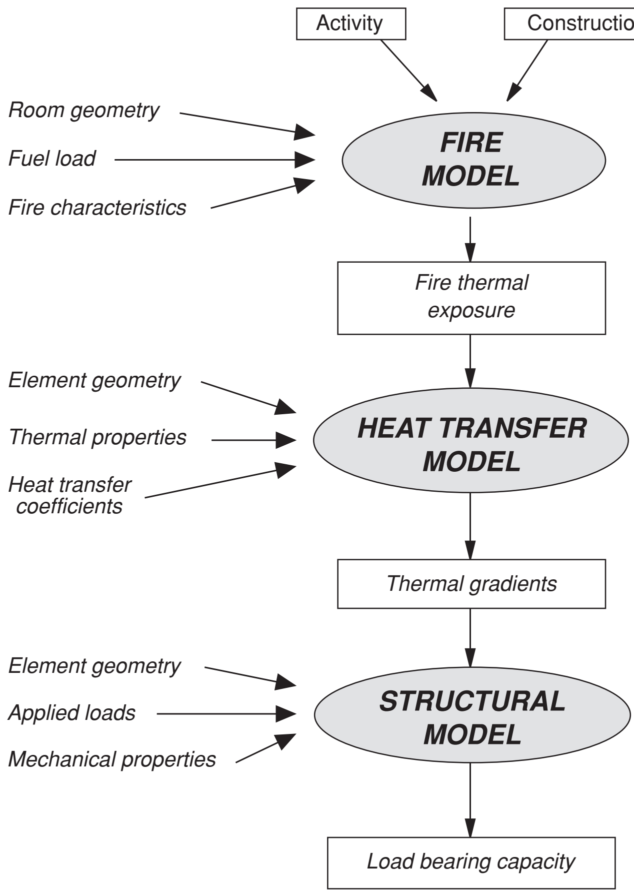


Figure 5.1: Flow chart for calculating fire resistance

5.6 Determination of fire resistance

The fire resistance t_r may be determined:

(a) by experiment, according to AS 1530 Part 4 or equivalent;

(b) by calculation (except for integrity);

(c) by interpolation or extrapolation and analogy from experimental or analytical results;

(d) by reference to listings of proprietary tested systems;

(e) by reference to listings of generic fire resistance.

In all of these cases, the fire resistance is measured in time of exposure to the standard fire.

Fire resistance by calculation

Structural fire design is a rapidly developing subject. At the present time there is a lack of authoritative references, but design guides and text books are being developed (Purkiss, 1996; Buchanan, 2001). Design for fire resistance by calculation must be supplemented by tests to show that the system will actually work as intended, and the applied fire protection will remain in place.

Figure 5.1 shows a flow chart for the overall process of determining fire resistance by calculation. There are three essential component models; the fire model, the heat transfer model and the structural model.

The *fire model* can be any selected time temperature curve including the standard fire, or a measured or estimated real fire. Fire temperatures are influenced by the room geometry, ventilation and fire load. If the time equivalent formula is used, it is not necessary to use a fire model, because the fire severity is already incorporated into the formula which gives an equivalent time of exposure to the standard fire.

Large fire resistance furnace at the Building Research Association of New Zealand

The *heat transfer model* is used to calculate the temperature gradients in the member exposed to fire. Calculation of heat transfer requires knowledge of the geometry of the element, thermal properties of the materials and heat transfer coefficients at the boundaries. Heat transfer to surfaces of the element is a combination of convection and radiation. Heat transfer through solid materials is by conduction. Heat transfer through voids is a combination of convection and radiation. Practical difficulties are that some thermal properties are very temperature dependant, and heat transfer coefficients are not well established. Accurate results can only be obtained with a finite element (or finite difference) computer program. Some approximate heat transfer models for common situations are given later in this chapter.

The *structural model* is the process of structural analysis in fire conditions. This process is essentially the same as for non-fire conditions, except that design for fire must additionally consider the following:

- Expected loads on the structure at the time of the fire
- Elevated temperatures in structural members causing:
    - thermal expansion and deformations
    - internal forces and restraints
    - reductions in mechanical properties
    - different load paths and failure mechanisms
    - redistribution of moments and structural actions
    - loss of cross section due to charring or spalling
- Reduced safety factors due to unlikely occurrence

Simple models for calculating the performance of structural elements exposed to fire are described later in this chapter. Most of these have been taken from the appropriate material design codes for steel, concrete and timber structures. Hand calculation methods can be used for simple elements but sophisticated computer models are necessary for the analysis of frames or larger structures. One widely-used program is SAFIR (Franssen et al, 2000). Real buildings are more than just a collection of elements, so estimation of the fire resistance of the whole building must consider the fire resistance of the component parts and their location in the building. Computer-based structural analysis models must be able to include the effects of thermal expansion, loading and unloading, large deformations and non-linear material properties which are temperature dependant. Many elements in real buildings may be of different sizes, shapes and with different connection details to those which have been tested.

Loads and strength reduction factors

Loads to be considered for fire design shall be either:

(a) the loads specified for the general type of occupancy in NZS 4203:1992 or AS 1170.1, or

(b) for a specific occupancy, the expected value of loads at the time of a possible fire.

In either case, load combinations shall be as specified in NZS 4203 or AS 1170.1 for fire emergency conditions. Note that the resulting combined loads may be less than those used in standard fire tests where the specifications call for full design loads (i.e. dead load plus full live load).

The load combination which is most often critical for non-fire design is

1.2 G + 1.6 Q (NZS 4203)   1.25 G + 1.5 Q (AS 1170.1)

where   G is the dead load , Q is the live load

For fire emergency conditions, the load combinations are:

G + 0.6 Q or G + 0.4 Q (NZS 4203)   1.1G + 0.6 Q or 1.1G + 0.4 Q (AS 1170.1)

the 0.6 factor being for storage occupancies and the 0.4 being for all other occupancies.

Material-related strength reduction factors (ϕ factors) are specified in the material codes, generally taking a value of $\phi < 1.0$ for cold design and $\phi = 1.0$ for fire conditions.

Generic Listings

Generic approvals are those that are not related to proprietary products or calculation methods. For example, these include concrete encasement of steel members or minimum thicknesses and cover requirements for reinforced concrete members. In New Zealand, many generic approvals are listed in the MP9 documents. In Australia, Specification 2.3 of the Building Code of Australia (ABCB, 1996) contains generic listings of fire resistance levels.

Proprietary Listings

Proprietary approvals are approvals of proprietary systems, which have been tested by manufacturers or trade organisations. These include light frame wall and floor systems and passive protection for structural steelwork. These approvals can be used directly in many cases, but do not always take actual load levels or complex structural behaviour into account. Individual manufacturers should be contacted for detailed information.

In New Zealand, the only comprehensive listing of approved fire-rated structural systems is the document known as MP9 (SNZ, 1991), which is a listing of all fire ratings approved by the Fire Rating Committee of Standards New Zealand. MP9 is not currently maintained, but it remains a useful document. Similar documents are available in other countries (e.g. Underwriters Laboratories in USA and Canada), but not in Australia.

5.7 Structural steel

Introduction

There is a large and rapidly expanding international literature on fire performance of structural steel. Background material on the fire resistance of steel structures is given by HERA (1994), Clifton and Feeney (2000) and Buchanan (2001). Understanding of the structural behaviour of steel buildings in fire has increased rapidly in the last five years, and this knowledge is becoming increasingly available for designers (Clifton and Feeney, 2000). The emphasis is shifting from design of single members to behaviour of structural systems and whole-building behaviour, largely based on recent results from full-scale fire tests in real buildings. This book gives a guide to simple design of single members.

Protection of structural steelwork

Unprotected structural steel members can suffer rapid temperature rise and loss of strength when exposed to a fire, unless they are heavy members with a relatively small perimeter exposed to the fire.

Unprotected steel beams and composite steel/concrete floor slabs showing large deformations but no collapse after severe fire in Cardington test building

There are many methods of protecting structural steel to reduce the rate of temperature increase when exposed to fires. These include:

- Sprayed on cement-based material;
- Board systems (gypsum plaster, sodium silicate etc.);
- Concrete encasement (full or partial);
- Intumescent paint;
- Water filling of hollow sections; and
- Sprinkler spray directly on to members.

For all steel members, protected or unprotected, the rate of temperature increase depends on the section factor, or H_p/A ratio (m^{-1}), where H_p is the heated perimeter and A is the cross section area of the steel section. Members with a low H_p/A ratio have a less rapid temperature rise than members with a high H_p/A ratio, as shown in Figure 5.2. Some publications use a surface area to mass ratio (m^2/tonne). Both ratios are recognised in NZS 3404, but AS 4100 only refers to the surface area to mass ratio.

From a conceptual point of view, it is easier to visualise the "effective thickness", which is the inverse of H_p/A. Section factors for standard UB and UC sections are given in Appendix F.

The designer must ensure that the specified insulation material has been exposed to full-scale load-bearing fire tests, to demonstrate that it will remain in place and perform its function throughout a fire which could result in large deformations in the steel members.

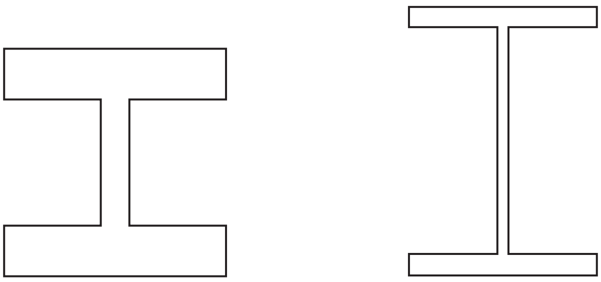


Figure 5.2: Effect of H_p/A on temperature rise

Recommended design methods

The recommended design methods for structural steel exposed to fire are described in the Steel Design Codes NZS 3404:1992 and AS 4100: 1990, which are essentially the same. The steel codes permit fire design to be done either by test, by calculation from first principles using any rational method, or by a simple prescribed calculation method, such as that summarized below.

Simple design method

The simple design method specified in NZS 3404 and AS 4100 is based on determining the limiting temperature of the steel member under consideration, then determining the time it would take for the member to reach that temperature in the standard fire test. Variation of yield stress and modulus of elasticity with temperature is shown in Figure 5.3. These curves apply to the normal range of structural steels.

Determination of limiting steel temperature

The limiting steel temperature is the temperature at which the steel member would be expected to yield, considering the strength of the steel and the load on the member. The limiting steel temperature T_1 (˚C) can be calculated from:

$$T_1 = 905 - 690\, r_f \qquad [5.15]$$

where r_f is the ratio of the design action on the member under the design load for fire to the design capacity of the member at room temperature. This formula has been derived directly from the equation of the dotted line in Figure 5.3.

Determination of time to reach limiting temperature

NZS 3404 and AS 4100 specify methods of calculating the time to reach the limiting temperature, based on test results. In the absence of such tests, the following approximate formula from ECCS (1985) may be used for predicting the time t in minutes for a steel member protected with light, dry insulation to reach the limiting temperature T_1:

$$t = 40\,(T_1 - 140)\left[\frac{\lambda}{d}\frac{H_p}{A}\right]^{-0.77} \qquad [5.16]$$

where H_p is the heated perimeter of the steel section (m)

A is the cross section area of the steel section (m^2)

λ is the thermal conductivity of the insulation (W/m K)

d is the thickness of the insulation (m)

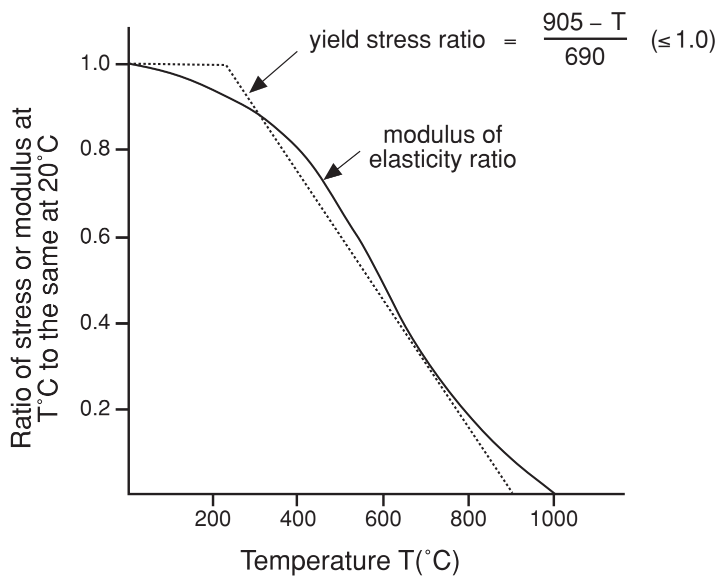


Figure 5.3: Variation of mechanical properties of steel with temperature

This equation is valid in the range of: t from 30 to 240 minutes, T_1 from 400˚C to 800˚C, H_p/A from 10 to 300, and d/λ from 0.1 to 0.3 m^2 K/W. The upper limit of 800˚C has been derived by Lewis (2000).

Typical values of density and thermal conductivity are given in Table 5.4.

For moist insulation, a time delay t_v in minutes can be added to the time t calculated from the above equation, using

$$t_v = \frac{m_d \rho d^2}{5\lambda} \qquad [5.17]$$

where m_d is the moisture content (%)

ρ is the density of the insulating material (kg/m3)

For heavy insulation, which will further reduce the rate of temperature increase in the steel because of its thermal capacity, ECCS (1985) gives other equations, but it is conservative to use equation 5.17.

For unprotected steel members, the following approximate formulae from AS 4100 and NZS 3404 can be used.

For three-sided exposure

$$t = -5.2 + 0.0221 T_1 + \frac{3.40 T_1}{H_p/A} \qquad [5.18]$$

For four-sided exposure

$$t = -4.7 + 0.0263 T_1 + \frac{1.67 T_1}{H_p/A} \qquad [5.19\ ]$$

Both of these equations are approximately valid for H_p/A in the range 15 to 275 m^{-1} and T_1 in the range 400˚C to 800˚C. For temperatures below 400˚C linear interpolation can be used based on the time at 400˚C and an initial temperature of 20˚C at the starting time.

Other methods

The above approximate equations are unconservative in some situations (Lewis, 2000), but they are acceptable for normal design, considering the behaviour of steel structural systems compared with individual members, and other factors. There are more accurate methods of calculating steel temperatures, using simple formulae (ECCS, 1985), a step-by-step lumped mass calculation, or finite element computer models. All of the above methods are based on exposure to the standard fire test. Considering the actual development of a “real” fire as compared to a “standard” fire, it is possible to design from first principles using the real fire temperatures to predict steel temperatures and structural response (Buchanan, 2001). For unprotected steel members, the design should be based on the calculated temperature response of the steel to the estimated fire temperatures.

For composite steel-concrete floor systems, the recommended design method is described by HERA (1988). For structural steel members outside a firecell, such as external beams and columns, the recommended design method is that discussed by Law and O’Brien (1983). For light steel framed walls protected by gypsum plasterboard, a range

Material	Density kg/m^3	Thermal conductivity W/mK	Specific heat J/kg K	Equilibrium moisture content (%)
Sprayed mineral fibre	300	0.12	1200	1
Perlite or vermiculite plaster	670	0.18	1200	3
Fibre silicate sheets	600	0.15	1200	3
Gypsum plaster	800	0.20	1700	20
Mineral wool slabs	150	0.20	1200	2

Data from ECCS (1995) except the perlite figures from PII (1967). Note that 20% mc for gypsum includes water of crystalisation.

Table 5.4: Properties of insulating materials under fire conditions

of approved proprietary systems with ratings from 15 minutes to two hours is given by Winstone Wallboards (1997), Boral, CSR and other manufacturers of gypsum board.

Worked example

For a simply supported steel beam of known span, load, yield strength, section properties and H_p/A ratio, calculate the time to failure under exposure to the standard fire as an unprotected beam and protected with sprayed-on insulation of known thickness and properties. Precast concrete slabs protect the top flange from fire.

Beam span	L = 8.5 m	Dead load	G = 12.0 kN/m (including self weight)
Beam size	410 UB 54	Live load	Q = 10.0 kN/m

Design modulus $Z_e = 1060 \text{ x } 10^3 \text{ mm}^3$

H_p/A ratio $H_p/A = 192 \text{ m}^{-1}$ (from Appendix F, for 3-sided contour protection)

COLD CALCULATIONS

Strength reduction factor $\phi = 0.9$

Yield stress $f_y = 300$ MPa

Design load (cold) $W_c^* = 1.2\,G + 1.6\,Q = 30.4$ kN/m

Bending moment $M_c^* = \dfrac{W_c L^2}{8} = 275$ kNm

Bending strength $M_s = Z_e f_y = 318$ kNm (assume that beam has adequate lateral restraint)

Design strength $\phi M_s = 286$ kNm Design is OK ($\phi M_s > M_c^*$)

FIRE CALCULATIONS

Design load (fire) $W_f = G + 0.4\,Q = 16.0$ kN/m

Bending moment $M_f^* = \dfrac{W_f L^2}{8} = 145$ kNm

Ratio of design action to capacity at room temperature $r_f = \dfrac{M_f^*}{M_s} = 0.454$

Limiting steel temperature $T_1 = 905 - 690\,r_f = 591°C$

UNPROTECTED STEEL

Use equation for three-sided exposure:

Resistance time $t_r = -5.2 + 0.0221 T_1 + \dfrac{3.40\,T_1}{H_p/A} = 18$ min

Design is OK if this resistance time is greater than the equivalent fire severity.

PROTECTED STEEL

The steel beam is protected with a 20 mm layer of gypsum plasterboard as box protection.

H_p/A ratio $H_p/A = 143 \text{ m}^{-1}$ (from Appendix F, for 3-sided box protection)

Thickness of insulation d = 0.020 m

Thermal conductivity $\lambda = 0.20$ W/mK (Table 5.4)

Resistance time $t = 40(T_1 - 140)\left[\dfrac{\lambda}{d}\dfrac{H_p}{A}\right]^{-0.77} = 67$ min

Moisture content of insulation	$m_d = 20\%$
Density of insulation	$\rho = 800\ kg/m^3$ (Table 5.4)
Time delay for insulation	$t_v = \dfrac{m_d \rho d^2}{5\lambda} = 6.4\ min$
Total time	$t_t = t_r + t_v = 73\ min$

Design is OK if this total time is greater than the equivalent fire severity.

5.8 Reinforced concrete and masonry

Introduction

Reinforced concrete and masonry structures generally have good resistance to fire. Concrete is non-combustible and generally remains in place during a fire, providing protection to the reinforcing steel or prestressing strand buried within the concrete. The level of fire resistance largely depends on the depth of cover protection to the steel. A background document by Wade (1991b) gives an excellent description of the behaviour of concrete structures in fire.

The New Zealand Concrete Design Code NZS 3101:1995 and the Australian Concrete Design Code AS 3600:1994 give generic approvals for reinforced and prestressed concrete structures exposed to fire. NZS3101 and AS 3600 give approval to the calculation method proposed by Wade (1991a). Generic fire resistance ratings for concrete and concrete masonry structures are also given by MP9 and the Building Code of Australia. The most useful North American documents are those by Gustaferro and Martin (1977) and Fleischmann (1995). A summary of British practice is by the Institution of Structural Engineers (ISE 1978).

Recommended design methods

Specific design for fire is not necessary if the generic requirements for cover and minimum dimension meet those specified in NZS 3101. Where specific design is needed, the recommended design methods are also described in NZS 3101, which is essentially the same as the Australian Code, AS 3600:1994. These codes permit fire design to be done either by test, by extrapolation from tests results, or by calculation from first principles using any recognised method.

The recommended calculation method is that by Wade (1991a), based largely on overseas practice. The method as it applies to simply supported beams or slabs is summarised below. A software version of the method can be downloaded from www.branz.org.nz/branz/resources/firesoftware.htm.

Temperatures and material properties

The temperature at various depths within a slab or wall exposed to the standard fire are shown in Figure 5.4. Any reinforcing steel within the concrete may be assumed to be at the same temperature as the surrounding concrete. For several bars with different cover, the weighted average of the distances from the centre of each bar to the nearest surface should be used.

Typical performance of reinforced concrete building in a post-flashover fire, resulting in surface damage but no collapse or serious deformation

Temperatures within reinforced concrete beams exposured to the standard fire are shown in Figure 5.5.

The properties of typical reinforcing steels and prestressing strands at elevated temperatures and the properties of typical concrete at elevated temperatures are shown in Figure 5.6(a). The equations of these lines are:

$k_{y,T}$ = (720 - T)/470 reinforcing steel

$k_{y,T}$ = (700 - T)/550 prestressing steel [5.20]

where $k_{y,T}$ is the ratio of $f_{y,T}$ (the yield strength at elevated temperature T) to f_y (the yield strength at 20˚C).

Structural calculation

The information above can be used to calculate the flexural capacity of a beam or slab after any time of standard fire exposure, to compare with the actual moment resulting from the applied loads at the time of a fire.

For simply supported slabs or T-beams where the compression zone is unaffected by heat, only the reduction in steel strength need be considered. For situations such as continuous beams where the concrete compression block is heated, the effect of elevated temperatures can be considered by ignoring any concrete with a temperature greater than 500˚C assuming that the remaining concrete is at room temperature.

Flexural continuity and axial restraint can greatly increase the fire resistance of reinforced concrete members under certain conditions. Wade (1991a) and Buchanan (2001) give procedures for assessing these factors.

Worked example

Reinforced Concrete Beam (Refer to Figure 5.7)

For a simply supported reinforced concrete beam with known span, load, geometry and reinforcing, check the positive flexural capacity after 90 minutes exposure to the standard fire.

Given information:

Beam span	L = 15.0 m	Dead load G_1 = 6.0 kN/m (Excluding self weight)
Beam width	b = 400 mm	

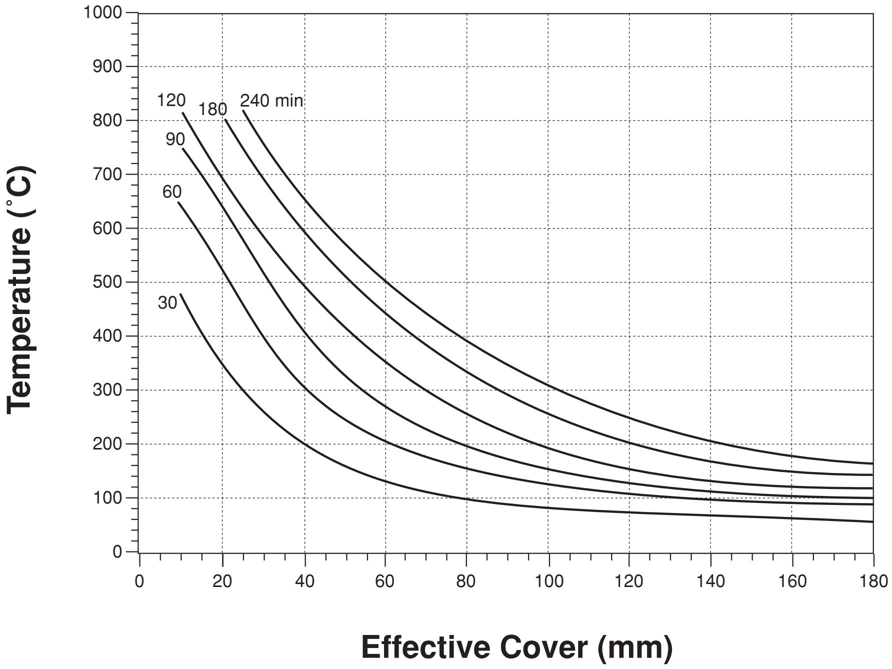


Figure 5.4: Temperatures within a fire-exposed slab

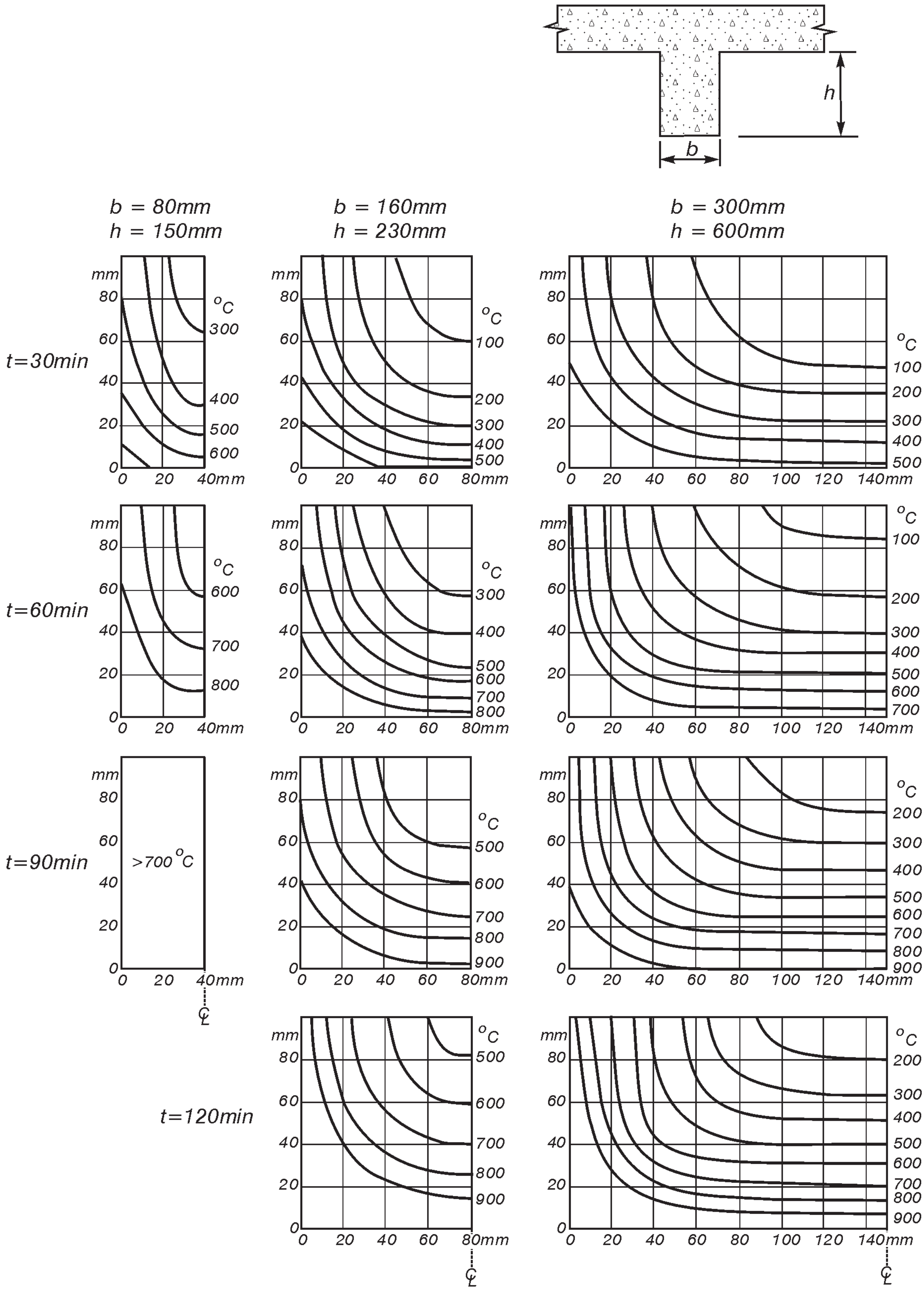


Figure 5.5: Temperatures within a concrete beam exposed to the standard fire

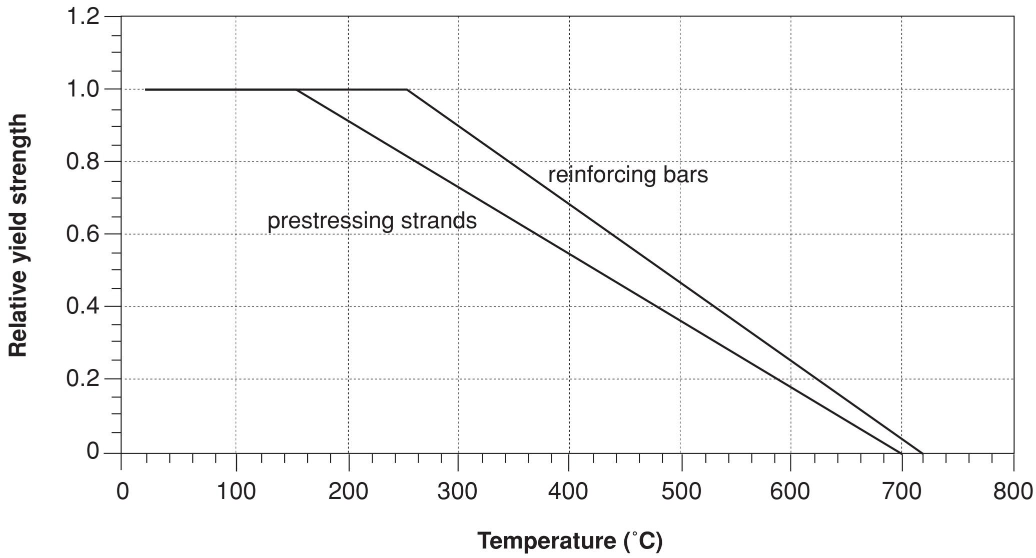


Figure 5.6(a): Properties of steel reinforcing at elevated temperatures

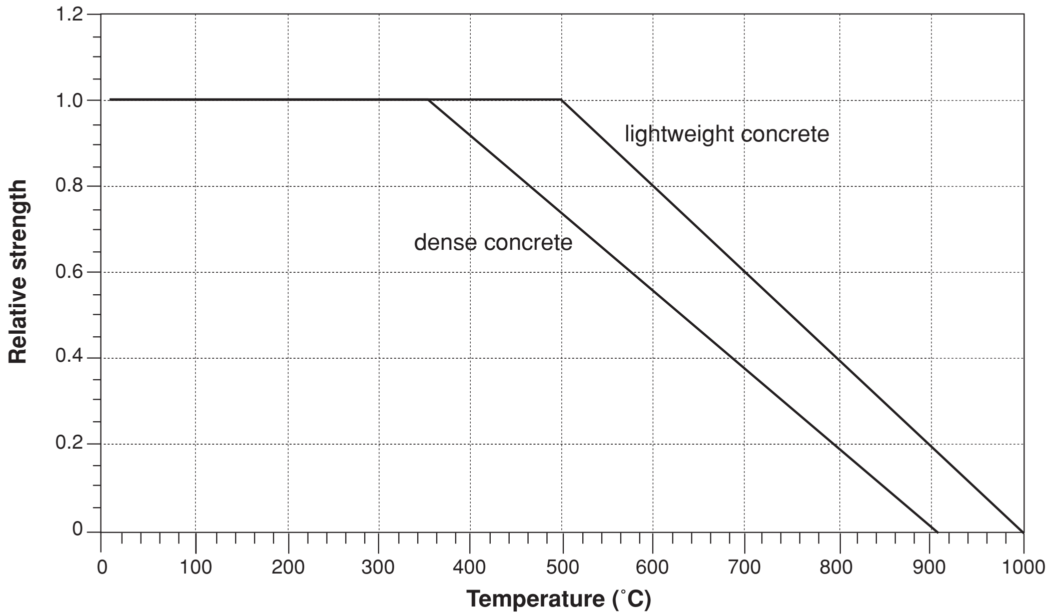


Figure 5.6(b): Properties of concrete at elevated temperatures

Beam depth	h = 800 mm	Live load	Q = 12.5 kN/m
Bottom cover	c_v = 25 mm	Concrete density	ρ = 24 kN/m^3
Bar diameter	D_b = 32 mm	Concrete compressive strength	f_c' = 30 MPa
Number of bars	n = 8 (2 rows of 4 bars)	Steel yield stress	f_y = 300 MPa

Calculations

Area of one bar	$A_{s1} = \pi r^2 = 804 \text{ mm}^2$
Total steel area	$A_s = n\pi r^2 = 6432 \text{ mm}^2$
Effective depth	$d = h - c_v - 1.5\, D_b = 800 - 25 - 48 = 727$ mm

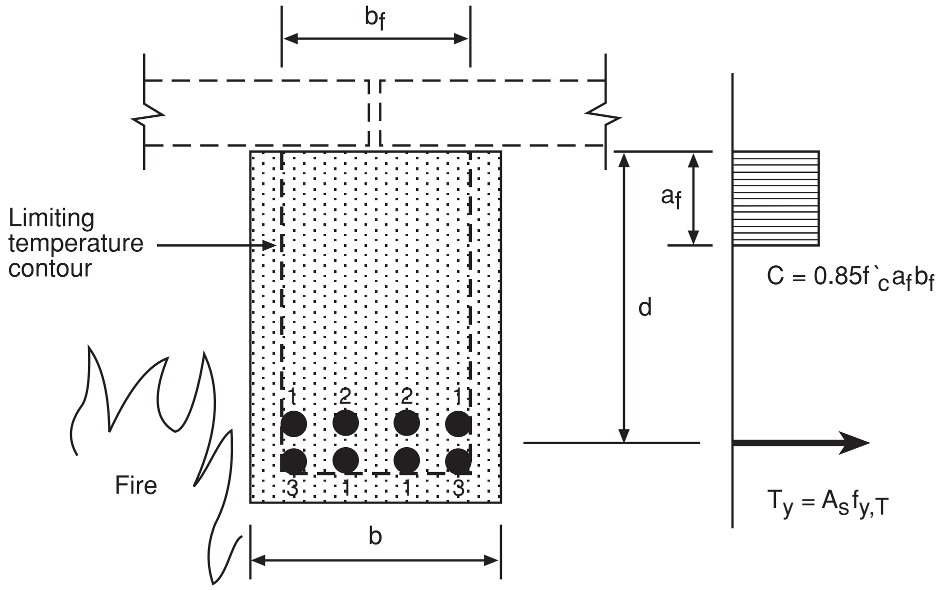


Figure 5.7: Calculation of concrete compressive block at elevated temperatures for negative moment resistance

Self weight	$G_2 = \rho bh = 24 \times 0.4 \times 0.8 = 7.7$ kN/m
Total dead load	$G = G_1 + G_2 = 6.0 + 7.7 = 13.7$ kN/m

Cold Calculations

Strength reduction factor	$\phi = 0.85$
Stress block depth	$a = A_s\, f_y / 0.85 f_c'\, b = 6432 \times 300 / 0.85 \times 30 \times 400 = 189$ mm
Internal lever arm	$jd = d - a/2 = 727 - 189/2 = 632$ mm
Design load	$w_c = 1.2\,G + 1.6Q = 1.2 \times 13.7 + 1.6 \times 12.5 = 36.4$ kN/m
Bending moment	$M^*_c = w_c\, L^2/8 = 36.4 \times 15^2/8 = 1024$ kN.m
Bending strength	$M_n = A_s\, f_y\, jd = 6432 \times 300 \times 632/10^6 = 1220$ kN.m
	$\phi\, M_n = 0.85 \times 1220 = 1037$ kN.m $\quad$ $M^*_c < \phi\, M_n$ so design is OK

Fire Calculations

Design load (fire)	$w_f = G + 0.4Q = 13.7 + 0.4 \times 12.5 = 18.7$ kN/m
Bending moment	$M^*_f = w_f L^2/8 = 18.7 \times 15^2/8 = 526$ kN.m
Fire duration	t = 90 min
Depth of 500˚C isotherm	$c_f = 33$ mm

(From Figure 5.4 or 5.5 assuming one dimensional heat transfer at side of beam.)

Reduced width	$b_f = b - 2c_f = 400 - 2 \times 33 = 334$ mm

Steel temperatures from the isotherms in Figure 5.5:

Bar group (1):	450˚C
Bar group (2):	< 200˚C

Bar group (3): 580˚C

Reduced yield strength of reinforcing bars at elevated temperatures (from equation 5.23):

$f_{y,T\,1}$ = (1.53 - 450/470)300 = 172 MPa

$f_{y,T\,2}$ = 300 MPa

$f_{y,T\,3}$ = (1.53 - 580/470)300 = 89 MPa

$A_s f_{y,T} = (4A_{s1} f_{y,T\,1} + 2A_{s1} f_{y,T\,2} + 2A_{s1} f_{y,T\,3})$

= 804 x (4 x 172 + 2 x 300 + 2 x 89) / 1000

= 1179 kN

Assume that the concrete with temperature above 500˚C has no compressive strength and concrete below 500˚C has full compressive strength.

Stress block depth $a_f = A_s f_{y,T} / 0.85 f'_{c,T} b_f$ = 1179 x 1000 / 0.85 x 30 x 334 = 138 mm

Internal lever arm $jd_f = d - a_f/2$ = 727 – 138 / 2 = 658 mm

Bending strength $M_{nf} = A_s f_{y,T} jd_f$ = 1179 x 1000 x 658 / 10^6 = 776 kN.m

$M^*_f < M_{nf}$ so design is OK

5.9 Structural timber

Introduction

Because wood burns, many people mistakenly assume that timber structures have poor behaviour in fires. However, timber structures can be designed to perform well in fires, either by using heavy timber members that have significant residual fire resistance after charring or by protecting light timber members with fire resisting material, such as gypsum plaster board.

The MP9 document and manufacturer's literature lists many proprietary approvals for light timber framed wall and floor systems. For heavy timber construction, NZS 3603 and AS 1720 specify a calculation method based on a constant rate of charring of timber beams, columns and floor units during exposure to the standard fire.

Recommended design methods

The recommended design methods for structural timber exposed to fire are described in the Timber Design Codes NZS 3603 and AS 1720. The timber codes permit fire design to be done either by test, by extrapolation from standard tests using well established criteria, by a simple prescribed calculation method, or by providing sufficient protective material to prevent onset of charring during the required fire resistance period.

Heavy timber

For heavy timber construction, the calculation methods in NZS 3603 and AS 1702 are recommended. Glue laminated timber (glulam) behaves in the same way as solid timber.

These methods are based on a constant rate of charring of exposed timber surfaces during the standard fire. In the New Zealand code, the nominal charring rate is 0.65 mm per minute, as measured in standard tests of radiata pine beams at BRANZ (Buchanan 1994). For timber members at least 90 mm thick, it is assumed that the wood below the char is not affected by elevated temperatures. Structural calculations are based on the loads at the time of the fire being resisted by the residual cross section, assuming short duration loads and a strength reduction factor ϕ =1.0. For small members, allowance should be made for charring at the corners of the cross section, as shown in Figure 5.8. Lateral stability of beam and columns must be taken into account using the dimensions of the reduced cross section.

Charring rates are different for timber with more or less density than that of radiata pine, with denser wood charring at a slower rate. AS 1702.4:1990 gives an equation for calculating the charring rate β (mm/min):

$$\beta = 0.4 + (280/\rho)^2 \qquad [5.21]$$

where ρ is the timber density at a moisture content of 12% (kg/m^3).

Design methods have been developed for heavy timber construction exposed to real fires. The design equations, which appear in the structural Eurocodes, are summarised by Buchanan (2001).

Equation 5.21 gives the same charring rate as the New Zealand code for a density of 550 kg/m^3. The Australian design method assumes a 7.5 mm thickness of zero strength heated wood below the char layer.

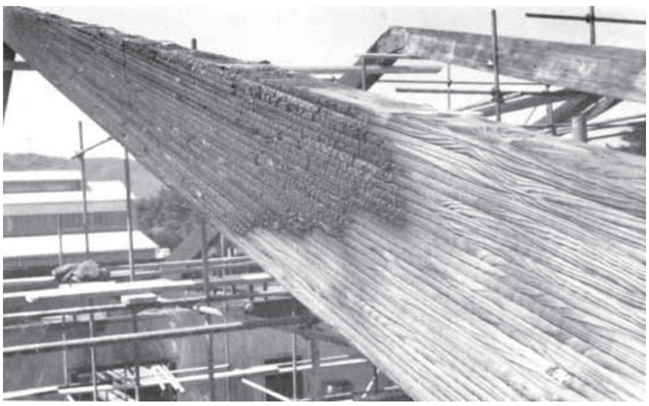
Connections

The weakest link in many fire exposed timber systems is the connection system. Metal fasteners should be embedded within the timber or should be protected by an applied layer of wood or fire resisting material such as gypsum plaster board, as described by Buchanan and King (1991).

Worked example

For a simply supported glulam beam with known span, size and load, check the flexural capacity after 60 minutes of exposure to the standard fire. Use the charring rate from NZS 3603. Assume beam has full lateral restraint. The beam is shown in Figure 5.9.

Beam span	$L = 10.0$ m	Dead load (excl. self weight)	$G_1 = 4.0$ kN/m
Beam width	$b = 180$ mm	Live load	$Q = 6.0$ kN/m
Lamination thickness	$t_1 = 45$ mm		
Number of laminations	$n = 17$		
Beam depth	$d = nt_1 = 765$ mm		
Beam area	$A = b\,d = 138{,}000$ mm^2		



Charring of glulam frames being removed by sandblasting for re-use after a severe fire in a factory

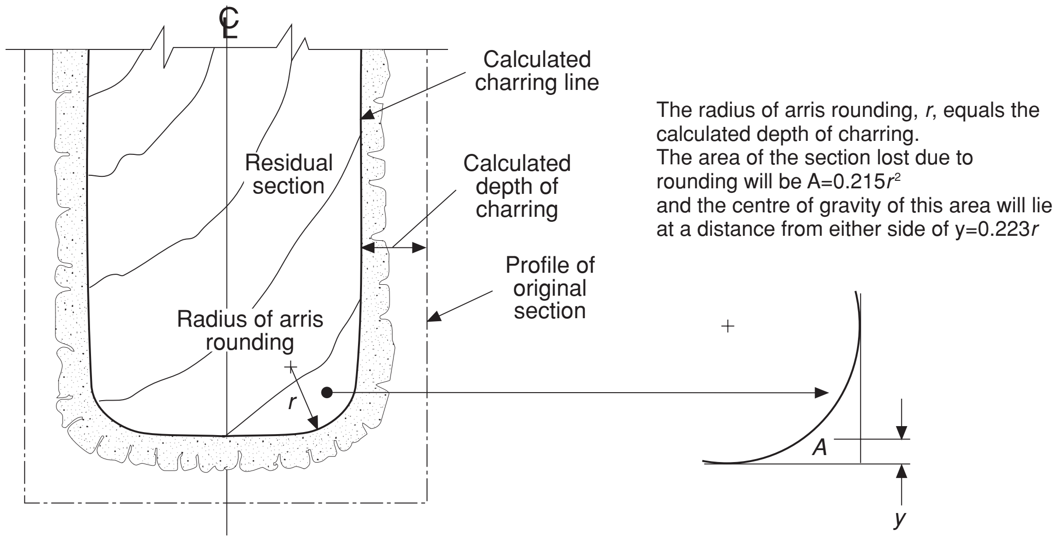


Figure 5.8: Charring of heavy timber beam exposed to fire

Density of wood	$\rho = 5\ \text{kN}/\text{m}^3$
Self weight	$G_2 = A\rho = 0.69$ kN/m
Total dead load	$G = G_1 + G_2 + 4.69$ kN/m
Section modulus	$Z = b\,d^2/6 = 17.6 \times 10^6\ \text{mm}^3$

Note: For the purpose of this example, the "k-factors" in the Timber Design Code for size effects, load sharing, etc., will all be taken as 1.0.

COLD CALCULATIONS

Characteristic stress	$f_b = 17.7$ MPa
Duration of load factor	$k_1 = 0.8$ (medium density loading)
Strength reduction factor	$\phi = 0.8$
Design load (cold)	$W_c = 1.2\,G + 1.6\,Q = 15.2$ kN/m

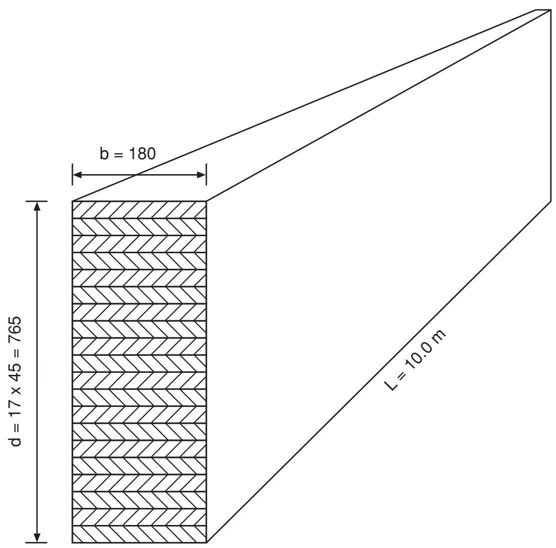


Figure 5.9:Glulam beam in worked example

Bending moment $M_c = W_c L^2/8 = 190$ kNm

Bending strength $M_n = k_1 f_b Z = 249$ kNm

$\phi M_n = 199$ kNm Design is OK ($\phi M_n > M_c$)

FIRE CALCULATIONS (three-sided charring, ignore corner rounding)

Fire duration $t = 60$ min

Char thickness $c = 0.65t = 39$ mm

Reduced dimensions $b_f = b - 2c = 102$ mm $d_f = d - c = 726$ mm

Section modulus $Z = b_f d_f^{\,2}/6 = 8.96 \times 10^6$ mm^3

Revised factors $\phi = 1.0$ $k_1 = 1.0$ (short duration loading)

Design load (fire) $W_f = G + 0.4Q = 7.09$ kN/m

Bending moment $M_f = \dfrac{W_f L^2}{8} = 88.6$ kNm

Bending strength $M_{nf} = k_1 f_b Z = 168$ kNm $\phi M_{nf} = 168$ kNm

Design is OK ($\phi M_{nf} > M_f$)

The calculation ignores the layer of zero strength wood specified in AS 1720.4.

FIRE CALCULATIONS (with corner rounding)

Section modulus $Z = \frac{1}{6}\left[(b-2c)(d-c)^2 - 1.29c^2(d-c)\right] = 8.72 \times 10^6$ mm^3

Bending strength $M_{nf} = k_1 f_b Z = 164$ kNm $\phi M_{nf} = 164$ kNm

Design is OK ($\phi M_{nf} > M_f$)

5.10 Lightweight drywall systems

Drywall construction consists of sheets of lining material fixed to both sides of lightweight timber or steel framing. The lining most often consists of sheets of gypsum plasterboard which are available in various qualities and thicknesses. Lightweight floor-ceiling systems usually have sheets of gypsum plasterboard as the ceiling material, supported by timber or steel joists. Gypsum plasterboard linings provide excellent passive fire resistance, as well as thermal and acoustic separation.

Gypsum plaster is mostly calcium sulphate dihydrate $Ca\,SO_4.2H_2O$. When gypsum plaster is heated in a fire the water of crystallisation is driven off between 100˚C and 120˚C, accompanied by a loss of strength, producing calcium sulphate hemihydrate $Ca\,SO_4.½H_2O$ (plaster of Paris). The chemical reaction is:

$$Ca\,SO_4\,.\,2H_2O \rightarrow Ca\,SO_4\,.\,½H_2O + 1½H_2O$$

The moisture in gypsum plaster is very important because it contributes to the excellent fire resisting behaviour. Significant energy is required to evaporate the free water and make the chemical change which releases the water in the crystal structure (Buchanan and Gerlich, 1997). The reverse reaction occurs when the plasterboard is manufactured by adding water to plaster of Paris, obtained by grinding gypsum rock into powder.

Most gypsum boards consist of a sandwich with a gypsum plaster core between two layers of paper, chemically and mechanically bonded to the core. Common thicknesses are from 9.5 mm to 19 mm. The external paper provides tensile reinforcing to the board. Special fire rated boards contain glass fibres and other additives to reduce shrinkage and maintain integrity after the paper burns off in a fire and after dehydration occurs. Some boards, known as fibrous plaster, have no paper facing, relying only on glass fibre reinforcing within the plaster to provide strength. The main New Zealand manufacturer is Winstone Wallboards Ltd, who provide an extensive range of fire rated systems lined with Standard Gib® plasterboard and Gib® Fyreline, achieving fire resistance ratings ranging from 15 minutes to 4 hours. Published details include the protection of penetrations and closures (Winstone Wallboards, 1997). Australian manufacturers are CSR and Boral, who also provide detailed design guides.

The main categories of lightweight gypsum plasterboard construction are

a) timber framed walls (non-loadbearing and loadbearing)

b) steel framed walls (non-loadbearing and loadbearing)

c) floor/ceiling systems

Timber Framed Walls

For both non-loadbearing and loadbearing walls, the fire resistance ratings published by manufacturers are suitable for construction in accordance with the design tables published in the Code of Practice for Light Timber Frame Buildings, NZS 3604:1999. Walls in taller buildings or with greater stud heights will require specific engineering design. Reference can be made to BRANZ (1996). For more information on fire performance of light timber frame construction, see Buchanan (2001).

A typical example of an approved specification for a fire resisting timber framed wall is given in Figure 5.10.

For Australia, the Building Code only permits timber-framed construction for low rise buildings (Type C).

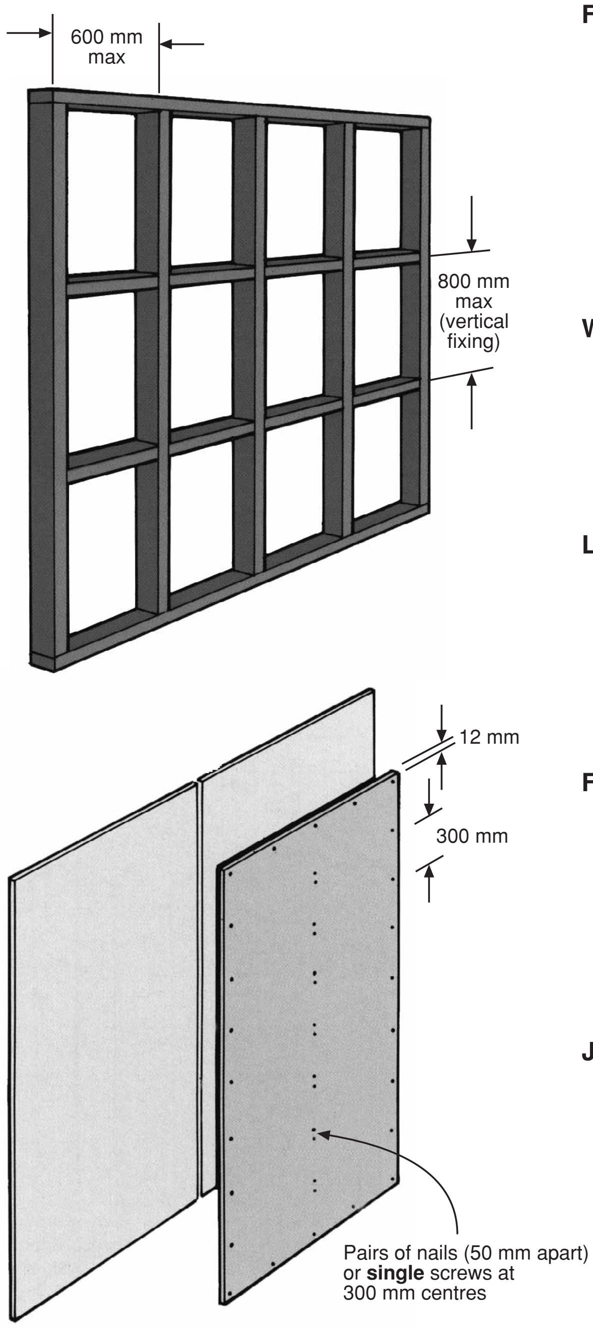
Steel Framed Walls

Wall heights for non-loadbearing steel stud systems are currently limited to the height of the tested specimens (hence to the height of the test furnace). Manufacturers can offer guidance for heights greater than the tested height, based on research being carried out by BRANZ. For loadbearing steel stud walls, the fire resistance may be derived by full scale test, by conservatively limiting the temperature of the steel studs to 300˚C, or by calculation (Gerlich et al 1996). Manufacturers offer both conservative systems and a more accurate method which can be used with knowledge of the applied stud load in fire emergency conditions and the load capacity of the stud at room temperature (Winstone Wallboards, 1997).

Floor/Ceiling Systems

Tests of floor/ceiling systems are limited by the size of the test furnace. The only suitable furnace in New Zealand is the BRANZ furnace which has a maximum span of 4 metres. In Australia, suitable furnaces are operated by Warrington Fire Research and CSIRO. During testing, the imposed loads on the test specimen are intended to induce maximum design stresses which should not be exceeded in applications where the span or load is different from that tested. Guidance for extrapolation is given by Collier (1991).

Specification Number	Loadbearing Capability	Fire Resistance Rating	Lining Requirements	Sound Transmission Class	System Weight Approx
GBT 90	**NLB**	**-/90/90**	**1 x 16 mm Gib® Fyreline each side**	**STC 37**	**36 kg/m²**
GBTL 90	**LB**	**90/90/90**			



Framing

GBT90 Non Loadbearing - No. 1 framing grade H1 treated Radiata Pine nominal dimensions 75 mm x 50 mm minimum.
GBTL90 Loadbearing - No. 1 framing grade H1 treated Radiata Pine nominal dimensions 100 mm x 50 mm minimum.
Studs at 600 mm centres maximum.
Nogs at 800 mm centres maximum for vertical fixing.
Nogs at 1200 mm centres maximum for horizontal fixing.

Wall Height

GBT90 Non Loadbearing - Framing dimensions and height as determined by NZS3604 stud tables for non loadbearing partitions.
GBTL90 Loadbearing - Framing dimensions and height as determined by NZS3604 stud and top plate tables for loadbearing walls.

Lining

1 layer of 16 mm Gib® Fyreline each side of the frame.
Vertical or horizontal fixing permitted.
Sheets shall be touch fitted.
When fixing vertically, full height sheets shall be used where possible.
All sheet joints must be formed over solid timber framing.

Fastening the Lining

Fasteners
50 mm x 2.5 mm Gib® Clouts or 7 g bugle head gypsum drywall screws.
Fastener Centres
300 mm centres around the sheet perimeter, 12 mm from the sheet edge.
Pairs of nails (50 mm apart), or single screws at 300 mm centres to intermediate studs.

Jointing

All fastener heads stopped and all sheet joints tape reinforced and stopped in accordance with the publication entitled "Gib® Stopping and Finishing Systems 1992" or a later approved edition.

Figure 5.10: Specification for a one hour loadbearing timber framed wall (Winstone Wallboards 1997)

Chapter 6
Fire Modelling with Computers

6.1 Introduction

The objective of this chapter is to give a brief description of some commonly used computer-based fire modelling programs, together with a brief discussion of the advantages, disadvantages and limitations of using computers for fire modelling.

Design of buildings for life safety requires the ability to predict the growth of a fire in a room, from ignition to full room involvement. In an effort to bring some of the advances in fire science and related technology to the market place, and thereby assist fire safety engineering professionals to efficiently achieve their objectives, a number of fire research organisations have produced fire simulation computer models for use with personal computers.

6.2 Warning

Fire modelling with computers is only at an early stage of development, and therefore all the computer programs for modelling the impact of a fire must be used carefully, and only by persons experienced with fire behaviour. Computer fire models are no substitute for actual experience of real fire behaviour in buildings.

As with all computer models, output should be checked to see that it is realistic. Simple hand calculations should be used to check that the output is consistent with the input data for the real physical situation being modelled. All computer models should be fully "transparent". That means that the input data, the basic methods of calculation, and the formulas and mathematical models on which they are based, should be readily available for reference and cross-checking by all parties.

All computer models should have their limits of application clearly defined to avoid using them outside the range of accurate application of the mathematical models on which they are based. Many formulae used in fire engineering are the result of study only on small test rooms so their application to large spaces needs to be carefully considered to ensure that the models are still applicable and the results reliable. The output from computer fire models can often be very sensitive to seemingly minor changes in the input data, which is sometimes difficult to assess accurately. Sensitivity analysis should be carried out as part of the normal use of computer models, to identify which variables are of most significance.

In the pre-flashover phase, most fire models require the user to input a "design fire", which is estimated from the fuel type, ventilation, growth rates and peak burning rates, all of which can vary considerably, and require a fair degree of experience and judgement to evaluate. Design fires are discussed in Section 6.6. Some fire models have been extended to cover the post-flashover stage in which available fuel surface area and fire ventilation are important, but results from analysis of post-flashover fire periods are normally less accurate than for the pre-flashover period. The models do not understand fire growth and are entirely dependent on the input of a user defined 'fire', typically expressed as a varying heat release rate as a function of time. By their very nature, the models' output is highly sensitive to the form of this input fire and practitioners need to be constantly aware of this limitation.

Computer fire models are tools for analysis, not design. They are useful for investigating the effects of alternative fire scenarios, as a small part of a comprehensive fire engineering design process.

6.3 Categories of Models

There are a large number of computer packages for a wide range of fire engineering applications including egress design, sprinkler design, smoke management and structural performance. This chapter describes a few of the available models, with an emphasis on fire growth models. Fire simulation computer programs are most useful for modelling the fire growth stage. They are not capable of modelling fire initiation or smouldering fires, which are inherently unpredictable, both in terms of the rate of fire growth, and the times at which they may develop into flaming combustion.

Fire models can be divided into two broad categories; probabilistic and deterministic.

Probabilistic models

Probabilistic models do not make direct use of the scientific principles involved in fires, but make statistical predictions about the transition from one stage of fire growth to another. The course of a fire is described as a series of discrete stages that summarise the nature of the fire. Time dependent probabilities are ascribed to the possibility of the fire changing from one stage to another. These are determined from a knowledge of extensive experimental data and fire incident statistics.

Deterministic models

Deterministic models use the physics and chemistry associated with the fire environment to make predictions about fire development. Deterministic models can be further classified into two main sub-groups; field models and zone models.

Field models

In field modelling the compartment is divided into thousands of computational cells throughout the enclosure. Field models, often called Computational Fluid Dynamic (CFD) models solve the conservation mass momentum, energy and species in each cell, thus giving a 3-dimensional field of the dependent variables including temperature, velocity, concentration, etc. Traditional field models use complex fluid mechanic models such as the k-ε method to solve for the turbulant flow present in fires. The k-ε method is a time averaging technique, which smears out much of the complex flow details that are sometimes required for detailed flow modelling.

Recently, the model Fire Dynamic Simulator (FDS) has become available, developed over the last decade by Kevin McGrattan, Howard Baum and Ronald Rehm at the National Institute of Standards and Technology (NIST) in the US. The FDS model solves an approximate form of the Navier-Stokes equations to simulate the mixing and transport phenomenon of combustion products. The spatial resolution of the model is fine enough that it is able to predict the large eddy structures that will develop within the flow.

Field models require a great deal of experience on the part of the user and place great demands on computational facilities. Field models have not yet been developed to a stage where they can be generally be applied for design purposes, and are at present restricted to research applications. However, substantial improvement has occurred in the user interface, and “smart” versions using expert system technology are becoming available. One example of this is SMARTFIRE available from the University of Greenwich.

Zone models

Zone models divide an enclosure into a small number of distinct regions, each of which is characterised by a set of time dependent variables that describe its physical state. Each zone is considered isothermal and homogeneous. Conservation equations for mass, and energy are applied to each zone, so that the relationships between the physically significant parameters and their evolution can be determined. Whilst zone models are more primitive in conception than field models, they are easier to apply, and provide results far more economically in terms of computational requirements. They are the most practical method for achieving first order approximations to real fire behaviour.

Zone models assume a hot upper layer (or zone) and a cool lower layer (or zone) as shown in Figure 3.2. Interaction between the two zones takes place through the fire plume above the burning object. The fire plume rises through buoyancy to the ceiling, entraining cool air as it rises. The combustion products and entrained air then spread across the ceiling. Once the walls are reached, the hot layer increases in thickness until such time as its depth is controlled by the ventilation through the openings. The fire then stabilises its burning rate to match the available air supply. If there are no large openings the hot layer will descend to the level of the fire, and the rate of combustion will drop as the fire is starved of oxygen.

6.4 Fire Models

A large number of computer-based fire growth models have been developed for various purposes and many of these are widely used for research and fire engineering. A survey of models is given by Friedman (1992). In this section only the more commonly used models are discussed.

FPEtool

FPEtool is a fire safety engineering program developed by the Centre for Fire Research at NIST (the National Institute for Standards and Technology) USA (Nelson 1990, Deal 1993). The program requires an IBM compatible computer (386 or better) with a hard disk drive, and runs in English or SI units. FPEtool is in the public domain so it is widely available at no charge.

The user-friendly interface of FPEtool and trivial cost of the program greatly enhanced its use in the fire engineering profession. With the continuing advances in computer speed, many of the simplifying assumptions made in the programs are no longer necessary to achieve a solution in a timely manner, so FPEtool is no longer supported by NIST and is considered obsolete, now superseded by FASTLite (discussed in the next section).

A discussion of FPEtool has been included here, as the program is still available and widely used. However, the user is cautioned that there are some errors in the code and the physics in FAST and FASTLite are more sophisticated than in Fire Simulator. FPEtool consists of three main components: FIREFORM, MAKEFIRE and FIRE SIMULATOR. FIREFORM is a 17-part package of relatively simple fire engineering equations and models. Each is a stand-alone procedure called from the main menu. Most of these are also available in the tools menu of FASTLite.

MAKEFIRE is a four-part package which enables the user to develop individual fire files for heat release rate versus time, which can be used by other routines within FPEtool, as well as for other separate computer programs. Within MAKEFIRE, MYFIRE contains standard fire growth rate files such as Ultra-Fast, Fast, Moderate and Slow t^2 fires, and any desired type of sequential heat release data file can be developed using FORMULA, and saved for future use. FREEBURN allows fires from a maximum of five separate burning objects to be combined as the fire spreads from one item to the next. LOOK-EDIT allows users to review existing fire data files, to make changes if required, and to store the results.

FIRE SIMULATOR is a single room zone model which requires the user to define the geometry and materials of the space involved, the key parameters for sprinklers and detectors, the selected heat release rate vs. time file from the MAKEFIRE files, and the pre-flashover and post-flashover conditions.

FASTLite

FASTLite is a suite of engineering tools for estimating fire growth and smoke transport in building fires. It was produced by NIST in 1996. Copies are available free of charge on CD ROM and can be downloaded from www.fast.nist.gov.

FASTLite has grown from previous programs which have been widely used in the fire engineering community, especially FPEtool. The main component is a zone model that can predict the behaviour of fire in one room or several inter-connected rooms, being a major improvement on the ASETBX and FIRE SIMULATOR modules in FPEtool.

The fire growth model in FASTLite is a stripped down version of the C-FAST zone model, which allows fire modelling of up to three interconnected rooms. The user specifies the geometry of the rooms and the heat release rate of an input fire. Before flashover, the input heat release rate is followed unless it becomes constrained by the available ventilation. The calculations are the same as in the C-FAST model. Typical output includes the layer height, temperatures and concentrations of gas species in both layers, floor and wall temperatures, and the heat flux to the floor. FASTLite can be used for post flashover fires (Buchanan 1997) but the results must be interpreted with care.

The TOOLS section of FASTLite contains most of the modules of FIREFORM from FPEtool, as listed below:

— Atrium smoke temperature
— Buoyant gas head
— Ceiling jet temperature
— Ceiling plume temperature
— Egress time
— Mass flow through a vent
— Lateral flame spread
— Law’s severity correlation

— Plume filling rate
— Smoke flow through opening
— Thomas' flashover correlation
— Radiant ignition of a near fuel
— Sprinkler/detector response
— Ventilation limit.

HAZARD I

HAZARD I is a fire safety engineering program developed by the Centre for Fire Research at NIST (Peacock et al 1991). HAZARD I was designed for fire simulation analysis on one or two family dwellings and apartments. Part of the reason for this limitation is that most of the data and mathematical models are from fire tests in small compartments. However most parts of the program may be applied with caution to larger buildings provided the relative sizes of the fire and building are similar. The program has not been fully validated for large firecells, as little experimental data is available. It consists of three main components, which are the FAST fire model, the EXITT egress model and the TENAB tenability model.

HAZARD I has evolved substantially since its original release in 1988, and in 1999 it was replaced by FAST, which is discussed in the next section.

FAST

FAST is a collection of procedures built around the multi-compartment fire model CFAST. Designed as a tool for estimating the fire hazard in compartmentalised buildings, it is the successor to HAZARD I and FASTLite. The simple fire engineering equations found in the FIREFORM module of FPEtool have been included as part of the new user interface. The new user interface was developed to be independent of the operating system and has a windows look and feel to it. The program is available in the public domain and can be downloaded from www.fast.nist.gov.

The FAST model has undergone extensive verification testing to assess the accuracy of the calculations. It has also been internationally beta tested to aid in the debugging process. FAST has been widely used throughout the world and is the benchmark for zone modelling computer programs.

FAST allows for a maximum of 15 compartments with various thermal properties for the walls, floors, and ceilings. Openings (vents) can be either vertical or horizontal and can be opened as a function of time. The user must input a design fire and can add objects which are ignited as part of the simulation. Gas species, such as CO_2, H_2O, CO, HCl, HCN, O_2, THC, soot, etc., can be incorporated as part of the design fire. Other features include detector activation, remote target temperatures, sprinkler suppression, forced ventilation, multiple burning objects, ceiling heat transfer and many others. FAST also includes an improved numerical solver making it more robust with reduced run-times.

Run-time graphics have been included to allow the user to monitor the simulation and terminate the run if desired. Several output options are available including report formats as well as spreadsheet files. There is also a plotting routine included with the program (CPlot) which is cumbersome and non-intuitive hence not widely used. Currently under development is a "walk through" program which allows the user to move through an animated representation of the simulated building. Further details about this add-on program can be found at www.cs.berkeley.edu/~bukowski/wkfire/index.html.

The program includes a user's guide (Peacock et al 1997) which shows how the model is run step-by-step and gives a discussion of its limitations. A technical reference manual (Jones et al 1999) documents the underlying physics used in the model. Both manuals are available in PDF format, which can be read with Adobe Acrobat Reader.

COMPF2

COMPF2 is a post-flashover fire model for predicting the temperature during the full burn-out of a compartment (Babrauskas, 1979). The COMPF2 calculations assume a single zone model, using a fuel-controlled or ventilation-controlled heat release rate to calculate the temperature within the compartment. Recent analysis using COMPF2 is described by Feasey (1999).

FIREWIND/FIRECALC

FIREWIND is a fire safety engineering program originally developed by the CSIRO Division of Building, Construction and Engineering, Australia (CSIRO 1993) as FIRECALC, from the original version of FPEtool. About half of the program modules produce the same results as the equivalent program modules in the FIREFORM section of FPEtool. One advantage over FPEtool, is direct print-out of graphs of the results from many of the program modules, but a disadvantage is that it has space for only 5 heat release rate files. The FIREWIND handbook (FMC, 1998) gives the application, background, formulas, limitations, operational procedure, and sample output from each program. The most useful program modules which were not in FPEtool, are those for calculating radiant heat flux from several radiant emitters, and for calculating egress times. The EGRESS TIMES module in FIRECALC computes the maximum time for people to escape from a building. FIREWIND has a more recent evacuation module called WAYOUT. These models are described briefly in Chapter 8.

FIRESYS

FIRESYS is a collection of relatively simple fire engineering programs developed by Macdonald Barnett Partners Ltd, of Auckland. The software has been designed to assist architects, engineers, building inspectors, draughtspersons, builders, and the like, who wish to make approximate fire engineering calculations for their building projects.

FIRESYS is also aimed towards producing answers that may satisfy Building Code requirements for specific fire engineering. FIRESYS is a user interactive program designed to be easy to operate and able to produce print-outs which can be readily included with documentation sent to Territorial Authorities for building consent approval. There is no Manual provided with FIRESYS as each separate program is provided with its own “Help” pages to provide an overview of the formulae, modelling techniques and references.

BRANZFIRE

BRANZFIRE is a zone model and fire growth model developed by the Building Research Association of New Zealand (Wade, 2000a, 2000b). The program requires a personal computer running Microsoft Windows 95 or later. The model simulates smoke spread within and between compartments with a maximum of 10 compartments permitted and includes some of the following general features:

- vents connecting compartments or outside spaces may be in walls or in ceilings/floors
- the number of vents permitted is unlimited
- mechanical ventilation (extraction and pressurisation)
- sprinkler, thermal and smoke detector actuation
- flame spread and fire growth contribution from combustible wall and ceiling linings
- tenability assessment, including determination of fractional effective dose for narcotic gases, thermal radiation doses, visibility calculations
- direct export of results to Microsoft Excel.

Many of the underlying zone model algorithms used within BRANZFIRE have been previously published in the literature including:

- vent flow through walls uses the CCFM code developed at NIST
- vent flow through ceiling/floors use the VENTCF2A code developed by Cooper at NIST
- radiation/heat exchange between room surfaces and gas layers uses methodology developed by Forney at NIST
- sprinkler detector algorithm uses JET model developed by Davis at NIST
- the first order differential equations for mass/energy conservation are similar to those used in the CFAST model.

The user is required to provided details about the rate of heat release of the design fire, although some data is available for selection from the program’s fire and materials databases. The program is available from BRANZ.

Other Models

As computers continue to improve and software development becomes more user friendly, many new computer models are becoming available. This ever-expanding array of fire modelling programs has the potential to increase analytical capabilities and lead to improved designs. However, the practitioner should be warned that many of these models have not been extensively scrutinised by independent third party users. Before using a complex computer-based compartment fire model in design applications, it is essential that there be an extensive beta testing program conducted and that the model be validated against independent data. It is far too easy for errors to creep into the code during development and go undetected. Indeed the FAST model was the most extensively beta tested fire model before final release yet there have been five revisions to the code since 1997 when it was officially released. Prior to independent beta testing a model should only be considered useful for research.

6.5 Risk Assessment Models

There are several risk-based tools becoming available for assessing fire safety in buildings. One of these is FIRECAM, which can be used to assess the fire safety performance of a building in terms of two parameters; the expected risk to life and the fire cost expectation (Yung et al 1997). FIRECAM considers the time-dependent interaction of fire growth, fire spread, smoke movement, human behaviour, and fire brigade response, in a probabilistic format. A similar risk-cost model nearing completion at Victoria University of Technology (VUT) is that called CESARE-RISK. Programs such as these are most useful as comparative tools for comparing one design with another, or for establishing equivalent safety compared with a code-complying design.

6.6 Design Fires

Most of the design calculations that a fire engineer makes are dependent on the heat release rate from the fire. The first step in most cases is to determine which fire is to be used as the "design fire". The design fire is an approximation of the reasonable worst-case fire scenario expected over the life of the building. Typically the design fire is described in terms of the heat release rate as a function of time. Indeed, the heat release rate history is considered the single most important variable in describing a fire hazard (Babrauskas and Peacock 1992). The description of the design fire may also include an estimate of the area of the fire, the smoke production rate, and the gaseous species being produced, all as a function of time. Unfortunately it is not possible to derive a design fire from first principles, so the fire engineer is forced to rely on experimental data, correlations, curve fits and engineering judgment to come up with the appropriate design fire.

The detail required for a design fire is dependent on the issue being investigated and what questions the engineer is trying to answer. For example it is not much use to have a design fire that includes a detailed description of the decay phase if the engineer is trying to model the activation of a sprinkler head. Likewise, the growth stage makes little difference if the engineer is trying to model the fire resistance of a structural member after several hours of fire exposure. Thus, the first question a fire engineer must ask is "What am I trying to achieve?"

Figure 6.1 shows an idealized heat release rate history for a compartment fire from ignition through to burnout. A fire described in this way is the most important item of input to most fire growth models. Each stage of this fire curve has been discussed in a qualitative framework in Chapter 3. Quantitative methods for calculating heat release rate are given in Chapter 4 for the growth period and Chapter 5 for the fully developed fire.

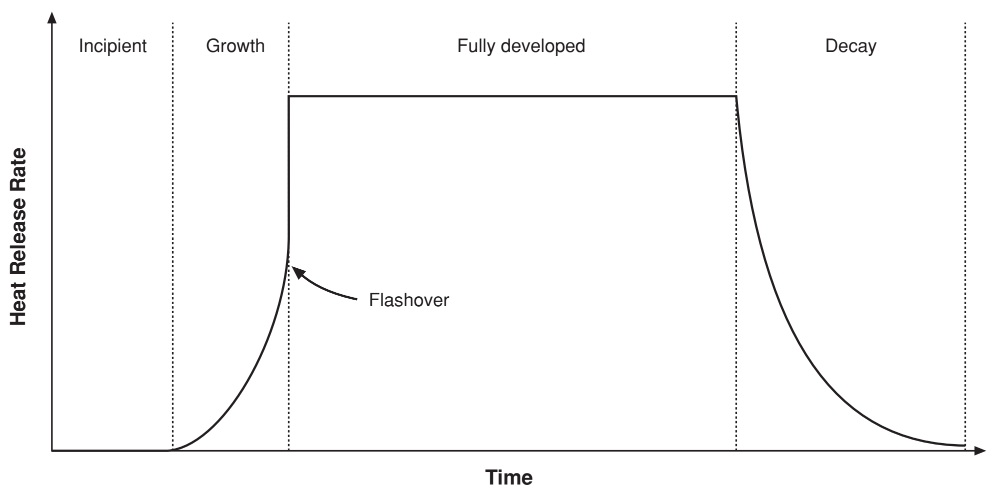


Figure 6.1: Idealised heat release rate history showing all stages

Chapter 7
Fire Spread

7.1 Introduction

The objective of design for fire spread is to ensure that no spread of fire or smoke prevents the performance requirements from being achieved. This includes spread of fire or smoke within the firecell of origin, to other firecells at the same level, to other levels in the fire building and to other buildings. Fire compartmentation is a practical and reliable form of fire control. The concepts outlined in this section are all applicable in Australia and New Zealand.

7.2 Fire spread within a firecell

Objective

The form of construction and type of materials inside a firecell must be such that the spread of fire and smoke within the firecell can be controlled to meet the performance requirements.

Surface spread of flame

Fire can spread very rapidly across certain combustible surfaces, greatly increasing the danger to occupants.

Interior finishes are required to resist the spread of fire, as stated in the New Zealand Building Code (see Appendix A).

C.3.3.1 *Interior surface finishes on walls, floors, ceilings and suspended building elements, shall resist the spread of fire and limit the generation of toxic gases, smoke and heat, to a degree appropriate to:*

(a) The travel distance,

(b) The number of occupants,

(c) The fire hazard, and

(d) The active fire safety systems installed in the building.

Surface spread of flame can be controlled by using materials that have desirable properties, as measured in the Early Fire Hazard Test (AS 1530 Part 3 1989). It is recommended that the requirements of the Acceptable Solution C/AS1 be complied with in regard to acceptable Early Fire Hazard Indices. Similarly, Australia uses AS1530 Part 3 to control spread of fire by interior finishes under the BCA.

Concealed spaces

Prevention of spread of fire and smoke through concealed spaces is a major part of fire engineering design. Many buildings contain concealed spaces through which fire can spread to other parts of a firecell, or to other firecells, creating danger to occupants and presenting serious difficulties to fire fighters.

The New Zealand Building Code requires that:

C.3.3.4 *Concealed spaces and cavities within buildings shall be sealed and subdivided where necessary to inhibit the unseen spread of fire and smoke.*

In this context, concealed spaces include ceiling voids, spaces within hollow construction, under floors, under exterior cladding, or any others where unseen spread of fire and smoke can occur. Any concealed spaces within walls or floors should be sealed off at common junctions, as described in C/AS1.

Large concealed spaces above suspended ceilings can create a serious hazard. Fire and smoke can travel large distances undetected, as shown in Figure 7.1. Any partitions subdividing a firecell into smaller spaces should be continued right up through the ceiling to the roof or floor above. Subdivisions should provide at least a half hour fire

Linings removed by fire fighters showing fire spread in concealed spaces

resistance rating. This is not feasible if the partitions are moveable, if there are many small spaces or if the ceiling is being used as an air plenum, in which case all exposed surfaces in the space should not support spread of flame, and large spaces should be sprinkler protected in accordance with NZS 4541 or NZS 4515.

Partitions

Internal walls or partitions within a firecell are generally not required to have any resistance to the spread of fire or smoke unless they have a special function, such as protecting a safe egress path.

However, designers may wish to provide certain internal partitions with fire resistance to meet the design objectives. Many internal partitions have significant fire resistance even though they have not been specifically designed for that purpose.

7.3 Fire separations

Objective

In unsprinklered buildings, fire separations should be provided to resist the spread of fire for the duration of a complete burnout of a firecell.

Separations

Firecells or fire compartments are areas within a building that are contained within fire separations to prevent spread of fire to other firecells or fire compartments.

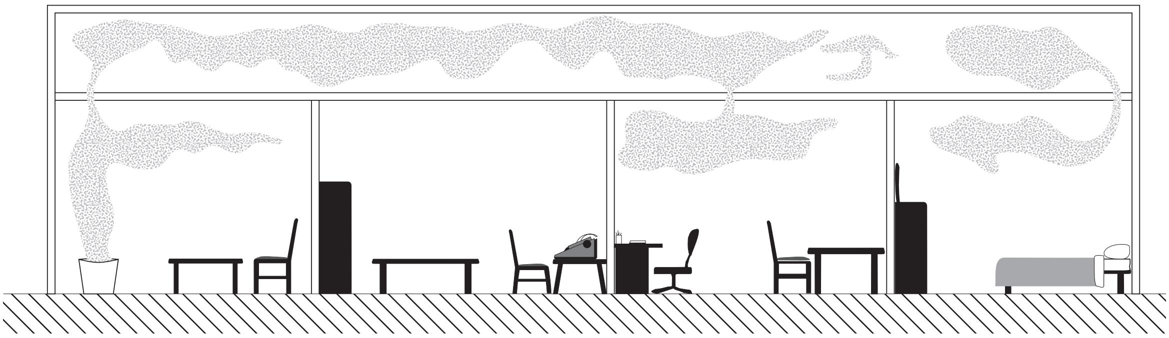


Figure 7.1: Spread of fire and smoke in concealed ceiling spaces

The New Zealand Building Code requires that fire separations be provided as follows:

C3.3.2 Buildings shall be provided with safeguards against fire spread so that:

(a) Occupants have time to escape to a safe place without being overcome by the effects of fire,

(b) Firefighters may undertake rescue operations and protect property,

(c) Adjacent household units and other property are protected from damage, and

(d) Significant quantities of hazardous substances are not released to the environment during fire.

The Building Code of Australia has similar requirements.

To prevent spread of fire from one firecell to another on the same level, walls which are separations between firecells must have sufficient fire resistance. Floor-ceiling systems act as fire separations between firecells on adjacent storeys to prevent spread of fire from floor to floor, as shown in Figure 7.2.

The level of fire resistance for separations depends on the performance requirements. In unsprinklered buildings, fire separations should generally be capable of containing a complete burnout of the firecell, in which case the fire resistance should exceed the expected severity of the fire, described in Chapter 5. In some circumstances, it may be possible to meet the performance requirements with lesser fire resistance, but provision for a complete burnout is strongly recommended. A reduction factor of 0.5 is recommended if sprinklers are present. Any supporting members such as beams, columns and walls must have at least the same fire resistance as the fire separations.

Right: Severe fire in a warehouse for stored plastic materials

Left: Collapsed steel rafters and damaged concrete masonary wall after the fire. The wall remained standing, preventing fire spread to adjacent properties

Right: Damaged timber frame wall between the warehouse and offices. This wall remained standing, preventing fire spread to other parts of the building

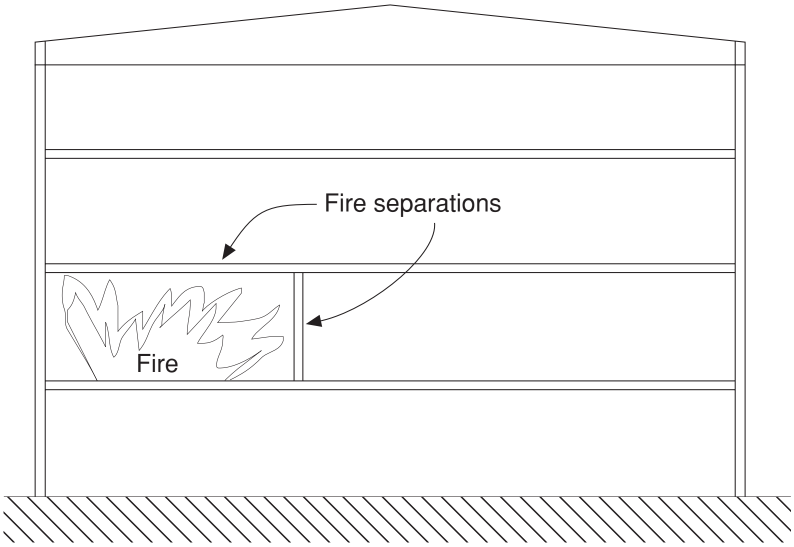


Figure 7.2: Floor ceiling systems acting as fire separations

If there are openings or penetrations through fire separations, they are covered by the New Zealand Building Code as follows:

C3.3.3 Fire separations shall:

(a) Where openings occur, be provided with fire resisting closures to maintain the integrity of the fire separations for an adequate time, and

(b) Where penetrations occur, maintain the fire resistance rating of the fire separation.

Fire performance of penetrations, and fire tests of protected penetrations, are described by England et al (2000).

Doors

Doors are often the weakest point in fire separations. Control over door openings is partly a matter of design and partly a matter of good housekeeping during the life of the building.

Doors can be specified as smoke stop doors or fire doors. In either case, the manufacture and installation should be in accordance with NZS 4232 Part 1 or AS/NZS 1905.1. Doors are of no use to control fire or smoke if they are open at the time of the fire.

Doors are often wedged open by building occupants to allow easy movement, and prevention of this is very difficult, especially if the occupants are not aware of the importance of the doors in the event of a fire. Modern systems allow doors to be held open by magnetic catches that automatically release when a fire alarm is activated or the power fails.

Fire doors in Australia are tested to AS/NZS1905.1 and listed by certifiers for quality in manufacture. Fire testing of fire doors is described by England (2000).

7.4 Fire spread to other storeys

Fire and smoke can spread from storey to storey by a variety of paths, including:

- Failure of floor/ceiling fire separation
- Concealed spaces
- Service ducts or shafts
- Stairways
- Exterior windows.

Fire protection of pipes and ducts passing through fire barriers. Many proprietary systems are available for these applications

Floor-ceiling separations

Floors, or floor-ceiling separations, prevent fire spreading to adjacent storeys as described above.

Service ducts and shafts

All multi-storey buildings have vertical ducts or shafts for transporting services or people. These must be designed such that the fire resistance of the fire separations is not compromised (England et al, 2000).

For vertical service ducts, there are two possible approaches: either provide fire resisting walls around the duct so that fire cannot get into or out of the duct, as shown in Figure 7.3 (a); or alternatively, seal all the openings within the duct at every floor level, as shown in Figure 7.3 (b).

Vertical shafts such lift shafts must be protected by fire-resisting walls over their full height. The structural fire resistance of the walls (stability rating) should be no less than that required for any elements being supported. The fire resistance for containment (insulation and integrity ratings) should be at least half of that required for the floor or wall separations on the basis that fire must first enter the shaft, then exit the shaft for fire to spread to an upper level.

Concealed spaces

Any concealed spaces on the facade of the building or elsewhere that could permit spread of fire or smoke to upper storeys must be firestopped to prevent spread of fire or smoke, as shown in Figure 7.4 (a).

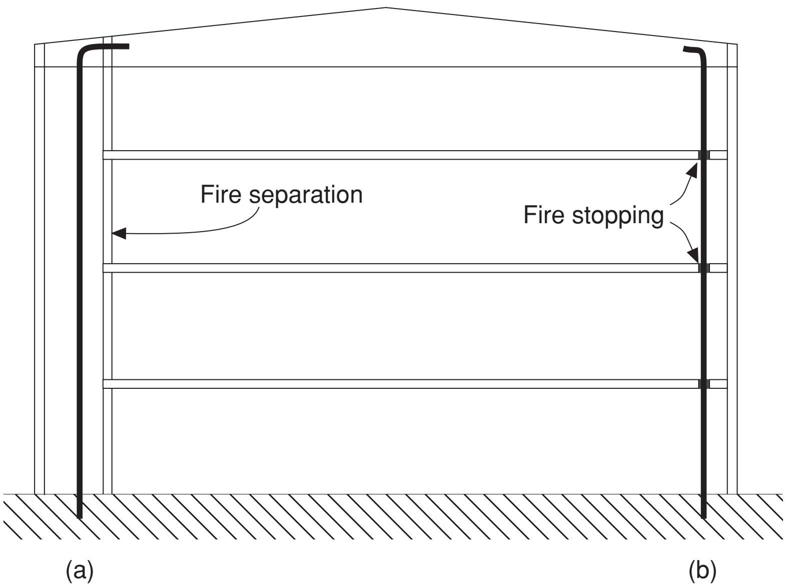


Figure 7.3: Fire separation of vertical service ducts

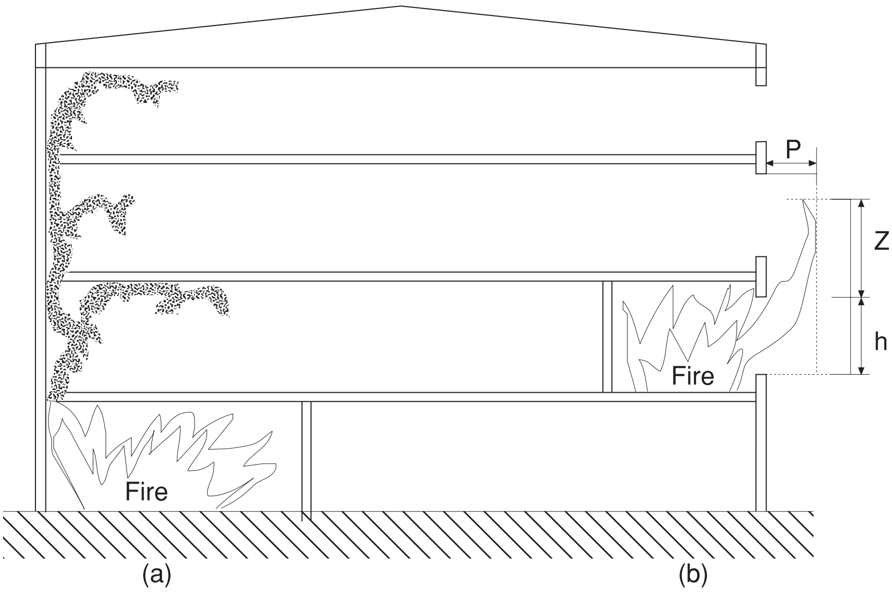


Figure 7.4: Spread of fire from storey to storey

Stairways

Stairways are open shafts. In order for fire spread via stairways to be prevented, there must be doors at every level with the same fire resistance as the enclosing walls, and the doors must be closed when a fire occurs. Stairways are particularly important because they form the main escape routes from the building.

Combustible cladding materials

Fire can spread vertically up a building via combustible cladding materials. It is recommended that combustible cladding not be used on buildings greater than two storeys in height without controls on the surface spread of flame classification.

Exterior windows

Spread of fire via exterior windows is a major hazard in multi-storey buildings, as shown in Figure 7.4 (b).

Building codes have traditionally specified vertical spandrels or horizontal apron projections to limit vertical flame spread. Vertical spandrels may be so deep that they severely restrict window openings. Horizontal apron projections are much more effective (Oleszkiewicz, 1991), although they are often less acceptable for architectural purposes.

A suggested design procedure is to calculate the size and shape of the expected flame from a window and then calculate radiation back to the building via the window above. Approximate flame size calculations are given below (Drysdale 1998). Flame sizes from windows are extremely variable, depending on room geometry, fuel orientation and especially wind conditions, so these calculations should be used with caution.

For a window opening in a wall that continues above the opening, the flame height Z (in metres above the soffit) is given by:

$$Z = 12.8\left(\dot{m}/w\right)^{2/3} - h \qquad [7.1]$$

where $\dot{m}$ is the peak rate of burning in the room (kg/sec)

w is the width of the window (m) and

h is the height of the window opening (m).

An approximate value of $\dot{m}$ (kg/sec) can be obtained from

$$\dot{m} = 1.5\,Q/h_a \qquad [7.2]$$

where Q is the average rate of heat release (MW) and
h_a is the calorific value of the fuel (MJ/kg).

The factor of 1.5 is an estimate of the ratio between the peak burning rate and the average burning rate.

The projection P of the flame tip from the wall (in metres) is given by:

$$P = 0.314\, h^{1.53}\, w^{-0.53} \qquad [7.3]$$

Radiation back to the building can be calculated using the flame area calculated above, with a flame temperature of 600 ˚C and an emissivity of 0.5. Fire is likely to spread if the incident radiation on combustible materials is sufficiently high.

Sprinklers can be used to control the fire in the storey of origin or as external drenchers to restrict flame projection from windows and prevent ignition at upper storeys.

Worked example

Given a fire cell with known geometry, fuel and size of one window, calculate the size of flame from the window and radiation from the flame back to the face of the building.

Floor area	$A_f = 25.0\, m^2$	
Window openings	Height h = 2.0 m	Width w = 3.0 m
Area of openings	$A_v = h\, w = 6\ m^2$	
Fire load energy density	$e_f = 800\ MJ/m^2$	
Total fuel load	$E = A_f\, e_f = 20{,}000\ MJ$	
Calorific value of fuel	$h_a = 16\ MJ/kg$	
Mass of fuel	$M = E/h_a = 1250\ kg$	

Calculate wood equivalent burning rate

Average burning rate	$\dot{m} = 5.5\, A_v \sqrt{h} = 46.7\ kg/min = 0.778\ kg/sec$
Peak burning rate	$\dot{m} = 1.5 \times 0.778 = 1.17\ kg/sec$
Duration of burning period	$t_b = M/\dot{m} = 1250/46.7 = 26.8\ min$
Average heat release rate	$Q = E/60\, t_b = 12.4\ MW$

Flame size from window

Height above soffit	$Z = 12.8\left(\dot{m}/w\right)^{2/3} - h = 4.83\ m$
Horizontal projection	$P = 0.314\, h^{1.53}\, w^{-0.53} = 0.51\ m$

Radiation back to the building from the flame (see section 7.5)

Stefan-Boltzmann constant	$\sigma = 56.7 \times 10^{-12}\ kW/m^2\ K^4$
Flame emissivity	$\varepsilon_f = 0.5$
Flame temperature	$T_f = 600˚C$
Ambient temperature	$T_o = 20˚C$
Configuration factor	$\phi = 1$

Radiant heat $I_R = \phi \, \varepsilon_f \, \sigma \left[(273 + T_f)^4 - (273 + T_o)^4 \right] = 16.3 \text{ kW/m}^2$

I_R is greater than the minimum radiation of I_{Rm} = 12.5 kW/m^2 to cause ignition of combustible cladding or curtains, so fire spread is likely.

7.5 Fire spread to other buildings

Spread of fire to other buildings can be prevented by providing walls with sufficient fire resistance to remain in place for the duration of the fire, with window openings small enough to control radiation to neighbouring property (Barnett 1988). In buildings protected with sprinkler systems, flashover is not expected, hence spread to other buildings is not such a problem.

Fire resistance

External walls close to boundaries or other buildings should be provided with sufficient fire resistance to withstand a complete burnout of the firecell, using the methods described in Chapter 6.

Radiation

For a fire in a building such as that shown in Figure 7.5, the radiant heat intensity I_R (kW/m^2) from a single opening of a burning building to a point some distance away is given by:

$$I_R = k_1 \, \phi \, \varepsilon \, \sigma \left[(273 + T_e)^4 - (273 + T_r)^4 \right] \qquad [7.4]$$

where k1 is the radiation reduction factor

Φ is the configuration factor (value between 0 and 1.0)

ε is the emissivity of emitter and absorptivity of receiving surface (value between 0 and 1.0). It is conservative to take ε = 1.0.

σ is the Stefan-Boltzmann constant = 56.7 x 10^{-12} (kW/m^2 K^4)

T_e is the temperature of emitting surface (maximum firecell temperature) (˚C)

T_r is the temperature of receiving surface (˚C)

The maximum firecell temperature should be obtained from an assessment of the expected time-temperature curve over the duration of the fire, using information such as that shown in Figure 3.5 or more recent curves such as those produced by Feasey (1999). The ISO 834 curve could be used for a crude calculation.

In Australia, the verification methods CV1 and CV2 are available for radiative fire spread between buildings to demonstrate compliance with Performance Requirement CP2, but these methods are somewhat subject to interpretation.

Glazing

When the burning building has normal glass in the windows, it can be assumed that the glass will break and fall out by the time of flashover, allowing flames to project from the openings. In this case the radiation reduction factor k_1 should be taken as 1.0 and the radiation calculations can include the effect of the flames projecting from the window opening. Radiation from the opening itself and the flames can be considered separately and combined, or calculation can be based on a notional radiating surface the size of the window, shifted away from the building by a suitable distance D to allow for the flames, as shown in Figure 7.5. It is common to ignore the flame projection, using D = 0. More information on flame projections from openings is given by Law and O'Brien (1983) and Drysdale (1998).

When the burning building has fire resistant glazing which will remain in place for the duration of the fire, a conservative value of k_1 = 0.5 may be used and the radiating surface should be taken at the glazing line. Fire resistant glazing can be provided with Georgian wired glass or proprietary fire resistant glass in a suitable window frame which is usually constructed from steel. If the receiving building shown in Figure 7.5 has non-combustible cladding, the received radiation inside the window should be checked. Unless more information is available, it is conservative to assume that any normal glass in the window will break, but fire resistant glass will remain in place, reducing the received radiation by an additional factor of 0.5.

Multiple openings

When the facade of the burning building has several openings, all emitting radiation at the same temperature, the incident radiation can be calculated by considering the emitting surface to be a rectangle enclosing all the openings. The calculated incident radiation should be multiplied by a facade factor F_f given by:

$$F_f = A_o / A_e \qquad [7.5]$$

where A_e is the area of an enclosing rectangle on the facade, containing all of the emitting openings (m^2)

A_o = area of openings within the enclosing rectangle (m^2)

Configuration factor

To determine the intensity of radiation received by a surface remote from an emitter, a configuration factor is needed to take into account the geometrical relationship between the emitting surface and the receiver.

An approximate value of the configuration factor for radiation at a distance R from a rectangular radiator as shown in Figure 7.6 is given by:

$$\phi \approx \frac{A_v}{\pi R^2} \qquad [7.6]$$

where $A_v = W_r H_r$ is the area of the radiating surface and R is the radiation distance between the emitting and receiving surfaces (m). The exact value of the configuration factor is give by:

$$\phi = \frac{1}{90}\left(\frac{x}{\sqrt{1+x^2}}\tan^{-1}\left(\frac{y}{\sqrt{1+x^2}}\right) + \frac{y}{\sqrt{1+y^2}}\tan^{-1}\left(\frac{x}{\sqrt{1+y^2}}\right)\right) \qquad [7.7]$$

where

$$x = H_r / 2R \qquad [7.8]$$

$$y = W_r / 2R \qquad [7.9]$$

H_r is the height of enclosing rectangle (m)

W_r is the width of enclosing rectangle (m)

$\tan^{-1}$ is the inverse tangent (in degrees).

For non-parallel surfaces, configuration factors can be obtained from a standard text on heat transfer, or the FIREWIND or FIRESYS computer programs can be used.

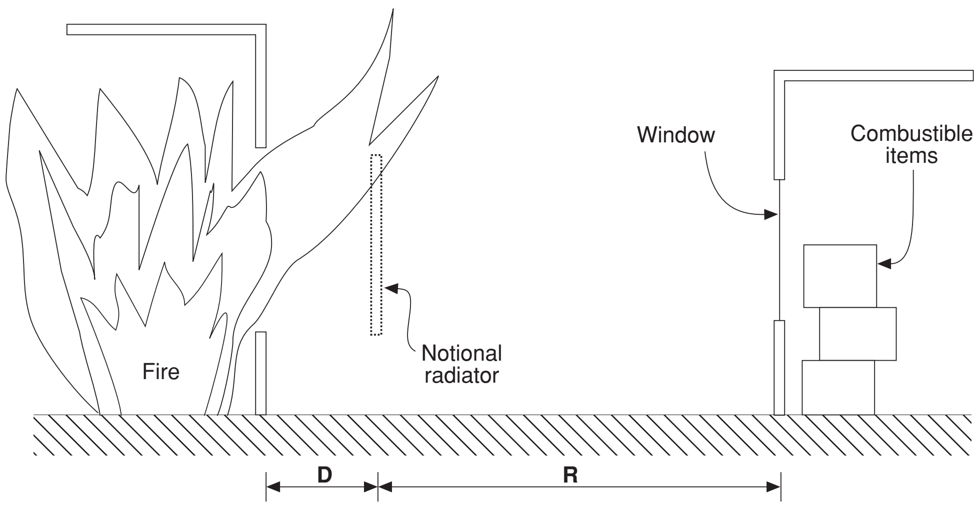


Figure 7.5: Radiation to adjacent buildings

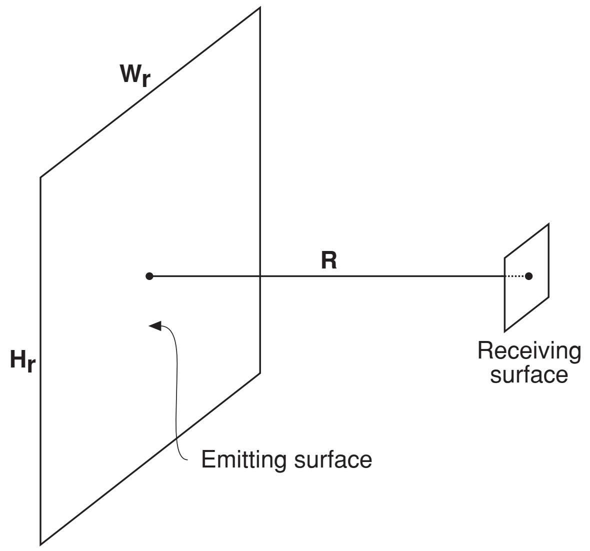


Figure 7.6: Emitting and receiving surfaces for radiation

Separation distances for calculations

Where a single owner has several buildings on one site, the separation distances can be taken as the actual distances between the buildings. Where buildings are near a property boundary, it is not always clear which distance to use. The situation should be discussed with the Territorial Authority and the owner of the neighbouring property.

For radiation from the owner's building, the following guidelines are recommended:

(a) Where a neighbouring building exists across a boundary, the separation distance should be taken as the distance between the external walls of the proposed new building and the existing neighbouring building, on the assumption that both buildings are permanent.

(b) Where no building exists across the boundary, two separate calculations should be made:

1. The radiation should be checked at the boundary, assuming that a new building with non-combustible cladding is constructed right on the boundary.
2. The radiation should be checked at a point 1.0 m over the boundary, assuming that a new building with combustible cladding or significant windows is constructed at that location.

For radiation from the neighbour's building to the owner's building, the calculations should be repeated to verify that the owner's building is safe from a fire in the neighbour's building.

Received radiation

The values of received radiation at the wall surface or inside the window should not exceed the values given in Table 7.1 unless further information is available. The value of critical received radiation is from Lawson and Simms (1954). Recent ignition tests on New Zealand timber are reported by Henderson (1998). The calculated value of received radiation inside the window should include a reduction factor of $k_1 = 0.5$ if the window is fitted with fire resistant glass.

Condition	Value (kW/m^2)
Neighbour's building or contents combustible	
— plastic	10.0
— cellulosic (wood based)	12.5
Neighbour's wall non-combustible	30.0

Table 7.1: Minimum values of received radiation to cause ignition

These calculations assume that in urban areas there will be no intervention by the Fire Service to reduce fire spread from building to building. In most fires there will be attendance by the Fire Service who can apply water to exposed buildings to reduce the likelihood of fire spread, depending on availability of water and ease of access.

Worked example

For the same fire considered above, calculate the compartment temperature assuming a standard fire for the duration of the burning period and the radiation from the window to another building 5.0 m away.

Assume a standard fire for the duration of the burning period, $t_b = 26.8$ min

Compartment temperature $\quad T_e = 345 \log(8t_b + 1) + T_o = 792^\circ C$

Compartment emissivity $\quad \varepsilon_c = 1.0$

Configuration factor for window:

Distance between buildings $\quad R = 5.0$ m

Assume no flame projection from opening

Height ratio $\quad x = H_r/2R = 0.20$

Width ratio $\quad y = W_r/2R = 0.30$

Configuration factor
$$\phi = \frac{1}{90}\left(\frac{x}{\sqrt{1+x^2}}\tan^{-1}\left(\frac{y}{\sqrt{1+x^2}}\right) + \frac{y}{\sqrt{1+y^2}}\tan^{-1}\left(\frac{x}{\sqrt{1+y^2}}\right)\right) = 0.0703$$

Glazing factor $\quad k_1 = 1.0$

Radiant heat $\quad I_R = k_1 \phi \varepsilon_c \sigma\left[(273 + T_e)^4 - (273 + T_o)^4\right] = 5.7 \text{ kW/m}^2$

I_R is less than the minimum radiation to cause ignition, so the fire will not spread.

Chapter 8
Means of Escape

8.1 Introduction

The objective of design for escape is to ensure that the life safety performance requirements can be met.

The New Zealand Building Code specifies the performance requirements for means of escape in Clause C2, reproduced in Appendix A of this Guide. Means of escape provisions form Section D of the performance requirements of the Building Code of Australia. It should not be necessary to exceed these requirements unless the client has an express wish to make the building safer than required by the Building Code. The objective of Clause C2 is to safeguard people from injury or illness from a fire while escaping to a safe place and to facilitate fire rescue operations. This is also the objective of Section D of the Building Code of Australia.

Design in accordance with Acceptable Solution C/AS1 is deemed to satisfy the minimum requirements of the New Zealand Building Code, while design in accordance with the deemed-to-satisfy provisions of BCA Section D is sufficient to satisfy the minimum requirements of the Building Code of Australia. Most other countries have similar prescriptive solutions for design of escape routes.

This chapter provides a framework for specific fire engineering design of escape routes as an alternative solution to the acceptable solutions. In many cases, the acceptable solution can be used as guidance for the specific design.

8.2 Basis for engineered design of escape routes

A flow chart for specific engineering design of escape routes is shown in Figure 8.1.

For all spaces in a building, the time taken to evacuate the space must be less than the time for the environment in that space to become life-threatening, inclusive of a safety margin, so that:

$$t_{ev} + t_s < t_{lt} \qquad [8.1]$$

where

t_{ev} is the calculated evacuation time measured from ignition

t_{lt} is the time for conditions to become life threatening, again measured from ignition

t_s is the safety margin.

Evacuation time and time for conditions to become life-threatening are both measured from the time of ignition. Evacuation time t_{ev} is given by:

$$t_{ev} = t_d + t_a + t_o + t_i + t_t + t_q \qquad [8.2]$$

where:

t_d is the time from ignition until detection of the fire (by a building occupant or by an automatic detection system)

t_a is the time from detection until an alarm is sounded

t_o is the time from alarm until the time occupants make a decision to respond

t_i is the time for occupants to investigate the fire, collect belongings, fight the fire

t_t is the travel time, being the actual time required to traverse the escape route until a place of safety is reached, including way-finding

t_q is the queuing time at doorways or other obstructions.

The term t_d may be determined from computer fire growth models. The term t_a should be estimated from knowledge

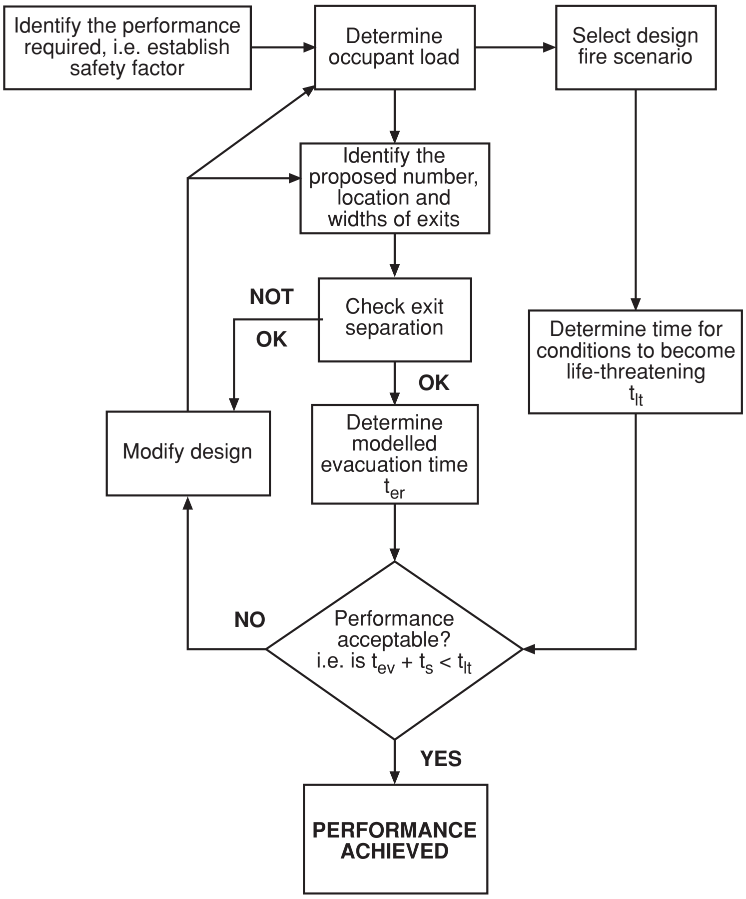


Figure 8.1: Procedure for an engineered means of escape

of the alarm system or from knowledge of human behaviour. The terms t_o and t_i are more difficult to calculate, but should not be taken as less than 30 seconds each. In many real fires, these times have been much more significant than the actual travel time. Calculation of travel time t_t is described below.

The safety margin in equation 8.1 is required to provide an additional safety factor between the calculated evacuation time and the time by which occupants must have escaped. Calculations of evacuation time can only be approximate and may vary considerably depending on the nature and mobility of the occupants.

The safety margin is required to account for uncertainties in calculating the likely evacuation and tenability times, difficulties in finding the way and other unforeseen circumstances. The safety margin selected may vary depending on occupant characteristics (age, disability, sleeping or active occupancies), presence of suppression systems, and building size or complexity. In the absence of better information, a safety margin of not less than t_{ev} is suggested for alert able-bodied people. A more detailed analysis may be carried out as justification for using a different safety margin. Selection of the safety margin depends on whether the compared times are expected values or extreme values of the parent distributions.

8.3 Number of occupants

Occupant load can be determined by multiplying the area available for occupation by the occupant density appropriate to the activity and nature of the space. Tables of occupant density are given in the Acceptable Solutions. Table 8.1 shows the occupant density for crowd activities from the 2000 version of the Approved Documents, with travel speeds from equation 8.4. In special cases it may be appropriate to base calculations on more accurate values from detailed studies or field surveys. In some circumstances it may be appropriate to specify the maximum occupant design load for a room or a building in which cases there must be a mechanism to ensure that occupant load is monitored and not exceeded during the life of the building. For example, an occupant load plaque could be affixed to a wall.

Activity	Occupant Density (users/m^2)	Maximum Travel Speed (m/min)
Crowd activities		
Airports - baggage claim	0.50	73
Airports - concourses	0.10	73
Airports - waiting areas, check in	0.70	68
Area without seating or aisles	1.00	62
Art galleries, museums	0.25	73
Bar sitting areas	1.00	62
Bar standing area	2.00	39
Bleachers, pews or similar bench type seating	2.2 users per linear metre	
Classrooms	0.5	73
Dance floors	1.7	46
Day care centres	0.25	73
Dining, beverage and cafetaria spaces	0.8	66
Exhibition areas, trade fairs	0.7	68
Fitness centres	0.2	73
Gymnasia	0.35	73
Indoor games areas/bowling alleys, etc	0.1	73
Libraries - stack areas	0.1	73
Libraries - other areas	0.15	73
Lobbies and foyers	1.0	62
Mall areas used for assembly purposes	1.0	62
Mall areas used for circulation and shopping	0.3	73
Reading or writing rooms and lounges	0.5	73
Restaurants, dining rooms and lounges	0.9	64
Shop spaces and shopping arcades	0.3	73
Shop spaces for furniture, floor coverings, large appliances building supplies and manchester	0.1	73
Showrooms	0.2	73
Space with fixed seating	as number of seats	
Space with loose seating	1.3	55
Spaces with loose seating and tables	0.9	64
Stadia and grandstands	1.8	44
Stages for theatrical performances	1.3	55
Standing space	2.6	26
Swimming pools (water surface area)	0.2	73
Swimming pools (surrounds and seating)	0.35	73
Teaching laboratories	0.2	73
Vocational training rooms in schools	0.1	73
Sleeping activities	as number of beds	
Working, storage etc	<0.5	73.0
Intermittant activities	<0.5	73.0
General densities	0.5	73
	1.0	62
	1.5	50
	2.0	39
	2.5	28
	3.0	17
	3.5	6

Table 8.1: Occupant densities and travel speeds

8.4 Escape route geometry

Escape route geometry should be kept as simple as possible. Corridors that frequently change direction and large numbers of doors make it more difficult for people to find their way. Signs are also important.

Number of escape routes

The general principle is to provide occupants with at least two escape routes from any space. There will, naturally, be exceptions to this for very small spaces. The requirements given in the Acceptable Solution for minimum number of escape routes are recommended.

For unsprinklered buildings, the New Zealand Acceptable Solution requires that one exit be considered unusable, in unsprinklered buildings, when calculating the required width of escape routes. If this approach is included in specific design calculations, a correspondingly lower safety margin may be appropriate. If the building is protected by an automatic sprinkler system, it is most unlikely that an exit will be blocked due to fire.

Separation of exits

Where alternative escape routes are provided, they must be adequately separated such that a fire could not block both escape routes simultaneously. The Acceptable Solution specifies adequate separation by requiring alternative escape routes to diverge from one another by at least 90° until they become separated by a certain distance or by smoke separations.

Exit width

An alternative method for determining the required width of an exit, and which takes into account stair geometry, is given by Wade (1992). It is designed to evacuate the occupants in the same time as achieved by using Acceptable Solution C2/A1in combination with the steepest common stair permissible in Acceptable Solution D1/AS1Access. It gives the designer more flexibility by allowing for increased flow on stairs that are well-proportioned. It is not applicable if a complete analysis of travel time in accordance with section 8.5 is to be carried out.

Where "flow time" is nominated separately and differs from the times implicit in the Acceptable Solution, then the model by Pauls (1995) may be used to calculate the required width of an exit way using appropriate densities, flows and speeds.

8.5 Travel time

This section describes a way of relating the open path distance to be traversed by the occupants to reach a place of relative safety to the time until the space is likely to become life threatening due to smoke and fire. The open path is the route traversed by the occupants while escaping until they exit the building or enter a safe place, such as an exit way that protects them from the effects of fire and smoke.

The length of travel L_t (m) is related to travel speed S (m/min) and traversal time t_{tr} (min) by:

$$L_t = S \times t_{tr} \qquad [8.3]$$

Speed of travel depends on the occupant density, age and mobility. At an occupant density less than about 0.5 persons

Narrow and steep external fire escape allowing egress from upper stories

per square metre, the flow will be uncongested and speeds of about 70 m/min can be achieved for level travel and 51-63 m/min down stairs.

Conversely, when the occupant density exceeds about 3.5 persons per square metre, flow is very congested and little, if any, movement will be possible. Nelson and MacLennan (1995) give expressions relating speed of travel, occupant density and flow. Figure 8.2 shows the relationship between evacuation speed and occupant density.

The relationship between speed of travel S (m/min) and density of occupants D_o (people per m^2) is given by:

$$S = k_t (1 - 0.266 D_o) \qquad [8.4]$$

for density D_o greater than 0.5 persons per square metre, where k_t is a factor given by:

$$k_t = 84.0 \text{ for level corridors or doorways and} \qquad [8.5]$$

$$k_t = 51.8 (G/R)^{0.5} \text{ for stairs} \qquad [8.6]$$

where G is the length of the stair tread going and R is the riser height of each step.

For any value of occupant density and corresponding value of speed from equation 8.4, there is a unique value of specific flow F_s (people/min/metre) given by:

$$F_s = S \times D_o \qquad [8.7]$$

Values of specific flow are plotted in Figure 8.3. It can be seen that the maximum specific flow on a flat corridor is approximately 75 persons per minute per metre at an occupant density of 1.88 persons per square metre.

Note that the occupant density D_o in equation 8.4 is the density of people as they are moving through a space or queuing at a doorway, which may be much greater than the design density given in Table 8.1.

The above information can be used to calculate the speed of travel, hence the traversal time for a group of people to travel along a space such as a corridor. The time for people to pass through a restriction such as a stairway or door of given width can also be calculated (Nelson and MacLennan 1995).

For a stairway or door of width W (m), the effective width W_e (m) is given by:

$$W_e = W - B \qquad [8.8]$$

where B (m) is the boundary layer width, usually taken to be 0.15 m on each side of a stairway, 0.05 m each side of a door or 0.09 m each side of a centre rail.

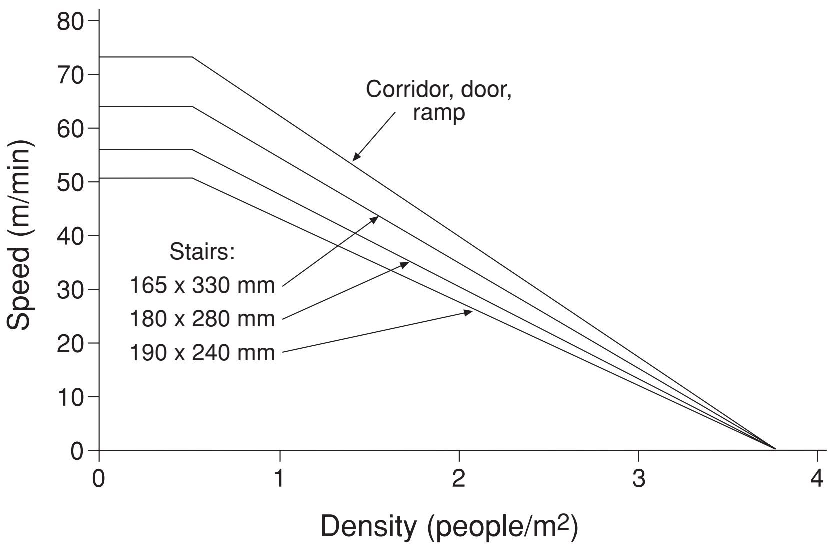


Figure 8.2: Evacuation speed for egress calculations
(Nelson and MacLennan, 1988)

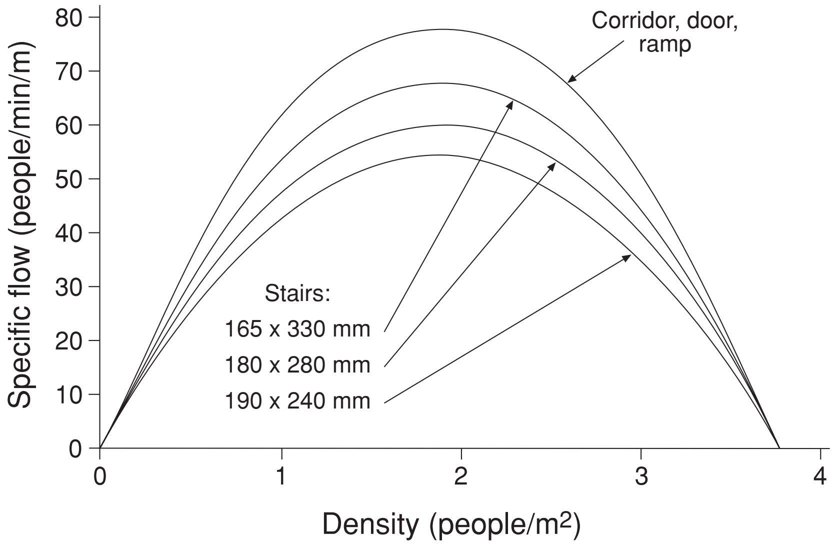


Figure 8.3: Specific flow

(Nelson and MacLennan, 1988)

The actual flow of people F_a (people/min) through the stairway or door is given by:

$$F_a = F_s \times W_e \quad [8.9]$$

The time t_{ts} in minutes for a number of people N to pass through the stairway or door is given by:

$$t_{ts} = N / F_a \quad [8.10]$$

This can be used to determine the queuing time that may occur.

Calculations can become complicated for an exit way with a series of doors, corridors, stairs etc., particularly when several flows of people are coming into the exit way at different levels of the building. Nelson and MacLennan (1988) give some example calc ulations.

8.6 Time for conditions to become life threatening

The time to clear a space of people must be less than the time for life-threatening conditions to develop within that space with an appropriate margin of safety.

Fire growth computer models can be used to calculate the time for conditions to become life-threatening. That time is the time when certain tenability limits are exceeded.

8.7 Tenability limits

The effect of fire environments on humans is an exceptionally difficult subject to quantify. Harm can be psychological, physiological or physical. Accurate data on humans is rarely available from real-fire incidents. Experiments on humans under the effects of fire is fraught with difficulties, even if such experiments were to be condoned. Human response to fire environments varies widely between individuals, depending upon the interactions between their physiological and psychological characteristics and the particular situations they are confronted with. Some people may refuse to pass through even dilute smoke, while others will attempt to move through dense smoke, particularly in extreme situations.

For some forms of incapacitation, particularly partial asphyxia such as that induced by exposure to environments containing low oxygen concentrations or carbon monoxide, experiments have been carried out on humans or non-human primates and well-defined endpoints of functional impairment are easily measured. However, due to variations in susceptibility, some individuals may be completely overcome well before other individuals are even mildly incapacitated.

With irritant products there is no sharp cut-off pain point, since the severity of the effects increases continuously with concentration, from mild eye irritation to severe eye and respiratory tract pain. The response of individuals would vary depending upon such factors as their pain thresholds, their lung function characteristics and the perceived danger.

Where zone-based fire growth models are used to predict smoke filling in compartments, tenability criteria are usually required to establish the acceptability (or not) of the design. These tenability criteria are measures of the time for life-threatening conditions to develop.

Tenability criteria will generally be concerned with the effect that one or more of the following phenomena have on occupants while within the building or within its escape routes.

- Convective heat
- Radiant heat
- Visibility through a smoke layer (or smoke obscuration)
- Concentration of narcotic gases
- Concentration of irritant gases

When evaluating these phenomena in conjunction with output from a zone model, a nominal reference or monitoring height will normally be assumed. This height corresponds to the position at which the conditions are to be evaluated and would normally be above nose or head height. When the smoke layer height is above this reference height, conditions in the lower layer are applicable and when the smoke layer height is below the reference height conditions in the upper layer are applicable. A height of 2.0 m or greater is recommended for design purposes. In Australia, the fire engineering guidelines recommends 2.1 m.

Convection

High levels of convective heat can lead to skin pain or burns. Inhaled hot gases can also lead to strokes. Critical temperatures for convective heat depend on the exposure time and the moisture content of the fire gases.

A conservative tenability criterion for exposure to convected heat is 60˚C (saturated, exposure time 30 minutes). Purser (1995) provides an expression for time to incapacitation as a function of the gas temperature.

Radiant Heat

Radiant heat causes erythema (reddening of the skin and pain), partial skin burns and eventually full thickness skin burns. Mudan and Croce (1995) give an equation for the onset of pain as a function of exposure time.

A conservative tenability criterion for exposure to radiant heat is that radiant heat flux from the upper layer should not exceed 2.5 kW/m^2 at head height (this corresponds to an upper layer temperature of approximately 200 ˚C). Above this, the tolerance time is less than 20 seconds.

Visibility

Visibility through smoke depends on the density of the smoke, the type of smoke and the characteristics of the target object to be viewed (e.g. whether exit signs are illuminated or not). Some zone models may calculate the visibility (in metres) directly while others determine an optical density (in 1/metres). The calculated visibility is greatly influenced by the soot (or carbon) yield (g/g) selected as input to the zone model and this value should be carefully selected and justified.

FCRC (1996) recommend the visibility tenability criteria shown in Table 8.2.

Location	**Minimum visibility (m)**	**Optical density (l/m)**
Small rooms	5	0.2
Other rooms	10	0.1

Table 8.2: Tenability criteria for visibility

Floor level lights marking escape route in modern airport building

Narcotic or Asphyxiant Gases

Narcotic gases may cause loss of consciousness or death by depriving the brain tissues of oxygen. Narcotic gases that are products of combustion include carbon monoxide, hydrogen cyanide, carbon dioxide and reduced oxygen.

The following gas concentrations lead to incapacitation in approximately 30 minutes (Purser, 1995).

CO	not > 1400 ppm (small children incapacitated in half the time)
HCN	not > 80 ppm
O_2	not < 12 %
CO_2	not > 5 %

A more detailed method to evaluate the hazard of narcotic gases involves the use of the "fractional effective dose (FED)" approach. This is described well by Purser (1995) and involves accounting for the cumulative effect of exposure to multiple narcotic gases. When the FED reaches unity, incapacitation is assumed to occur. The FED approach also allows for a specified exposure period to be considered rather than the more conservative assumption of the space remaining occupied for the full duration of the analysis.

Irritant Gases

Irritant gases cause discomfort, pain or tissue damage to the mucous membranes eyes, nose, throat and lungs, which may lead to incapacitation or death. Irritant gases that are products of combustion include inorganic acid gases (such as hydrogen chloride) and organic compounds such as formaldehyde and acrolein, to name a few.

Purser (unpublished) recommends that the limiting conditions for irritants gases are unlikely to be exceeded if the visibility is 5 m or greater.

FCRC (1996) suggest a simplified approach where limiting conditions for all toxic products (narcotic and irritants) are unlikely to be exceeded if the smoke optical density does not exceed 0.1 1/m or produce less than 10 m visibility.

8.8 Computer modelling

There are a number of computer-based methods or models for assisting in evacuation calculations. They are summarised as follows:

- EVACNET+ (Kisko and Francis 1985) is a public domain program for modelling building evacuations. The building is input in the form of a series of nodes and arcs. The nodes represent spaces in the building and they are allocated an initial number of occupants. The arcs require traversal time and flow capacity to be supplied. The program determines an optimal plan to evacuate the building in the minimum possible time and is best used in conjunction with hydraulic flow calculations, such as described by Nelson and MacLennan (1995).
- EXODUS is a program for simulating the escape movement of a large number of people (Owen et al, 1977).
- FPETool is a package of programs originally developed by Bud Nelson dealing with fire phenomena for practical

engineering purposes (Nelson, 1990; Deal, 1993), which includes a sub-routine for examining egress performance. This program has been enhanced and incorporated into FASTLite (Peacock et al, 1996).

- FIRECALC is a package of programs produced in Australia (CSIRO 1993), including a sub-routine for examining egress performance. This package is no longer supported by CSIRO and has been replaced by FIREWIND.
- FIRESYS contains a program for calculating fire egress from rooms through doors, corridors and stairs, using the basic principles outlined in this chapter.
- EXITT is a program supplied with the hazard assessment program HAZARD I. It has very limited application for sizeable commercial or public buildings because it does not include queuing theory.
- SIMULEX is a program for simulating the escape movement of many people from large or complex buildings (Thompson and Marchant, 1994).

8.9 Other issues

Discounting of exits

When determining exit width in unsprinklered buildings, each exit should be excluded in turn, with the remaining exits being able to accommodate the full occupant load. That is, if only two exits are provided, they must each individually cater for the full occupant load. It is recommended that this concept be applied in fire engineered design of unsprinklered buildings where it is practical to do so. This is not required under Section D of the deemed-to-satisfy provisions of the BCA, but is common practice in fire engineered design in Australia.

People with disabilities

The New Zealand Building Code requires that in certain buildings, people with disabilities should be able to enter and carry out normal activities and functions. Means of escape may, therefore, also need to meet the requirements of NZBC Clause D1 Access Routes. In addition, C/AS1 requires refuge areas in vertical safe paths of tall buildings. These provide additional space within a safe path to allow slow moving persons to rest and others to pass.

Occupant behaviour

Background information on occupant behaviour in fire situations is given by Bryan (1988).

Multi-storey buildings

A useful summary of means of escape from multi-storey buildings is given by Wade (1991c).

In very large or very tall buildings, it is recommended that some form of evacuation management (such as staged evacuation) be included to avoid unnecessary congestion resulting from an excessive number of people all attempting to evacuate at one time. Proposed managed evacuation systems should be designed in consultation with the New Zealand Fire Service. Guidance is given in the Fire Safety and Evacuation of Buildings Regulations 1992.

Under the Building Code of Australia, buildings over 25 m in height are normally expected to have a managed evacuation plan, including the use of an AS2220 emergency warning and communication system.

Worked example — egress design

Problem 1

Given a room with known occupant load and the dimensions shown in Figure 8.4, calculate the time for the occupants to evacuate the room and the time to evacuate the protected stairway. Compare with the time to reach life-threatening conditions.

Length of the room	$L_r = 10$ m
Width of the room	$W_r = 10$ m
Length of the protected stair	$L_s = 10$ m

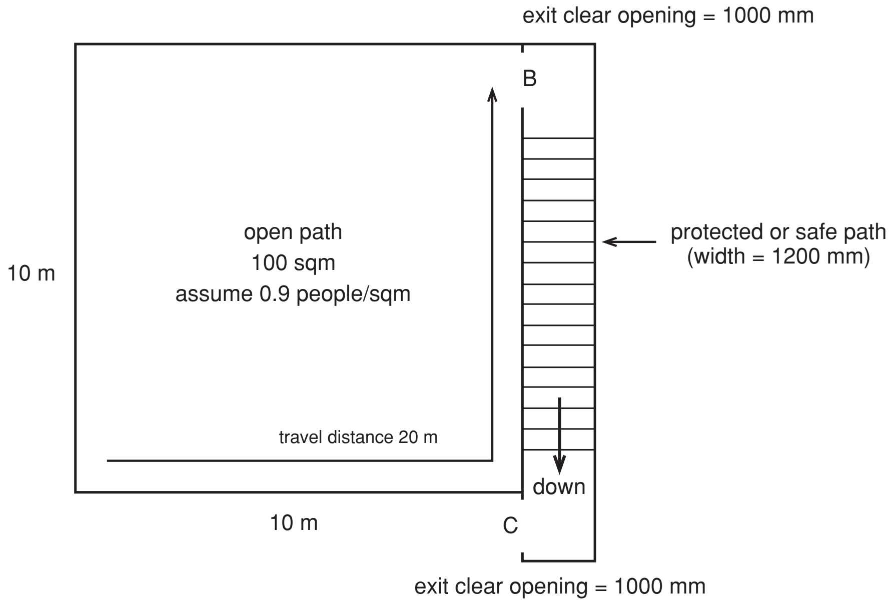


Figure 8.4: Room and stairs for worked example

Floor area of room $A_f = L_r W_r = 10 \times 10 = 100\ m^2$

Occupant density $D_o = 0.9$ people/m^2 (from Table 8.1)

Number of occupants $N_o = A_f D_o = 100 \times 0.9 = 90$ people

k_t factor $k_t = 84$

Travel speed $S = k_t (1 - 0.266D_o) = 63.9$ m/min

Length of the escape route from the furthest point to exit B $L_t = 20$ m

Traversal time $t_{tr} = L_e / S = 0.31$ min

Detection time $t_d = 0.75$ min (from FPETOOL, say)

Alarm time after detection $t_a = 0.1$ min (guess)

Occupant decision time $t_o = 0.5$ min (guess)

Occupant investigation time $t_i = 0.5$ min (guess)

Evacuation starts at $t_d + t_a + t_o + t_i$ =1.9 minutes and the first person is assumed to enter exit B at this time.

Time for the last person to reach exit B $t_{ev} = t_d + t_a + t_o + t_i + t_{tr} = 2.2$ min

This is the predicted time for the last person to reach exit B considering the predicted travel speed in the open path, and assuming no extra time is required for way-finding. It is not necessarily the time for all the people to be in the stairway. Queuing effects at the doorway must first be considered as shown below:

Width of the door $W = 1.0$ m

Width of the boundary layer $B = 0.15$ m

Effective width $W_e = W - 2B = 0.7$ m

Specific flow through door $F_s = SD_o = 63.9 \times 0.9 = 57.5$ people/min/m

Actual flow through door $F_a = F_s W_e = 57.5 \times 0.7 = 40.3$ people/min

Queuing time to travel through exit B $t_q = N / F_a = 90 / 40.3 = 2.2$ min

The last person enters exit B 2.2 min after the first person entered exit B, i.e. $t_t = 2.2$ min, hence evacuation time $t_{ev} = t_d + t_a + t_o + t_i + t_q = 1.9 + 2.2 = 4.1$ min. Take safety margin $t_s = 4.1$ min.

Design time to escape $t_d = t_{ev} + t_s = 4.1 + 4.1 = 8.2$ min

Design is OK if the design time is less than the time for untenable limits in the room to be exceeded.

Problem 2

Extend problem 1 to calculate the time for the occupants to evacuate the stairway.

Width of the stairs $W = 1.2$ m

Width of boundary layer $B = 0.15$ m

Effective width $W_e = W - 2B = 0.9$ m

Using the actual flow of people as they pass through exit B and the width of the space they enter, the specific flow in the stairway can be determined.

Specific flow $F_s = F_a / W_e = 40.3 / 0.9 = 44.8$ persons/min/m

Length of stair tread going $G = 280$ mm

Height of the stair riser $R = 180$ mm

k_t factor $k_t = 51.8(G/R_s)^{0.5} = 64.6$

The specific flow and people density can be related as follows to determine the density of people in the stair.

Density of occupants $S = k_t (1-0.266D_s)$ and $F_s = S\ D_s$

so $F_s = k_t D_s (1 - 0.266D_s)$

$$0.266\ k_t D_s^2 - k_t D_s + F_s = 0$$

This is a quadratic equation in the form $ax^2 + bx + c = 0$, where $a = 0.266\ k_t$, $b = -k_t$, $c = F_s$ and $x = D_s$. Solve for D_s.

$$D_S = \left[-b \pm \sqrt{\left(b^2 - 4ac\right)}\right] \big/ 2a \quad = 0.92 \text{ or } 2.84 \text{ people/m}^2$$

Sensibly choose $D_s = 0.92$ people/m^2.

Travel speed in stair $S = k_t (1-0.266D_s) = 48.8$ m/min

Length of stair $L_s = 10.0$ m

Time to traverse the stairs $t_{ts} = L_s / S = 10 / 48.8 = 0.20$ min

The first person reaches and enters exit C at 1.9 + 0.2 = 2.1 minutes. The last person reaches exit C at 4.1 + 0.2 = 4.3 minutes.

Actual flow through exit C $F_a = F_s W_e = 44.8 \times 0.7 = 31.4$ people/min

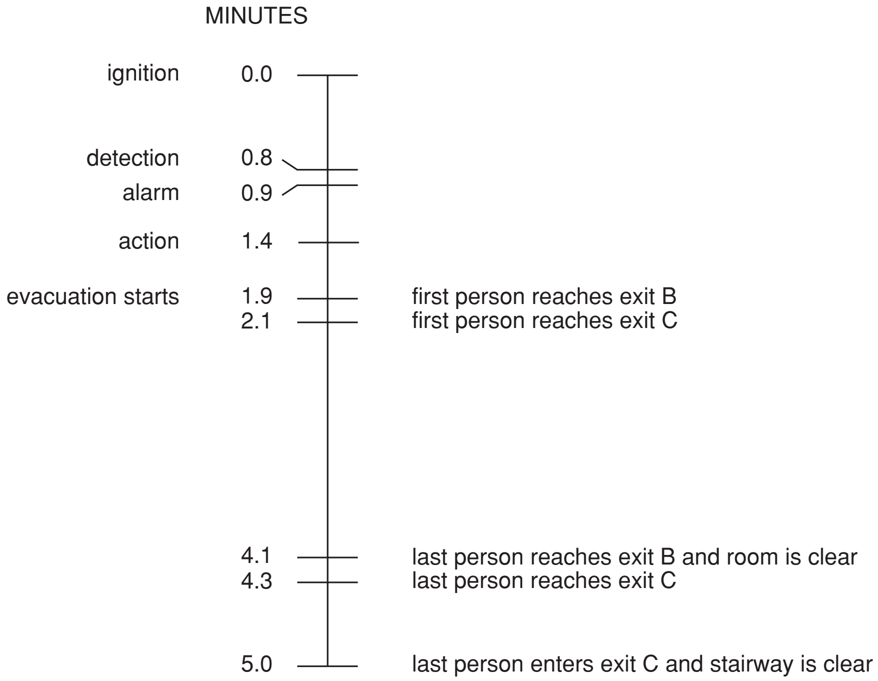
Time to travel through exit C $t_{qc} = N / F_a = 90 / 31.4 = 2.9$ min

The last person enters exit C 2.9 minutes after the first person has entered exit C, therefore the stairway is clear and the evacuation time for the “building” is 2.1 + 2.9 = 5.0 minutes.

The design time for escape for the protected stairway is $t_d = t_{ev} + t_s = 5.0 + 5.0 = 10$ minutes.

This time should be compared with time for untenable conditions in the stairway.

A timeline for the escape design is shown overleaf.


MINUTES
ignition
0.0
detection
0.8
alarm
0.9
action
1.4
evacuation starts
1.9
first person reaches exit B
2.1
first person reaches exit C
4.1
last person reaches exit B and room is clear
4.3
last person reaches exit C
5.0
last person enters exit C and stairway is clear

Chapter 9
Detection and Suppression System Design

9.1 Introduction

The objective of the design and installation of detection and suppression systems is to ensure that these active fire safety systems meet the performance requirements and will operate as intended in the event of a fire.

9.2 Fire alarm systems

Figure 9.1 shows the main components for most alarm and detection systems.

Fire alarm control and detection equipment is generally constructed to high reliability standards and a design life of 25 years. This is achieved by careful choice of materials and conservative use of components. The fire event may occur many years after installation and the system must operate without failure at that time.

The purpose of the control equipment is to:

1. Operate a network of detectors that will register an alarm.
2. Effect prompt evacuation of people through warning devices.
3. Summon fire fighting assistance.
4. Effect plant control to reduce fire damage.
5. Display the origin of the fire signal.
6. Monitor the well-being of the equipment.

In New Zealand, automatic and manual fire alarm systems should be designed and installed in accordance with NZS4512:1997, which applies to the design, testing, installation and maintenance of electrical and pneumatic automatic fire alarm systems. An appendix deals with signalling to a remote receiving centre, for example the Fire Service. See Section 11.5 for a discussion of fire alarm reliability. In Australia, fire detection and alarm systems are designed, installed and commissioned to AS/NZS1670 and maintained to the relevant part of AS1851.

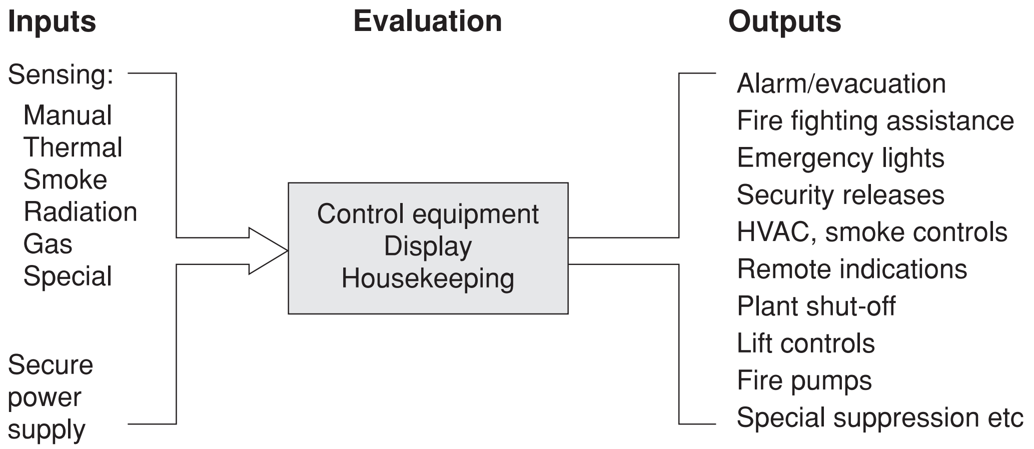


Figure 9.1: Main components of an alarm system

Detector technology is very specialised. Items used in New Zealand are manufactured in many countries, including Australia, Japan, USA, UK and Switzerland, under a wide range of national and international standards. Details of installation and application are prescribed in national standards and by manufacturers' instructions. Details of installation and applications are prescribed in national and internationally accepted codes. AS1670, NFPA72 and BS5839 are useful references to augment NZS4512 for advice on detector positioning. Additional guidance on design of fire detection systems is given by Schifiliti et al (1995).

9.3 Detectable effects of fire

The effects seen in the early stages of a fire vary from risk to risk. The rate of development, ignition mechanism and the fuel type all contribute to early development characteristics.

Products of combustion are grouped as aerosols, vapours and gases.

- An **aerosol** consists of particulate matter suspended in air. Aerosols are produced by nearly all combustible materials — wood products, hydrocarbons and insulating materials. They may be solid matter or tiny fluid droplets. Depending on the concentration and particle size, they may or may not have light obscuration or light scattering properties.
- A **vapour** results from overheating of some materials before true combustion occurs or as a side effect to the combustion process. The cooling vapours condense to form droplets and can be detected effectively by their light scattering property when using visible light for analysis.
- A **gas** results from the chemical reactions of combustion. The principal combustion gases are carbon dioxide and carbon monoxide.

About 80% of fires start with smouldering and produce abundant gases and then aerosols as the first detectable effects of fire. The area of interest is about 2 micron diameter and less. Vapours are rarely found without aerosols.

Specific electro-magnetic radiation occurs when flames break out. The flames will grow and recede with the supply of oxygen and have a typical flicker rate of 0.5 to 30 Hz. The radiation has a number of other distinctive characteristics. The yellow body of the flame is probably incandescent carbon and looks like a black body source of continuous radiation with a peak radiation temperature of 800˚C. There will be infrared line spectral emissions that are associated with CO, CO_2 and H_2O water vapour. Any other "colour" seen in the flame will also indicate a line emission associated with that material. The presence of CO, CO_2 and H_2O emissions are important correlation details in separating out signals that are not due to a fire event, but which exist in everyday life. Other radiation effects are apparent in the ultra-violet (UV) region (blue end of the visible spectrum).

The open flame condition marks the initiation of rapid growth of the fire and considerable quantities of heat are now generated. This heat is transferred to the ceiling environment by a well-defined plume of rising air and combustion products. Heat detectors absorb heat from the convected air and operate after a period of time, when sufficient energy transfer has taken place.

9.4 Detector response

The main objective is to detect fires early, so as to minimise the effects of smoke during the evacuation phase. Smoke is the collective word for many products of combustion. It includes a wide range of particle sizes that will be more or less buoyant in the surrounding air. The hotter the fire, the finer the particle division. Many products of combustion are toxic and highly corrosive, presenting life threatening conditions.

Detectors are positioned on the ceiling and conform to spacing rules to achieve acceptable response times to standardised test fires. If the cold smoke phase is not recognised by detectors, then the alarm must wait for the hot fire phase to activate the sensors. Table 9.1 shows the expectations of fire size in the early growth phase for various detectors.

Smoke generated by small smouldering fires is difficult to model. Gases, however, spread by well-modelled diffusion laws. After flame breaks out, the dynamics can be described and smoke generation and movement can be modelled. The generation of combustion products can be separated into cold smoke and hot smoke phases, as shown in Figure 9.2.

Type	Area Cover m^2	Response Time min	Fire Size
Aspirating	2000	1	10-100 W
Gas	90	1-3	10 W-1 kW
Smoke detector	90	1-3	100 W-1 kW
Heat detector	30	2-5	5-10 kW
Normal sprinkler	20	5-10	10-15 kW
Quick response sprinkler	35	2-5	5-10 kW

Table 9.1: Comparison of various fire detector types

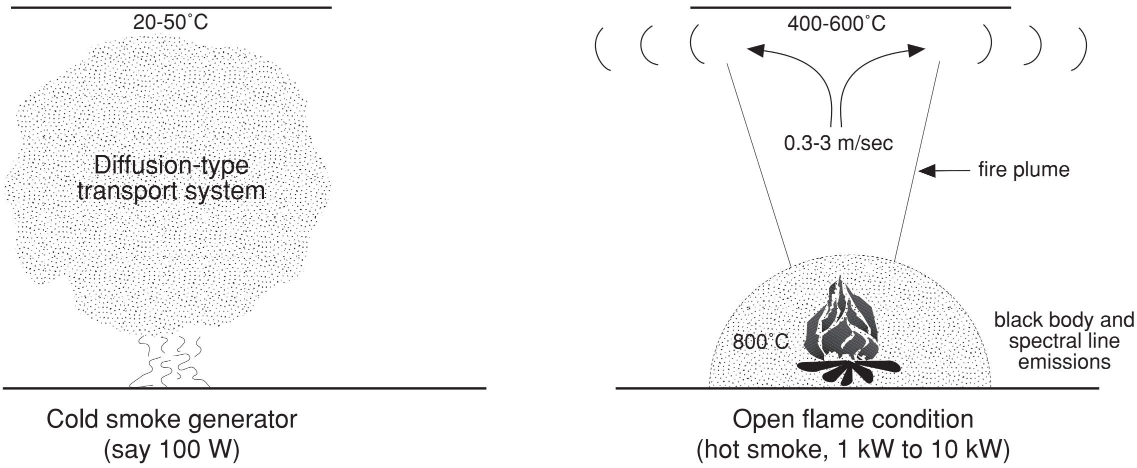


Figure 9.2: Cold and hot smoke generation in fires

Figure 9.3 shows the important time variables in detecting and suppressing fires. The impediments in t_1 and t_2 are subject to wide variation of effect. Ceiling slopes, profiles and beams hinder smoke movement compared to flat ceilings. Air conditioning and natural ventilation air movements may also reduce or increase the times.

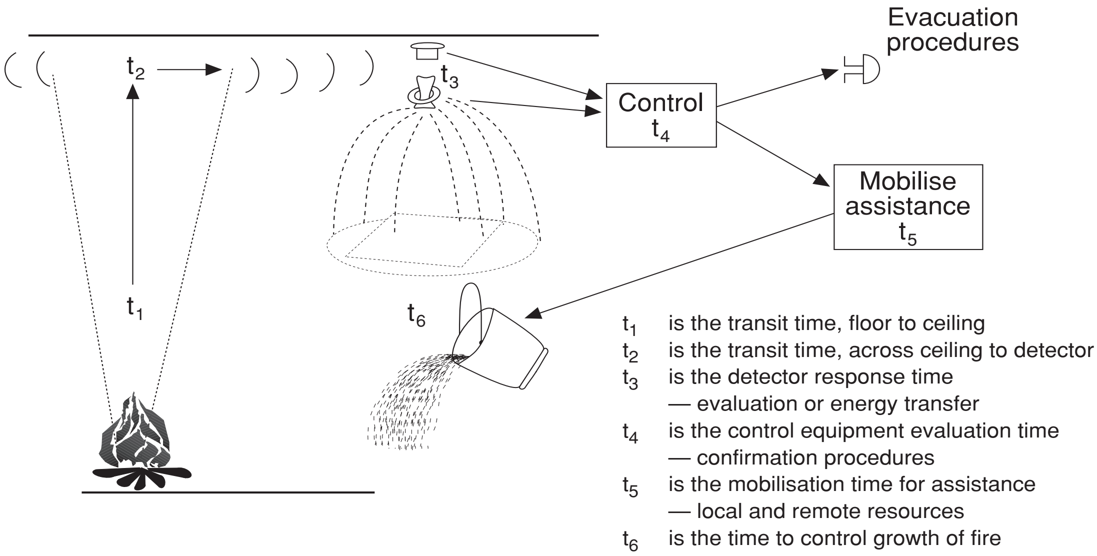


Figure 9.3: Time processes in fire development, detection and control

9.5 Thermal detectors

These are widespread in New Zealand and were almost the only detector type installed prior to recent emphasis on smoke detection for improving life safety.

Thermal detectors respond to heated air that has risen by convection to the detector location. Depending on the type of detector, the response time is dependent on the sensing element mass to be heated and the surface area effecting the heat transfer. Individual sensing devices are called point sensitive detectors, and continuously sensitive material is called a linear heat sensing detector.

A variation on fixed temperature response detectors is the "rate of rise" thermal detector (ROR types). In addition to the normal alarm threshold, these will give an earlier alarm if the temperature rises faster than a given rate. These are useful for liquid fuel applications where fire growth is very rapid.

Commonly available systems fall into these two categories as follows:

Point Sensitive	Linear Sensing
Eutectic metal switch	Nylon tube/pneumatic switch
Bimetallic switch	Nylon mono filament switch
Thermoresistive material	Digital thermoplastic switch
Conductive glass switch	Analogue thermoplastic switch
Eutectic metal sprinkler	Fibre optic time domain reflectometry
Glass/liquid bulb-sprinkler	
Glass/mercury switch	
Pneumatic switch	
Differential expansion switch, etc	

The industry has defined a range of operating temperatures that allow a choice of sensitivity to temperature (e.g. 57˚C, 74˚C, 93˚C etc.).

Heat detector systems should be designed and installed in accordance with NZS 4512. In Australia, heat detectors are designed and tested to AS1603.1 and installed to AS/NZS1670 (1995).

9.6 Smoke detectors

There are four common types of smoke detecting devices:

1. Smoke beam detector — obscuration sensitive
2. Ion chamber/products of combustion detector
3. Photoelectric/light scatter detector
4. Aspirating smoke detector

Smoke beams and ion chamber detectors have been in use for about 50 years. They are now very refined and reliable in use. Modern electronic devices have made all forms of detector more available due to cost reductions and allowed scope for innovative signal processing. There are many examples of new technological developments resulting in a reliable increase in sensitivity, but all forms of detection are limited in their sensitivity by local background effects.

Stand-alone smoke detection devices for residential and similar occupancies should be certified by an appropriate organisation such as Factory Mutual or Underwriters Laboratories (USA or Canada). The installation of residential smoke alarms should be in accordance with the manufacturer's instructions These devices may be stand alone 9-volt battery powered, or interconnected for power and alarm sounders (see Chapter 14).

The most common form of smoke alarms in residential occupancies are stand-alone 9-volt battery-powered devices which are widely available. A higher level of safety can be achieved using mains-powered interconnected smoke detectors which cannot be disabled by removing the battery and which sound at all detector locations when only one is triggered by smoke. Residential smoke alarms generally have a life of about 10 years. The Australian standard

AS3786(1993) covers smoke alarms and their installation. In Australia the appropriate standard for design, construction and testing of smoke detectors in Australia is AS1603.2.

Ion chamber/products of combustion detector

These consist of a sensing chamber open to the atmosphere to sense aerosols and vapours. A second chamber is sealed against the entry of smoke and connected electrically in series with the first, as shown in Figure 9.4. It forms a voltage divider across the supply when a small current is allowed to flow through the two chambers. This current is defined by a small radioactive source that ionises oxygen and nitrogen molecules present within the chambers. The current is defined by the rate at which these charged particles traverse the space between the sides of the chamber. When combustion products enter the chamber, they are able to attach themselves to the ionised molecules and slow the movement of the ionised molecules due to the increased mass. This is apparent as a change in voltage seen at the junction of the two chambers and sensed by the specialised electronics that follow.

This type of detector responds to the product Nd where N is the number of particles present in a unit volume of air and d their mean diameter. Converting to mass density gives response related to m/d^2 where m is the total mass of particles in a unit volume of air. These detectors respond to particles around 1 micron and below. There is no practical cut off as the size diminishes, but the concentration has to increase drastically if the detector is to respond.

As this particle size is not visible, there is the practical difficulty of assessing smoke conditions when testing. This gives rise to considerable variation in commissioning tests because there is an unknown relationship between visible and non-visible particle generation. The accepted correlation between the visible effects of fire and "product of combustion" detection is about 3% obscuration per foot (or 10% per metre).

Photoelectric smoke detectors (light scatter/Tyndall effect)

These rely on the principle of light scatter from smoke particles in an analysing chamber as shown in Figure 9.5. Light scatter is dependent in a complex way on surface conditions and particle size. This detector responds to the function m/d where m is the mass density and d the diameter. When using visible light from, say, an LED source there is a response cut off at about half the wavelength of light (0.5 micron size). These detectors are responsive to larger particles and are particularly useful in obtaining earlier alarms where plastics are a major contribution to the products of combustion.

These sensors take significant current to operate and it is important to minimise this. The light source is usually pulsed and the receiver synchronised to the light pulse. Reduction of 1000:1 is readily achieved. Alarm sensitivity is more related to the observed level of visible smoke present due to the larger particle sizes.

The development of high intensity LED/laser sources has increased the available sensitivity of photoelectric type

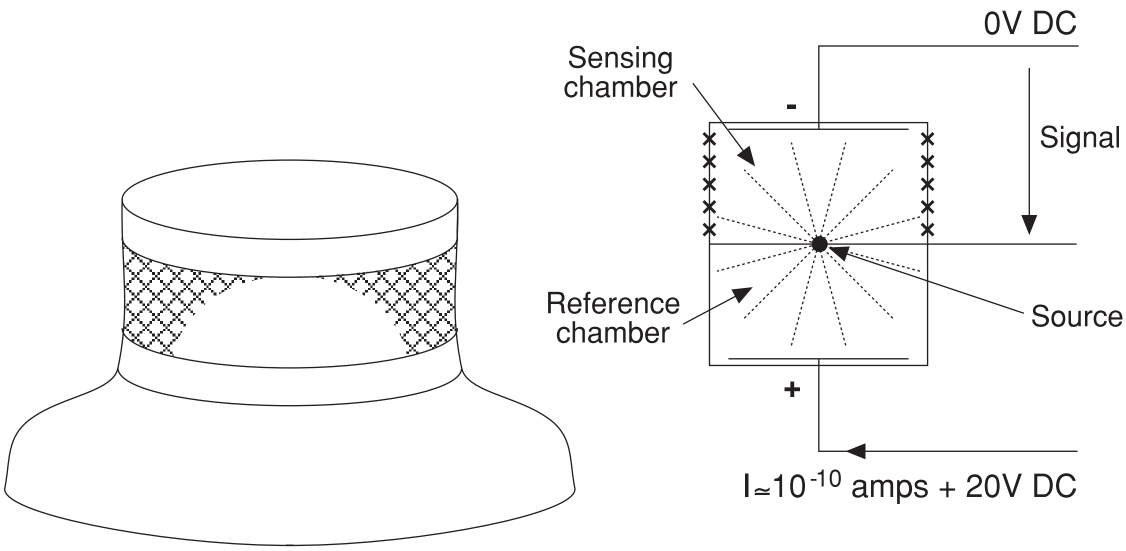


Figure 9.4: Ion chamber/products of combustion smoke detector

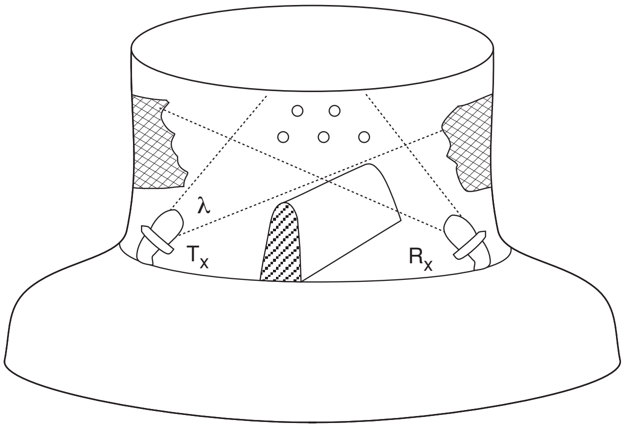


Figure 9.5: Photoelectric smoke detector

detectors by as much as 100 times (from 10% to 0.1% obscuration per meter). This sensitivity has to be used with particular care, as the normal background levels of smoke, dust and airborne particles needs to be ignored.

Aspirating smoke detector

The method of sampling the atmosphere for products of combustion by drawing air through a tube has been used in industry and shipping for many years. The system, shown schematically in Figure 9.6, is a type of photoelectric detection. The recent development of the hardware has produced systems of extraordinary sensitivity. This is commonly referred to as a HSSD (High Sensitivity Smoke Detector). The most widely-used in New Zealand is the proprietary VESDA® system (Very Early Smoke Detecting Apparatus). The equipment is photoelectric-based and uses a powerful UV or laser source for illumination of the analysis chamber. The combination of controlled spectral band width and intensity of the light pulse results in a reliable increase in sensitivity of about 300 times over a conventional point sensitive detector.

The sample system is operated by a low-pressure fan-driven pump design. Air samples are drawn into small holes in a conduit system and the design objective is a one minute response for up to a 100 metre installation. Reliable detection is achieved at an obscuration level of about 0.01% per metre.

Light beam (obscuration) detectors

Light beam detectors have been improved with modern technology. The main area of use is to monitor large and high areas where point detection has a poor response due to dilution of the fire plume at greater heights, or service access for point detectors is difficult.

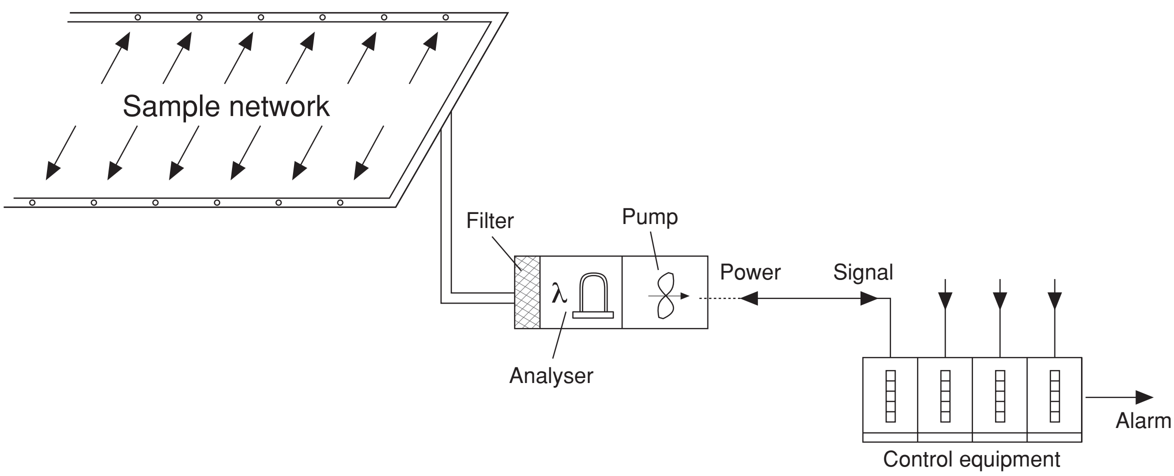


Figure 9.6: Aspirating smoke detector

Obscuration of a few percent per metre accumulates to a large factor over distance. The usual limit is about 100 m beam length and 14 m separation. The alarm threshold is typically 40% of set level, and a variety of signal processing procedures are available to improve the integrity of alarms. Lower level beams are sometimes required to overcome stratification in very high areas.

There are some important factors to accommodate in the successful use of these detectors, including the facts that the optical beam is narrow and, therefore, alignment must be maintained to ± 0.5˚ on a long-term basis, and water vapour, dust clouds, refractive index, building deformation, birds and insects may all affect the beam.

Electro-magnetic radiation flame detectors

Flame detectors have a major advantage in that they do not rely on convection to carry the fire signal. The radiation is instantaneously available at the detector and the challenge to designers of equipment is to discriminate radiation from a real fire to that present in the everyday world. For example, the sun is a major source of infra-red (IR) radiation. There are absorption effects in the atmosphere that result in regions of little solar radiation at some wavelengths at the earth's surface. These quiet areas of solar radiation are good places to look for radiation signals from nearby fires.

Radiation sensitive detectors are now very reliable. These detectors are high-technology items generally used for long distance and open area fire detection. Considerable care is needed in their application to minimise background effects. The signal correlation techniques include phase and amplitude comparison for more than one cell. The cells may be responsive in the IR, UV, two colour IR and IR/UV regions. For larger sources of radiation they are responsive at great distances. Sensitivity to liquid fuel test fires are typically 5-10 seconds to respond to a fire at a distance of 40 m. The characteristic flame flicker frequency of a fire can be used as a prime filter. However, care must be taken with non-fire signals, such as IR reflection from a motor vehicle windscreen, which may be modulated by the engine vibration at 10-12 Hz (600/700 rpm), precisely in the region of flame flicker.

Radiation pyrometers measure surface temperature by non-contact means. They have not been noted for reliable results in fire detection, mostly due to inexpert application in the process industries and failure to translate the experience of the successful detector manufacturers to the application. Recent developments have provided specialised versions of pyrometers for detecting moving fires, as on conveyor systems.

Gas Detectors

Gas detection has long been recognised as a potential means for reliable and early detection of fires. Combustion gases are produced in all stages of fire growth. In the case of slow smouldering fires, gases appear long before significant aerosols or vapours. Gases also diffuse rapidly, so do not need the convection of a fire plume to transport them to a detector.

Carbon monoxide (CO) is the most readily and uniquely identifiable signature gas from typical fires involving carbonaceous materials. This toxic, odourless, colourless and tasteless gas is responsible for a very high proportion of fire fatalities. Recent advances in electrochemical cell technology have allowed the commercial release of fire detectors that sense CO gas. These detectors have overcome historical problems with high power consumption, sensor deterioration, slow response and low sensitivity.

CO fire detectors operate on the principle of the oxidisation of CO gas to CO_2. This oxidisation reaction occurs on catalytic surfaces within a sensing cell and requires an exchange of electrons, which generates a detectable electrical current. CO detectors are virtually immune to the common false-alarm phenomena of ion chamber and photoelectric devices — steam, dirt, dust and cooking fumes. This, coupled with their superior response to slow smouldering fires, makes them particularly suitable for life-safety protection in sleeping occupancies.

Equipment Trends and Addressable Analogue Detectors

Addressable Analogue Detectors (sensors)

Detectors are increasingly being manufactured with an additional electronic package that reads analogue levels of smoke and/or heat. These individual sensors are interrogated for identity and sensor value by the control panel. This allows for early intelligent trend measurement and preventative responses in fault circumstances. The effect is that the alarm integrity and identification is much improved. Alarm thresholds may be software defined on an individual detector basis within the control panel. Use of these detectors will increase in future and unwanted alarm responses will diminish. Addressable detection systems also allow distributed control of sounders in zoned evacuation systems.

Multiple-criteria detectors

Ion chamber and photo-electric sensors respond differently to smoke characteristics in small fires. Each type of sensor must respond to a range of test fires, and that results in higher sensitivity settings than would be obtained for just a fast fire, or a slow fire.

Various combinations of ion chamber, photo-electric and heat sensors in a single detector gives even more response to a wider range of fire characteristics and provides double back up. An intelligent internal signal processor is programmed to draw conclusions from each sensor and decide on the environmental conditions. The overall performance improvement is sufficient that the individual sensitivity of each sensor can be reduced by up to 25%, yet the integrity of the alarm decision remains very high. Various forms of multiple sensor detectors are now commercially available. Future developments will see the use of gas sensing in combination with traditional criteria to further improve performance and rejection of deceptive phenomena

Control panels

The control panels are microprocessor based, often with redundant processing paths and data collection from the field devices via loop wired circuits. This method is tolerant of one wiring fault, and has significant value with two faults. The modern fire alarm control panel is able to map input function to output control actions by software assignment. Considerable effort is made to create electrically robust peripheral devices and power supplies, and to maintain isolation from other services.

False Alarms

No one wants false alarms. They are annoying, disruptive and desensitise people to genuine alarms. They also cost money, both for the Fire Service and for businesses that are disrupted.

Genuine fires make up just a small percentage of fire alarm and sprinkler activations. Based on figures received from the New Zealand Fire Service, only 4% of fire alarm activations are due to fires. Table 9.2 summarises the more usual causes of alarm activity.

Cause	%
Component failure	21.9
Environmental effects	19.7
Building work	15.4
Unknown or other reason given	9.8
Malicious	8.5
Operator error	5.5
Incorrect building maintenance	5.5
Good intent	5.0
Genuine fire	3.8
Mechanical damage	3.3
Installation fault	1.5

Table 9.2: Causes of fire alarm activations

It can be seen that there are a variety of reasons for false alarms. However, there are some simple strategies that will greatly diminish these. One is to ensure that the detector specified is appropriate for the environmental conditions.. Table 9.3 summarises common detector types and their characteristics.

Location of detectors can also have a significant impact on false alarm rates. One example is to ensure ionisation detectors are placed away from potential draughts.

Detector Type	Suitable for	Not suitable for	Susceptible to
Heat detector (fixed and rate of rise)	General use Utility areas High humidity environments Dirty or smoke environments	Sleeping areas Egress routes High ceilings Smouldering fires High value risks	Vibration Corrosion/water Physical damage
Ionisation smoke	General use Open flaming fires	Slow smouldering fires Ductwork Vehicle parks	Wind gusts Cooking fumes, dust Vehicle exhaust Insects Dust and dirt Tobacco smoke
Optical smoke	General use Dense visible smoke Electrical cable fires Areas with high air flows	Clean flaming fires	Vibration Building movement Strong light sources Thermal turbulence Dirt and insects Condensation
Linear Beam Optical detectors	High atria Limited access areas Heritage ceilings	Small fires Clean burning fires Slow smouldering fires	Vehicle exhausts Heavy tobacco smoke
Gas detection	Smouldering fires False alarm minimisation	Rapid flaming fires High humidity/temperature	

Table 9.3: Characteristics of common detector types

Changing the response of the system to match changing conditions can help false alarm performance. In its simplest form this may be a time switch to give pre-alert to the occupants during normal business hours. There are also detectors on the market that dynamically adjust to the environmental conditions.

Perhaps the best false alarm performance using current technology can be obtained by the use of analogue addressable systems with multi-sensor detectors. This provides excellent false alarm performance and has advantages in terms of ongoing system maintenance.

9.7 Automatic fire sprinkler systems

General

This section is intended to give an overview of automatic fire sprinkler systems and the New Zealand and Australian Standards for these systems. It should be noted that the New Zealand Standards now contain a significant amount of performance-based requirements rather than prescriptive detail, and this is likely to increase in the future. The Insurance Council of New Zealand is the authority having jurisdiction for the New Zealand Standards 4541 and 4515, and any questions regarding interpretation should be addressed to that organisation. The Australian Standard is AS2118:Parts 1 - 6.

The New Zealand Standards were originally based on British codes such as LPC (Loss Prevention Council), but as most of the latest sprinkler design advances are US-based, more rulings are being incorporated into the New Zealand Standards based on documents from NFPA (National Fire Prevention Association), FM (Factory Mutual) and UL (Underwriters Laboratories). This is similar for AS2118.

Sprinklers have been used in New Zealand for over 100 years, the first system being installed by Wormald Brothers in 1889. Sprinkler systems are the most reliable general protection systems available. They consist of a system of pipes and heat-operated valves (sprinkler heads) which allow a fire to be automatically detected, the alarm given, and water delivered directly to the seat of the fire. By this means, a fire is extinguished or kept under control until the Fire Brigade arrives.

Only the sprinklers in the fire area operate. It is shown from statistics for the years 1886-1986 (Maryatt 1988) that 65% of the fires were controlled by one sprinkler head, 92% were controlled by 1-5 sprinkler heads, 96.3% were controlled by 1-10 heads and only 3.7% required more than 10 heads to operate.

Automatic sprinkler systems in all buildings other than small residential buildings should be designed and installed in accordance with NZS 4541:1996, which specifies the design, performance, installation and maintenance of sprinkler systems in buildings or structures. In Australia, systems should be installed generally to AS2118.1. This standard covers classes of system, water supply requirements, sprinklers, pipework, valves, pumps and other ancillary equipment. Alternative design codes such as NFPA, FM or LPC are used if overseas insurers or unusual risks are involved.

For small residential buildings, automatic sprinkler systems should be designed and installed in accordance with NZS 4515:1990, which specifies design, installation and maintenance requirements for automatic fire sprinkler systems for use in domestic and other residential buildings not exceeding four storeys or 2000 m^2 floor area under certain conditions. Within Australia, the equivalent standard for residential sprinkler systems is AS2118.4.

Water supply requirements for sprinkler systems are discussed in Chapter 14.

Sprinkler heads

The heart of a sprinkler system is the sprinkler head, which has a fusible element to hold a valve shut. When the fusible element reaches a specific temperature, the head operates, opening the valve and producing a spray of water. The water distribution pattern depends on the type of deflector fitted.

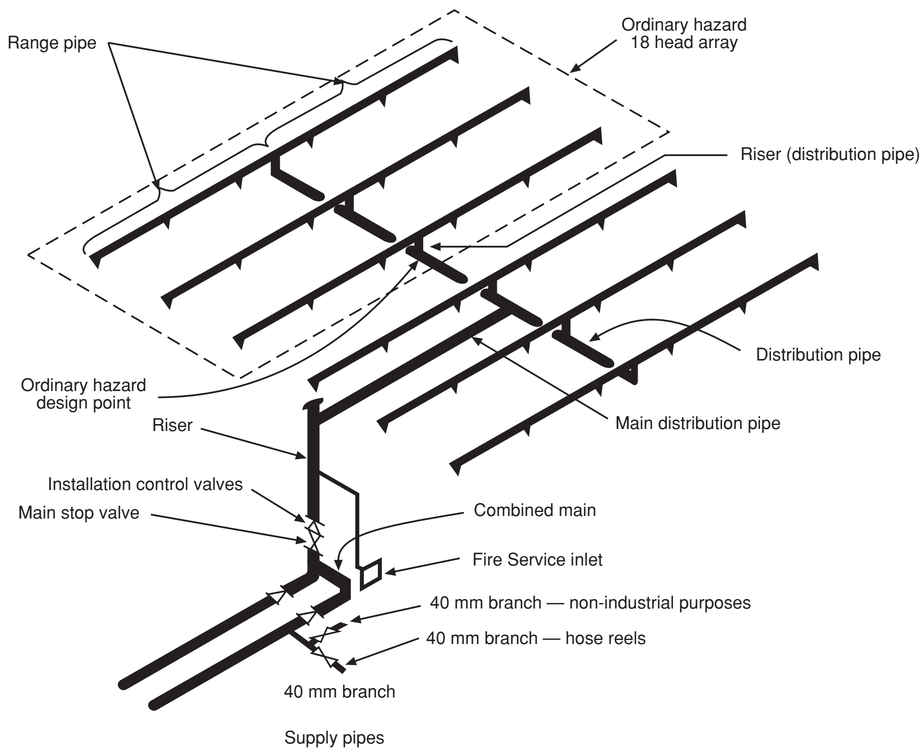
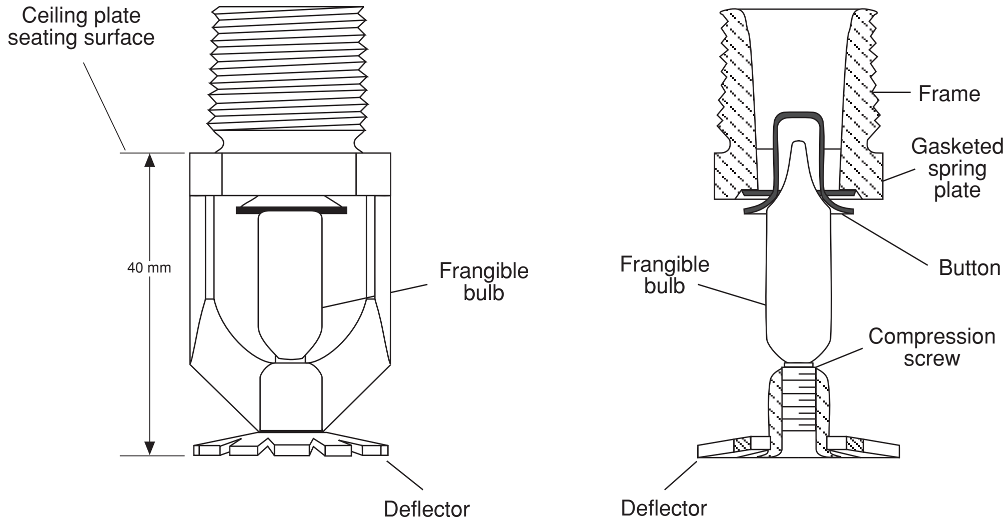
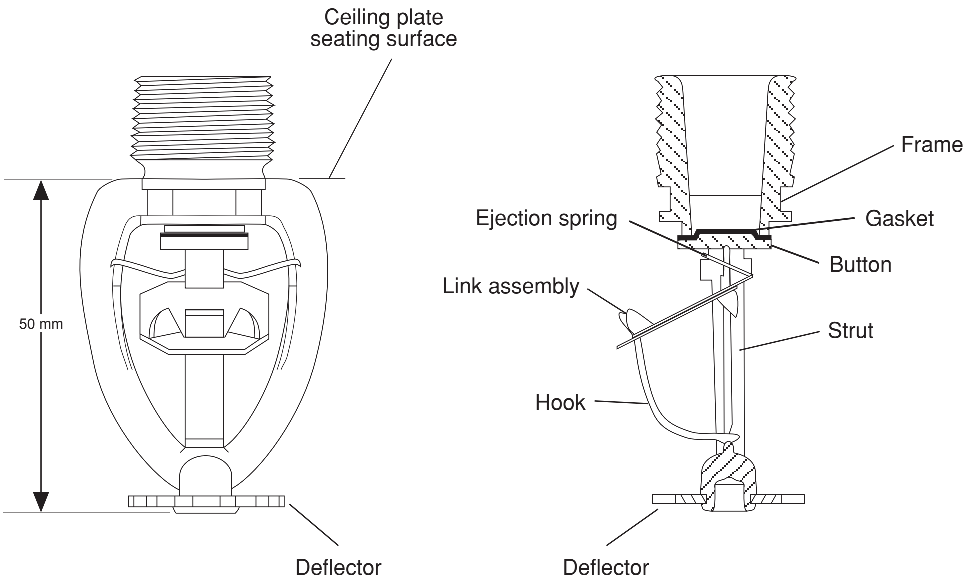


Figure 9.7: Typical fire sprinkler system



(a) Frangible bulb



(b) Fusible link

Figure 9.8: Typical sprinkler heads

Method of operation

There are two basic types of fusible elements for sprinkler heads, these being the frangible bulb and the fusible link. The frangible bulb is a sealed glass bulb that contains a liquid which nearly fills the bulb. As the temperature rises, the liquid expands to fill the volume. When it is heated further, the liquid bursts the glass bulb, allowing the valve to leave the orifice and the water to flow. The fusible link (eutectic metal) element separates at a specific temperature, allowing the valve to leave the orifice and the water to flow.

Temperature ratings

Sprinklers are designed to operate at temperatures ranging from 57˚C to 260˚C. The temperature rating of the head should be about 30˚C above the maximum expected ambient temperature. The temperature rating of a sprinkler is identified by a colour code. In the case of a glass-bulb type sprinkler, the liquid is coloured, while the fusible-link type sprinkler has a colour band on the frame.

Sprinkler response

A major development in sprinkler technology was the quick response sprinkler, which is a sprinkler with a bulb or link that is designed to absorb the heat of the fire plume or ceiling air temperature more quickly. This allows the sprinkler to deliver the water spray on to a fire at an earlier stage in fire development than with a standard response sprinkler.

The response times can be inserted into a computer modelling program and give designers an estimate of time for sprinklers to operate given ceiling height, fire size and response time index (RTI). Response time index is a measure of the sensitivity of the sprinkler bulb or link.

There are three ranges of RTI quoted in the standards:

- fast response — less than 50 $m^{1/2}s^{1/2}$
- intermediate response — more than 44 $m^{1/2}s^{1/2}$ but less than 110 $m^{1/2}s^{1/2}$
- standard response — greater than 110 $m^{1/2}s^{1/2}$

For calculation purposes, it is normal to use the values of:

- fast 50
- intermediate 80
- standard 200

Actual test values for specific sprinklers should not be used for calculation purposes as they are a laboratory test for classification and the RTI of a sprinkler under test can vary significantly depending on orientation, etc.

Distribution patterns

There are three main types of deflectors fitted to sprinklers. These are conventional pattern, spray pattern and sidewall pattern. Each produces a slightly different distribution pattern. Conventional pattern sprinklers are designed to produce a spherical discharge pattern with some water being thrown up to the ceiling. They are usually made with a universal deflector, allowing the head to be fitted in a pendant or upright position.

Spray pattern sprinklers produce a hemispherical discharge below the plane of the deflector, with little or no water being discharged onto the ceiling. They are made in two types, one for upright use and the other for pendant.

Sidewall pattern sprinklers are designed for installation along the walls of a room close to the ceiling. The deflector discharges the water to one side, somewhat resembling a quarter of a sphere, with some water discharging on the wall behind the sprinkler.

Recessed sprinklers

Recessed sprinklers are standard pendant spray sprinklers that have been fitted with an adjustable recessed escutcheon to be positioned just below the ceiling surface with the body above, and thus be less obtrusive. However, this means that baffling from light fittings, etc., is a greater problem.

Concealed sprinklers

Concealed sprinklers are a specially constructed unit that are mounted above the ceiling surface, with a flush cover plate on the ceiling. The cover plate is held with fusible tabs that release at a lower temperature than the sprinkler bulb rating. When the cover plate releases, the sprinkler deflector (which is on sliding pins) drops below the ceiling ready to spray water when the sprinkler bulb fuses.

Residential sprinklers

Residential sprinklers are designed and tested to control fire in a residential room. They have a low response time index (RTI) bulb or fusible element and a discharge trajectory that wets the walls much higher than a standard spray-type sprinkler. They are available in pendant and horizontal sidewall types. Recessed and concealed residential sprinklers are also available. The location and use of these sprinklers is model specific and the manufacturer's data sheet (used for ICNZ listing) must be followed exactly and takes precedence over obstruction rules and location rules

Flexible couplings in a sprinkler main where it crosses a seismic gap between two buildings

in NZS4515 or AS2118.4. Because of the flat trajectory and low water flows, residential heads are particularly sensitive to ceiling obstructions, construction and geometry.

Large drop sprinklers

Large drop sprinklers are designed to discharge larger water droplets than conventional or spray sprinklers. This enables the sprinkler discharge to penetrate the fire plume of high challenge fires, such as those in vertical rolled paper or rack storage without in-rack sprinklers. Specific rules concerning building construction, spacing, location and operating pressures apply to these sprinklers.

ESFR sprinklers

Early Suppression Fast Response sprinklers are special, large orifice sprinklers designed to deliver a water discharge that is intended to suppress fires. The rapid operation ,coupled with the high volume discharge, enable these sprinklers to suppress fires in high-piles storage racks without in-rack sprinklers. Specific rules concerning building construction, spacing, location, category of combustibles and operating pressures apply to these sprinklers.

Extended coverage sprinklers

ECOH sprinklers are a spray pattern sprinkler that is designed to protect areas larger than 12 m^2/sprinkler within ordinary hazard occupancies. The installation of these sprinklers must be in strict accordance with the manufacturer's data sheet and the listing information. While these sprinklers have a bulb or fusible link that is more responsive than a standard sprinkler, they are not necessarily listed as quick response sprinklers.

Dry drop sprinklers

These sprinklers have the water valve separated from the heat sensitive element and the deflector by a drop pipe. This allows the sprinkler head to be in a low temperature area while the water filled pipework is in a space outside the cold area so the water will not freeze.

They are used for the protection of freezers and wet pipe systems, and can also be used for low-level sprinklers on dry pipe systems. Another use is for protection of ovens where it is necessary to keep the water from boiling in the pipework to the sprinkler.

On-off sprinklers

These sprinklers are designed to open at a set temperature and then shut off when the temperature drops once the fire is controlled. They can open again if the fire increases.

On-off sprinklers are used where water sensitive equipment is protected.

Orifice size

Water flow through an orifice Q (litres/min) can be calculated from:

$$Q = k_o \sqrt{p} \quad [9.1]$$

where k_o is the discharge coefficient and p is the pressure (kPa).

Standard sprinklers come in nominal orifice sizes of 10 mm, 15 mm and 20 mm with k_o factors of 5.7, 8.0 and 11.5 respectively. This allows a varying amount of water to be discharged for a given pressure. The 10 mm size is used for extra light hazard systems where a water density of 2.7 mm/min is required. Ordinary hazard systems requiring 5 mm/min use 15 mm heads. Extra high hazard systems requiring densities of 7.5 mm/min to 30 mm/min use 15 mm or 20 mm heads, as required.

Residential sprinklers and other special sprinklers have various orifice sizes, but are normally fitted with a 15 mm thread. External Coverage (EC), large drop, Extra Large Orifice (ELO) and Early Suppression Fast Response (ESFR) sprinklers usually have a 20 mm NPT thread, while low-pressure ESFR have a 25 mm NPT thread.

The larger sprinklers have standard "k_o" factors of 16, 21 and 35. Refer to the manufacturer's data sheet for actual k_o factors but the standard k_o factors are used for calculation.

Installations

Wet pipe

A wet pipe sprinkler installation is one that has all pipes from the water supply through the control valves to sprinkler heads permanently filled with water under pressure.

This is the usual type of sprinkler system and as water is available throughout the system, it can effectively control a fire with the least delay. As long as ambient temperatures do not fall below 4˚C or exceed 70˚C consistently, a wet pipe system should be installed. Antifreeze can be added for cold conditions. See Figure 9.9(a).

Dry pipe

The dry pipe sprinkler installation has the pipes above the control valves charged with air or nitrogen under sufficient pressure to prevent the entry of water, as shown in Figure 9.9(b). On the operation of a sprinkler head, the compressed gas escapes, allowing the control valves to operate and fill the system with water. Dry pipe systems are necessary where there is a danger of water in the pipes freezing or where temperatures above 70˚C are encountered. However, there is a short delay before water reaches the fire.

Pre-action sprinklers

A pre-action sprinkler system is similar to a dry pipe system (with air-filled pipework) except that it has an additional array of pipework fitted with lower temperature sprinklers and pressurised with air or nitrogen. When these detection sprinklers operate, the pre-action control valve opens and water is allowed into the main sprinkler system pipework. The heat of the fire then opens a sprinkler on the main pipework and water is sprayed on the fire. Other specialised detection systems can be used to trip pre-action systems.

Pre-action systems are used to give greater security from accidental release of water through mechanical damage to a sprinkler head. Two detections must take place before water can issue from a sprinkler.

Deluge systems

A deluge system uses open sprinkler heads on dry pipework, which all discharge at the same time in a zoned area. The deluge valves hold back the water until it is released by a detector system. The detector system is often a series of closed sprinkler heads on a separate array of air-filled or water-filled pipes in the same area as the open sprinklers. Deluge systems are used where very rapid fires can occur, such as aircraft hangars, fireworks factories, etc. Aircraft hangers are usually designed to NFPA409 while other systems comply with other NFPA standards.

Drencher systems

Drencher systems are designed to project a spray of water on to a wall to completely wet the area exposed to fire, thereby reducing the likelihood of ignition from exposure to a fire in an adjacent building. Drencher systems may

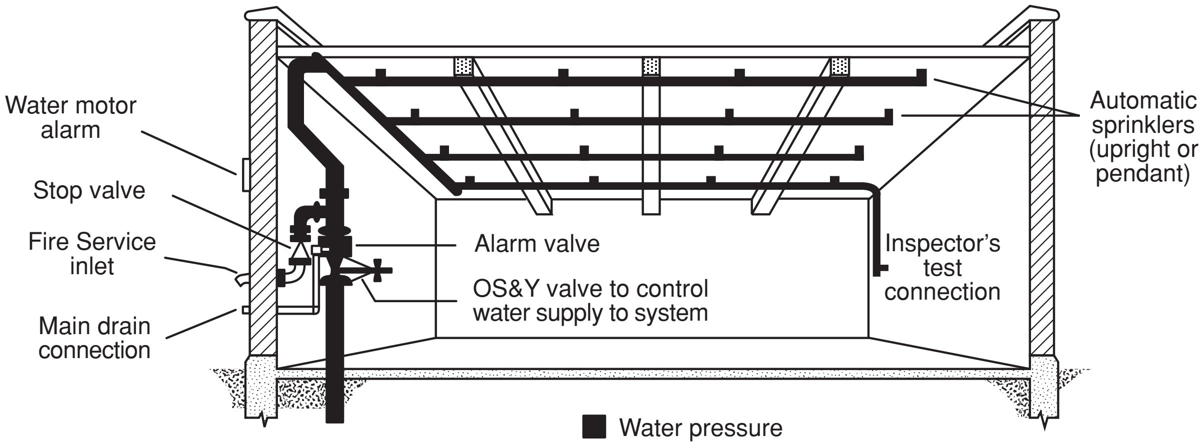


Figure 9.9(a): Typical wet pipe sprinkler installation

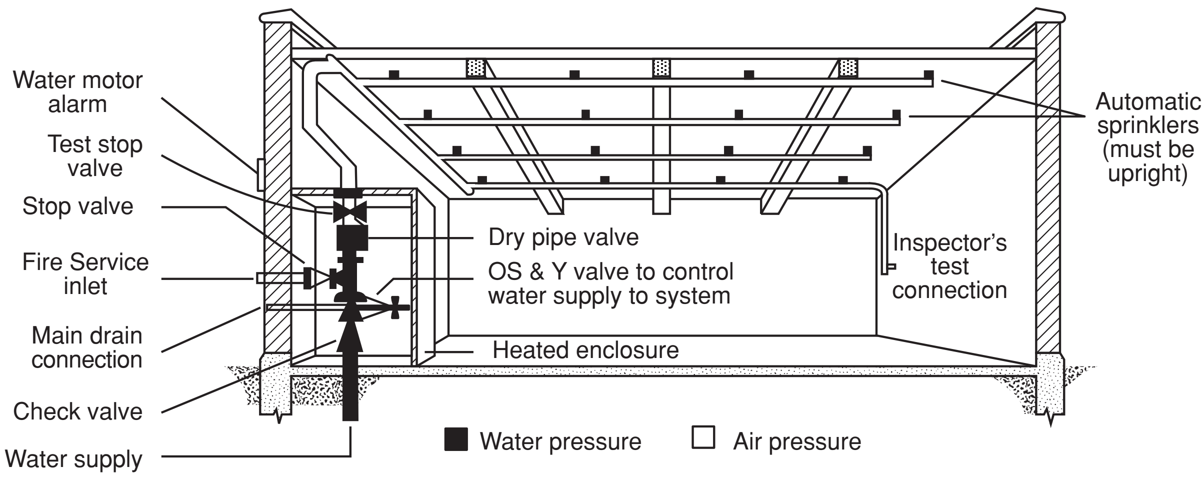


Figure 9.9(b): Typical dry pipe sprinkler installation

simply be external sprinklers if a fire sprinkler system is installed in the building. They are similar to sprinkler systems but may be equipped with either open or fusible-type drencher heads. The use of open drenchers is an inefficient use of fire fighting water supplies because areas not exposed to fire will be sprayed with water. NZS 4541:1996 specifies required pressures and flow rates for external sprinklers, and full hydraulic calculation is used to calculate the pipe sizes and the required capacity of the water supply.

Water spray systems

Water spray systems are used to protect and cool some high fire risk systems, such as large LPG tanks and high voltage oil-filled electrical equipment. The system design parameters and various types of open spray nozzles used to produce the required droplet sizes and velocities are specified in the applicable standard, which is normally NFPA 15 "Water Spray Fixed Systems for Fire Protection". Major manufacturers provide their own design guides for water spray systems. Full hydraulic calculation is used to calculate the required capacity of the water supply.

Foam water systems

Where large quantities of flammable liquids are stored or handled, the performance of sprinkler, deluge or water spray systems can be enhanced by the addition of Aqueous Film Forming Foam (AFFF). This allows a lower discharge density; hence, less water is required. The foam is stored in specialised containers and is inducted at the control valves. Design parameters are specified in the applicable standard, which is usually NFPA 16.

Water mist systems

These systems apply very fine droplets to areas of combustion and the surrounding atmosphere to achieve rapid cooling with minimal water. Mist systems require very specific design backed by extensive testing data. Some equivalency with automatic sprinkler systems to cater with risks of up to Ordinary Hazard Group 3 occupancies has been demonstrated.

Hazard classification

It is necessary to classify the fire hazard of an occupancy to establish the design parameters for a satisfactory sprinkler system. The density of water discharge and expected maximum area of operation are the main criteria for a sprinkler system that will control and/or extinguish a fire. In NZS4541, occupancies have been divided into three main hazard classes based on past sprinkler experience, fire tests and statistics. The following hazard classifications are those of NZS4541. AS2118 classifications are similar.

Extra Light Hazard (ELH)

Extra light hazard occupancies are non-industrial premises where the amount and combustibility of the contents is low.

Ordinary Hazard (OH)

Ordinary hazard occupancies are commercial and industrial premises involved in the handling, processing and storage of mainly ordinary combustible materials unlikely to develop intensely burning fires in the initial stages. The range of occupancies in this class has been subdivided into four groups, based on the expected maximum number of heads required to operate:

- Group One (OH 1) 6-12 sprinklers
- Group Two (OH 2) 12-18 sprinklers
- Group Three (OH 3) 18-30 sprinklers
- Group Three Special (OH 3 sp) 30-38 sprinklers

If goods are stored above certain heights listed in the sprinkler code, then the occupancy should shift into the extra high hazard group.

Extra High Hazard (EHH)

Extra high hazard risks are those commercial and industrial occupancies having high fire loads. These are divided into two groups:

- Process risks — where materials handled or processed are likely to develop rapid and intensely burning fires; and
- High piled storage risks — where goods are stacked above acceptable limits for fire protection by ordinary hazard sprinkler systems.

As the height of goods is increased, the density of water application has to be increased to cope with the expected fire. NZS 4541 contains lists of typical occupancies in each class or group; however, the classification of occupancies are subject to interpretation and need to be confirmed with the “Authority Having Jurisdiction”, which is the Insurance Council of New Zealand. The occupancy classification is the most important item, as it determines the basis of design for any fire sprinkler system. One property could have a large number of occupancies. For example, a hotel is ELH but can include a bottle store that is OH3 or EHH, depending on storage heights, and a restaurant that is OH2. A university is ELH, but can include a bulk store (OH3 or EHH), workshops (OH2) and sports hall (OH1).

Residential

A residential building is one used solely as a residence. For the purposes of NZS 4515:1995, it is to be less than 500 m^2 and no more than two storeys. The water supply must be able to produce the design flow for 20 minutes. However, if the water supply is able to sustain 60 minutes of flow, and the system is connected to the Fire Service and fitted with a Fire Service inlet, then the size of the building may increase to a maximum of 2000 m^2 and four storeys.

Design parameters

Table 9.4 gives the basic design parameters for fire sprinkler systems, which were designed to pre-calculated tables. The sprinkler standards (including NZS 4541) now require full hydraulic calculation in most cases. More information on water supply requirements is given in Chapter 14.

Sprinkler spacing

The spacing of sprinkler heads is dependent on which class of system is to be installed, and the type of sprinkler heads to be used.

Extra Light Hazard

The sprinkler head used for ELH systems is of 10 mm orifice (k_0 = 5.7) and fitted with a spray-type deflector. Between sprinklers, the maximum spacing is 4.6 m by 4.6 m, giving a maximum coverage of 21 m^2. However, if sidewall pattern sprinklers are used, the area of coverage is reduced to 17 m^2 and throw from the wall is 3.7 m.

Ordinary Hazard

The sprinkler head used for OH systems has a 15 mm orifice (k_0 = 8.0) and can have a conventional or spray deflector. Maximum spacing of sprinklers is 4.0 m with maximum area per sprinkler of 12 m^2. Sidewall sprinklers are reduced to an area of 9 m^2 and 3.7m between heads.

Extra High Hazard

A choice of 15 mm (k_0 = 8.0) or 20 mm (k_0 = 11.5) orifice is possible with either conventional or spray deflectors. The maximum area is generally 9 m^2, although within storage racks this is reduced to 7.5 m^2. Spacing between heads is generally a maximum of 3.7 m, or 2.5 m within storage racks.

Sprinkler location

Sprinkler heads perform two functions. They both detect the fire and spray water. To gain best detection the sprinklers should be within 50 to 150 mm of the ceiling. However, to be able to spray past ceiling beams, joists etc. it is often necessary to position heads at a greater distance, depending on ceiling or roof construction. The spacing of sprinkler heads to beams is governed by the depth of the beam and the allowable distances are given in tabular form in the Standard. The maximum distance of sprinklers from walls is normally half the design spacing. The requirements of the listing data (for special sprinklers) must be followed and not varied.

Hazard	Water Density mm/min	Area of Operation m^2	Water Flow litres/min	Primary Water Storage m^3		Secondary Water Storage m^3	
E.L.H	2.7	84	270	16.2		10.8	
O.H.1	5.0	72	375-540	32.4		21.6	
O.H.2	5.0	144	725-1000	60.0	60	40	40
O.H.3	5.0	216	1100-1350	81.0	min	54	min
O.H.3sp	5.0	360	1800-2100	126		84	
E.H.H.	7.5 to 17.5	260 "	2300 to 4850	207 to 436	90 min	138 to 391	60 min
	20.0 to 30.0	300 "	6400 to 9650	576 to 868		384 to 579	

Table 9.4: Basic design parameters for fire sprinkler systems with precalculated pipe sizes

9.8 Other systems

Hydrant mains systems

Hydrant mains systems consist of permanently installed pipework to allow the Fire Service to get water on to a fire much more quickly than would be possible by laying hose, especially in multi-storey buildings. Design and installation of hydrant mains systems should be in accordance with NZS 4510:1998, which specifies the design, construction, performance testing and water supply requirements for wet and dry riser mains systems. AS2419.1 should be used within Australia. More information on hydrant main systems is given in Chapter 14.

Fixed non-water fire extinguishing systems

Fixed non-water fire extinguishing systems are used for special applications where water would cause problems. Such systems include carbon dioxide, halon gases, dry powder and halon substitutes such as INERGEN.

Halon systems were considered very effective and safe fire extinguishing systems because the concentration of halon (5%) required to put out a fire is not a serious health hazard for short duration exposure. However, halon systems are now being phased out because the gases contribute to the destruction of the atmospheric ozone layer. Extensive research is being carried out into environmentally friendly halon replacement chemicals.

Carbon dioxide is hazardous because the concentrations needed (34% to 75%) for fire extinguishment are life threatening. Carbon dioxide systems are generally installed in accordance with NFPA 12.

Dry chemical systems usually consist of compressed nitrogen cylinders that pressurise a large powder vessel, allowing dry powder to be discharged through fixed nozzles shortly after the detection system operates. Dry chemical systems are usually designed in accordance with NFPA 17.

INERGEN is a patented mixture of nitrogen, carbon dioxide and argon gases, which is used to reduce the oxygen content of a room to below the limits of combustion but still enables a person to breathe. These systems are designed to the manufacturer's criteria and NFPA 2001.

Hand-held fire extinguishers

Hand-held fire extinguishers fall into several categories, depending on the fire fighting medium. The most common are dry powder, water, carbon dioxide, foam or Halon chemicals. Fire extinguishers are categorised according to the extinguishing agent and the types of fire on which they can safely be used:

- Class A — ordinary combustibles (wood, paper, plastic, textiles etc.)
- Class B — flammable liquids
- Class C — flammable gases
- Class D — flammable metals
- Class E — energised electrical equipment

Extinguishing agents

Fire extinguishers with different fire fighting media can be used on the following types of fires:

- Water — Class A risks (can also be used with specialised fixed systems for some B, C and E risks)
- Dry powder (standard) — Class B, C and E
- Dry powder (multi-purpose) — Class A, B, C and E
- Dry powder (specialised) — Class D
- Carbon dioxide — Class B and E
- Foam (air foam) — Class A and B (except polar solvents)
- Foam (chemical) — Class B (except polar solvents)
- Wet chemical — cooking oils and fats
- Halon 1211 (obsolete) — Class B and E

Installation and maintenance of fire extinguishers should meet the requirements of NZS 4503:1993 or AS2444:1995. Testing and rating of fire extinguishers is specified in AS/NZS 1850. Design, construction and labelling of water, foam and dry powder types is specified in NZS 4506:1978. Construction, testing and labelling of carbon dioxide fire extinguishers is specified in NZS 4508:1979.

Fire hose reels

Fire hose reels consist of a coiled flexible hose permanently fixed on a reel attached to a wall of a building. Fire hose reels are intended to be operated by the occupants of a building in the event of a fire. Fire hose reels should be able to project a jet of water 6 metres when two adjacent reels are operating. They must be installed so that the nozzle end of the hose can reach any part of the building when it is occupied.

Fire hose reels should be manufactured in accordance with NZS 4504:1981 or AS/NZS 1221 and installed in accordance with NZS 4503:1993, or AS2441.1 1988 in Australia.

Currently, the fire sprinkler standard NZS4541 requires first aid equipment to comply with NZS4503 or fire hose reels to comply with the building code. Where there is high-piled storage, then 25 mm hose reels or 40 mm flaked hose is required. It is proposed in the next amendment of NZS4541 that the mandatory requirement for first aid equipment, as part of the sprinkler system, will be removed.

Chapter 10
Mechanical Smoke Movement

10.1 Introduction

Worldwide, codes on fire safety systems in buildings recognise the danger to life from smoke and require that buildings be designed and operated to prevent migration of smoke through the building.

Occupant safety can be greatly improved by providing efficient smoke control and extraction systems. Moreover, such systems can limit property damage by limiting the spread of smoke and by providing better visibility and thus easier access to the seat of the fire for fire fighters.

The purpose of this chapter is to provide basic guidance and information to the designers of active systems for smoke control. It should be noted, however, that as buildings can differ widely, building design for smoke control involves experienced engineering judgement to tailor all the systems involved to the building and specific design objectives. Additional design guidance is given by Butcher and Parnell (1976), Klote and Milke (1992) and Klote (1995).

10.2 Mechanics of smoke production

General description

Smoke is a hot buoyant gas — basically hot air plus contamination. As such, it obeys the fundamental laws of fluid mechanics. Several basic principles should be understood by designers of smoke control and extract systems. A smoke extract system does not “push” or “suck” the smoke from an area being protected. Instead, it merely exhausts smoke which has migrated to the area of the extract opening under the influence of its own buoyancy.

The amount of smoke produced by a fire will vary both from fire to fire and from time to time in the same fire. It is a function of its size (and heat output) and the path through which the smoke flows. In particular, it is related to the size of the rising smoke plume, i.e. its perimeter and height. This is because the turbulence around the perimeter of the rising plume entrains the surrounding air as it rises. This air is then incorporated into the plume, increasing the total volume of smoke but reducing its temperature and concentration. Conversely, a non-turbulent smoke layer, such as may be formed beneath a horizontal ceiling, does not entrain significant quantities of air unless excessive horizontal travel occurs.

Constituents of smoke

The plume of hot gases above a fire will have many constituent parts, which will generally fall into three groups:

(a) hot vapours and gases given off by the burning material;

(b) unburned decomposition and condensation matter (which may vary from light-coloured to black and sooty);

(c) a quantity of air heated by the fire and entrained into the rising plume.

Smoke consists of a well-mixed combination of these three groups and it will contain gases, vapours and dispersed solid particles.

The density and toxicity of the smoke produced will depend on the fuel burning, but the total volume of smoke produced will depend on the size of the fire and the building in which it occurs. The nature of the fuel only affects the quantity of smoke produced in so far as the size of the fire depends on what is burning and the rate at which it is burning. This smoke may, therefore, be very dense or not so dense, but in any case it will be hot and will probably contain enough toxic products to be a danger to life.

The combustion of the solid materials in a fire involves the heating of those materials, usually by the adjacent burning material. Hot volatile combustible vapours are given off, which ignite so that above the fire there rises a column of flames and hot smoky gases, which because of its density is lower than the cold surrounding air and will have a definite upward movement. As a result, the surrounding air is entrained into the rising stream and mixes with it, as shown in Figure 10.1.

Smoke formation

Part of the entrained air will supply the oxygen needed for the combustion of the gases evolved by the decomposing fuel, and flames will be produced. However, because the temperature in the plume is not high enough and the mixing of the oxygen into it is not complete, the combustion of these gases will be incomplete and dispersed solid particles which form the sooty component of the smoke will be produced.

At the height of the tips of the flames, the column of rising hot gases invariably contains much more air than is required or used for the combustion of the fuel gases, but by this time the excess air has been heated and well mixed with the hot smoky products of combustion and so forms a large inseparable component of the smoke.

As smoke production is largely related to fire size, it is obviously not directly related to floor area nor compartment volume except as far as this affects fire size and height of smoke rise. Simple approaches relating extract requirements to a percentage of floor area or number of air changes per hour cannot, therefore, generally be justified, with the exception of the work done by the National Research Council in Canada into required extract rates from sprinkler protected office floors (as described later).

Smoke extraction

Smoke removed by a smoke extraction system must be replaced by an equivalent volume of inlet or make-up air. This air must enter at a sufficiently low velocity where it encounters a smoke layer. If it enters at high velocity, it can induce turbulence and mix air into an otherwise stable smoke layer and cause downward mixing of the layer.

To maintain a smoke layer at a given height, the mass flow rate of smoke entering the layer must equal the mass flow rate of smoke being extracted from that layer.

As certain types of extraction systems rely on the buoyancy of the smoke, there is a limit to the size of a "reservoir" from which smoke can be extracted as smoke in a very large reservoir may cool and lose its buoyancy. Large areas may, therefore, require division into separate smoke extraction zones of limited area.

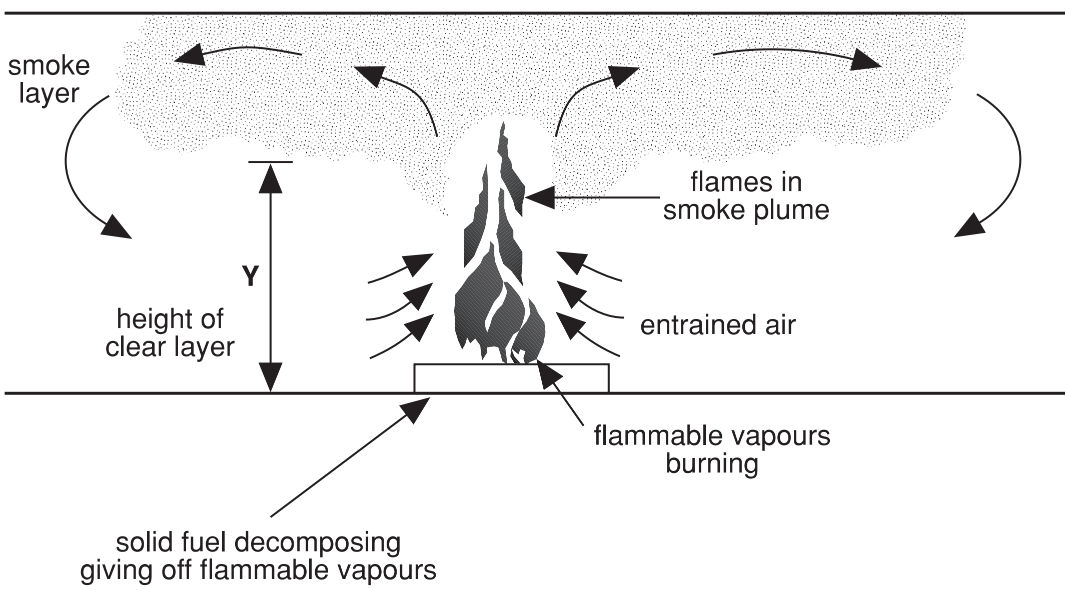


Figure 10.1: Smoke production
(Butcher and Parnell, 1979)

Smoke billowing from the MGM Grand Hotel, Las Vegas. Most of the 84 people who died were overcome by smoke remote from the fire.

Fundamentals of design

The first question to be answered before attempting any smoke control and extraction design is "What is the purpose of this system?". There are three basic possibilities:

(a) Life safety — The system is to be designed to maintain tenable conditions on escape routes and in other areas throughout the period they are likely to be in use by occupants of the building.

(b) Fire fighting access/property protection — The system is to be designed to increase visibility for, and reduce heat exposure to, trained fire fighters, thus allowing earlier and less hazardous attack on the fire. Such systems will help to reduce property damage by increasing fire brigade effectiveness.

(c) Smoke purging —The system is to be designed to enable smoke to be cleared from a building after the fire has been brought under control.

It is necessary to decide which of these, or combination of the three objectives (if any), is to be achieved before commencing a design. However, a system designed for life safety will usually provide a secondary benefit in terms of fire-fighting and property protection functions.

Estimating the volume of smoke produced by a fire

Compared with the total volume of air entrained by the fire, the volume of the fuel gases is relatively small and it is, therefore, possible to say that the rate of production of smoke by a fire is approximately the rate at which air is entrained (and contaminated) by the rising column of hot gases and flames. This rate of air entrainment will depend on:

- the perimeter of the fire;
- the heat output of the fire; and
- the distance between the floor and the bottom of the hot layer of smoke and hot gases that forms under the ceiling.

Hinkley (1971) showed that the mass of gas M_s (kg/s) entrained in a fire (and, therefore, the quantity of smoke produced) can be estimated using the following relation:

$$M_s = 0.096 p \rho_o Y^{3/2} \left(g \frac{T_o'}{T_f'} \right)^{1/2} \qquad [10.1]$$

where: p is the perimeter of fire (m)

Y is the distance between floor and bottom smoke layer under ceiling (m)

ρ_o is the density of the ambient air (1.22 kg/m^3 at 17˚C)

T_o' is the absolute temperature of ambient air (290 K)

T_f' is the absolute temperature of flames in smoke plume (1100 K) g is the acceleration due to gravity (9.81 m/s^2)

Using the numerical values listed, the expression for estimating the rate of smoke production reduces to:

$$M_s = 0.188\,p\,Y^{3/2} \qquad [10.2]$$

This expression shows clearly that the rate of smoke production is directly proportional to the size of the fire (p) and dependent upon the height of clear space (Y) above it.

Butcher and Parnell (1979) outlined that the conversion of the mass rate of production of smoke to a volume rate can be made by calculation using the following information:

- the density of air at 17˚C is 1.22 kg/m^3
- the density of air (as smoke) at T˚C is ρ_s (kg/m^3) given by:

$$\rho_s = 1.22 \text{ x} \left(\frac{290}{T + 273}\right) \qquad [10.3]$$

- the rate of smoke production in kg/s can be changed into m^3/s by dividing by the density appropriate to the smoke temperature.

Determining the size of the fire

While the amount of smoke produced depends to a large extent on the size of the fire, it is simply not practical to design a smoke extract system to cope with any size of fire. Careful consideration should be given to determining a fire size for design purposes. Smoke control and extraction systems cannot be designed to cope with a post-flashover, fully-developed fire involving the whole fire compartment because the rate of smoke production is exceedingly large. One case where fire size is not relevant is a smoke purging system where the rate of smoke extraction is not critical and a “rule-of-thumb” approach can be adopted. A design based on six air changes per hour is often used.

With systems for life and property safety, the choice of an appropriate design fire is essential. The most satisfactory way of arriving at this size is by direct consideration of the building contents. For example, in a car parking building, tests have shown that any fire is likely to be confined to a single car.

The strategy in sprinklered buildings is to relate design fire size to sprinkler operation. Experience has shown that fires in “normal” combustibles rarely exceed a heat output of 0.5 MW/m^2. In sprinklered premises, it is a reasonable design assumption that the maximum fire area will be the area defined by the spacing of sprinkler heads, i.e. 4.6 m x 4.6 m or 4 m x 3 m etc., depending on the hazard category. If there are no sprinklers and no obvious fire centres, choosing a fixed design fire size becomes unrealistic. It must be expected that, barring fire brigade intervention, the fire will continue to grow until flashover occurs, in which case a smoke extract system cannot generally be expected to cope.

A common approach is to assume a growing fire. Using a fire growth computer programme, the designer can select the size of fire expected after a set time interval related to sprinkler or automatic fire alarm activation, escape time, smoke layer level or other tenability limits.

Automatic fire control based on the operation of sprinkler systems relates directly to three distinct delay periods between fire initiation and sprinkler discharge.

Mowrer (1990) defines these three periods as:

(i) *Transport time* — the time between the actual generation of heat or other fire signature and the transport of that signature to the fire detection device.

(ii) *Detection time lag* — the time period from the first transport of a fire signature to the sprinkler or fire detector until the device activates.

(iii) *Suppression time lag* — the time from fire detection until water discharges from the sprinkler head.

Mowrer illustrates these three lag periods schematically on the representative heat release curve, shown in Figure 10.2.

The suppression curve in Figure 10.2 illustrates an example of satisfactory performance because the total lag period is less than the time to critical condition. Critical condition could be structural damage, no tenable space conditions or total egress times, depending upon the specific requirements of the design.

Computer programs for fire modelling make use of the sprinkler response time (or response time index, RTI) of sprinkler heads in determining the activation time of the sprinkler. The sprinkler response time depends largely on the heat release rate of the fire, the temperature rating of the sprinkler (glass bulb or fusible link) and the sensitivity of the head, which essentially relates to the thermal inertia of the glass bulb or fusible link. RTI has units of $m^{1/2}\ s^{1/2}$, and the lower the RTI the more sensitive the head.

10.3 Smoke migration

In its simple form, the prevention of smoke migration between firecells is called smoke control. The principal expectation from all smoke control systems is that smoke is kept on one side of a well-defined plane within a building. The plane may be horizontal or vertical and is usually simply defined by the construction features of the building, e.g. the plane of an opening in a wall or a floor. If smoke migrates across the boundary represented by the plane, a degree of failure of the smoke control provisions has occurred.

In multi-storey buildings, smoke can and does cross the boundary represented by the plane and can rise through the building's many leakage paths to floors which may be well above the actual fire.

Figure 10.3 shows the variety of paths along which smoke may migrate in a simple multi-storey building. Smoke's natural buoyancy enables it to rise quickly through the building, blocking stairwells, lift shafts, reducing visibility, creating panic and making fire fighting more hazardous. Typically such paths include:

- Air ducts connecting floors
- Extract duct systems serving toilets, tearooms, etc.
- Lift shafts

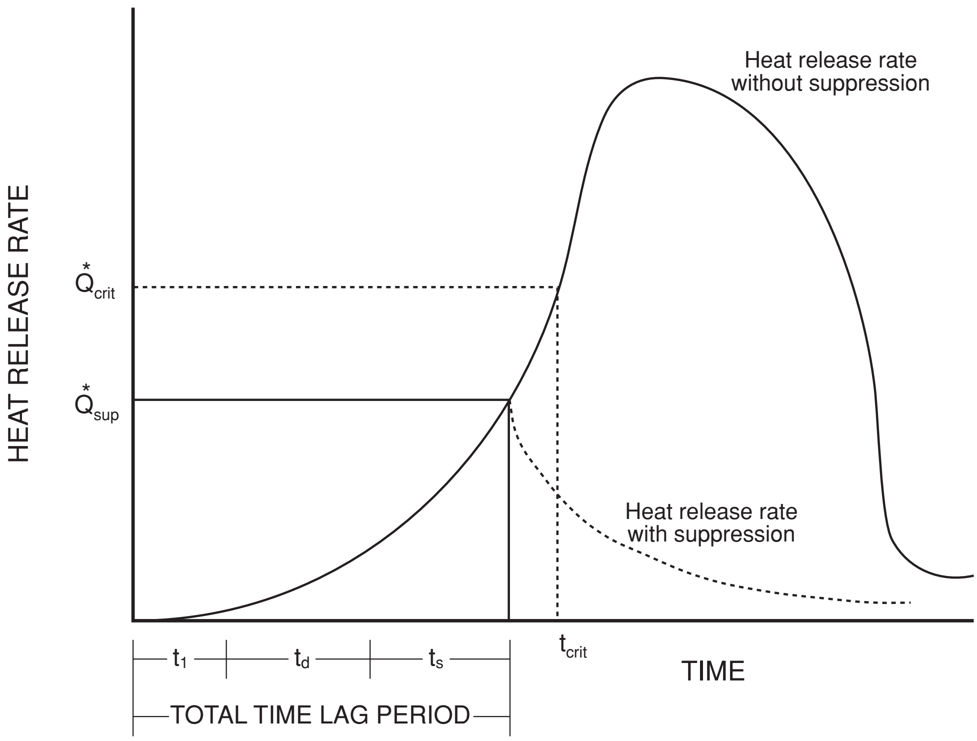


Figure 10.2: Schematic illustration of the influence of transport, detection and suppression lag periods in terms of a representative heat release rate curve

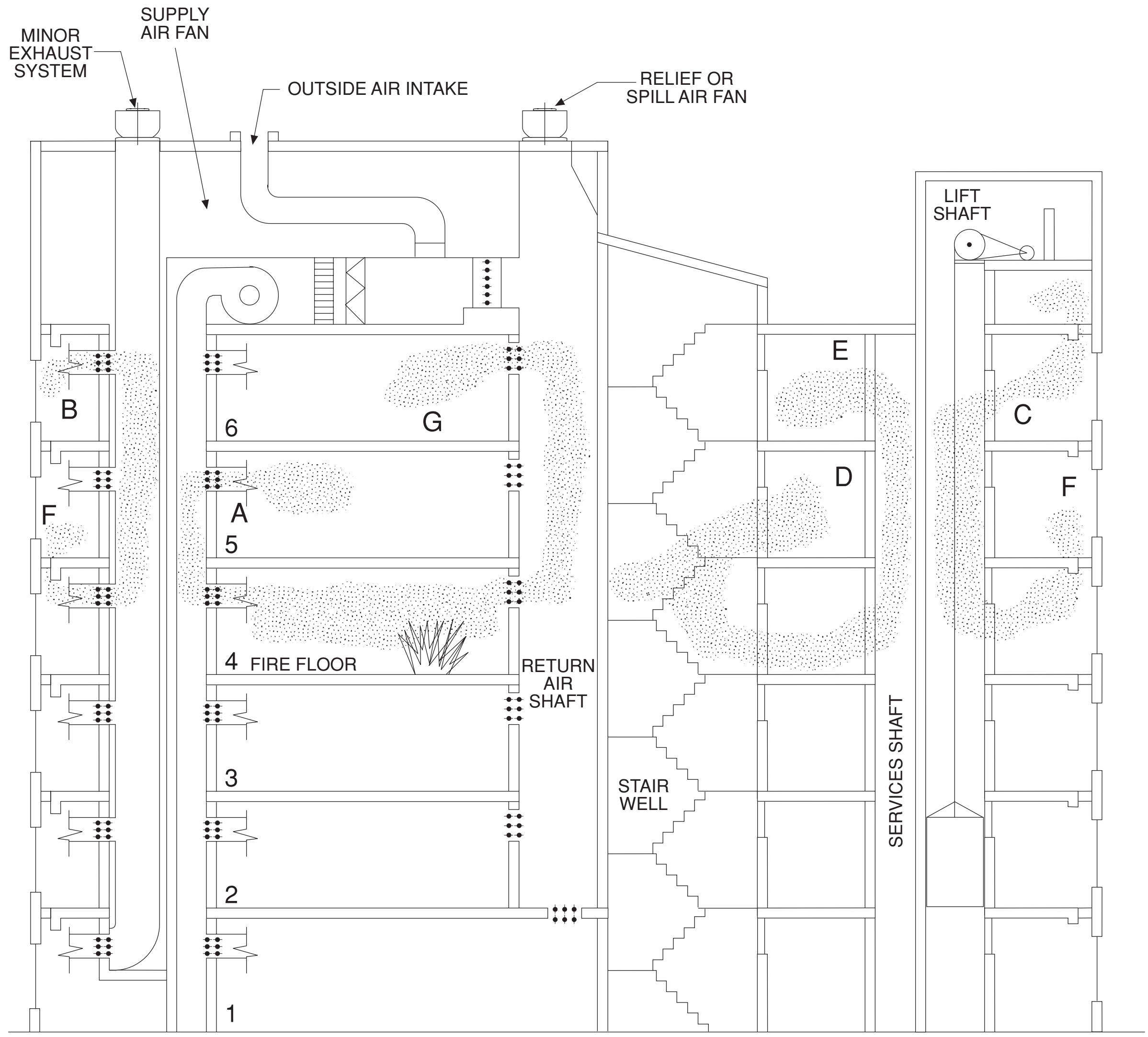
(Mowrer, 1990)

- Stairwells
- Service ducts
- Gaps between curtain wall glazing and floor.

10.4 Typical HVAC systems

Heating, ventilation and air conditioning (HVAC) systems can create significant smoke migration paths between floors. It is essential in buildings with HVAC systems that these systems be designed to control smoke and prevent the spread of fire.

HVAC systems can be broadly described as follows.



Leakage paths:

A Leakage between floors via air ductwork
B Leakage between floors via ductwork of minor exhaust, e.g. toilet exhaust
C Leakage between floors via lift shaft
D Leakage into fire stairs and then onto typical floors from fire stairs
E Leakage between floors via service duct or riser shaft
F Leakage between floors via poorly sealed spandrel
G Leakage between floors via relief or return air path

Figure 10.3: Typical smoke migration routes

- **Central plant HVAC**

  In a central plant HVAC system, air handling and conditioning equipment is housed in central plant room with air ducted to floors by vertical supply and return air duct risers, as shown in Figure 10.4. Plant rooms can be located at the top, bottom and at intervals throughout the building height, depending upon building size and floor area to be served by each plant. Because central plant HVAC systems link a number of floors, they present an ideal path for smoke to be circulated from the affected area to unaffected areas of the building, as shown in Figure 10.7.

- **Floor-by-floor**

  In a floor-by-floor system, the air handling and conditioning equipment is housed on the floor that it serves, as shown in Figure 10.5. Floor-by-floor systems can allow smoke to be circulated from the affected area of the floor to unaffected areas on the same floor, as shown in Figure 10.8.

- **Local air conditioning**

  Local air conditioning systems utilise ceiling or exposed mounted fan coils, or water-cooled heat pump systems to provide air handling and conditioning local to the floor area where the equipment is located (Figure 10.6). Local air conditioning systems typically do not assist in circulating smoke from the affected area on the floor to unaffected areas on the same floor (Figure 10.9).

There are many variations to the three basic systems outlined, each variation allowing smoke migration to a greater or lesser extent, depending upon system configuration. Each HVAC system requires careful analysis to identify and deal with the potential paths for smoke migration.

10.5 Configuring HVAC systems to control smoke migration

Fire spread can be controlled by subdividing a building into fire compartments with fire resistant physical barriers, but effective smoke control is not as simple. Where fans etc., are used to modify smoke movement in buildings, this is generally referred to as a smoke control system. Smoke control systems use the air flow generated by the fans, generally in conjunction with the building's physical barriers, to modify the natural movement of the smoke. HVAC systems used to control smoke movement in buildings would typically be configured as follows:

A Central plant HVAC (Figure 10.10)

- Smoke from the fire floor is diluted with uncontaminated air and the air/smoke mixture is exhausted via the return air shaft and the smoke extract fan.
  - — Return air fan (1) stops, return air damper (2) and spill air damper (3) shut.
  - — Outdoor air (4) is supplied to all floors via the central plant air handling unit (AHU).
  - — Dampers (5) in the return air openings on the non-fire floors close, which causes a rise in pressure on these floors.
  - — Supply air damper (6) to fire floor, closes.
  - — Stairwell pressurisation fans, if installed, (7) start.
  - — Damper (5) on the fire floor remains open, the smoke spill fan (8) operates exhausting the air/smoke mixture from this floor.

B Floor-by-floor AHU (Figure 10.11)

- Smoke is removed from the fire floor via the outdoor air shaft and the smoke extract fan.
  - — Dampers (1) in the outdoor air openings to the AHU rooms on the non-fire floors close. AHUs on the non-fire floors shut down.
  - — Outdoor air plant (2) shuts down and outdoor air damper (3) shuts.
  - — Smoke extract damper (4) opens on the fire floor only.
  - — Stairwell pressurisation fans, if installed, start.
  - — Smoke extract damper (5) opens and smoke extract fan starts.

  Considerable work on this type of system has been carried out by Tamura (1982). Systems have been tested in multi-storey buildings in North America determining that, with the fire being controlled by sprinklers, an extract

continued on page 129

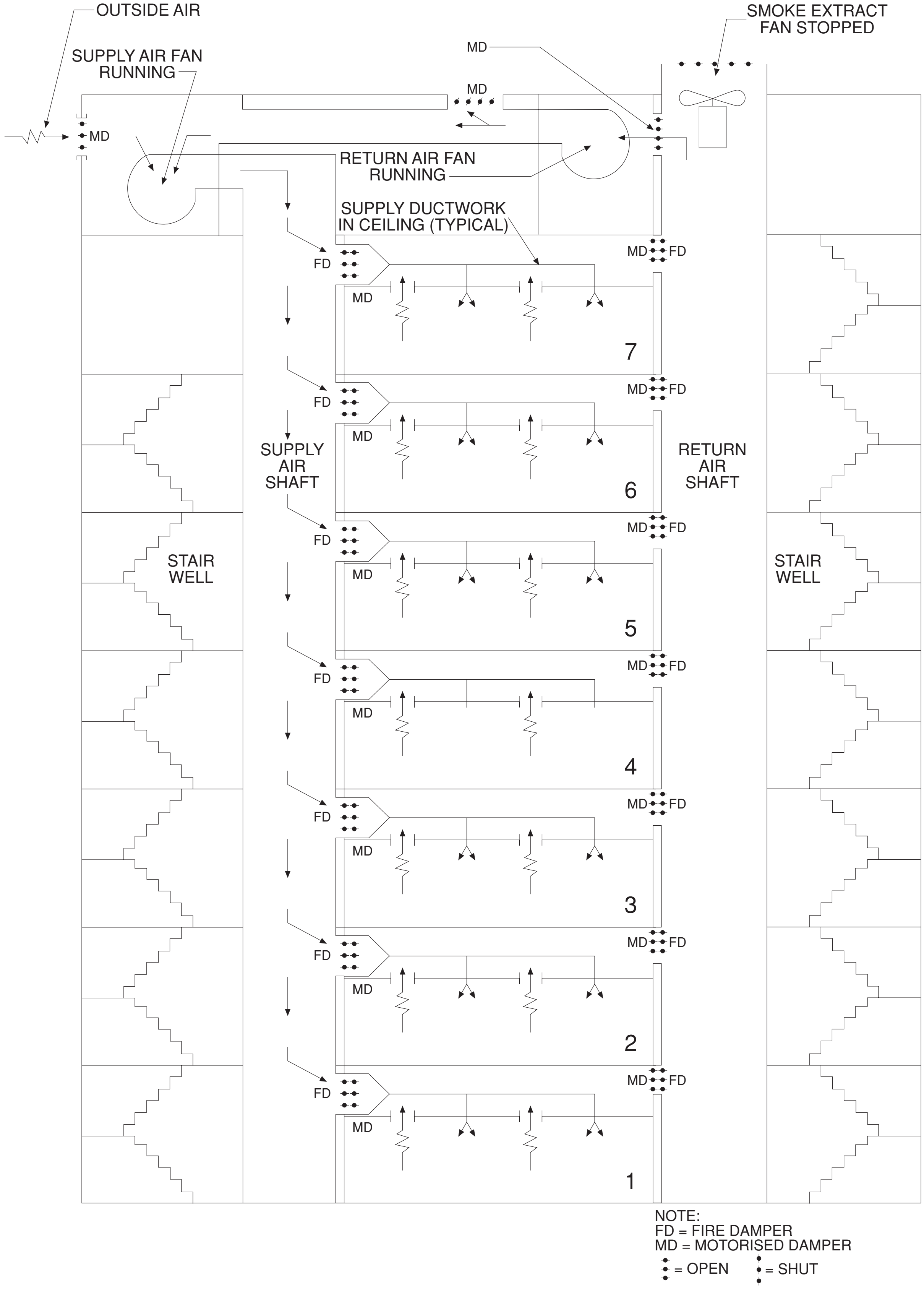


Figure 10.4: Typical central HVAC

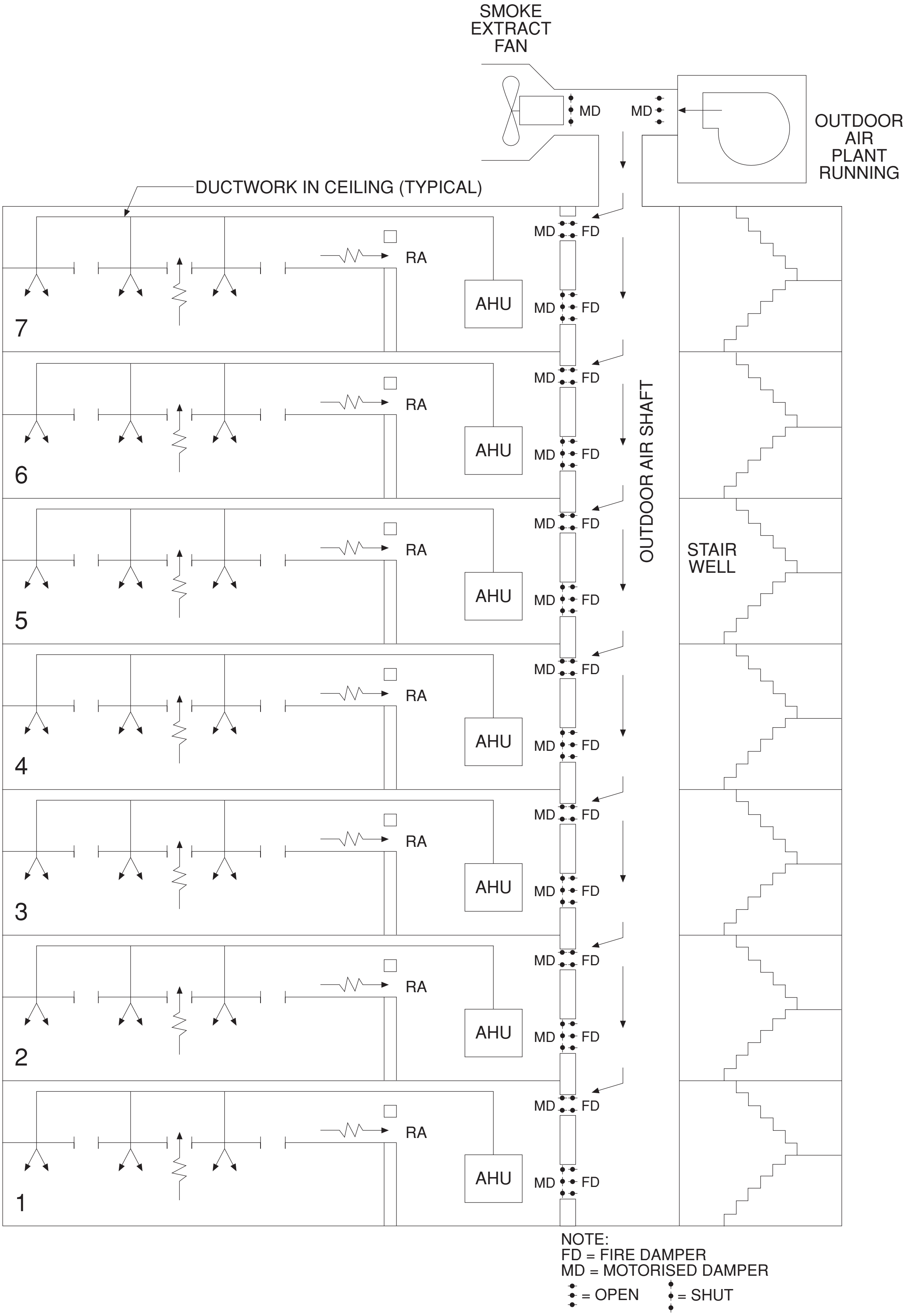


Figure 10.5: Typical floor-by-floor HVAC, on-floor AHU

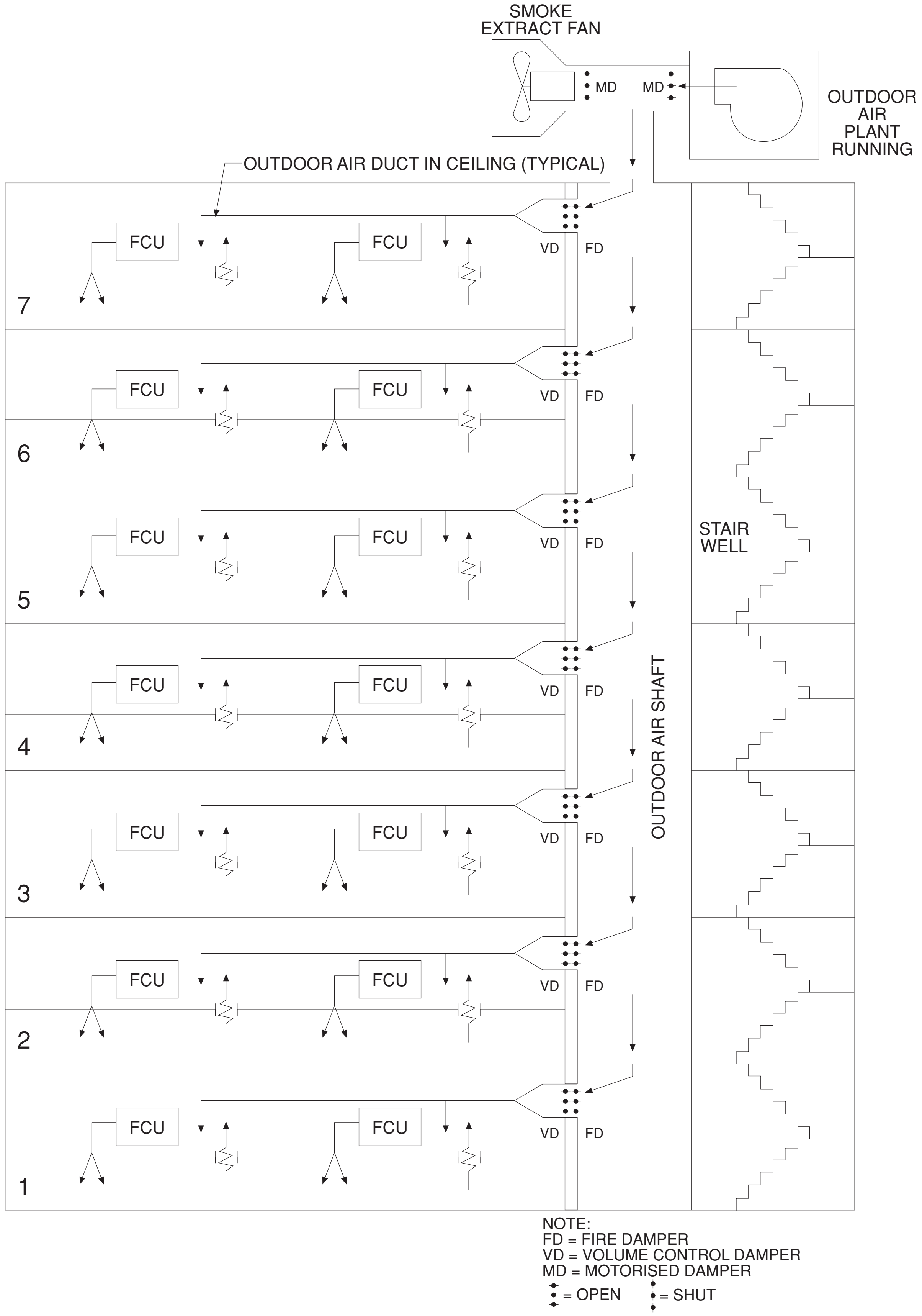


Figure 10.6: Typical floor-by-floor HVAC, fan coils

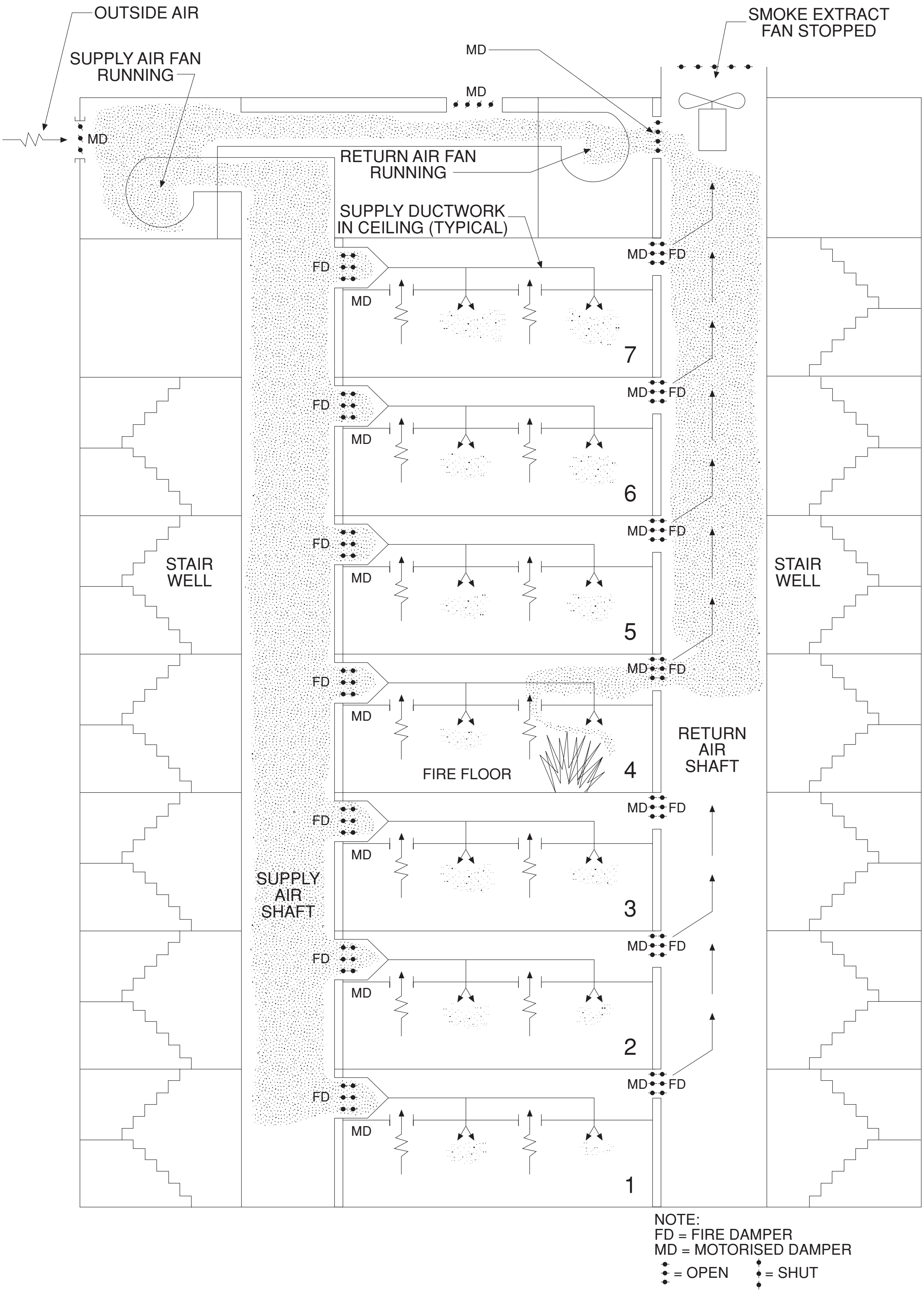


Figure 10.7: Typical central HVAC

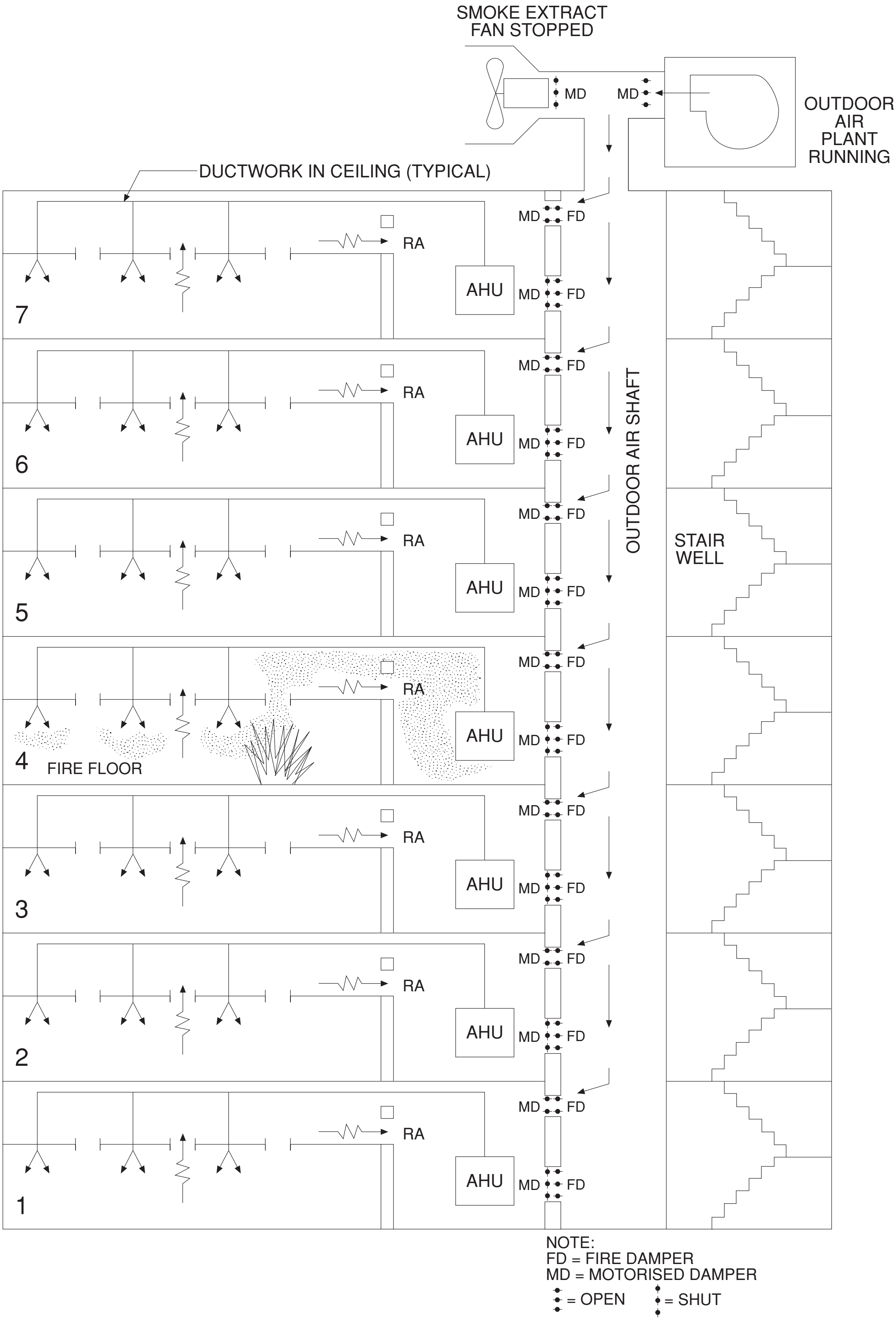


Figure 10.8: Typical floor-by-floor HVAC, on-floor AHU

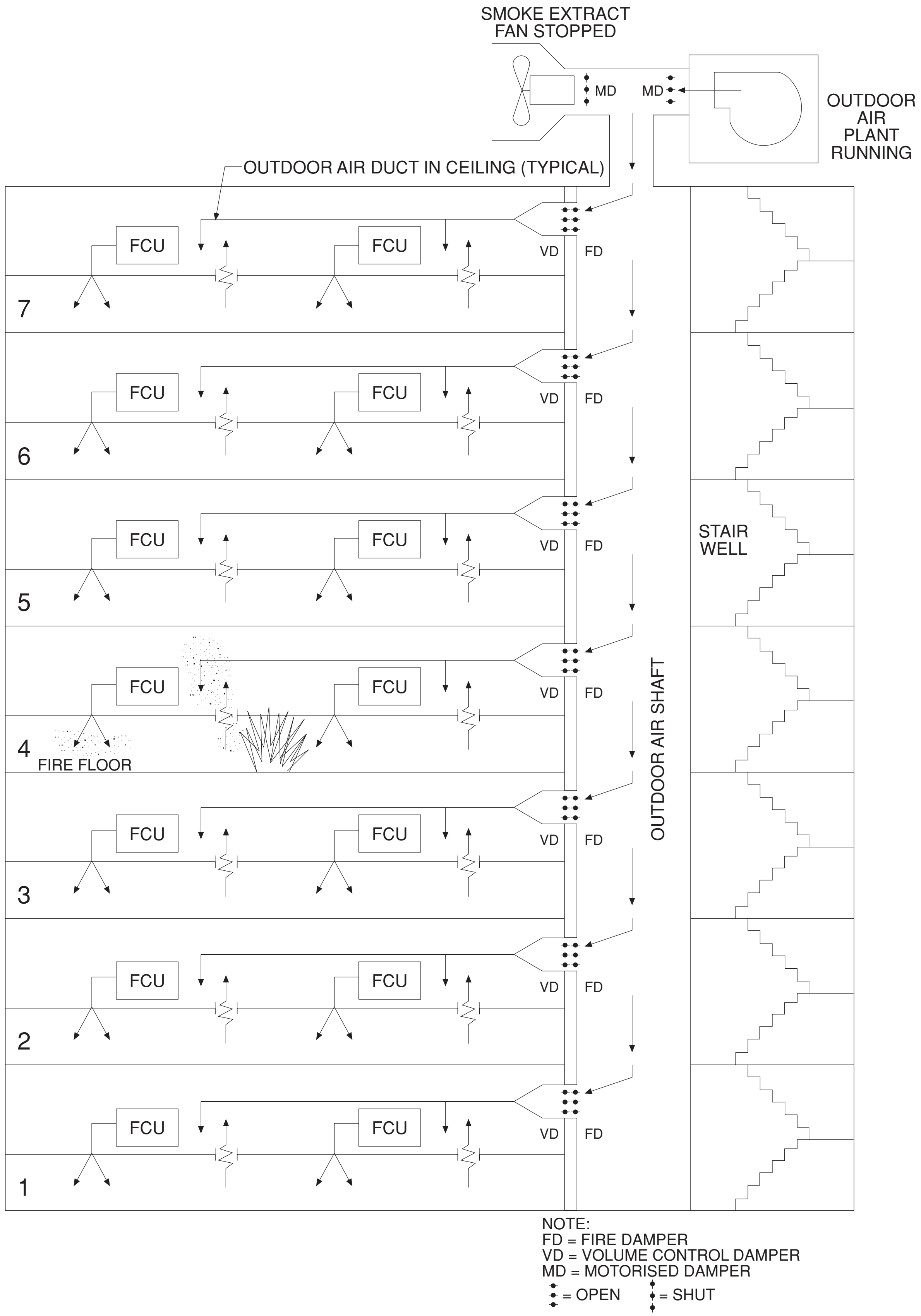


Figure 10.9: Typical floor-by-floor HVAC, fan coils

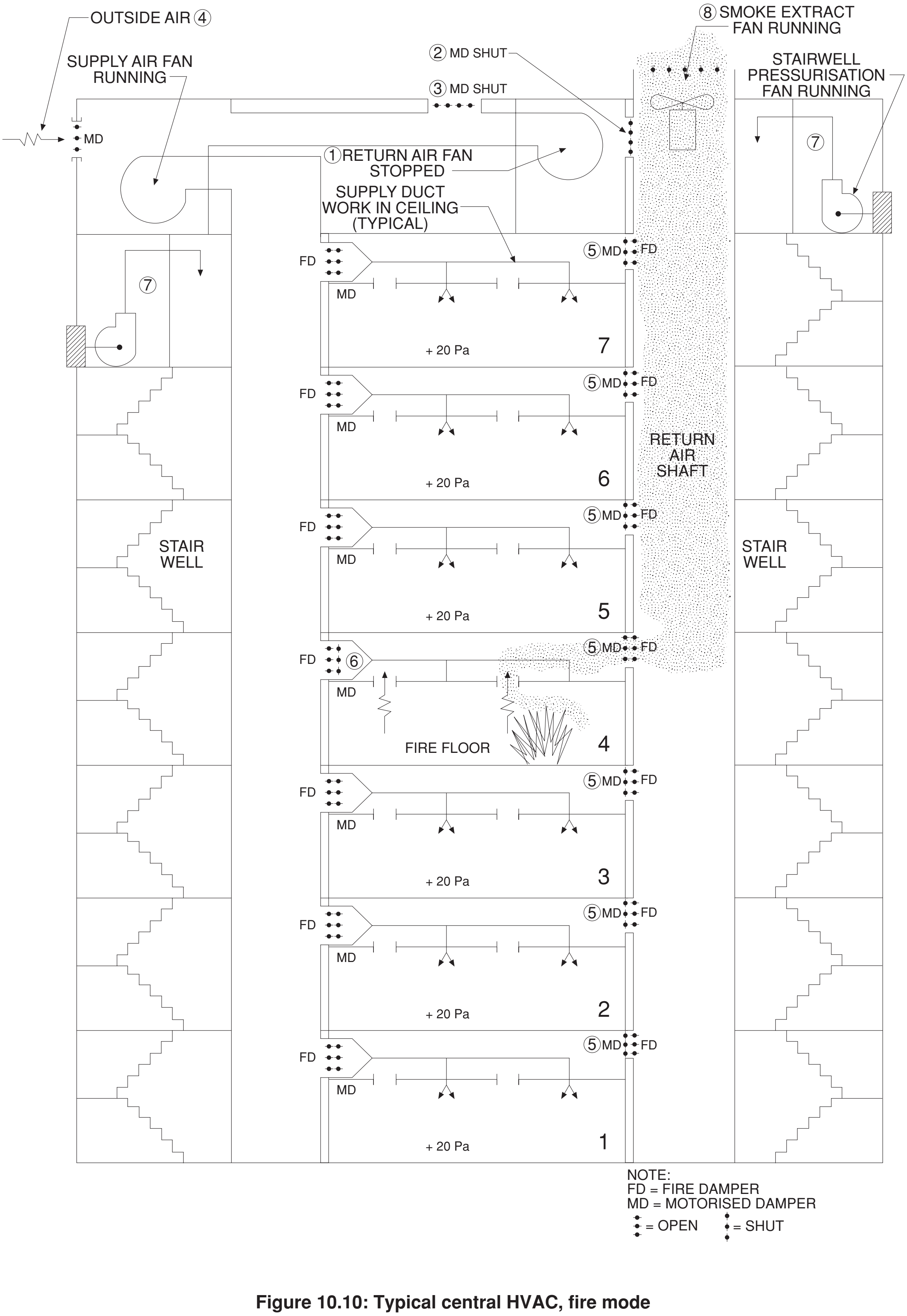


Figure 10.10: Typical central HVAC, fire mode

rate of six air changes per hour is required on the fire floor. For an office with a 2.7 metre ceiling, this equates to an exhaust rate of 4.5 l/sec/m^2.

Make-up air is from stair and lift shafts, providing a forced air flow across stair and lift doorways thus helping to prevent smoke from entering the stairs or lift shafts.

C Local air conditioning systems (Figure 10.12)

Smoke removal can be achieved in a similar way to that described in B above provided additional smoke removal dampers are provided between the floor and the outdoor air shaft.

However, typical systems in New Zealand have not included this feature and in smoke removal mode, they have tended to draw air from the non-fire floors as well as air and smoke from the fire floor, as shown in Figure 10.12. As the ductwork is designed for normal ventilation of around one air change per floor per hour (0.75 to 1.0 l/sec/m^2 floor area), this restricts the smoke extract rate to approximately the same volume.

The smoke production rate of a fire of, say, 1.5 MW with a perimeter of 7 m, as suggested in the Acceptable Solution C3/AS1 for a typical commercial office and, assuming a smoke layer at 2.5 metres, is in the order of 5 m^3/sec. If the fire occurred on an office floor of, say, 1000 m^2, the extract rate would have to be 5.0 l/sec/m^2 to remove the smoke produced, or five times the volume for which the ventilation duct work is designed.

The system design would need reconfiguring to enable the design smoke volumes to be extracted if smoke migration is to be controlled.

The system in Figure 10.12 would typically operate as follows:

— Fan coil units (FCUs) shut down.

— Outdoor air plant (1) stops and outdoor air damper (2) shuts.

— Stairwell pressurisation fans, if installed, start.

— Smoke extract damper (3) opens and smoke extract fan (4) starts.

10.6 Smoke clearance systems

General

Smoke clearance systems are specifically designed only to operate when a fire occurs. Such systems are usually included in buildings that, because of the building configuration and fire load, present particular life safety problems. Buildings in this category would include:

- Large shopping malls
- Buildings containing atria
- Large concert halls and convention centres.

System components

The basic components of a smoke clearance system are:

- Smoke reservoirs — areas within the building designed to allow smoke to accumulate. Extraction occurs from the reservoir.
- Smoke screens
- Smoke extraction fans
- Duct work — required if either the smoke extraction fans or the discharge louvres, or both are located remote from smoke reservoir
- Smoke exhaust discharge louvres
- Outdoor air inlets
- Automatic controls and activation systems.

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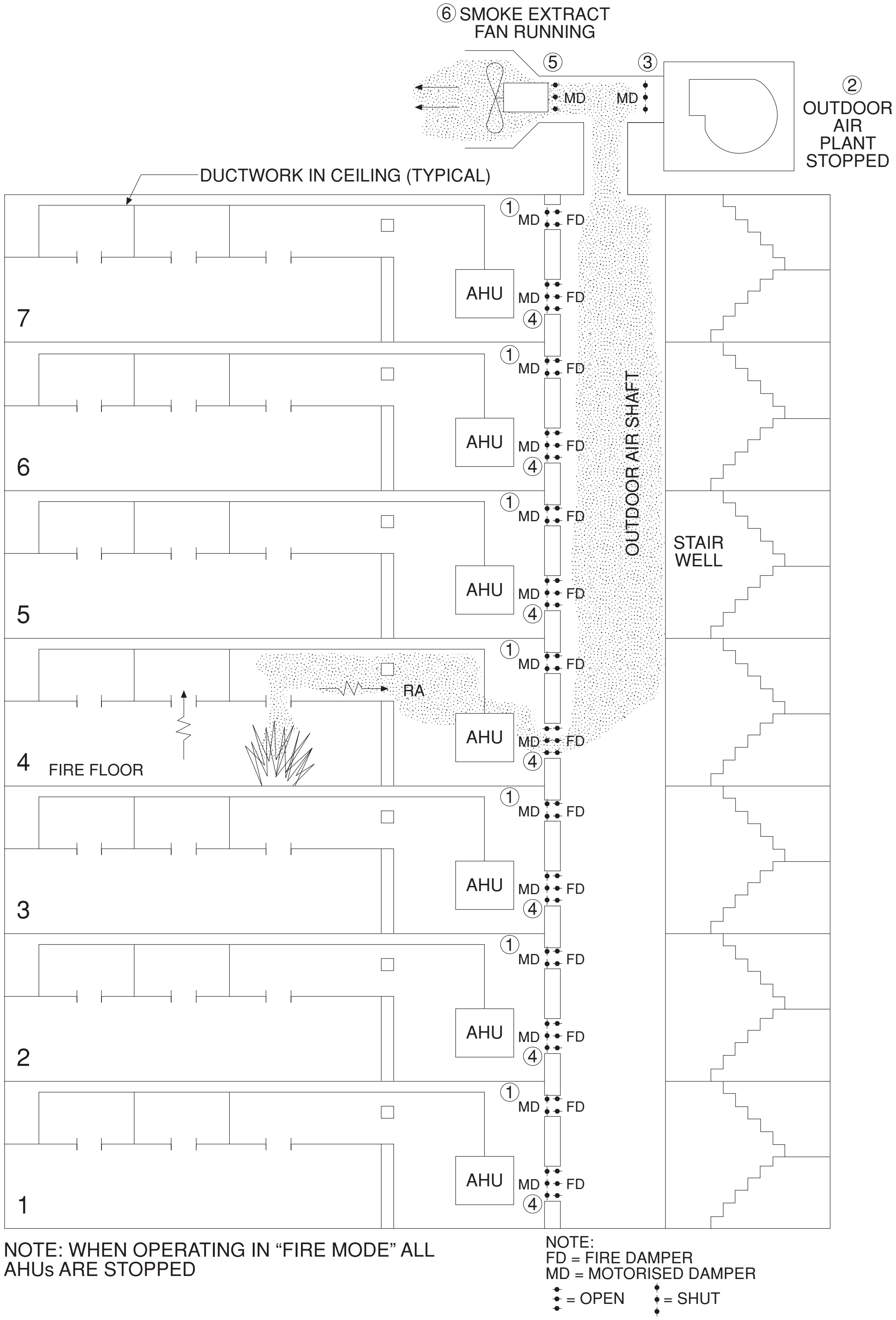


Figure 10.11: Typical floor-by-floor HVAC, on-floor AHU

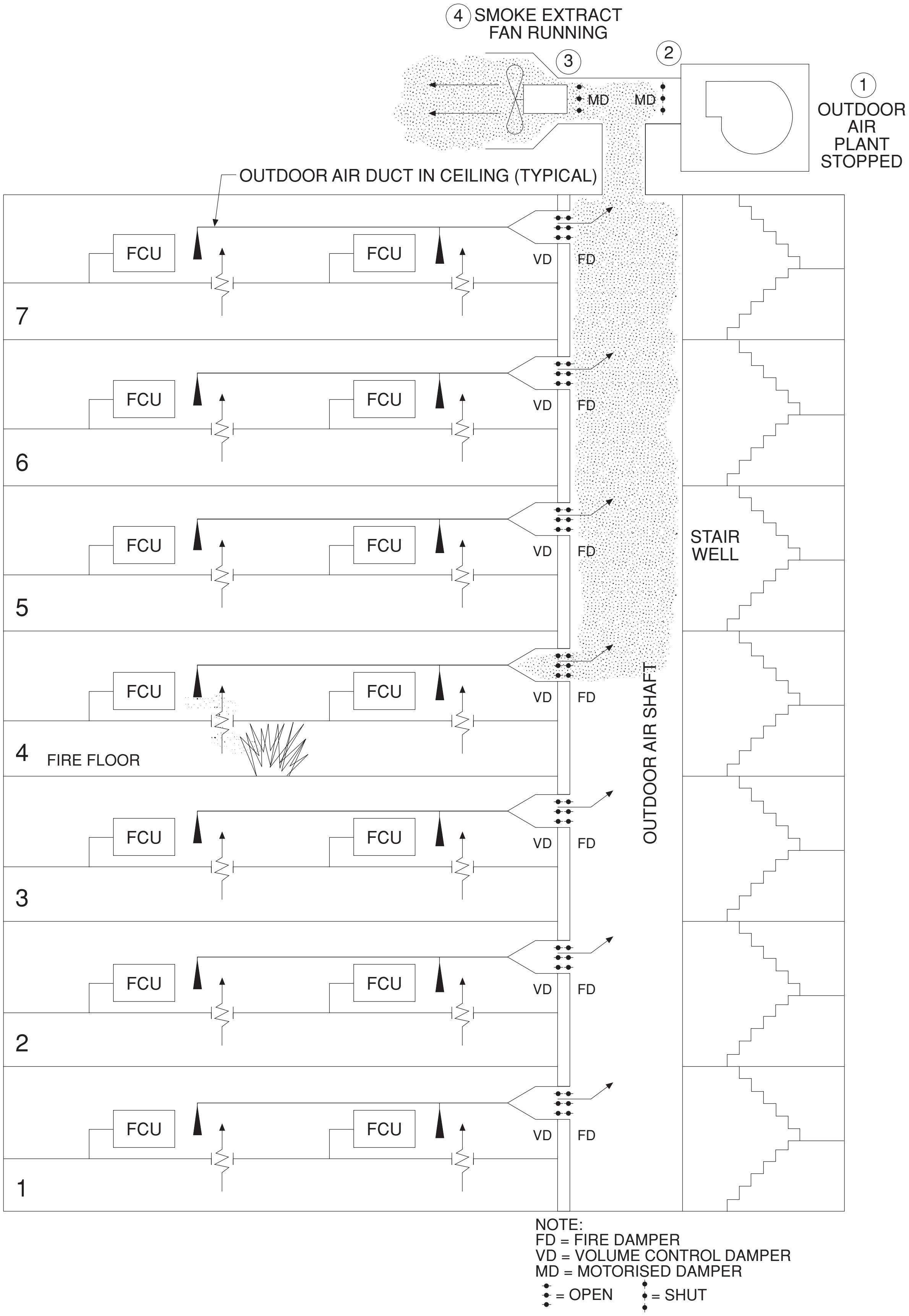


Figure 10.12: Typical floor-by-floor HVAC, on-floor AHU

System design

Design commences with calculation of fire size and, hence, smoke production rate. As in Section 10.2, the fire size would typically be determined on the basis of a sprinkler controlled fire.

Location of extract points requires careful consideration since extracting too much smoke through one vent can result in a “hole” in the underlying smoke layer and, hence, fresh air and a reduced quantity of smoke being extracted. Extract points should be spaced evenly over the smoke reservoir (Figure 10.13).

Required fan sizes are those necessary to remove the calculated volume of smoke at the system pressure loss. Fans should be rated to operate at a temperature equal to the smoke temperature plus the ambient temperature. NZS 4238:1991 “Code of Practice for Fire Safety in Atrium Buildings” requires fans, complete with drive, flexible connections and control gear, to be constructed and installed such that they are capable of continuous operation when handling smoke at 200˚C for a period equal to the fire rating of the shaft.

This requirement is the same as Australian/New Zealand Standard AS/NZS 1668, Part 1:1998 and is considered reasonable for most situations unless specific calculations show that a more stringent specification is necessary. Table 10.1 (Courtier and Wild 1991) gives the temperature/time specifications for various countries.

Careful selection of fans is needed and certification should be provided by the manufacturer to demonstrate that the fans have been successfully tested and rated for the required operating conditions.

Adequate outdoor air must be provided to the area affected by the fire to provide replacement air for that removed via the smoke extract system. Replacement air must enter the area below the smoke layer and at a velocity that avoids disturbing the smoke layer. Fan selection must allow for incoming air resistance. The velocity of the incoming air should not exceed 3 m/sec where air is drawn through exit routes and not more than 5 m/sec elsewhere.

Typical inlet air routes are:

- External doors — automatic doors arranged to open on a fire alarm and fail open. (Note that for security reasons, this is usually only during building operating hours.)

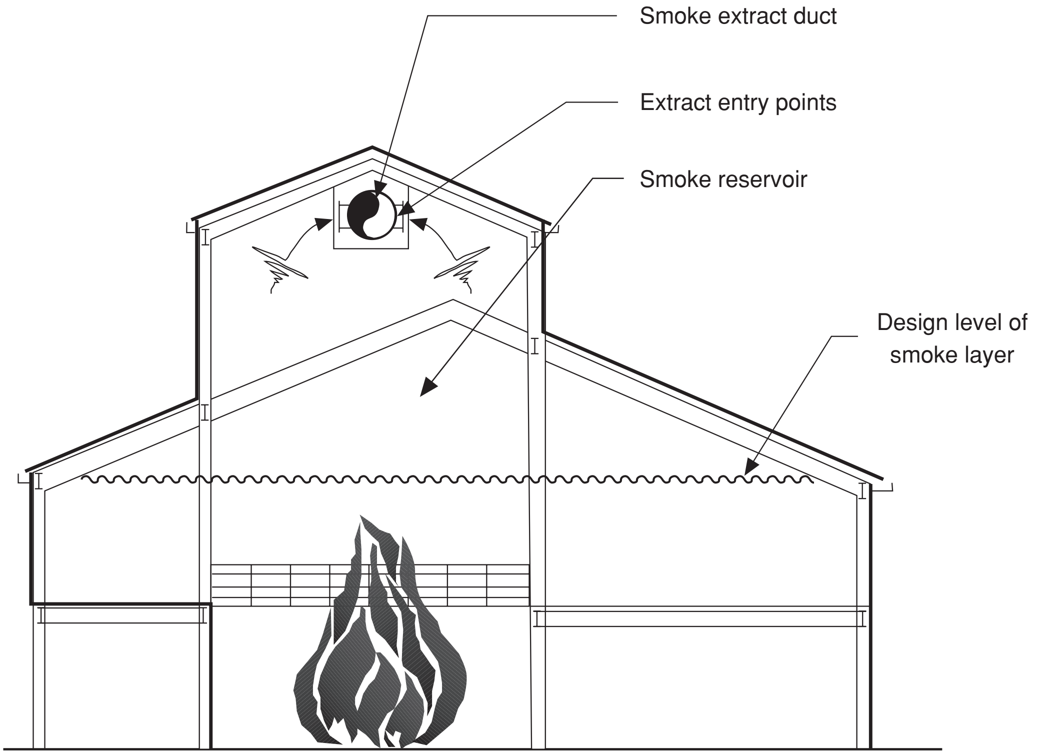


Figure 10.13: Smoke reservoir

- Permanently open or automatically opening louvres in walls or roof.
- Central plant air conditioning configured to full outdoor air supply on a fire alarm.
- Drawing from adjacent unaffected spaces, provided outdoor air is able to enter these adjacent spaces.

Care must be taken to separate smoke exhaust discharge and outdoor air inlet points to avoid recirculation of smoke.

10.7 Escape route pressurisation

General

The objective of escape route design is that occupants should be able to reach a place of safety, unharmed, in the event of a fire occurring.

The Approved Document for New Zealand Building Code - Fire Safety defines a safe place as *"A place of safety in the vicinity of a building from which people may safely disperse after escaping the effects of a fire. It may be a place such as a street, open space, public space or an adjacent building."*

For occupants in a building, a place of safety may also be:

1. A protected corridor;
2. A protected stair;
3. A place of refuge within the building.

Country	Temp (°C)	Time (hrs)	Comments
Australia	200	2	
Canada	-	-	Each consultant legally responsible for safety
Hong Kong	250	1	
Italy	200	2 or 3	
	400	2	
Belgium	250	2 or 3	
	400	2	
France	200	2	Certificate of independent test required by law
	400	2	
W. Germany	600	1.5	
Malaysia	250	2 or 3	
New Zealand	300	0.5 or 1	Following UK practice
Singapore	150	1	Likely to adopt UK practice
	250	1	
Egypt	400	2	French consultant specifications adopted
Finland	350	1	
Saudi Arabia	-	-	No current specification
South Africa	-	-	Follow UK, USA
UK	300	0.5 or 1	
USA	650	1	No national approach;State regulations vary
	260	1	

Table 10.1: Temperature/time specifications for smoke removal fans

Note: "Protected" as used in the context of this chapter should not be confused with "protected path" as defined by the Acceptable Solution C/AS1.

Once in a protected route, people should be able to make their way to a final exit and, hence, safety. For an escape route to remain useable in an emergency, it must be protected from fire and the products of combustion.

Passive fire protection in the form of fire-resisting construction forms one part of the protection. However, the passive fire protection will not always prevent the movement of smoke from the fire area into the escape route because of open doors and leakage around closed doors.

There are two main factors that determine the movement of smoke arising from a fire in a building. These are:

- the mobility of smoke due to it consisting of hot gases less dense than the surrounding air;
- the normal air movement (which may have nothing to do with the fire) that can move smoke from affected to unaffected parts of the building.

Air movement is itself controlled by:

- the stack effect;
- wind — all buildings have some air leaks and wind action will contribute to air movement through the leaks;
- the building HVAC and ventilation systems.

Pressurisation provides pressure differences that oppose and overcome those generated by the factors causing movement of smoke.

Wind and stack effect

The stack effect, shown in Figure 10.14, is due to the differences between the external and internal climates. These temperature differentials cause movement of smoke either upwards (winter) or downwards (summer) until a neutral plane is reached and lateral smoke movement is induced.

Stack effects in buildings are typically most pronounced in countries where there is a significant difference in the indoor and outdoor temperatures, i.e. North America, where in winter outdoor temperatures fall below 0˚C, whilst indoor temperatures are artificially maintained at around 20˚C, or Australia, where external temperatures may exceed 40˚C while maintaining 22˚C to 23˚C internally. Stack effect will occur to a lesser extent in New Zealand, mainly in tall buildings in winter when the interior temperature is greater than the exterior temperature.

Wind can have a pronounced effect on smoke movement within a building. The pressure P_w (Pa) that wind exerts on a surface can be expressed as:

$$P_W = 0.5 C_W \rho_O V^2 \qquad [10.4]$$

where: C_w is a pressure coefficient

ρ_o is the outside air density (kg/m^2)

V is the wind velocity (m/sec)

The pressure coefficients C_w range from -0.8 to 0.8, with positive values for windward walls and negative values for leeward walls.

Figure 10.15 shows typical air flow patterns around a building on its own and the compound effect of adjacent buildings. Because the air flow pattern and, hence, the wind effect on the building has been changed, there could well need to be a change in the way the pressurisation system in the building operates to compensate for that change.

If a window breaks in a fire, the wind effect, positive or negative, can be large and can dominate air movement throughout the building. The design of smoke control and pressurisation for a building in New Zealand or Australia may not need to take stack effects into account. Wind effects do need to be considered and outdoor air inlet louvres and smoke discharge louvres need careful siting to avoid wind effects.

Stairways and lift shafts that have doors opening into external conditions also need careful attention to compensate for wind effects. Draft stop lobbies are often used to prevent wind effects from creating pressure differentials within the shafts.

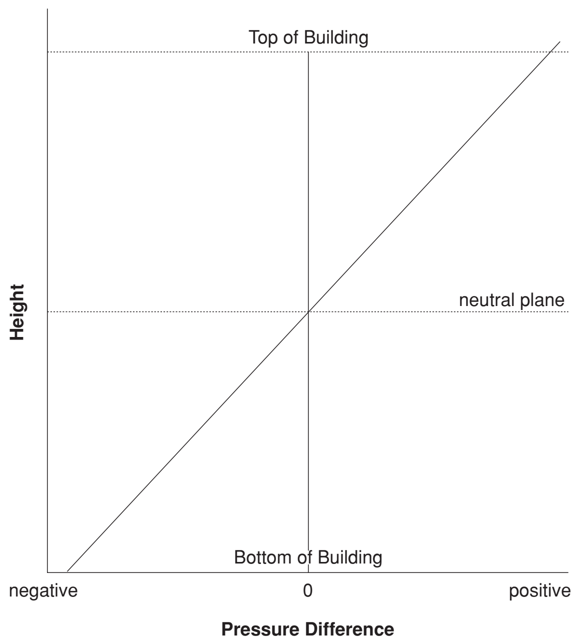


Figure 10.14: Pressure difference between a building shaft and the outside due to stack effect

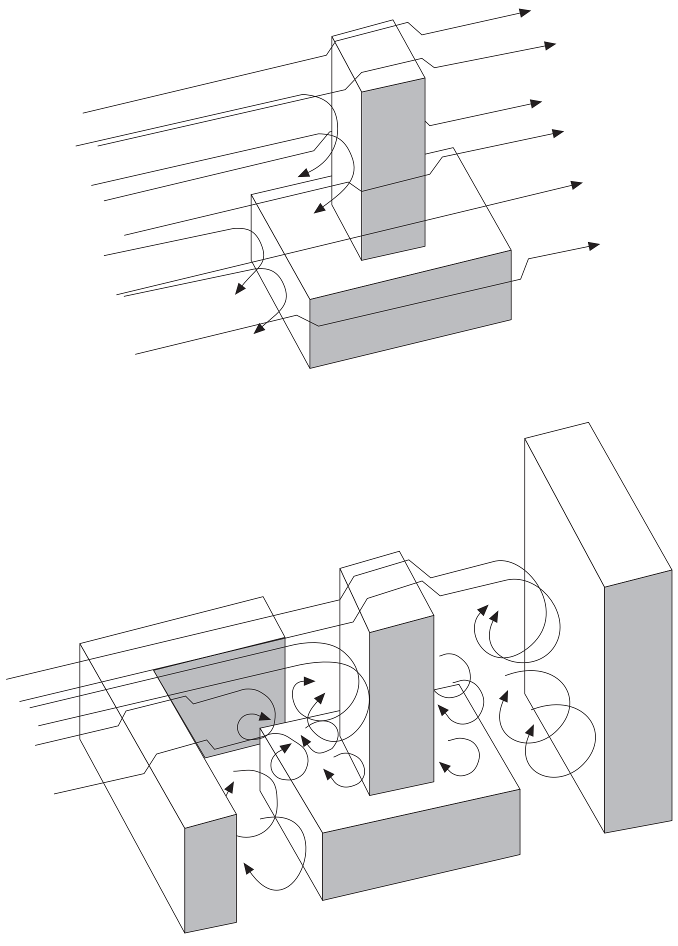


Figure 10.15: Airflow patterns around buildings

Pressurisation systems design

General

Pressurisation of escape routes is achieved by pumping air into the protected space. In this way, a pressure difference across doors and divisions between the protected and adjacent spaces is created. If the maintained pressure differential is sufficiently large, the pressure forcing the smoke from the fire area towards the protected area will be insufficient to overcome this differential.

A pressurisation system, if it is to be effective, must be an integral part of the building design and not something imposed upon the design afterwards. There are two basic types of pressurisation systems, positive and negative. Figure 10.16 illustrates the positive type where clear air is forced into the protected space. This method is typically used for protecting stairways and may also be used for lift shafts.

Figure 10.17 illustrates the negative type where smoke extraction occurs in the fire area, thereby creating a pressure differential and an air flow between the protected space and the fire area. This method is typically used for protecting lift shafts. Air flow is via gaps around doors, construction cracks and doors opened during egress. One or both of these systems may be used in buildings.

Air leakage via door gaps etc.

To calculate air leakage flow rates, Klote and Milke (1992) express air flow rate through a door gap as proportional to the pressure difference across the gap raised to the power n. For a gap of fixed geometry, n is, theoretically, in the range of 0.5 to 1.0.

For gaps in doors, except extremely narrow gaps, n can be taken as 0.5, and the volumetric flow rate V_f (m^2/s) can be expressed as:

$$V_f = C A_1 \left(2\Delta P/\rho\right)^{1/2} \qquad [10.5]$$

where: C is a flow coefficient

A_l is the flow area (m^3) (also called leakage path)

ΔP = pressure difference across the flow path (Pa)

ρ = density of air entering the flow path (kg/m^3)

The flow area is generally taken as the cross-sectional area of the flow path.

For stair, lift doors etc., taking C = 0.65 and r= 1.2 $kg/m^{3:}$

$$V_f = 0.839 A_1 \left(\Delta P\right)^{1/2} \qquad [10.6]$$

Air leakage via door gaps, constructions gaps and the like must be included in the design air flow to maintain the required pressure difference between the escape route and the fire area.

Open doors

The number of doors that may be open simultaneously must also be considered in the design process. For open stairwell doors, Cresci (1973) found that complex flow patterns exist and that the resulting flow was considerably below the flow calculated by using the area of the door way as the flow area "A" in the above equation. Based on this research, it is recommended that the design flow area of an open stairwell door be taken as half the actual area.

Deciding how many doors will be open simultaneously depends largely upon building occupancy. In densely populated buildings or buildings with a total evacuation policy, it is likely that a large number of the doors will be open. For buildings where staged evacuation is the policy, only a few doors may be open during a fire. No defined policy is given in the references used and each building needs to be individually assessed.

Door opening forces

The door opening forces resulting from pressurisation of the stairwell must be considered. Unreasonably high door-opening forces can result in occupants having difficulty or being unable to open the doors.

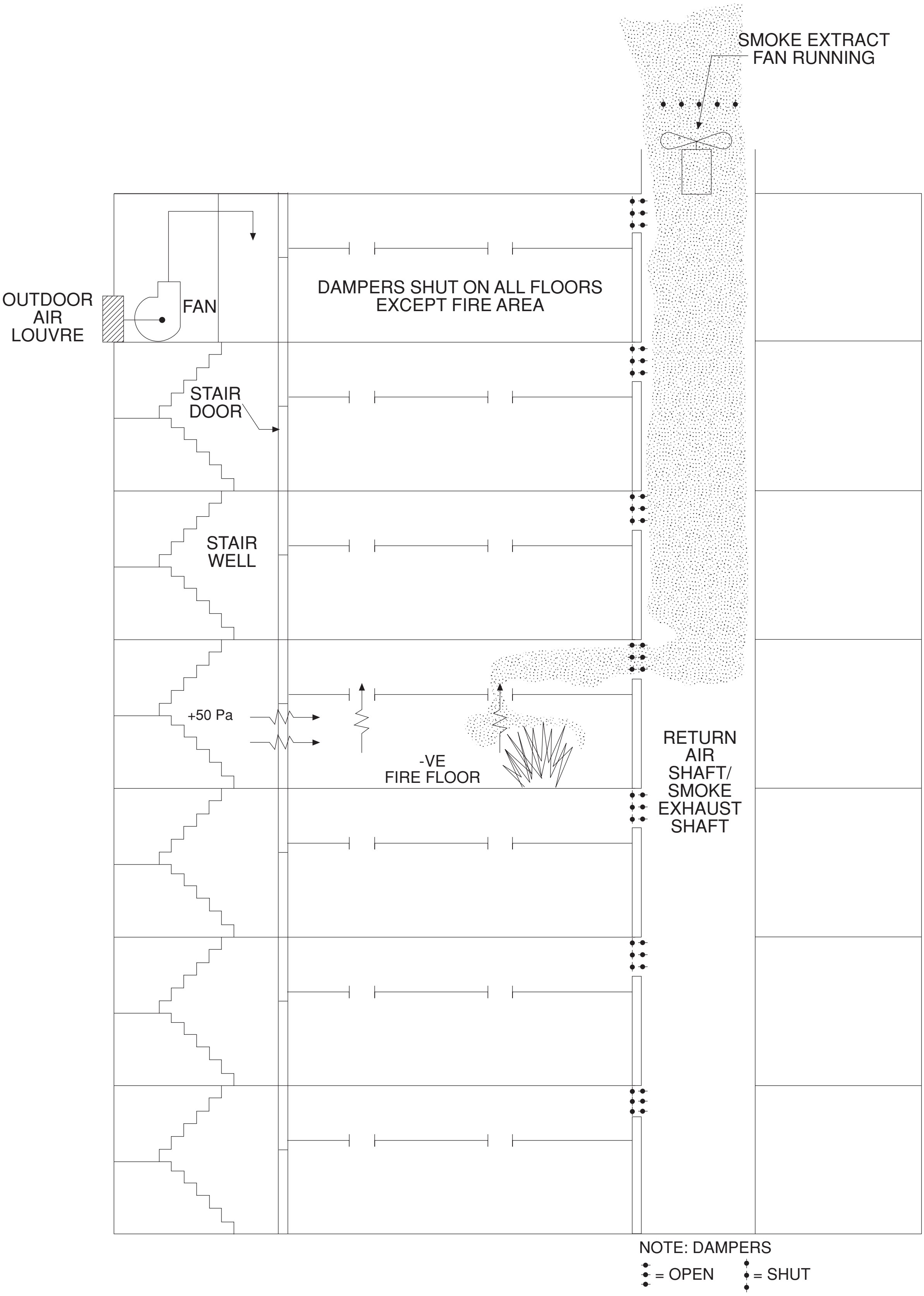


Figure 10.16: Positive pressurisation

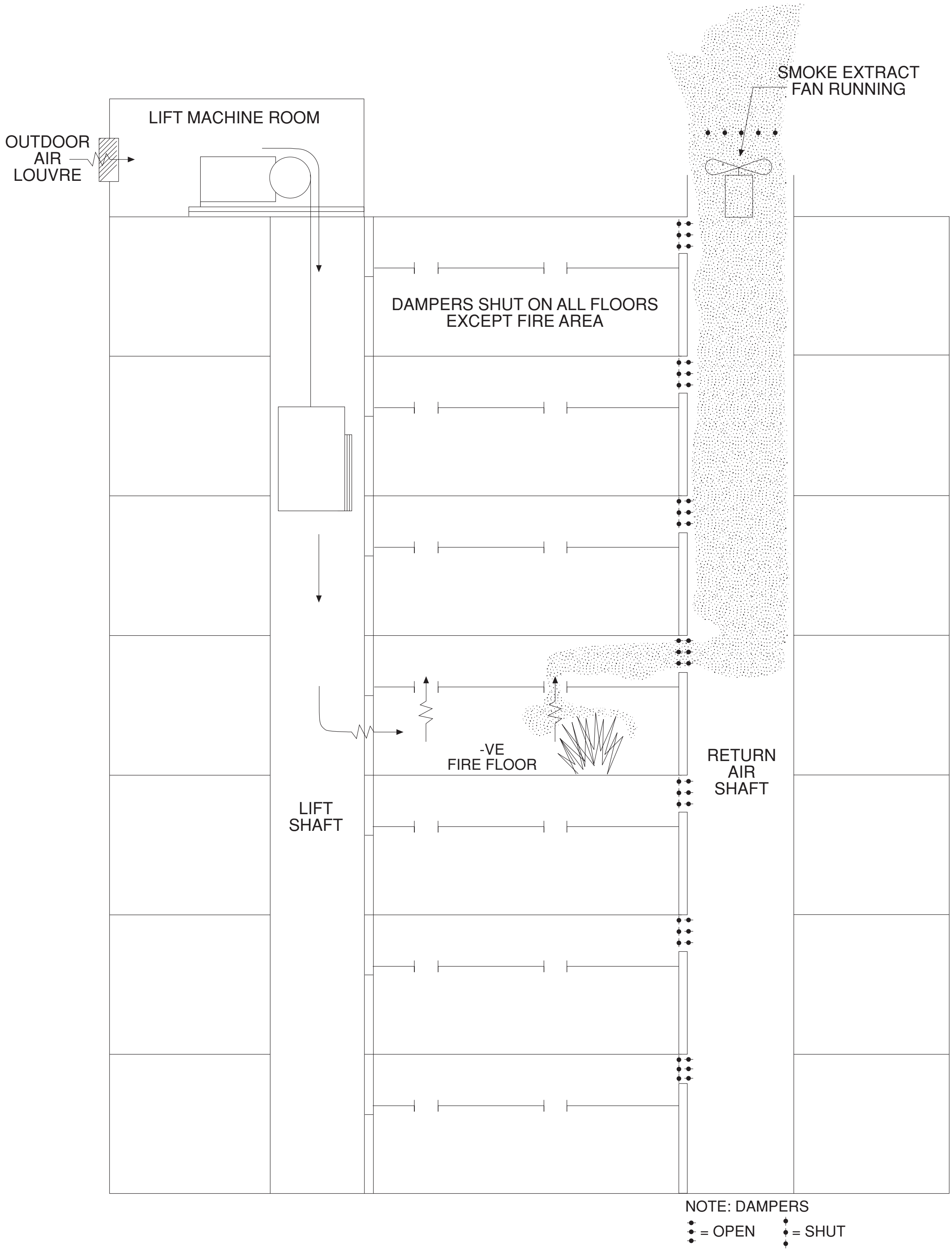


Figure 10.17: Negative pressurisation

The force required to open a door is the sum of the forces to overcome the pressure difference across the door and the door closer. This can be expressed as F (N), given by:

$$F = F_{dc} + \frac{W A_d \Delta P}{2(W - D)} \qquad [10.7]$$

where: F_{dc} is the force to overcome the door closer (N)

W is the door width (m)

A_d is the door area (m^2)

ΔP is the pressure difference across the door (Pa)

D is the distance from door knob to edge of knob side of door (m).

This relationship assumes that the door opening force is applied at the knob. Door opening forces due to pressure difference can be determined from Figure 10.18. It is suggested that the total force required to be applied at the knob should not exceed 120 N.

BS 5588 Part 4:1998 recommends that the level of pressurisation used for design purposes for any pressurised space in a building should not exceed 60 Pa (50 Pa is typically used as the design pressurisation level).

For a door 1.0 m wide by 1.98 m high, with the knob 75 mm from the edge of the door, and a pressure difference of 60 Pa, the force to overcome the door closer, F_{dc}, and hence the force exerted on the door by the closer, can be calculated from equation 10.7 as:

$$120 = F_{dc} + \frac{1.0(1.98 \text{ x } 1.0)60}{2(1.98 - 0.075)} \qquad \text{i.e. } F_{dc} \leq 89\,\text{N}$$

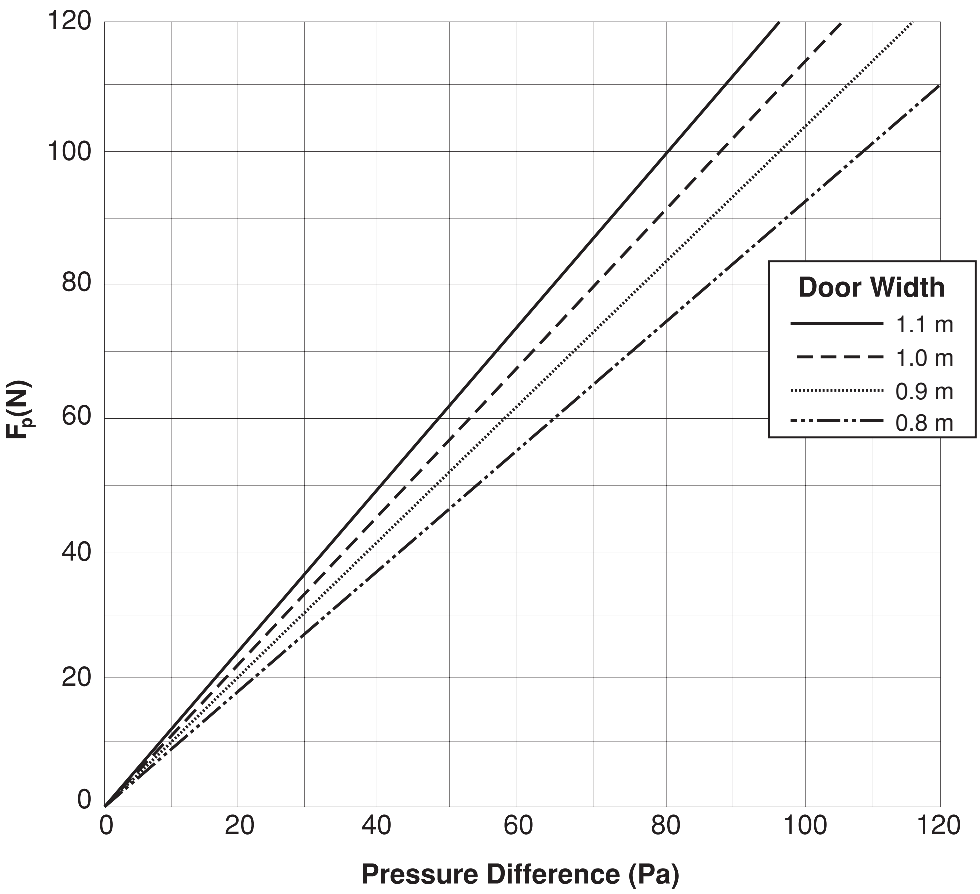


Figure 10.18: Door opening force due to pressure differences

Buildings used for the very young or old or for handicapped people may need special consideration to ensure that doors can be opened against the combined force of the closer and the pressure differential resulting from pressurisation of the escape route. Designers must check and coordinate the self-closing mechanisms on doors opening into pressurised spaces to ensure that the closing mechanisms are adjusted to the minimum force required for the effective closing of the door in normal use (a simple spring balance can be used).

Positive pressurisation of exit ways

Objective

The objective of positive pressurisation of stairways is to establish a pressure gradient pattern which will ensure that exit ways are kept free of smoke. To do this, the exit way is maintained at an excess pressure with respect to other areas of the building in a fire emergency.

During a fire emergency, all protected staircases and associated lobbies and corridors forming part of the whole pressurisation scheme should be simultaneously pressurised. System components include:

- A mechanically driven supply of outdoor air supplied directly or via ductwork to each pressurised space, i.e. stairwell, lobby or corridor.
- Relief venting or other pressure control devices to maintain the design pressure in the pressurised space, depending upon the various combinations of doors open and closed.
- Automatic control system integrated with the smoke removal system and interfaced with the fire alarm and suppression system.

Single-stage pressurisation

Single-stage pressurisation is designed to be operated only in an emergency. This type of system is most commonly used.

Two-stage pressurisation

Two-stage pressurisation is incorporated as part of the building's normal ventilation system and operates continuously during normal occupancy hours to provide a low level of pressurisation. There is provision for an increased level of pressurisation to be brought into operation in an emergency. A two-stage system may be considered preferable in buildings such as hospitals, rest homes and hotels because some measure of protection is always operating, thus helping to prevent smoke spread in the early stages of a fire.

Pressurisation of stairwells

The protection is confined to the stairwell only and in general is used when the stair is accessed directly, or via a simple lobby, from the occupied floor. If access is via a simple lobby, the lobby should not contain access to lifts or toilets etc., as these would add leakage paths, allowing the pressurising air to bypass the designed direction of flow (Figure 10.19).

Supply of outdoor pressurisation air to the stairwell can be achieved by either single-point injection or multiple-point injection. A single-point supply system is one that has pressurisation air supplied to the stairwell at one location. The most common supply point is at the top (Figure 10.20). Single supply systems can fail when a few doors are open near the air supply point and the system may fail to maintain the design pressure further down the stairwell.

Multiple-point supply systems utilise supply air ductwork running in a separate fire-rated shaft adjacent to the stairwell, with air being supplied to the stairwells at regular intervals through the height of the stair. The actual number of supply points requires careful analysis for each stair. The optimum is to supply at each floor where this can be easily and economically achieved, as shown in Figure 10.21.

As the design requires a specific pressure to be maintained when a specific number of doors are open, over-pressurisation can occur when all doors are closed. Control of the pressure in the stairwell can be achieved by relief venting directly to outside using barometric dampers set to the desired pressure, venting to outside via barometric dampers and an exhaust duct, or by controlling fan speed. Klote and Milke (1992) also suggest venting to the occupied space, provided vents are configured to prevent smoke or fire entering the stairwell.

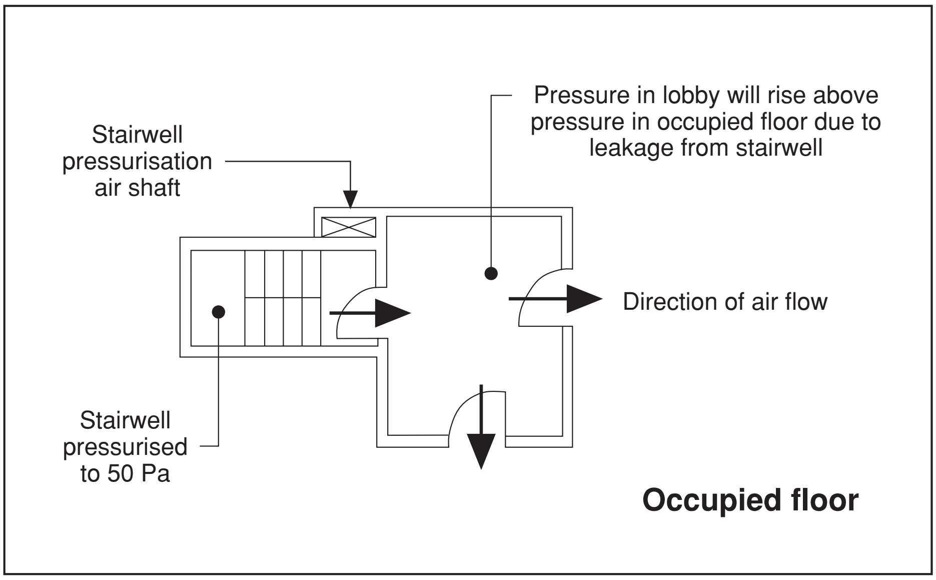


Figure 10.19: Pressurised stairwell with simple lobby

Pressurisation of lobbies and corridors

Lobbies, other than simple lobbies, and corridors should be pressurised independently of the stairwell. The pressure in the lobby or corridor should be less than the pressure in the stairwell, by an amount not more than 5 Pa (Figure 10.22).

Summary

When designing pressurisation systems for a building, the following steps should be taken:

1. Consider the design use of the building and the possible changes in use during the design life of systems installed (until major refurbishment would be considered necessary).
2. Identify the spaces to be pressurised and evaluate possible interaction between pressurised and unpressurised space, and HVAC and smoke removal systems.

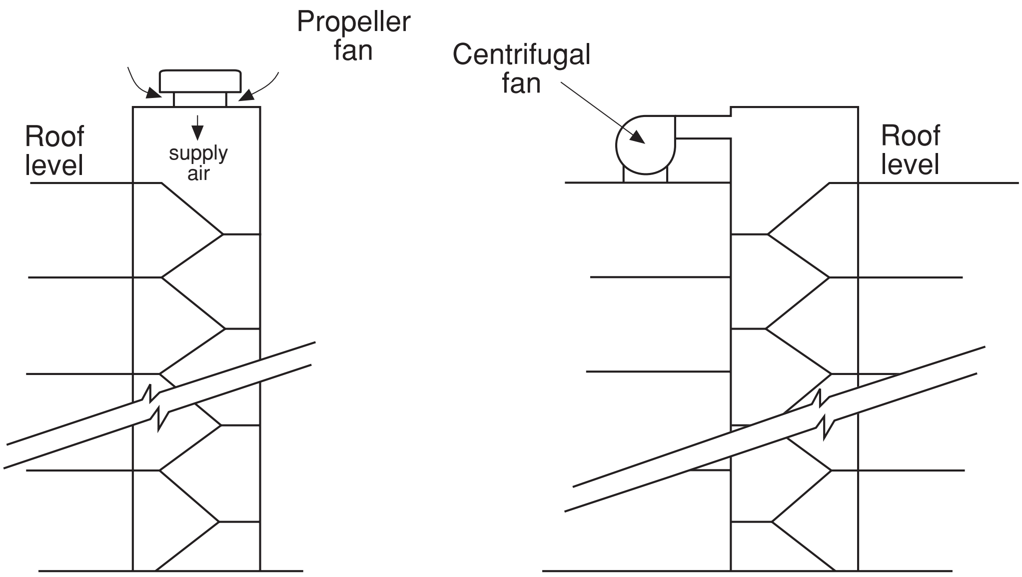


Figure 10.20: Stairwell pressurisation — single-point supply

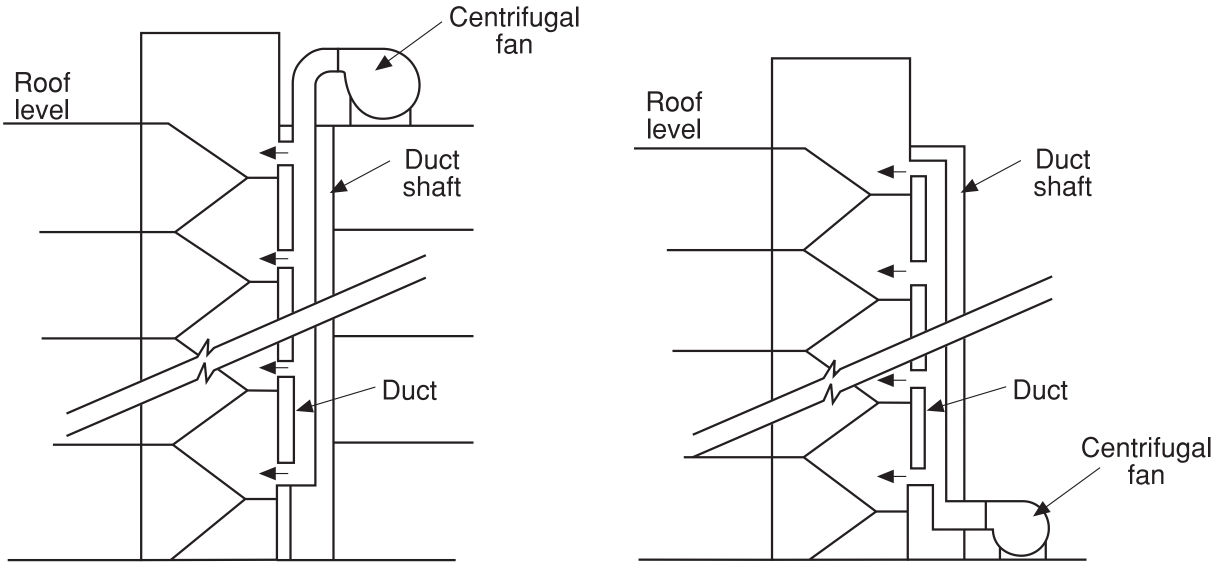


Figure 10.21: Stairwell pressurisation — multiple-point supply

3. Decide whether the system is to be single-stage or two-stage and select pressurisation levels to be used for emergency operation and, if appropriate, for reduced capacity operation.
4. Decide whether single-point supply or multiple-point supply is required and determine the method for handling over-pressurisation. This will affect vertical duct space requirements.
5. Identify all the leakage paths through which air can escape from the pressurised spaces and determine the rate of air leakage through each. Total all air flows out of each pressurised space. Since leakage through cracks, gaps etc., in the building structure cannot be quantified in the same way, it is necessary to increase the total calculated air flow. A 25% increase is suggested by BS 5588 Part 4:1998.

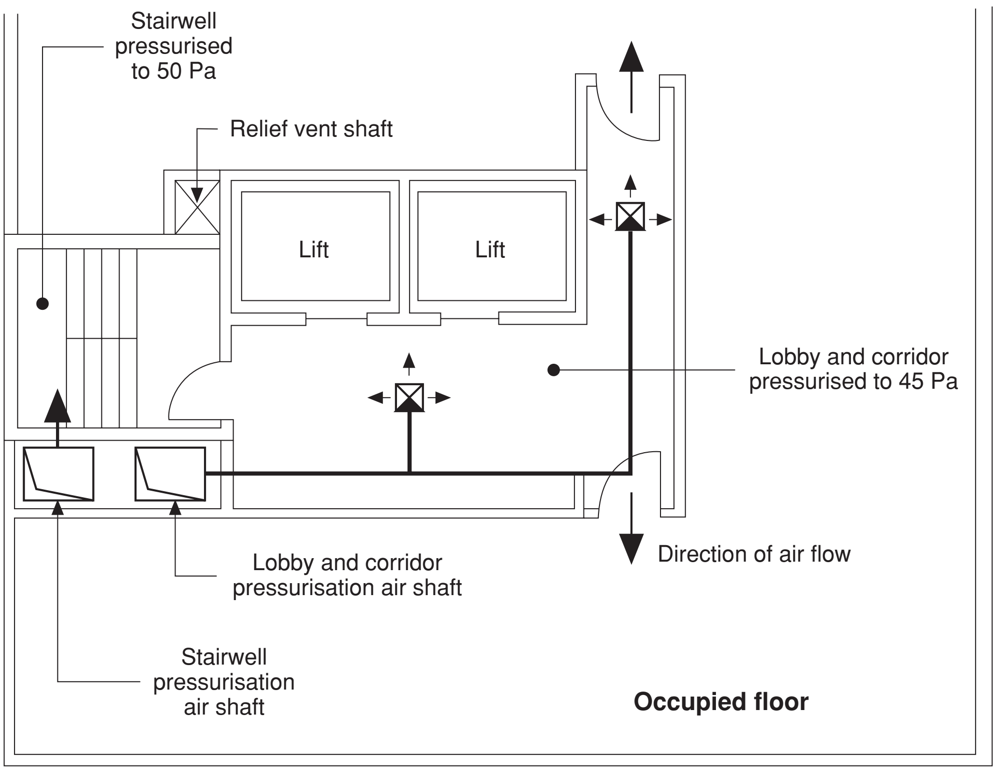


Figure 10.22: Stairwell and lobby/corridor pressurisation — single-point supply

6. Calculate the air flow through the design number of open doors.
7. The air supply, 5 plus 6, must be provided in each pressurised space. Locate air supply points to achieve the required air flows.
8. System dynamic design, i.e. fan capacity, duct size, pressure and relief, should be carried out by a suitably qualified HVAC engineer.
9. The location of outdoor air intakes and relief vent outlets requires careful consideration of wind effects and must be located away from any exhaust systems to prevent recirculation of contaminated air or smoke into the building.
10. Interface with HVAC and fire alarm and suppression systems requires careful analysis. The controls system must be programmed to operate all devices required for the system to function correctly.
11. The architect needs to be advised of:
    - Maximum door closer force allowed for in the design of the system.
    - Leakage areas assumed with the note that these should not be exceeded in the finished building.
12. A measurement procedure needs to be determined so that the satisfactory operation of the installation in the completed building can be established.
13. To meet the "Compliance Schedule" requirements of the Building Code, a maintenance and testing procedure needs to be determined and agreed with the owner and the Territorial Authority.

10.8 Interface with active fire systems

General

Configuring HVAC systems to control smoke, activation of smoke extract systems and activation of escape route pressurisation systems requires identification that a fire has occurred and the location of the affected areas of the building. Typically, the fire detection and suppression system installed in the building is used to identify the fire affected area. For interface with smoke control systems, it is recommended that the detection device be a smoke detector, but detection devices may be any one, or a combination of, the following:

- Fire sprinklers, including main alarm valve pressure switch and floor flow switch (alarm signal and discharge of water on to the fire);
- Heat detectors, of various types and method of operation (alarm only);
- Smoke detectors, various types and methods of operation (alarm only);
- Flame detectors (alarm only);
- Manual fire alarms — require activation of manual call point to initiate alarm only.

Fire safety codes differ on which device or devices should be used to initiate the "fire mode" operation of smoke control systems. For example:

- The Building Code of Australia 1990, in Clause E2.6, states:

All smoke exhaust fans must start sequentially and be activated by the operation in the area served by the fan of:

(a) a sprinkler system;

(b) a fire detection and alarm system which complies with Specification E1.7; or

(c) a detector system comprising —

  (i) smoke detectors spaced not more than 30 m apart and 15 m from any draught curtain, bulkhead or wall and not less than one detector for each 500 m^2 of floor area; or

  (ii) rate of rise heat detectors spaced not more than 15 m apart and 7.5 m from any draught curtain, bulkhead or wall and with not less than one detector for each 250 m^2 of floor area; and

  (iii) not less than 2 detectors located on opposite sides of each fan inlet.

- The National Fire Code — NFPA Code 92A suggests smoke detector, heat detector and sprinkler flow switch activation.

- The Acceptable Solutions C2/AS1 and C3/AS1 requires activation by heat and/or smoke detectors.
- The National Building Code of Canada requires the control alarm and control facility to incorporate controls to initiate the "fire mode" of HVAC systems. In Canada, smoke detectors would usually be used as the operating device.

In addition to identifying the fire floor for the HVAC control, the fire detecting devices may also initiate a fire alarm signal to:

- Lifts
- Escalators
- Emergency lighting
- Security.

The operation of each of these systems, and the HVAC systems, in "fire mode" would be controlled by the systems' own control logic and not by the fire alarm initiating device. It follows then that any fire alarm initiating device should be part of the building fire alarm system (which includes sprinkler systems) and be serviced, tested and surveyed as required by the New Zealand or Australian Standards applicable to the particular system, in accordance with the Compliance Schedule requirements of the Building Code, or the Essential Services requirement in Australia.

Identifying the fire floor

Smoke control design and mechanical plant control logic requires that the floor on which the fire has occurred (not to be confused with floor on which the fire alarm has occurred) be identified. The logic to determine the fire floor, from the alarm sources, should be contained within the fire alarm panel such that signals identifying the fire floor can be initiated to the HVAC control system the building evacuation system and any other of the building management systems requiring this information.

For the alarm system to identify the fire floor, alarm source reliability needs to be considered. Alarm source reliability is listed below in order of decreasing reliability:

1. Sprinkler pressure switch (with floor verification by flow switch) — A time delay should be installed to prevent simultaneous activation on all floors.
2. Smoke detectors and/or heat detectors.
3. Smoke detectors in HVAC plant — type, location and installation require careful consideration if detectors are to achieve their required function. There is a danger of smoke dilution reducing the effectiveness of detectors.
4. Manual call points — Should not be used to initiate HVAC plant or smoke clearance systems.

It is essential to identify the fire floor correctly. Consider the HVAC system shown in Figure 10.10 with a fire on level 4. In fire mode, the following sequence should occur within the HVAC system:

1. Return air fan stops.
2. Damper from return air shaft to return air fan shuts.
3. Outdoor air damper to return air shuts.
4. Outdoor air damper to supply air fan opens.
5. Return air dampers to return air shaft, on floors 1, 2, 3, 5, 6 and 7 shut.
6. Supply air dampers on 4th floor shut.
7. Stairwell pressurisation fans start.
8. Smoke exhaust fan starts.

Note that similar control operations will occur with the HVAC systems shown in Figures 10.11 and 10.12 when operating in fire mode.

If the fire floor is wrongly identified, i.e. if the fire is on level 4 but the fire is identified as being on level 5, the systems will configure to remove smoke from level 5 where there is no fire, while smoke from the fire on level 4 continues unvented. Pressurisation of level 4 by air from the supply air system may cause smoke to migrate via lift shafts and stairwells, creating a very dangerous situation.

10.9 Alarm and HVAC systems reliability

Fire sprinklers

In New Zealand, fire sprinkler systems have a very good reliability record, due in the main to the strict requirements for routine servicing, testing and surveying. Consider a simplified sprinkler system as shown in Figure 10.23. All the system above the alarm valve is pressured to a predetermined pressure by the jockey pump (pump normally switched off). When heat causes a sprinkler head to operate, pressure immediately falls and the following occurs:

1. The fire brigade alarm pressure switch closes, signalling the Fire Service through a continuously monitored circuit.
2. The pressure switch for the building fire alarm closes, signalling the fire alarm panel to activate alarms as programmed. This circuit is continuously monitored by the fire alarm panel and a defect is signalled if a fault occurs.
3. The pump pressure switch operates and the pump starts.

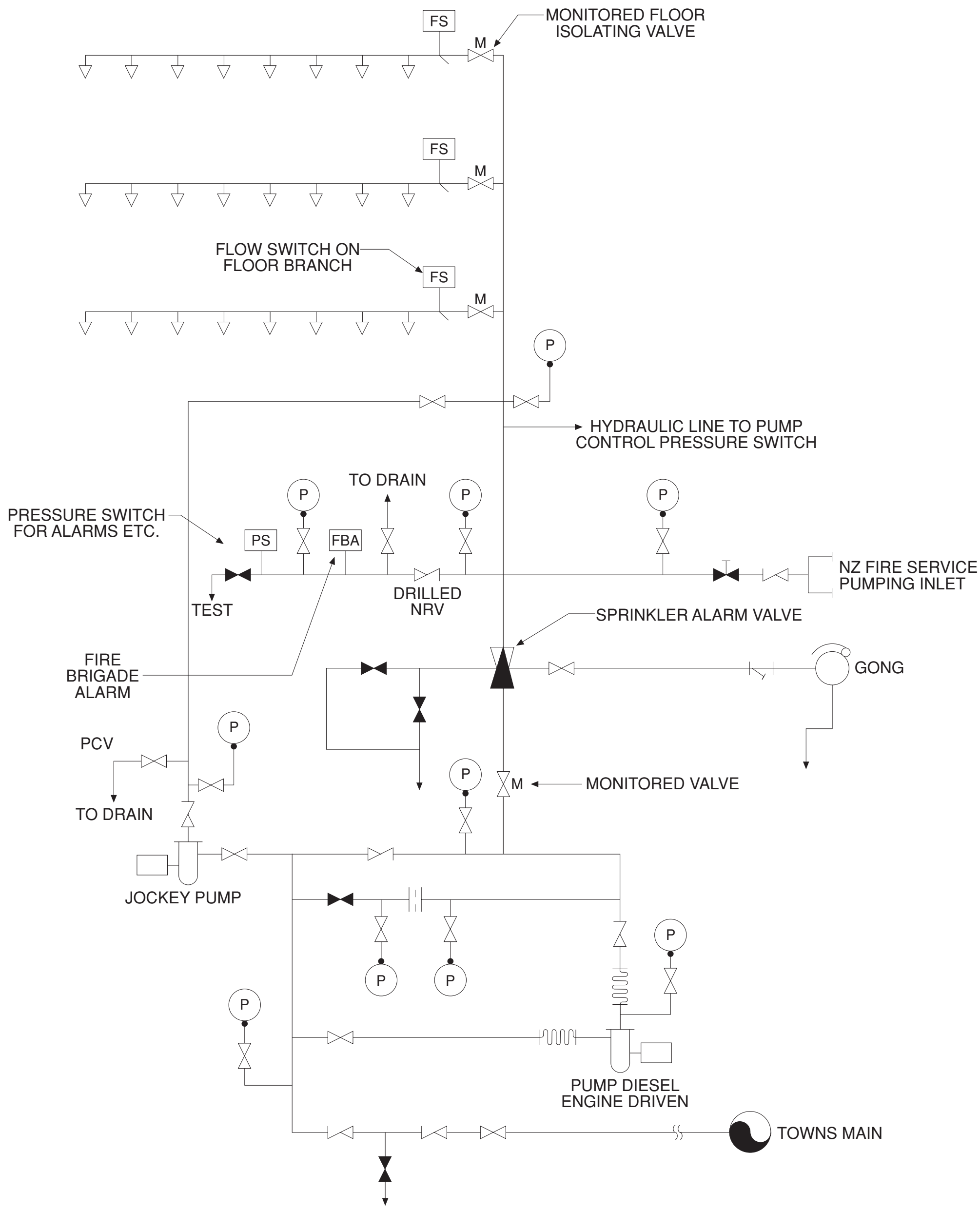


Figure 10.23: Fire sprinkler system (single boosted towns main supply)

4. Water flows through the pipework to the sprinkler head, past the flow switch, which activates, thereby identifying the fire floor. The flow switch cabling is typically not monitored.

Fire sprinklers give simple, effective signalling using system pressure and monitored circuits. Because false activation of sprinkler heads is rare, fire sprinklers provide very reliable fire floor identification. Flow switches must be correctly selected, installed and maintained in order to operate correctly and to reliably identify the fire floor.

Automatic fire alarms

Heat operated fire alarms have a good reliability record, again mainly due to strict requirements for routine servicing, testing and surveying. Smoke detectors tend to be less reliable. Consider a simplified automatic fire alarm system as shown in Figure 10.24. When the detector is activated by a fire, the following occurs:

1. A signal is sent to the fire alarm panel. The circuit to the detectors is monitored and a fire call registered if a fault occurs in the circuit.
2. The fire alarm panel sends a signal to the Fire Service alarm receiving equipment. The circuit to the Fire Service (telephone line) is monitored.
3. The fire alarm panel activates sounders. Circuits to sounders were typically not monitored, although monitored circuits are now required by the New Zealand Standard.

Again, there is simple, effective signalling with monitored circuits. However, where detectors are used, smoke and heat migration to other floors can result in other floors being identified as the fire floor in addition to the actual fire floor. Alarm reliability has, therefore, been assessed as less reliable than sprinkler reliability.

Developments in detector technology have produced new generation control technology in the form of analogue-

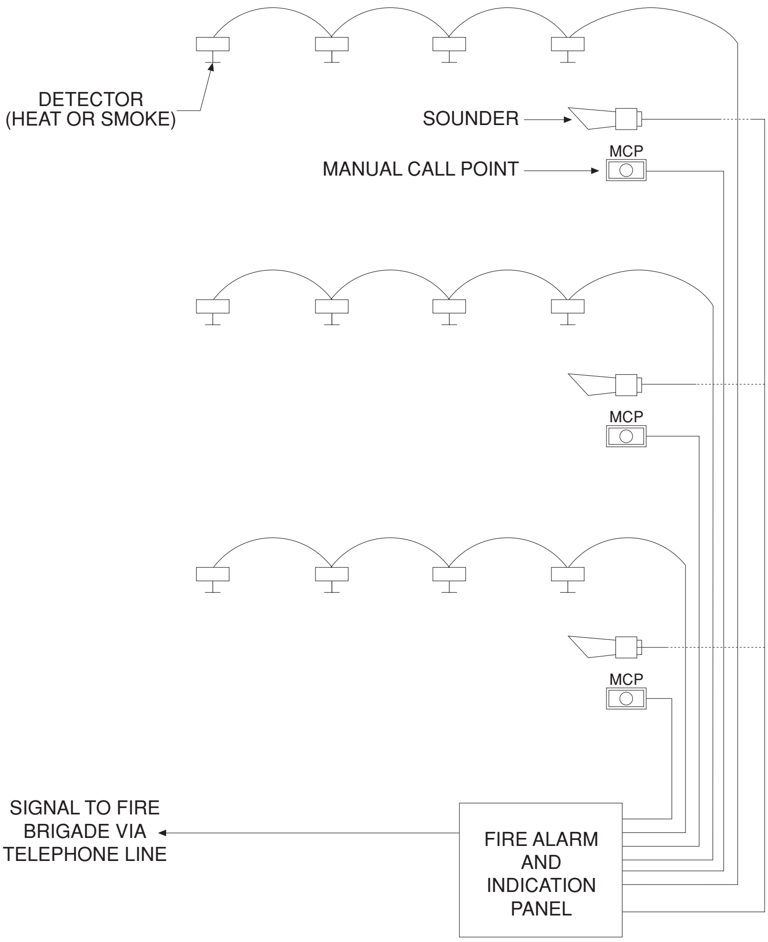


Figure 10.24: Fire sprinkler system (single boosted towns main supply)

addressable detection devices. In HVAC terminology, this is referred to as communicating controls. These advances provide a number of benefits to improve system reliability and reduce the incidence of false alarms.

Monitoring and control of detector status, identifying need for service and sensitivity adjustment to suit occupancy or environment are some of the reliability functions available with analogue addressable alarm systems. Accurate identification of which detector has activated will enable HVAC and smoke control operations to be optimised.

Fire engineering designs utilise intelligent systems that communicate with a central controller to enhance life and property safety and reliability. Such systems also simplify maintenance by regular automatic status checking of all devices in the system. Intelligent communicating fire alarm systems used as part of the smoke control system should contain the smoke control logic within the fire alarm panel. Initiation of HVAC plant should be via signals from the fire alarm panel transported by the alarm system communications wiring to the motor control centre controlling a particular part of the HVAC system.

Using the fire alarm communications wiring is preferred to using the HVAC control cabling as the fire alarm wiring is monitored, whereas the HVAC control cabling is generally not monitored. Failure of the fire alarm wiring will be recorded by the alarm panel as a fault and the fire alarm service company will be notified. The communication wiring, generally referred to as "loops", can also be fitted with fault isolation modules which enable isolation of the failed section of the loop whilst maintaining communication via the unaffected portion of the loop. The communication loops should be installed in fire-resistant cabling to increase system reliability in a fire.

HVAC systems

The HVAC system controls will have preprogrammed sequences that will initiate the fire mode configuration on receipt of a fire alarm identifying fire on a particular floor. If the HVAC, smoke clearance and escape route pressurisation systems are to be reliable, the controls need to be monitored to alert building users of a malfunction.

A similar situation applies to power supplies. The controls may be designed to initiate a change in state (i.e. an open damper to close), but if the power supply is isolated, damaged or generally inoperative, the system may not work as intended. There are also questions about the reliability of the power supplies to HVAC systems, as the wiring may be damaged in a fire.

Building codes typically require that in the event of a fire, air handling systems shut down or change to smoke control mode, smoke control and removal systems operate as programmed, and exit way pressurisation systems operate as programmed. It follows that such systems, including controls, power supplies and any other devices necessary for correct operation in "fire mode", should be serviced, tested and surveyed in a similar manner to fire protection systems (for reference refer NFPA 92A.4-4). The Building Code of Australia recommends testing and maintenance to AS1851 and other equipment maintenance codes as appropriate.

The New Zealand Building Code requires a compliance schedule for life safety systems in buildings and to comply it will be necessary to carry out routine servicing, testing and surveying of the life safety systems, including all initiating devices and controls.

HVAC equipment

As outlined above, codes require smoke handling equipment to be suitable for operating in the expected conditions, i.e. in a hot smoky environment, perhaps with flames or with water vapour.

Designers should pay particular attention to the requirement for properly rated equipment and manufacturers should demonstrate that the equipment they are offering has been successfully tested and rated for the operating conditions. Equipment that operates in fire mode should be treated no differently to, say, fire rated doors and other fire-rated building elements which require certification.

Typical examples of equipment requiring testing and rating would include:

- fans;
- fan drives, including motors, where they are located in the same environment as the fan;
- flexible connections — between fan and ductwork;
- motorised dampers — including smoke seals, actuating motors, bearings, etc. which should be tested and certified as an assembly.

10.10 Emergency electrical power supply

Building codes typically require life safety systems to have standby emergency power. The Acceptable Solution C/AS1 specifies an emergency power supply to ensure the continued operation of essential equipment such as smoke control systems, emergency lighting and lifts. NFPA 92A advises that *"standby power should be considered for dedicated smoke control systems and their control systems"*.

The requirement to provide emergency power seems, on the face of it, to be quite sensible and reasonable, but if it does not have the same reliability as the life safety systems it supplies, it may not operate when required.

The question is whether the emergency power supply can provide the level of reliability required and whether that same reliability can be achieved via the normal power supply to the building.

Consider a typical electrical power diagram, as shown in Figure 10.25. The generator control panel senses failure of mains power to the essential side of the mains switchboard and disconnects the transformer by opening ACB 1. The generator supply breaker 2 would close and, with interlocks on 1, 2 and 3, a start signal would be confirmed and the generator started.

Power would then be fed through the normal building electrical distribution (essential section only) to the various HVAC and smoke clearance systems. A number of questions arise:

- How reliable are all the electric and electronic controls that have to operate before the start signal is confirmed?
- Is the generator start reliable?
- How often is the automatic change-over from mains supply to the generator supply tested?
- Is the normal building electrical distribution as reliable as, say, the fire protection systems?

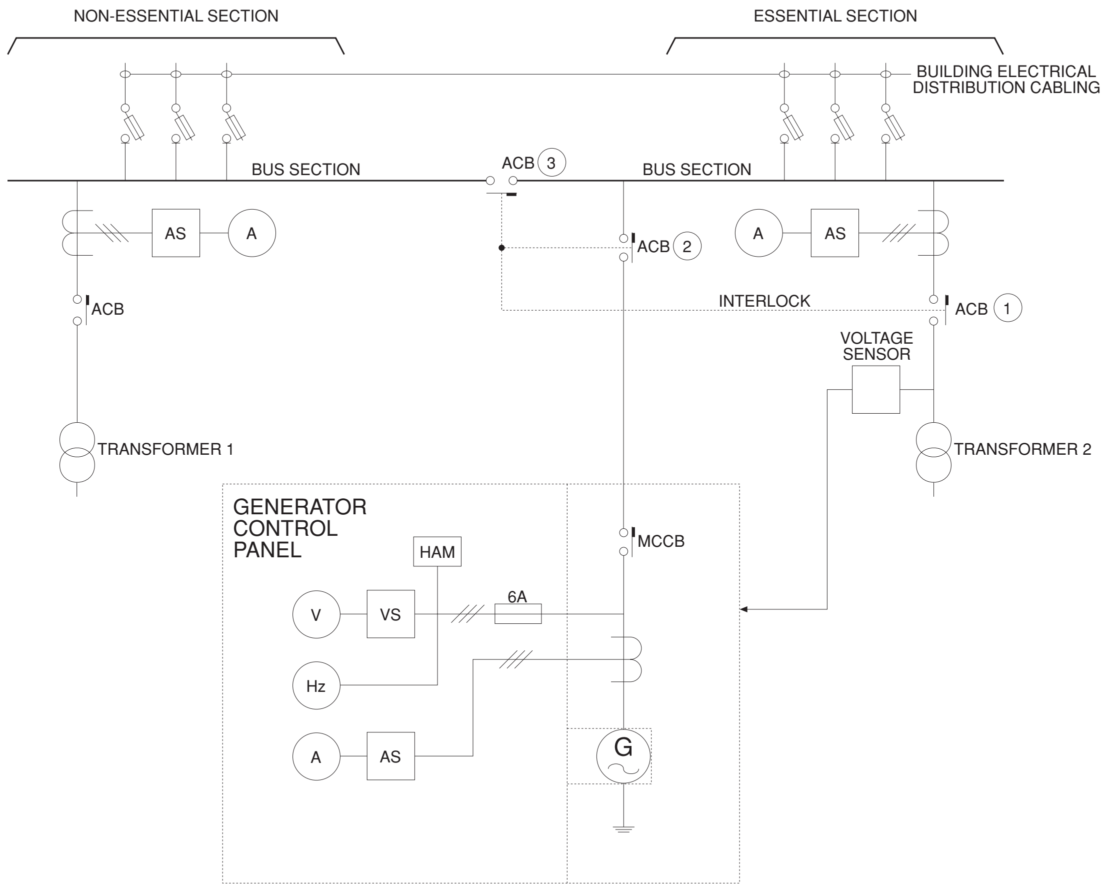


Figure 10.25: Typical electrical power diagram

- How is the normal load shed when emergency supply is operating so that supply is adequate for the smoke control systems?
- What if load is excessive due to failure of load shedding to operate?
- Where there are numerous smoke control and other life safety systems within a major building complex, how does one determine which systems are deemed to be operating simultaneously?

Sprinkler systems are designed on the basis that the fire has occurred in one area only and is contained by the sprinklers in that area. Sprinkler systems are not designed to cope with two simultaneous fires in different parts of the same building. Where the sprinkler system is connected, via an automatic alarm connection, to the New Zealand Fire Service alarm receiving equipment, operation of the system will call the Fire Service, so that the probability of a subsequent fire overtaxing the sprinkler system capabilities is greatly reduced.

It follows that smoke control and life safety systems in sprinkler-protected buildings can be considered as only operating in the same area as the sprinklers; thus identification of the fire floor will enable the systems operating simultaneously to be determined.

There is also the question of “compliance” with the compliance schedule requirements of the Building Act, which requires routine servicing, testing and annual confirmation that the system complies.

Where emergency power is provided, it may be necessary to test all the life safety systems on both emergency power and normal power. Designers should carefully consider all the options for power supply and the reliability of all components in the decision making process regarding whether or not provision of emergency power is required.

10.11 Conclusions

All fires produce smoke which, if not controlled, will spread throughout the building or portions of the building, thereby endangering life and damaging property.

HVAC, smoke clearance and escape route pressurisation systems can and should be used to control smoke movement in buildings.

Designers should be aware of the reliability limitations of components in these systems and take steps to enhance the reliability in a sensible and cost effective manner.

Chapter 11
Fire Safety System Interfaces

11.1 Introduction

The objective of design of fire safety system interfaces is to ensure that all building element systems, including fire safety systems, are functionally compatible.

11.2 Methodology

During the development of the fire safety concepts for a building, the design of the overall fire safety system should consider a variety of possible methods of producing functional compatible systems without incorporating excessive redundancy or becoming unnecessarily complex. The suggested method of achieving this is to employ fire science principles to determine the most cost effective approach so that a customised programme can be incorporated as an integral part of the conceptual and detailed design.

Modern developments allow the choice of either integrating or interfacing the fire safety system with other control and communication systems. With the reduction in cost of control systems, and to maintain product approvals, there is little advantage in the total integration of all systems. It is recommended that the optimal solution is the interfacing of dedicated fire safety systems with other building control systems, while ensuring that compatibility exists.

11.3 Systems

The following fire safety systems must be incorporated cohesively into the conceptual and detailed design of the whole building to remove any disruptive impact they may have on each other and to ensure compatibility of operation of the fire safety systems and all other related equipment:

- Passive fire control

    Compartmentation

    Vertical and horizontal smoke and heat barriers

    Exposure control

    Egress routes

    Fire Service access

    Surface finish selection

    Structural fire resistance

- Active fire control

    Automatic suppression

    — sprinklers

    — special hazards

    Manual suppression

    — risers and hydrants

    — hose reels

    — fire extinguishers

    Information management

    — emergency communication visible, audible and informative

— phased or partial evacuation

— Fire Service communication

— fire systems centres

— fire detection and alarm

— supervision of suppression, detection, emergency power, mobile protection, alarm and communications systems

Control interfaces

— air handling

— vertical transportation

— door releases

— mobile separation

— fuel sources

Smoke control

— active smoke barriers

— extract systems

— air inlet

— emergency power supplies

— positive and negative pressurisation zones

- Egress guidance

  Emergency lighting

  Photoluminescent systems

  Signage

- Security

  Access control

  Perimeter protection

  Internal beam or passive detection

  Closed circuit TV — internal and external

  Lighting

  Door hardware

  Exit delay

  Alarm communication

Note: The integration of the fire egress requirements with security access control is essential to ensure that the requirements of both are met.

11.4 Interfaces

A method of determining the initial interfaces and responses is to produce a logic matrix with “alarm cause” on one axis, and “alarm effect” on the other, as shown in Table 11.1. This matrix does not necessarily show all of the items required to operate on a fire signal. In many cases, there will be additional items, many of them additional to the requirements of NZS4541 or AS2118 and NZS4512 or AS1670.

The matrix system shown in Table 11.1 is applicable to site-wide application, but is not recommended to incorporate complex smoke control systems. These systems require a different approach, as follows:

(a) List all fans;

(b) List all operational dampers;

(c) List all air handling safety features;

(d) Determine feasible fire locations for each level, and for all communicating levels;

(e) Determine required air flow patterns for smoke migration control;

(f) Determine required air supply sources, volumes and paths for smoke entrainment.

Using a similar matrix to that for alarm cause/effect, determine the required responses for each of the fans, dampers and air handling safety features for each fire scenario.

The complexity of this task can be great if, say, 200 fans, dampers etc. are interfaced with, say, 100 fire locations. This interface may directly determine the type of HVAC controller which can be selected for a project. Sandwich systems may make the interface even more complex.

11.5 Reliability analysis

The more complex the site and the smoke control matrices, the more important it is to ensure that an acceptable level of reliability is built into the system. This may take the simple form of such items as backup power supplies, pre-selected damper positions set by spring actuators, or protected cabling to components, right through to redundant componentry, voting logical system and full determination of the level of reliability, i.e. as practised in the nuclear power and petrochemical industries.

The determination of an acceptable level of reliability should be undertaken by the client and the client's advisers, including the fire engineer.

11.6 Commissioning and certification

One of the consequences of a complex interface system is the determination of the person who takes responsibility for certification of the completed installation. This is commonly the fire engineering consultant, who becomes responsible for observation of the entire commissioning procedure.

Each of the subsystems is required to be completely tested and approved as a stand alone entity, and all interface scenarios then require testing. This phase, particularly in regard to air handling plant, can take a large amount of time. The provision of air flow switches downstream of fans and independent damper position indicators can shorten this period substantially.

The building warrant of fitness requirements of the Building Act requires that these scenarios be certified annually.

Response of HVAC / Detector Location	Services/Plant	Penguin Area	Queueing	Kiosk	Scott 1911	Scott 2000	Inter-active	Quarantine	Link	Existing Att.	NE Offices
1 Plant Ex	1	1	1	1	1	1	1	1	1	1	1
2 Plant Ex	1	1	1	1	1	1	1	1	1	1	1
3 Ceiling Void	0	0	-	-	-	-	-	-	-	-	-
4 Ceiling Void	0	0	-	-	-	-	-	-	-	-	-
5 Fresh Air	R	1	R	1	R	1	1	1	1	1	1
6 Lt. Duct	-	-	-	-	-	-	-	-	-	-	-
7 Lt. Duct	-	-	-	-	-	-	-	-	-	-	-
8 Toilet Ex Sth	1	0	0	0	0	0	0	0	0	0	0
9 Spill Orca	-	0	-	-	-	0	-	-	-	-	-
10 Fresh Air	1	1	1	1	1	R	1	1	1	1	1
11 Fresh Air	1	1	1	1	1	R	1	1	1	1	1
12 Workshop Ex	0	0	0	0	0	0	0	0	0	0	0
13 IA Supply	0	0	0	0	0	R	0	0	0	0	0
16 Batt Ex	0	0	0	0	0	0	0	0	0	0	0
18 ABS re-circ	-	-	-	-	-	0	-	-	-	-	-
19 Orca re-circ	-	0	-	-	-	0	-	-	-	-	-
20 Compressor	-	0	-	-	-	0	-	-	-	-	-
21 Kiosk	0	0	0	1	0	0	0	0	0	0	0
22 Loading	-	0	-	-	0	0	0	-	-	-	-
23 Cod tank	-	-	-	-	-	0	0	-	0	-	-
24 Projector	-	0	-	-	-	0	-	-	-	-	-
25 Projector	-	0	-	-	-	0	-	-	-	-	-
26 IA Spill	0	0	0	0	0	R	1	0	0	0	0
27 IA Spill	0	0	0	0	0	R	1	0	0	0	0
Tank Ex Sth	0	0	0	0	0	0	0	1	0	0	0
Tank Ex Nth	0	0	0	0	0	0	0	1	0	0	0
Quarantine Inlet	1	1	1	1	1	1	1	0	1	1	0
Quarantine Ex	0	0	0	0	0	0	0	1	0	0	0
Kitchen Ex	0	0	0	0	0	0	0	1	0	0	1
Toilet Ex Nth	0	0	0	0	0	0	0	0	0	1	0
Theatre Ex	0	0	0	0	0	0	0	0	0	1	0
NW Inlet	1	1	1	1	1	1	1	1	1	0	1
Toilet Sth MFD	S	1	1	1	S	1	1	1	1	1	1
Penguin/Plant Damper	S	1	S	S	S	S	S	S	S	S	S
Queueing MFD	S	1	1	1	S	1	1	1	1	1	1
Scott 1911 MFD	S	1	S	1	1	1	1	1	1	1	1
Orca MFD	1	S	1	1	1	S	1	1	1	1	1
Evap Fans A,B,C	1	0	1	1	1	0	1	1	1	1	1

Key
1 = On - normal direction and Open (dampers)   R = On - reverse direction
O = Off   S = Shut (dampers)   - = Does not matter

Table 11.1: Example of a logic matrix for a recent new building

Chapter 12
Provision for Fire Service Operations

12.1 Introduction

The objective of provisions for Fire Service operations is to ensure that the Fire Service is able to perform those functions required by legislation and those functions required to meet the specified performance criteria for the building.

12.2 Scope

Various factors are important in the design of buildings to facilitate Fire Service operations in the event of fire and other emergencies. The Building Act and the Building Code place functional requirements on buildings to enable Fire Service rescue and fire suppression operations to take place, with requirements to safeguard fire fighters. The Approved Documents to the Building Code set out some of these requirements in the Acceptable Solutions in a prescriptive fashion as one means of meeting the objectives of the Building Code.

The Fire Service Act empowers the New Zealand Fire Service Commission to recommend that the Minister issue codes of practice relating to building fire safety and sets out the basis for the Fire Service to provide advice to territorial authorities on fire safety issues. The Act also requires the National Commander of the New Zealand Fire Service to issue a Code of Practice for fire fighting water supplies to enable effective fire fighting operations to take place.

This chapter describes areas where the Fire Service Chief Fire Officer should be consulted for information on particular aspects relating to building design and Fire Service operations. Building designers, owners and managers are encouraged to contact the Fire Safety Department of the Fire Service for advice and information on any other issues relating to building fire safety and fire protection. Further details about Australian fire brigade acts are given in Chapter 16.

12.3 Fire Brigade intervention model

The Australasian Fire Authorities Council (AFAC, 1997), on which the New Zealand Fire Service is represented, have produced a document describing a quantitative model of fire brigade operations. This model is suitable for use in conjunction with performance-based fire engineering design. The model incorporates a wide range of factors including the following:

- Time to fire detection both by automatic systems and by human factors. (Human factors are uncertain and very subjective, depending on building occupancy and times when occupied);
- Time to notification of the Fire Service;
- Fire Service travel time to arrive at the incident;
- Access and search times for all floors;
- Fire attack time.

12.4 Vehicular access

The Fire Service requires vehicle access to buildings in order to provide rescue equipment and fire fighting water in the event of a fire. The New Zealand Fire Service is developing guidelines based on the requirements of the Building Code Acceptable Solution C/AS1. These guidelines (NZFS 2001) provide vehicular access information required by the Fire Service:

Fire Service foot access. Dense smoke can kill occupants and make entry very difficult for fire fighters.

- Minimum access road load bearing capacity;
- All weather trafficability;
- Minimum access route widths, clearances and turning circles;
- Hard standing areas;
- Maximum distances from buildings to access roads; and
- Access to Fire Service inlets, fire alarm panels and building entrances.

Pumping appliances should be able to approach within 18 m of a building, but aerial appliances generally need to be parked adjacent to the building, usually on a corner. Some requirements for Fire Service access to buildings for fire fighting purposes are set out in the Acceptable Solution to the New Zealand Building Code. If access is provided to entrances on more than one side of the building, then fire fighting and rescue operations will be easier.

The Acceptable Solution to the Building Code require that access be provided to within 18 metres of at least one side of every building on the site except where sprinkler systems and fire hydrant systems are provided, in which case access need only be provided to within 18 metres of the Fire Service inlets. Buildings of purpose groups SC and SD (sleeping care and sleeping detention), greater than seven metres high, require hard-standing areas adjacent to the buildings so as to provide access.

The Building Code of Australia outlines requirements for fire brigade access under Performance Requirement CP9 (see Appendix B of this book).

12.5 Fire systems centres

Fire systems centres, where required, are protected rooms in buildings, provided for locating controls, indicator panels, EWIS systems and information on fire safety and fire protection systems for Fire Service use during emergency incidents.

The New Zealand Fire Service is developing guidelines based on the Building Code Acceptable Solution C/AS1, for the design and functional requirements for fire systems centres. These guidelines also include recommendations for the location of fire safety and protection system controls and indicator panels for buildings not required to have fire

Fire Service vehicle access

systems centres. The Fire Service guidelines (NZFS 2001) provide information on the following features required for fire systems centres:

- Buildings which are required to have fire systems centres;
- Location of fire systems centres within buildings;
- Protection from the effects of fire and falling debris; and
- Equipment, controls and indicator panels required to be located in fire systems centres.

In Australia, those protected locations for fire brigade use are called Fire Control Centres. The Building Code of Australia states that a fire control centre is needed for all buildings over 25 m in height and over 18,000 m^2 in floor area.

12.6 Fire fighting water supplies

The New Zealand Fire Service has published a Code of Practice for Fire Fighting Water Supplies, as is required under Clause 30(3) of the Fire Service Act 1975. This Code of Practice (NZFS 1992) sets out minimum Fire Service performance requirements, Fire Service testing requirements and other requirements for fire fighting water supplies. Contents include the following:

- Risk classifications;

Experimental firefighting using compressed air foam (CAF)

- Minimum flows required and number of hydrants to be used for flow testing for each classification;
- Minimum running pressure;
- Specification for fire hydrants to the requirements of New Zealand Standard NZS/BS750:1984;
- Spacing of hydrants;
- Installation of hydrants to the requirements of New Zealand Standard NZS/BS750:1984;
- Marking of hydrants to the requirements of New Zealand Standard NZS4501:1972 or British Standard BS3251:1976;
- Consideration of the flow requirements for fire protection systems when determining the required water flow rates, including auxiliary water supplies;
- Consultation between Regional Commanders and Territorial Authorities on water supply schemes;
- Minimum reserve storage capacities for water supply schemes;
- Limitation on dead end mains;
- Procedure and performance requirements for testing the adequacy of water supplies;
- Maintenance of water supplies.

The Fire Service is in the process of revising this code. The main purpose of the revision is to reflect the move to performance-based fire engineering. With the introduction of the Resource Management Act, the concept of grouping buildings together that have similar functions has ceased. In this regard, the Code of Practice will require the matching of water supplies to the specific building and its fire risk. This will take into account the fire safety features fitted within the building, the size of the firecells and the type and density of building occupants.

12.7 Fire resistance ratings

Certain building components need to be provided with fire resistance ratings for specified minimum times in order to safeguard fire fighting personnel who enter the building to carry out rescue and fire suppression operations.

Many factors have an impact on the time taken to control and extinguish a particular fire. Times may range from a few minutes for small fires involving few combustibles and not having reached flashover, to a day or more for large deep-seated fires involving large quantities of fuels with limited access. It is not possible to predict with any certainty how long it will take the Fire Service to control and extinguish a fire in a given building.

There are a number of factors which must be taken into consideration when determining the minimum structural fire resistance time needed to allow egress and Fire Service operations to safely take place and to meet the Building Code requirements for firefighter protection. These include:

- Time factors from the start of a fire to the time of Fire Service notification, including the effects of fire alarm systems;
- Fire Service response time and set up time at the fire ground, including the time required to establish water supplies;
- Search and rescue time;
- Time to locate the fire;
- Floor access time;
- Fire fighting time, including control of fire spread both internally and externally, protection of firefighters and time limits for self contained breathing apparatus use;
- Equivalent fire resistance rating compared to real time fire growth.

To allow for these factors, it is recommended that safe paths of exitways be protected in accordance with clause 6.9 of Acceptable Solution C/AS1 in New Zealand or Section C of the deemed-to-satisfy provisions of the Building Code of Australia. Variations from these values, if necessary to meet the performance requirements, should be by specific fire engineering design.

Chapter 13
Fire Fighting Water Supplies

13.1 Introduction

The objective of provision of fire control water supplies is to ensure that sufficient water is available for all automatic and manual fire suppression systems to operate as intended, and for subsequent Fire Service operations.

13.2 Scope

Water is, and is expected to remain, the principal medium used for fire control. The purpose of this chapter is to identify the relevant parameters and outline the design procedures required to ensure the satisfactory performance of water supply systems for fire fighting purposes.

This chapter provides guidance on the water supply aspects of fixed fire protection systems, an outline of Fire Service operational procedures and necessary facilities, and parameters for the design of the fire fighting aspects of water supply network systems.

Within this scope, the objectives are to:

(a) Promote the best possible standard of fire control water supplies to ensure that fires can be controlled and extinguished;

(b) Promote water conservation and limit the release of hazardous substances to the environment as a result of fire;

(c) Provide guidance to the designers of fixed fire protection systems using water as the extinguishing medium;

(d) Set out the important parameters and procedures for water supply facilities that enable the Fire Service to effectively fight building fires;

(e) Identify the important parameters and procedures necessary for the design of water supply network systems for fire fighting purposes;

(f) Provide reference material to enable designers to locate the detailed information necessary to design water supply systems for fire fighting purposes.

13.3 Principal considerations

Water is an excellent fire control medium because it is widely available, clean and cheap, has a large cooling capacity and the resulting steam can assist extinguishment by displacing oxygen from the fire proximity.

Fire will only be effectively suppressed by water application if the rate of cooling through water application exceeds the rate of heat output of the fire. Not all the water applied to the fire will be converted to steam and achieve the maximum possible cooling effect. The extent to which the applied water exceeds the required water is a measure of the efficiency of the water application system (Barnett 1979, 1989, 1992).

The cooling power of water is illustrated in Figure 13.1, which shows that 2.605 MJ of energy are absorbed by one kilogram (or litre) of water as it is heated from 0˚C to steam at 100˚C. This is equivalent to a cooling power of 2.605 MW for each litre/second of water applied to a fire and heated to steam. Additional heat is required to heat the steam to higher temperatures.

These figures can be used to calculate the flow of water required to cool a fire burning at a known heat release rate (in MW), taking into account that not all the water at the fire incident will be put on the fire itself and not all of that water will be heated into steam.

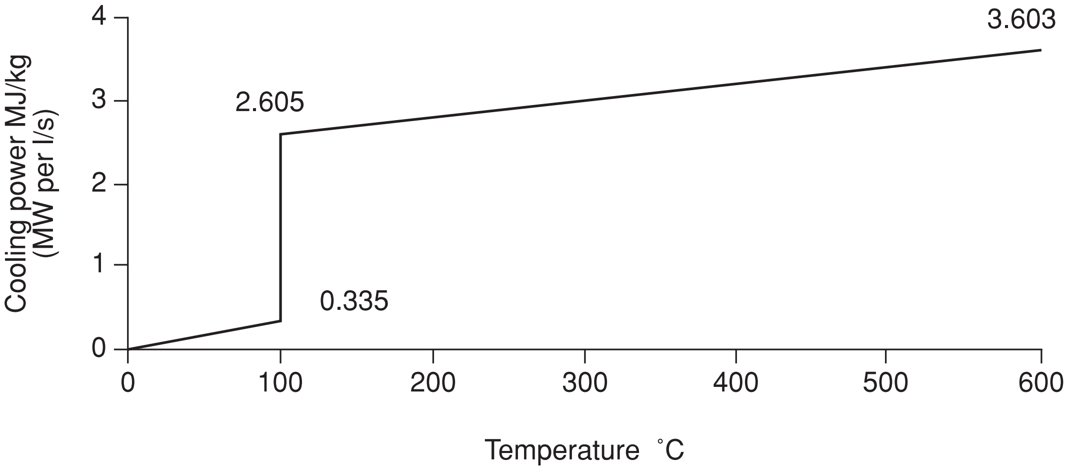


Figure 13.1: Cooling power of water (Barnett, 1989)

An additional benefit of water is its ability to expand and displace oxygen after it has been turned into steam by the heat of the fire. Figure 13.2 shows that steam at 100˚C occupies 1700 times the volume of water, which increases to 4000 times at 600˚C.

Fire sprinkler systems and water spray systems are the most efficient means currently available for suppressing fires by use of water in most types of occupancies. This is because they operate when the fire is small and only over the area affected by fire.

Fire Service operational fire fighting can be a less efficient means of suppressing fire, mainly because of the inevitable delay that allows the fire to grow to a larger size before the Fire Service can apply water to the fire. Streams of water from fire hoses may be less efficient than a well-directed spray of water, such as from a sprinkler, and generally results in considerably greater water supply demands. This also gives greater runoff of water and, where hazardous materials are involved, can be a greater source of pollution.

13.4 Water supply requirements

Water quantity

In order to determine the necessary performance characteristics of a fire fighting water supply, the following must be determined or calculated:

(a) the expected fire growth rate curve;

(b) the fire intensity at the time the fire is attacked;

Fire hydrant connection from street main to Fire Service hose

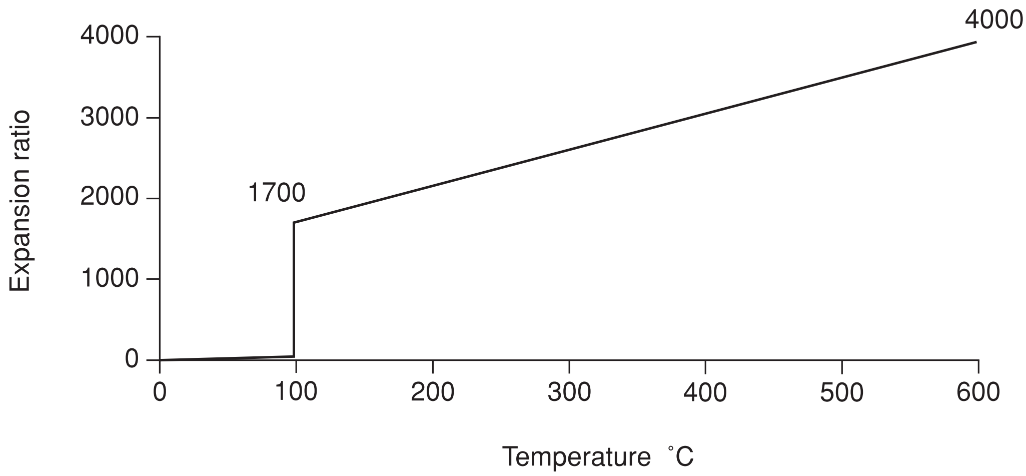


Figure 13.2: Expansion of steam (Barnett, 1989)

(c) the expected duration of the fire and the peak fire intensity;

(d) the water supply required to match the peak fire intensity; and

(e) the ratio of applied water to required water for the intended fire fighting water application system.

If the anticipated point of fire attack on the fire growth curve precedes the peak fire intensity, then it is also necessary to understand and allow for the response time variables involved in the chosen method of water application.

Reliability

Reliability must be considered so that assumptions concerning the availability of water at a particular point in the fire growth curve will prove valid at the time of the fire. Reliability issues include the following:

(a) mechanical reliability;

(b) vulnerability to damage from either malicious or other causes;

(c) planned shutdowns of the system;

(d) uses of the water supply not related to fire, which may increase over time;

(e) gradual deterioration in the water supply due to corrosion and deposition in pipes, and other reasons;

(f) repairability;

(g) earthquake damage;

(h) climatic or other natural phenomena.

Uncertainty factors need to be allowed for by incorporating appropriate safety margins in the water supply design.

Water conservation

The widespread use of fire sprinklers can have important implications in terms of water conservation and limiting the release of hazardous substances to the environment by rapidly controlling fires while they are small.

Statistics demonstrate the effectiveness of fire sprinklers — over the last 106 years, 96% of fires in sprinklered buildings have been controlled by the operation of ten or fewer sprinklers (Maryatt 1988). An analysis of these figures gives a predictable average total water consumption of approximately 5000 litres to control each fire. In comparison, for fires in unsprinklered commercial and industrial buildings controlled by Fire Service intervention, much greater volumes of water per fire will generally be used. This implies that a much greater volume needs to be available from the water supply reticulation for unsprinklered buildings.

If sprinkler systems were made mandatory in all buildings, it is likely that savings in water supply system costs, water consumption and fire fighting costs could be achieved. This has been demonstrated in some places in North America, where territorial authorities are required to provide fire fighting services.

Water quality

Water of a wide range of purity is effective as a coolant, but the characteristics of the water delivery system (including those of any additives used to improve fire suppression properties) may require that water quality is within specific limits. The corrosive effects of seawater on fire protection systems and excessive water damage after a fire due to corrosion normally precludes the use of seawater, except where no other water source is available.

Statutory requirements

A variety of statutory requirements apply to some forms of fire control water supplies, and in the case of particular types of water application systems, technical codes such as New Zealand or other Standards may impose requirements on the water supply upstream of the system under consideration.

Risks greater than normal

Where a proposed development will result in a fire risk considerably greater than the normal fire risk for the available water supply in a particular area, the responsibility for providing sufficient fire control water supplies to protect the proposed risk should be established. The territorial authority may be prepared to provide an adequate fire fighting water supply or may require that the developer provides suitable fire fighting water supplies. The developer may be required to upgrade the water mains or provide on site water storage and pumping capacity sufficient to protect the fire risk of the proposed development.

Worked example: water supplies

For a ventilation-controlled wood fuel fire, calculate the amount of water to give cooling power equal to the heat release rate. Assume a room with one window.

Window width	$w = 4.0\,\text{m}$
Window height	$h = 2.0\,\text{m}$
Window area	$A_V = w\,h = 8\,\text{m}^2$
Rate of burning	$\dot{m} = 5.5\,A_V\sqrt{h} = 62.2\ \text{kg/min}$ (eqn 5.5)
Calorific value of wood	$h_a = 16\ \text{MJ/kg}$
Heat release rate	$Q_V = \dot{m}\,h_a = 996\ \text{MJ/min} = 16.6\ \text{MW}$
Cooling power of water	$Q_W = 2.605\ \text{MW}/(\text{l/s})$
Cooling efficiency, say	$k_c = 0.10$
Water flow required	$V_W = \dfrac{1}{k_c}\dfrac{Q_V}{Q_W} = 63.7\ \text{l/s}$

13.5 Sprinklers

Fire sprinkler systems

Fire sprinkler systems consist of a network of pipes in a building connected to a water supply with sprinkler heads throughout the building. The sprinkler heads are fitted with a heat sensitive element that operates at a defined temperature under fire conditions. This opens the sprinkler orifice to spray water on to the fire, and the water flow activates an alarm (see Chapter 9).

Fire sprinklers are a very efficient means of controlling fires, as they operate when the fire is small and only at the required location with an optimum spray pattern for control and extinguishment.

It is essential to ensure that the sprinklers are not defeated by storage practices that unduly increase the fire hazard, fuel load or storage height.

Design alternatives

In the Acceptable Solutions to the Building Code, certain design alternatives are available for the use of fire sprinkler systems, such as a reduction in fire resistance ratings and an increase in the maximum firecell size. These alternatives originated as an incentive to install sprinklers in recognition of their effectiveness.

Caution must be exercised when applying design alternatives using sprinklers because of the possibility of the sprinklers not operating, in which case an uncontrolled fire would be likely to occur.

Design alternatives should always be thoroughly investigated by building designers, as they may result in greater levels of protection without the expected increase in cost.

13.6 Fire Service operational fire fighting

The principal method of fighting fires in New Zealand is by manual fire fighting by the Fire Service. The Fire Service needs significant quantities of water to carry out fire fighting duties.

The operational procedures used for fire fighting are set out in the New Zealand Fire Service Manual of Operations (NZFS 2000). Specific operational fire fighting requirements may be identified in consultation with the local Regional Commander of the New Zealand Fire Service. The requirements for fire fighting water supplies are specified in the New Zealand Fire Service Code of Practice for Fire Fighting Water Supplies (NZFS 1992). Australian fire brigades have similar operational procedures and requirements.

Fire hydrant systems

Fire hydrant systems are necessary in tall buildings to allow the Fire Service to provide water on the fire floor without having to lay hoses and carry portable booster pumps up stairs, a slow and laborious procedure. Fire hydrant systems are also needed in large low rise buildings such as shopping malls and airport terminals for similar reasons.

Fire hydrant system design and installation requirements are specified in the applicable codes such as NZS 4510:1998 Fire Hydrant Systems for Buildings in New Zealand and AS2419:1994 in Australia. Fire hydrant systems will not function adequately if the water supply is deficient.

13.7 Testing of water supplies

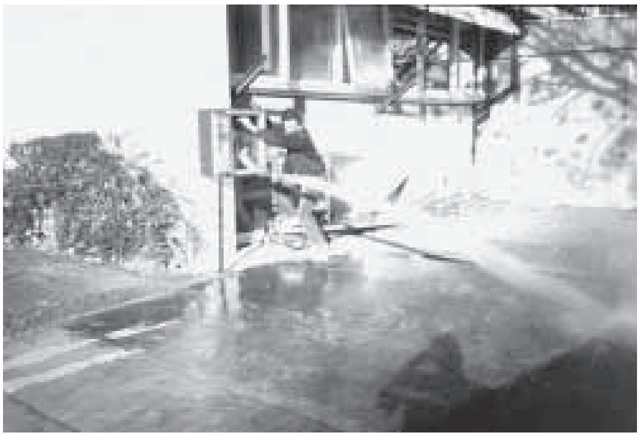
Timing of water supply tests

The timing of water supply tests should be set in consultation with the territorial authority and any other authorities having jurisdiction. The territorial authority is unlikely to agree to undertaking a full mains flow test during times of peak domestic and industrial demand due to a probable reduction in supply to other consumers. However, the territorial authority will generally be able to provide information on the domestic and industrial water supply demand under normal conditions at different times of the day. This information should be taken into account when calculating the available fire fighting water flows. On the other hand, when evaluating flow tests on water supplies for sprinkler systems, the Insurance Council of New Zealand will want to make sure that acceptable flows and pressures are available at all times, even during times of peak domestic and industrial demand.

Major fluctuations in water supply flow rates and pressures occur during a day and during a year. These fluctuations are not detected by flow tests because these are carried out infrequently.

Fire sprinkler system flow tests

Fire sprinkler system water supplies are normally flow tested by using a flow meter connected to the Fire Service inlet coupling. A special connecting pipe between the Fire Service inlet coupling and the flow meter, which has a projection that opens the non-return valve that normally prevents flow out of the Fire Service inlet, is used. The flow is regulated by the valve provided in the pipe connecting the Fire Service inlet to the sprinkler system. Normally, the flow is increased in steps up to the highest flow that the system has been designed for and pressure readings are taken in conjunction with the flow readings. The flow tests are normally carried out by sprinkler contractors or agents of the Insurance Council. The pressures and flows must be above the minimum levels calculated for the correct functioning



Testing of water supply for sprinkler system

of the particular sprinkler system using the procedure specified in Standards such as NZS 4541:1996, Automatic Fire Sprinkler Systems, and NZS 4515:1995, Residential Fire Sprinkler Systems (AS2118:Parts 1 - 6 in Australia).

When designing sprinkler systems, it is unwise to design for the use of all of the allowable percentage from NZS 4541 of the available water pressure and flow, because the performance of water supply networks tends to deteriorate over time due to corrosion and deposition in the pipes and a gradual increase in domestic and industrial demand. If allowance is not made for these factors, it is likely that the water supply will become deficient in the future. It is usual to design using somewhat less than 80% of the available pressure at the design flow.

Flow tests for fire hydrant systems in buildings

Fire hydrant systems are tested by flowing water from the highest outlet, which is commonly found on the roof. They are flow tested from the Fire Service inlet using a water supply from a street hydrant through a pump. The flow and pressure available are measured as the highest outlet. Wet hydrant systems (which have a permanent water supply from a town main connection) are flow tested using the installed water supply and pumps. The flow and pressure are recorded at the outlet and the pressure at the water supply inlet is also measured. These pressures and flows must be within the limits specified in NZS 4510:1998 Fire Hydrant Systems for Buildings or AS2419 in Australia.

Fire hose reel system flow tests

Fire hose reel systems are flow tested at each hose reel to verify that the flow rate specified in NZS 4503:1993 Code of Practice for the Distribution, Installation and Maintenance of Hand Operated Fire Fighting Equipment in Buildings is achieved. The Standard does not specify the minimum pressure required at the hose nozzle, although this standard specifies that the nozzle must produce a jet of at least 6 m at a discharge rate of 14 l/min. A simple flow test is normally performed by timing how long it takes to flow a measured quantity of water with the hose valve and nozzle fully open and two adjacent hose reels in simultaneous operation. Each reel must produce 14 l/min, so the total flow required for a hose reel system is 42 l/min. The test flow rate must be above the minimum specified for the particular hose and nozzle combination used.

Fire Service water flow tests

The requirements and the procedures to be used for flow testing water mains for fire fighting water flows are set out in the New Zealand Fire Service Code of Practice for Fire Fighting Water Supplies (NZFS 1992). The Fire Service (in consultation with territorial authorities) currently tests water supplies in urban Fire Districts as required by the Fire Service Act. These tests take the form of flow tests from street hydrants with a simultaneous pressure reading. The Fire Service procedure is to simultaneously flow test the mains within a radius of 270 m while taking pressure readings at the same time. As there are likely to be several hydrants within the 270 m radius, the number of hydrants that need to be flow tested to assess the required total water flow are specified in the Code of Practice. The pressure reading must be taken from a non-flowing hydrant or from another take-off on the main.

Water supply system computer simulation

Some territorial authorities use computer programs to model their water supply reticulation systems. These programs have yet to be properly verified and thus may not be used to predict available water supply pressures and flows. Once validated, these programs for water supply system simulation may reduce the need to perform flow tests with consequent savings in both water usage, time and labour.

13.8 Design of fire fighting water supply networks

Design of fire fighting water supplies must recognise the relevant physical laws, including pressure losses due to hydraulic friction, the effects of elevation and altitude, specific gravity, vapour pressure and other fluid mechanics and mechanical engineering principles.

General

Many factors must be taken into account when specifying the performance required from mains water supplies used for fire fighting purposes. For the vast majority of fires controlled by the Fire Service, water from a reticulated mains supply is the only extinguishing medium used. In urban areas, the territorial authority underground water mains are the primary water supply. In rural areas and as a secondary supply in urban areas, water supplies pumped from natural or constructed bodies of water are used. Another factor which should be taken into account is seasonal variations in water supply performance. In some areas, the available water pressure and flow is less in summer than in winter due to lower river flows and higher domestic demand.

Sources of supply

The predominant water supplies are underground reticulated mains. The sources of supply for most systems are bores or rivers with the water extracted from dams or intake structures. The raw water normally requires treatment and is then pumped to elevated storage reservoirs. Storage reservoir capacity sufficient for at least two days average consumption is normally provided to allow for the supply pumps being temporarily out of service and to allow for sudden excessive demands. For fire fighting, the water source, reservoirs and pumping systems must be as reliable as possible all the year round. This can be a problem where smaller rivers are the source and river flows are low in summer. It is preferable to have at least two sources of supply for greater reliability and security of supply.

Reticulation networks

The water is piped from the reservoirs to the reticulation network, and a relatively constant pressure is attained in well-designed networks due to the gravity head provided by the elevated reservoirs. In undulating areas, the network may be divided up into pressure zones controlled by pressure control valves to avoid excessive pressures in low lying areas. Flat areas are sometimes pressurised by continuously running pumps where gravity storage reservoirs are not used. These pumped systems are satisfactory for fire fighting purposes provided that standby pumps are installed and the pumps are not dependent solely on the mains electrical supply.

Water supply network design criteria

In the design of water supply networks two demand criteria must be met. These are:

(a) potable water demand for domestic and industrial consumption;

(b) water demand for fire fighting purposes.

Domestic and industrial water supply design

Factors the designer must take into account in designing for the domestic and industrial water demand come under the following categories (Barnett 1979):

(a) hydraulic design of the network to provide for the estimated present and future water demand;

(b) the provision of pressure zones with minimum and maximum allowable pressures under all demand conditions;

(c) provision of sufficient number and capacities of storage reservoirs to cope with demand fluctuations and temporary interruptions to the supply from the water sources;

(d) selection of materials and installation techniques to provide the required levels of durability and life from the system. It should be noted that plastic or fibreglass pipes may provide a considerably longer service life than metallic pipes in corrosive ground conditions and they do not suffer from corrosion or significant flow reduction due to internal deposition. The use of asbestos cement pipes has been discontinued due to concerns about safety with asbestos both during installation and use.

Fire fighting water supply design

For fire fighting purposes, a minimum running pressure of 100 kPa from street hydrants should be attained and minimum flows of from 200 to 25 l/s in Classes A to E areas, based on fire risks, from specified numbers of hydrants within a radius of 270 m.

These requirements are specified in the Code of Practice for Fire Fighting Water Supplies (NZFS 1992). Water supply systems are normally designed to NZS 9201 Chapter 7:1974, Model General Bylaw, Water Supply. Note that the normal practice in New Zealand for the design of water supply networks is to design for the greater of the maximum potable or fire fighting water demand, but not for the simultaneous maximum demand (Barnett 1979). Factors that must be taken into consideration when designing for the fire fighting water demand are as follows:

(a) Hydraulic design to provide for the required fire fighting water flows — these flows may be greater or less than the domestic and industrial water demand in different circumstances.

(b) Selection of the required locations, spacing and marking of street fire hydrants — the requirements for street hydrants and surface boxes are specified in NZS/BS 750:1984 Specification for Underground Fire Hydrants and Surface Box Frames and Covers.

(c) The provision of sufficient flow capacity for known and probable future fixed fire protection systems.

Hydraulic design procedure

The hydraulic design of the water supply network is normally performed with the assistance of computer programs capable of performing a detailed hydraulic analysis under all flow conditions. The hydraulic calculation method normally used is the Hardy Cross method. While the designer must have a full understanding of hydraulic design calculation procedures, practical manual calculations can only provide estimated results due to the number of simultaneous equations to be solved. The design parameters are based on accepted municipal water supply design practice and statistics of the water demand in areas similar to those under consideration. A representative value for the domestic water demand in New Zealand is approximately 220 litres per person per day and total demand is increasing at a rate of approximately 2% per year.

13.9 Design of water supplies for fixed fire fighting systems

General

The procedure used for sprinkler system water supply design consists of deciding what design flow is required to protect the risk, the water sources and classes of water supply to use, whether pumps and water storage tanks are required and, finally, the required pump performance. The pipework must be designed to ensure that the minimum pressures required at the sprinklers are achieved at the design flows with the required safety margins. Three classes of water supplies are recognised in NZS 4541:1996, Automatic Fire Sprinkler Systems, and these provide different levels of reliability and availability in the water supply.

The three classes of water supplies are as follows:

(a) Class A — Two fully independent water supplies such as a town main and a tank and pump system;

(b) Class B — Two independent town main water supplies;

(c) Class C — Single water supply.

Class B supplies can only be provided where the reticulation is supplied by at least two independent water sources. The reticulation is arranged such that at least one supply always remains available should a breakdown occur in any one part of the system.

Even for a single town main, it is preferable for it to be fed from two directions.

Where insufficient water pressure is available, an approved automatic starting diesel pump must be used. Such a pump may be designed to pump from the town main, a tank, a well, an artesian bore or open water, provided that the supply is reliable and the pump always operates under flooded suction conditions.

On a dual supply (Class A) system, one supply may have an electric powered pump. All sprinkler systems, except some residential systems, are also required to have a Fire Service inlet to enable the Fire Service to boost the water supply with their pumps.

The installation of a water meter is prohibited by the Sprinkler Rules; however, it has become acceptable to install a full bore meter that has no working parts or obstructions in the water way. Backflow prevention at the site boundary is also required where the secondary water supply is from a non-potable water source; this means that strainers and pressure gauges may be required to be installed upstream of the backflow prevention.

Pipework design for fire sprinkler systems

The pipe friction losses for sprinkler system pipework are calculated using the Hazen Williams formula, and sprinkler flows are calculated using the sprinkler discharge formula. The applicable Standard will specify the required hydraulic calculation procedure. Sprinkler system design Standards used are NZS 4541:1996, Automatic Fire Sprinkler Systems, NZS 4515:1995, Residential Fire Sprinkler Systems. Some American companies use NFPA 13 Installation of Sprinkler Systems as a standard for all their installations throughout the world, including New Zealand, or AS2118 from Australia can be used.

NZS 4541 specifies the method for calculating the design pressures and flows for sprinkler systems.

Full hydraulic calculation is normally used to calculate the pressures and flows from all the sprinkler heads operating in the design area and the pressure losses back to the control valves. This method provides an accurate result for the required water demand, but it is normally necessary to use a computer program to determine the pressure losses and the optimum pipe sizes from both a hydraulic and economic point of view. The required pressure and flow rate from the water supply is the minimum pressure and flow which is required at the control valves to supply the hydraulically most remote design area of sprinkler operation and the minimum flowing pressure to the most remote sprinkler head. NZS4541 specifies two methods for determining the allowable water demand from town main supplies. Up to 80% of the available pressure from a single flow test at the design flow may be used or, alternatively, up to 90% of the minimum available pressure at the design flow based on a pressure recorder test taken over not less than 14 consecutive days. However, it is prudent to design for less than those maximums, as the performance of town mains deteriorates over time due to tuberculation of pipes and increasing overall water demand.

Fire hydrant systems in buildings

Hydrant main systems are installed in multi-storey buildings and certain other large buildings to provide a water supply for operational fire fighting at all levels of the building. The required pressures and flows at the outlets are specified in NZS 4510:1998 Fire Hydrant Systems for Buildings. Hydraulic calculation is used to determine the required pressure and flow from the water supply at the Fire Service inlet or at the pump inlets for wet fire hydrant systems. The designer of the system must ensure that the pressures and flows required at the Fire Service inlet meet the requirements of the New Zealand standard. Provided minimum pressure criteria can be met, this means that the normal fire fighting water supply for fire hydrant systems and the secondary supply for wet fire hydrant systems comes from street fire hydrants through Fire Service pumping appliances.

Fire hose reel systems

Fire hose reels are intended for use on small fires by the building occupants before the arrival of the Fire Service. Sufficient water pressure and flow must be available at each of the hose reels for them to be an effective fire fighting tool.

Fire hose reel systems can be supplied from any water supply system capable of reliably providing the necessary pressure and flow, and that has metallic pipe for all of the above-ground pipework. The flow rates required for hose reels are considerably lower than those required for most other fixed fire protection systems; this normally means that the fire hose reels can be supplied from the normal building potable water supply system.

NZS 4503:1993, Distribution, Installation, and Maintenance of Hand Operated Fire Fighting Equipment for use in Buildings, specifies the minimum flow required at the hose reels and hydraulic calculation is used to calculate the required pressure and flow from the water supply. The pressure required to achieve the flow is given in the hose reel manufacturer’s data and is printed on the reels.

Note that some territorial authorities may insist that the water supply to fire hose reel systems be metered to account for water used for purposes other than fire fighting. The flow rates required for hose reels are not significantly reduced by the presence of a water meter, but positive displacement type water meters provide an unacceptable restriction in the supply to sprinklers or wet hydrant systems.

Notification to the Fire Service

After designing or modifying a fixed fire protection system, the designer should notify the local Chief Fire Officer of the New Zealand Fire Service of the water flows and pressures required for that system, so that the Fire Service can incorporate this information in their operational plan for the water supply in the area. The designer must also consult with the Fire Service when deciding the location of Fire Service inlets and sprinkler valve sets to ensure that they meet Fire Service operational requirements. Most fixed fire protection systems, such as fire sprinkler systems, must be continuously monitored by the New Zealand Fire Service, normally by means of the telephone network.

13.10 Operational fire fighting

Fire Service procedure

Mains water supplies are used for operational fire fighting in the following manner. Feeder hoses are connected to standpipes fitted to street fire hydrants. These hoses are then connected to fire appliance pumps. This provides the Fire Service with the ability to boost and control pressures. Delivery hoses or high pressure hose reels are run out from the pumps, to be used by firefighters to fight the fire. Fire appliances are equipped with water tanks to enable faster fire attack, but these tanks may be rapidly depleted and other supplies are required to suppress all but very small fires. Some industrial sites are equipped with pressurised fire fighting water supplies to enable fire fighting operations to take place directly from hydrants without having to boost the supply using a fire appliance pump. However, this is not a substitute for normal Fire Service procedures. Private fire mains are often designed to NFPA 24:1995 Standard for the Installation of Private Fire Service Mains and their Appurtenances.

For successful operational fire fighting, the water supply must be capable of producing sufficient water flows to provide the extinguishing capacity necessary to control the largest fire that can be reasonably predicted without subjecting the mains to suction pressures close to atmospheric pressures. For some occupancies, due to the fire load and possible fire intensity, it may be necessary to install a sprinkler system to ensure that fires can be controlled.

Fire Service access and facilities

In order for the Fire Service to be able to effectively fight building fires, suitable access and facilities must be provided. First, sufficient street fire hydrants must be provided within a reasonable distance to enable the fire fighters to quickly establish an adequate water supply. Second, suitable access and hard standing areas need to be provided to enable the Fire Service appliances to approach to within a reasonable distance of the burning building.

13.11 Legislation

The legislation relating to fire fighting water supplies comprises sections of various acts of parliament. Copies of the relevant clauses of these acts and regulations are included as appendices to this chapter.

There is no direct legislation that requires territorial authorities to provide fire fighting water supplies, but where reticulated mains water supplies are provided, fire hydrants must also be provided.

The Local Government Act 1974 sections 647 and 648 state the requirements for territorial authorities to fix fire hydrants to water mains with the approval of the New Zealand Fire Service Commission, to mark and maintain them to an acceptable standard and to keep the pipes charged with water at all times.

The Fire Service Act 1975 section 28(4)(g) states that the Fire Service has the power to cause the water supply to other users to be shut off to conserve the supply for fire fighting. The Fire Service Act Section 30 states that the Fire Service shall have full use of the available water supply for fire fighting free of charge. They may test water supplies to determine their adequacy for fire fighting and fixed fire protection systems and shall advise the territorial authority of the results of these tests. The National Commander shall prepare a code of practice for fire fighting water supplies setting out the volumes and pressures required for fire fighting and fixed fire protection systems. The requirement to include the pressures and flows for fixed fire protection systems was included in the Fire Service Act in an amendment made in 1990. Under the Fire Service Act (2) Section 30, water used for fire fighting must be provided free of charge, but territorial authorities are entitled to charge for the costs of installing and maintaining fire protection water supplies as well as annual fees for the connections.

The Building Act 1991 and the Building Regulations 1992 indirectly create requirements for water supplies for fire fighting purposes. For example, Section 6(2)(c) of the Building Act states that effects on the environment caused by fire in buildings containing hazardous substances be controlled. In practice, this means that adequate water supplies must be available, either from the reticulated supply or from an on site supply, to rapidly control fires. Provision may also need to be made to contain contaminated fire fighting water runoff. The use of automatic sprinkler systems in these cases may reduce the water supply demands and the size of any required water containment provisions. The Acceptable Solution to the Building Codes also specify that some buildings must be provided with fixed fire protection systems; this implies that suitable water supplies must be provided for those buildings. The Building Code Acceptable Solution C/AS1 states that one of the factors affecting the required fire resistance is the availability of an adequate water supply.

The Water Supplies Protection Regulations 1961 Section 7 states the requirements for back flow preventers and other requirements to prevent contamination of mains water supplies. These requirements must be met by all water users, including fire fighting and fixed fire protection systems. The requirements for maintenance and testing of backflow preventers are included in the compliance schedules listed in the Approved Documents to the New Zealand Building Code.

Five sprinkler system alarm valves, with the addition of a check valve, have been considered to be adequate back flow prevention. However, some Territorial Authorities are now demanding a separate back flow preventer at the boundary.

APPENDIX 1 The Local Government Act 1974 Sections 647 and 648

647. Fire hydrants

(1) In every part of the district in which there is a water supply provided under Part XXIII of this Act, the council shall fix fire hydrants in the main pipes, other than trunk mains, of the waterworks at the most convenient places for extinguishing any fire as the council determines, or, in any part of the district that is included in a fire district under section 26 of the Fire Service Act 1975, as the New Zealand Fire Service Commission approves, and shall keep those fire hydrants in effective working order.

(2) Where a water supply is provided in the district or in any part of the district by any other local authority, the council may arrange with that local authority to fix fire hydrants in the main pipes, other than trunk mains, situated in the district or in that part, as the case may be.

(3) Fire hydrants shall be fixed at such distances from each other as the council decides or, in the case of hydrants fixed in any part of the district that is included in a fire district of the New Zealand Fire Service Commission, as that Commission approves.

(4) The council shall put near each fire hydrant a conspicuous notice or a mark of a kind approved by the New Zealand Fire Service Commission, in the case of a hydrant fixed in any part of the district that is included in a fire district of that Commission, or, in any other case, approved by the council, showing the situation of the hydrant, and that notice may, if the council thinks fit, be put on any building.

(5) In this section the term “trunk main” means a main used for the purpose of conveying water from a source of supply to a filter or reservoir, or from one filter or reservoir to another filter or reservoir, or for the purpose of conveying water in bulk from one part of the limits of supply to another part of those limits, or for the purpose of giving or taking a supply of water in bulk.

(6) Where the council is dissatisfied with any decision of the New Zealand Fire Service Commission under this section, it may, within one month after receiving notice of the decision, appeal against that decision to a District Court, whose decision shall be final.

648. Pipes to be kept charged with water

(1) Except in case of unusual drought, or of accident, or of shortage from any cause of the water supply, or during necessary repairs, connections, or inspections, or of a civil defence emergency under the Civil Defence Act 1983, the council shall at all times keep charged with water the pipes in which fire hydrants are fixed by the council under section 647 of this Act.

(2) Subject to the overall requirements of the Regional or Local Controller of Civil Defence while a state of civil defence emergency exists under the Civil Defence Act 1983, the council shall allow all persons to take and use water from any waterworks or water race for extinguishing fire without any payment for the same.

APPENDIX 2 The Fire Service Act 1975 Sections 28(4)(g) and 30

28. Functions, duties, and powers of Chief Fire Officer

(4)(g) May, subject to section 30 (1) of this Act, cause water to be shut off from, or turned into, any main or pipe in order to obtain a greater pressure and supply of water:

30. Fire Service to have use of water in mains, etc.

(1) Subject to the overall requirements of the Regional or Local Controller of Civil Defence, as the case may be, while a state of civil defence emergency exists under the Civil Defence Act 1983, every fire service, defence fire service, and industrial fire service shall, free of charge,

(a) Have the use of all hydrants and control valves installed in any water mains and of all water in the water mains for the purpose of extinguishing any fire or stabilising or rendering safe any hazardous substance emergency or for the purpose of fire service drills conducted under the authority of the Chief Fire Officer: Provided that no such fire service shall use for drills water supplied by any person or authority (except within its own Fire District without the consent of that person or authority; and

(b) Have the use of all water in any river, creek, stream, watercourse, channel, lake, lagoon, well, tank, or other source of water supply whatsoever for the purpose of extinguishing any fire or stabilising or rendering safe any hazardous substance emergency.

(2) The National Commander may from time to time cause to be made such checks as the National Commander considers necessary as to the adequacy of water supplies, including tests of water volume and pressure in any water main, in any Fire District or within any area concerning any property that the Fire Service is under an obligation to protect pursuant to section 38 or section 39 of this Act, and shall advise the territorial authority or authorities as to the sufficiency or otherwise of the water supply of the Fire District or the area available for fire fighting and for the effective operation of such fire protection systems that may from time to time be installed in buildings or property installations within the Fire District or the area.

(3) In carrying out its duties pursuant to subsection (2) of this section the National Commander shall publish a Code of Practice specifying standards for water supply volume and pressure which are required. This Code of Practice shall be notified by the National Commander in the Gazette.

APPENDIX 3 The Water Supplies Protection Regulations 1961 Section 7

PART II BACKFLOW PREVENTERS

7. Backflow preventers

(1) For the purposes of these regulations

(a) Double check valve assemblies, reduced pressure principle backflow prevention devices, and vacuum columns, as described in paragraphs (b), (c), and (d) of this subclause, are backflow preventers:

(b) A double check valve assembly is an assembly of at least two independently acting check valves including gate valves on each side of the check valve assembly and suitable leak detector drains together with connections available for testing the watertight efficiency of each check valve:

(c) A reduced pressure principle backflow prevention device is a device that incorporates an automatically operating differential relief valve located between two check valves, and also incorporates two gate valves, and is equipped with the necessary appurtenances for testing, and complies with the following requirements:

(i) It shall operate to maintain the pressure in the zone between the two check valves less than the pressure on the public water supply side of the device:

(ii) At cessation of normal flow the pressure between check valves shall be less than supply pressure:

(iii) In the case of leakage of either check valve the differential relief valve shall operate to maintain this reduced pressure by discharging to the atmosphere:

(iv) When the inlet pressure is 14 kilopascals or less the relief valve shall open to the atmosphere, thereby providing an air-gap in the device:

(v) The devices shall be readily accessible for maintenance and testing and be installed in a location where no part of the valve will be submerged:

(d) A vacuum column is an arrangement of pipes which forms an inverted U extending upwards to a point not less than 10.5 metres above the highest point in the service pipe and in which there cannot be excess pressure on the property side of the column.

(2) A check valve for the purpose of these regulations is one which seats readily and completely when closed, and which complies with the following requirements:

(a) It must be carefully machined to have free moving parts and assured watertightness:

(b) The face of the closure element and valve seat must be bronze, composition, or other corrosion-resistant material which will seat tightly under all conditions:

(c) Pins and bushes shall be of bronze or other corrosion-resistant non-sticking material, machined for easy dependable operation:

(d) The closure element shall be internally weighted or otherwise internally equipped to promote rapid and positive closure.

Chapter 14
Domestic Fire Safety

14.1 Introduction

The objective of this chapter is to provide fire safety guidance for designers, owners and residents of single family homes and attached townhouses. The chapter describes a wide range of strategies for improving domestic fire safety.

Much of this chapter is based on recent studies carried out in Australia and New Zealand. A report carried out for the Building Control Commission of Victoria (Beever and Britton 1999) examined the ability of fire safety measures to impact on reducing the risk of loss of life, property and injuries in Victoria. Various fire safety measures were evaluated using a calculation of "cost per life saved". Wade and Duncan (2000) made a similar study for New Zealand, following an earlier analysis of Fire Service statistics by Irwin (1997). A similar study using an alternative benefit-cost ratio was carried out by Byrne (2000).

14.2 Scope

The primary thrust of this chapter is single family homes and attached townhouses, for which the New Zealand and Australian Building Codes do not have any significant requirements for fire safety. Larger residential buildings such as apartment buildings, hostels and hotels are covered by the Building Codes, but some of the recommendations in this chapter, such as for upholstered furniture, apply to all types of residential buildings, large or small.

14.3 Scale of the domestic fire problem

In Australia, about 30% of fire fatalities and fire injuries occur in one and two family dwellings, most of these fires starting in a bedroom or living room (Beever and Britton 1999). The New Zealand Fire Service attends about 22,000 fires each year. Of these, 21% are in domestic premises, but these fires result in about 60% of all fire deaths and injuries (Irwin 1997). Most fatal domestic fires occur in the early hours of the morning, when people are asleep. There are more fires on weekends than during the week. The most likely room for fires to start in is the kitchen, but fatal fires are more likely to start in a bedroom.

Cultural issues are an influence on fire safety. It is well known that the number of fires, fire deaths and injuries tend to be greater (per capita) in areas of lower socioeconomic activity (Beever and Britton 1999). Fire losses are significantly greater in rented than in owned accommodation. A recent study (Thomas et al 2000) carried out interviews with 300 Maori families in the central North Island area in an effort to propose new strategies for improving fire safety in this particular risk group.

14.4 Prevention of ignition

The fire safety problem can be eliminated if ignitions can be prevented. It is impossible to prevent all ignitions, but any measures which reduce the probability of ignition have the potential to reduce national fire losses. Most fire ignitions are attributed to people's activities. A smaller number are caused by equipment malfunction.

Human activities

Smoking is the single biggest cause of fatal fires. Other major sources are heaters, candles, children playing with matches, and cooking accidents. Simple precautions such as keeping matches from children and requiring child-proof cigarette lighters can reduce the probability of fire ignitions. Other simple precautions include education regarding drying of clothes near space heaters or open fires, and unattended open flames of any sort.

Equipment failure

Electrical equipment malfunction can cause fires. The home-owner can reduce the likelihood of fire by keeping equipment well maintained, avoiding overloading of electrical outlets, and turning off appliances when not in use. Poorly maintained electric under-blankets is a major cause of fatalities of elderly people in colder areas.

Modern apartment with smoke detectors and automatic sprinklers installed on the ceiling

14.5 Smoke alarms

Smoke alarms consist of a detection device connected to a warning device, usually an audible sounder. The effectiveness of a smoke alarm depends on its ability to detect the smoke, and the ability of the occupants to respond to the alarm. Properly installed and maintained smoke alarms reduce the chances of dying in a fire by half. At around $20/alarm there is no reason to not have at least one in every home.

Smoke detectors are generally of two main types, ionisation or photoelectric, as described in Chapter 9. Spearpoint (1997) has conducted a cost-benefit study of domestic smoke alarms. The most common inexpensive smoke alarms (less than $20 each) are of the ionisation type. Beever and Britton (1999) recommend these over the photoelectric type, except in locations where false alarms are expected.

Location of alarms

Some home-owners believe that they are safe if they have a single battery powered smoke alarm in the hallway. It is much safer to have smoke alarms well distributed through the house, including one in each bedroom, in the hallway and on every level of the house. The closer the smoke alarm is to fire, the sooner the alert will be given. Smoke alarms should not be located in kitchens or other areas where frequent false alarms are likely.

Stand-alone vs interconnected

With an interconnected alarm system, activation of one detector causes all the devices to give a warning signal. These provide much better safety than stand-alone alarms, because people throughout the house will be alerted at the same time, regardless of the fire location.

Battery powered vs. mains-wired

The biggest problem with stand-alone smoke alarms is maintaining batteries. A large percentage of installed alarms have no batteries. For this reason, many authorities are recommending that smoke alarms be hard-wired to the mains electricity in the house. This is more expensive, but offers a much more reliable system. Mains wired smoke alarms should have battery back-up so that they will operate in the event of a power cut.

Taking all of these factors into account, Beever and Britton (1999) found that mains powered smoke alarms were more cost-effective than battery powered alarms. They report that current legislation in Victoria which requires new households to have a mains-powered smoke alarm system is both appropriate and cost-effective.

14.6 Suppression systems

Sprinklers

By far the most effective fire protection device in almost every situation is an automatic sprinkler system. This certainly applies in domestic premises. In many North American jurisdictions, sprinklers are mandatory in all new residential construction. This is particularly true for multi-storey residential construction. There are benefits of reduced fire-fighting costs if entire neighbourhoods are fitted with sprinkler systems, but this has not been seriously considered in Australia or New Zealand.

Despite the immediate and obvious benefits, several cost-benefit studies have found it difficult to justify sprinkler installations in domestic premises because of the high cost of installation (Strategos 1989, Rahmanian 1995, Beever and Britton 1999). The perceived difficulty is the cost of installation, and there is a difficult trade-off between cost and quality.

There have been recent proposals in New Zealand (Duncan et al 2000) for low-cost sprinkler systems which are operated directly off the cold water pipe network in the house. These sprinkler systems may not have the reliability of systems based on comprehensive standards, but they offer potential for greatly improved life safety if the cost can be low enough to encourage widespread installation. The risk assessment in Duncan's report shows very large projected reductions in fire injuries and fire deaths. Multi-purpose fire sprinkler/plumbing systems of this type are best suited for new construction and are within the current scope of NFPA 13D - 1999.

Hand-held fire fighting devices

Fire extinguishers

The installation of dry-powder fire extinguishers in kitchens is recommended, with the primary objective of reducing property losses rather than reducing fatalities. Beever and Britton (1999) quote a Norwegian report which shows that

Total loss of family heirlooms in a post-flashover house fire

portable fire extinguishers in single family houses reduces fire losses by 26%. Household ownership of such extinguishers is compulsory in Norway.

Hoses

Fixed fire hose-reels are often installed in commercial and industrial buildings. They are not required in most buildings covered by the Approved Documents to the New Zealand Building Code, because of the perceived additional risk of inadequately trained occupants staying in a building to long to fight a growing fire, and they are not widely promoted for use in family homes (Byrne 2000). A significant number of house fires result from burning of cooking fat in a deep-fat fryer, in which case use of a hose-reel could assist spread of the fire. However, the New Zealand Fire Service recommends that garden hoses should always be left connected to taps outside houses so that they are available in the case of a fire emergency.

14.7 Materials

For many years there has been the belief that a brick house is safer from fire than a timber house. The fact is that both types of house are equally dangerous when it comes to fire, because it is not the structure that is important but rather the contents that we bring into the home that creates the fire hazard. By the time the building structure becomes involved it is far too late for the occupants of a single family home to do anything.

Upholstered furniture

Few people realize how quickly upholstered furniture can ignite and burn. Figure 14.1 shows a typical armchair less than 2 minutes after ignition. This figure was taken in a fire research laboratory in which 4 m^3/s of smoke and toxic gases were being removed by the laboratory extraction system. If this were in a real lounge the flames would be reaching across the ceiling and the entire room would be filled with hot toxic smoke.

The experiment in Figure 14.1 is part of an on-going research programme at the University of Canterbury investigating the fire safety of domestic furniture (Enright and Fleischmann 1999). They have found that compared with typical European furniture, the New Zealand furniture items exhibit higher peak heat release rates for similar total energy content. Further, typical New Zealand furniture presents a higher fire hazard than its European counterparts by reaching these higher peak heat release rates in shorter periods of time. On going research is focusing on different combinations of common foams and fabrics (Denize 2000). Results indicate that natural fibres such as cotton and wool have higher ignition resistance and lower heat release rates when compared to synthetic fabrics such

Figure 14.1: Armchair fire (1MW) in a furniture calorimeter. Typical polyurethane foam furniture produces rapid fire growth and very high heat release, with potentially lethal consequences.

as polyester and polypropylene. It is expected that the outcome of this research will be recommendations for voluntary standards or regulations on the flammability of fabrics and foams used in upholstered furniture similar to those found in parts of Europe. Beever and Britton (1999) recommend that the development of suitable low cost fillings be promoted, information on the flammability of combinations of fillings and fabrics be distributed to the furniture industry, and that public education be increased.

Plastics materials

Increased use of plastics in many household items over the past decade or two has greatly increased the fuel load energy density in houses. All plastics materials burn, so plastics in any item should be considered a potential fire load. Most plastics materials are much more dangerous in fires than traditional materials such as wood, wool, cotton, or kapok.

Many plastics are marketed as “fire retardant” or “combustion modified”. Such materials are more resistant to initial ignition and flame spread than unmodified materials, but they all burn if subjected to sufficient heat flux, and the implied increase in fire safety may be illusory.

Curtain fabrics and carpets

Many new synthetic fabrics are very dangerous in fires. Curtains are a particular problem because they are easily ignited, and they can result in very rapid vertical flame spread. There are no controls on the flammability of home furnishing fabrics in New Zealand or Australia.

Wool is the traditional material for carpets in New Zealand and Australia. Synthetic carpets are cheaper, and are hence becoming more popular. Synthetic carpets are more dangerous in fire than wool carpets, although carpets are not such a big hazard as other items because they usually become involved in the fire later than upholstered furniture or curtains. Synthetic carpet applied as a decorative finish to walls can be very dangerous because of rapid vertical flame spread.

14.8 House construction

The New Zealand and Australian Building Codes do not have any significant fire safety requirements for the construction of single family homes and attached townhouses, except that the current draft of the New Zealand Acceptable Solution does not allow the use of foamed plastics as lining materials without an approved protective barrier. There are some important design decisions which can influence occupant safety in the event of a fire, but Byrne (2000) found that none of these construction items provided an attractive cost-benefit ratio.

Linings

Flammable wall and ceiling linings can contribute to rapid initial fire growth, especially if a fire starts near the corner of a room. Many experimental studies have shown that time to flashover is greatly reduced if the lining materials support rapid flame spread. The safest lining material is a non-combustible material such as gypsum; wood based lining materials provide moderate safety and most plastics materials are very dangerous.

Paper-faced gypsum plaster board is by far the most common lining material in domestic construction. Gypsum is a very good material in fire situations because it is non-combustible, and it contains water of crystallisation which slows the rate of temperature increase when it is heated. Gypsum plaster board is a very safe material for wall and ceiling linings because it does not support surface flame spread. Multiple layers of paint or wallpaper can promote flame spread if the heat flux is large enough. The only exception is that many multiple layers of wallpaper in very old buildings can result in rapid fire growth.

Wood based materials are the traditional lining materials, providing a moderate level of safety which has been accepted for many years. However, large areas of wood-based lining materials can lead to rapid fire growth, especially if on the ceilings. This applies to sawn timber, hardboard, medium density fibreboard (MDF) or plywood, all of which have similar thermal properties. Low density fibreboard (“pin-board”) supports much faster flame spread because of its lower thermal inertia, so should not be used to cover large areas of walls or ceilings.

Most plastic lining materials pose a much greater hazard than wood-based materials. Foamed plastic materials are especially dangerous because of low thermal inertia leading to rapid flame spread, large amounts of stored energy, melting droplets in fire, and excessive amounts of toxic smoke. Most codes do not permit the use of foam plastic materials as internal linings in dwellings.

Doors

Closed doors are one of the most simple and effective ways of reducing the spread of fire and smoke in a burning house. Open doors are no use whatsoever. Automatic door closers are becoming common in commercial buildings, but are generally too expensive for houses, so it is up to the occupants to ensure that doors are closed in case there is a fire.

Different types of doors have a wide range of fire resisting properties. A post-flashover fire can burn through a cheap hollow-core door in a minute or two, but a standard solid core door can resist a severe fire for a much longer period, provide that it is closed, and fits well in its frame. The use of solid core doors is recommended, especially in locations where prevention of fire spread would be beneficial (between garage and house, between lower and upper floor, for example). The much larger cost of approved fire-doors is not warranted.

Fire resistance

Most building codes require elements of construction to be provided with fire resistance to prevent spread of fire and to prevent structural collapse during a fire. No such requirements apply to single family houses, although typical light timber frame construction with gypsum plaster board linings has a nominal level of inherent fire resistance.

There may be some areas in a house where it is appropriate to increase the fire resistance in order to slow or prevent fire spread. This is more likely to benefit property protection than life safety, unless there is a possibility of people being trapped on an upper storey. There is no point in spending money on increased fire resistance unless the doors and other penetrations through the wall or ceiling provide equivalent resistance to fire spread, as mentioned above. If installed at the time of construction, the fire resistance of a wall or ceiling can be increased at low cost by using fire-rated gypsum board in place of regular board, or an additional layer of regular board.

Escape routes

In some multi-storey houses, depending on the size and layout, a significant increase in fire safety may be achieved by providing a second means of escape from the upper floors. This will be expensive if not required for other reasons, but very large houses may have two stairs anyway, in which case they should be designed to be fire-separated to provide two independent means of escape. Other alternative escape routes such as access ladders to lower roof decks may be appropriate in some individual cases.

14.9 Education

Fire safety education is the most cost effective means of reducing fire losses (Beever and Britton 1999). Some fire safety educational efforts have been less effective in non-European ethnic groups (Thomas et al 2000). In a survey of public attitudes to domestic fire safety Rusbridge (2000) found that most people feel safest from fire in their own homes, when in reality most fire deaths occur in homes. This finding demonstrates the need for more public education on fire of which there are many possible components, including the following:

Smoke alarm installation

The more smoke alarms you have the better, however it is recommended that a smoke alarm be placed in hallways outside each bedroom area, inside each bedroom, and at least one on every level of a multi-storey or split level home including the basement.

Smoke alarm maintenance and replacement

A properly installed and maintained smoke alarm greatly increases one's chances of surviving a fire, however, a faulty smoke alarm is worse than no smoke alarm because it provides a false sense of security. The maintenance of a smoke alarm is relatively simple:

- Test the smoke alarm monthly, by pressing the test button or according to manufactures recommendations.
- Follow the manufacturer's recommendations for cleaning. As a minimum, gently vacuum the alarm twice a year.
- Once a year replace the battery with a new one. It is recommended that you pick a holiday or birthday to help you remember. A popular campaign of changing battery when you change your clock for daylight savings has served as useful reminder for many people.
- If the smoke alarm starts to "beep" or "chirp" replace the battery immediately with a new one. Do not remove the old battery until a new one is installed.

Special strategies may be necessary for elderly or disabled people, and those with impaired hearing. It is recommended that smoke alarms be replaced with new ones every ten years.

Waking effectiveness of alarms

Audible smoke alarms are not any use unless someone hears them. There is a wide variation in people's response to alarms, and a wide range of audible alarm signals on the market (Grace, 1997). Confirming other studies, Duncan (1999) found that some people are not woken by alarms because of factors including location, age (teenage and younger often do not wake), hearing disability, and drugs or alcohol. Correct placement of sufficient alarms can provide greater probability of alerting the occupants (Spearpoint and Smithies 1999).

Doors open or closed

There has been some debate as to whether it is better for bedroom doors to be open or closed when occupants are sleeping. The argument for leaving doors open is better audibility of alarms, and faster activation if the fire is not in the same room. On the other hand, open doors result in much faster spread of smoke and fire, leading to potentially much greater fire size before the alarm activates, and greater threat to a sleeping occupant. Palmer (1999) used the FIRE-CAM fire risk model in a probabilistic study to show that it is safer for bedroom doors to be kept closed. This practice is generally recommended by fire services. However, in a recent study Rusbridge (2000) found that only 22% of the people surveyed kept their bedroom doors closed at night.

Escape planning

It has been shown on many occasions that home fire safety is greatly increased if the occupants have a pre-determined escape plan, and an agreed place to meet, if an emergency evacuation becomes necessary. It is recommended that you have a home escape plan that is practiced at least twice a year. In 1998 the National Fire Protection Association (NFPA) in North America started a public education campaign "Fire Drills: The Great Escape" to encourage people to develop and practice a home fire escape plan. Since this campaign was started there have been 58 documented lives saved as a direct result of the campaign.

A home fire escape plan should include the following:

- Make sure you have at least one smoke alarm on each level of the home and in or near each sleeping area as described above
- Draw a floor plan of your home. Mark all doors and windows, and the location of each smoke alarm. If windows or doors have security bars, equip them with quick-release devices.
- Locate two escape routes from each room. The first way out would be the door, and the second way out could be a window.
- As you exit your home, close all doors behind you to slow the spread of fire and smoke.
- If your exit is blocked by smoke or fire, use your second exit to escape. If you have to escape through smoke, stay low and crawl under the smoke to safety.
- Choose a meeting place a safe distance from your home and mark it on the escape plan. A good meeting place would be a tree, telephone pole, or a neighbour's home.
- Make sure the street number of your home is visible to fire fighters.
- Memorize the emergency services telephone number (111 in New Zealand). Once outside, call that number immediately from a neighbour's phone, or use a portable or cellular phone you can grab quickly on the way out.
- Practice your escape drill at least twice a year.

- NEVER go back inside a burning building!

Additional information on home escape planning can be found on the NFPA web site (www.firepreventionweek.org/Home_Escape/home_escape.html).

Flammability of fabrics

Public education is needed on the fire safety of various types of fabrics and furniture coverings. People need to know what they are buying, and will exercise discretion if they have sufficient information to make educated decisions.

14.10 Recommendations

The main recommendations for improving domestic fire safety are given in the list below. This list is prioritised in order to give best value for money at the top of the list:

- Improve public education programmes.
- Require stand-alone smoke alarms as the minimum requirement in all dwellings.
- Strongly recommend interconnected mains-wired smoke alarms. They should be compulsory in all new houses.
- Encourage the placement of fire extinguishers in kitchens.
- Recommend the installation of low cost residential sprinklers as the best method of protecting life and property. They should be compulsory in all new houses.

Chapter 15
Regulatory Framework in New Zealand

15.1 Introduction

Fire events in buildings influence safety and amenity of building users as well as threatening neighbouring property.

The objective of the regulatory framework in terms of fire is to:
- Establish minimum standards for life safety;
- Establish minimum performance standards for property protection in terms of safety of firefighters and protection of neighbouring property; and
- Protect the environment from hazardous emissions resulting from fire in buildings used for the storage or processing of hazardous substances contained within buildings.

This is achieved through both "statutory" and "voluntary" provisions within various legislation.

15.2 Regulatory framework

For fire engineering purposes, the relevant statutory provisions encompass:
- Statutory controls applying to all buildings, e.g. Building Act 1991 (BA), and Building Regulations, including the New Zealand Building Code.
- Fire Service requirements applying to particular types of buildings, e.g. Fire Service Act 1975 (FSA), Section 21A, and related regulations, including the Fire Safety and Evacuation of Building Regulations 1992.
- Fire Service requirements for access to buildings FSA(29) 1, 5, 6.
- Fire Service responsibility to provide information on water supplies to Territorial Authorities FSA(30).

In addition, there are "voluntary" provisions relating to fire safety aspects of the work place. These arise primarily through the Health and Safety in Employment Act 1992 (HSE). Within the regulatory framework, there are thought to be some regulatory "gaps" in the fire safety infrastructure that impact on the fire safety of buildings outside these particular areas. One example of this is the extent of the obligation on the Territorial Authority (TA) to provide and maintain adequate water supplies for fire fighting at a particular site, a matter that is being monitored by the New ZealandFire Service.

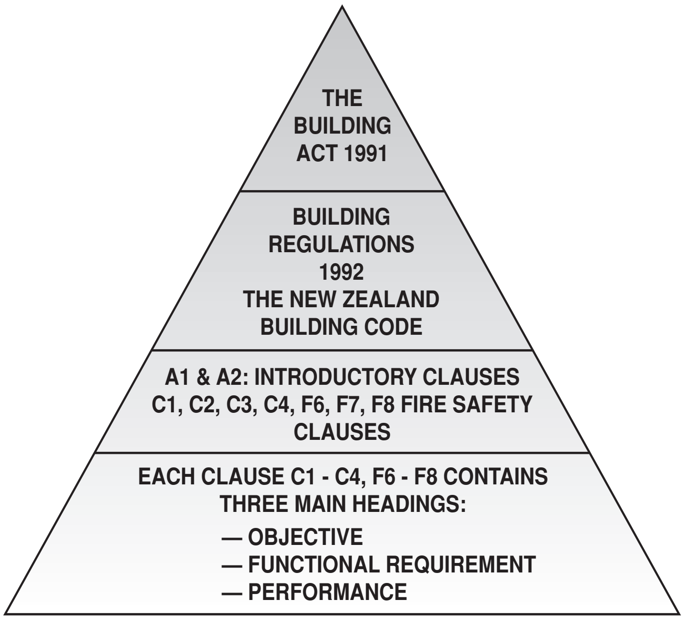
15.3 Building Act 1991

Figure 15.1 shows the overall hierarchy of the building control system in New Zealand. The items in the triangle are the legal requirements applying to all new buildings, and all buildings subject to alteration or change of use. The box below the triangle lists four alternative methods of satisfying the requirements of the law.

The TA is established by the Act as the sole building control agency within its district. Building controls encompass both new and existing buildings and establish performance standards through Regulations in the form of the New ZealandBuilding Code (see Appendix A of this book). Extracts from "Purposes and Principles" of the Building Act are given in Appendix1 of this chapter. Those provisions relating to fire safety are specifically highlighted for reference. These purposes under BA(6) 1 are to provide for:

(a) necessary controls relating to building work and the use of buildings and for ensuring that buildings are safe and sanitary and have means of escape from fire; and

(b) the coordination of those controls with other controls relating to building use and the management of natural and physical resources.



PERFORMANCE REQUIREMENTS OF BUILDING CODE CLAUSES MAY BE SATISFIED IN FOUR DIFFERENT WAYS

1 BIA APPROVED DOCUMENT, BA (49) VERIFICATION METHOD (ENGINEERING APPROACH)

Comment: At present, there is no approved Verification Method for fire design. This Design Guide may at some stage be expanded into a Verification Method for Building code Compliance.

2 BIA APPROVED DOCUMENT, BA (49) ACCEPTABLE SOLUTION (NON-ENGINEERING PRESCRIPTIVE APPROACH)

Comment: The BIA Approved Document includes an Acceptable Solution

3 ALTERNATIVE SOLUTION, BA (34)3: TA must have “reasonable grounds” (SPECIFIC FIRE ENGINEERING DESIGN)

Comment: This Design Guide will give guidance to those designers offering an “alternative solution”.

4 ACCREDITATION, BA (59) BIA accredits use of materials, components or methods

Comment: Various fire resistant, protection and supression components may be accredited under this Section.

Figure 15.1: The Regulatory Environment— Fire Safety Provisions

New buildings

The construction of new buildings is controlled through the issue of building consents by the TA, following a technical review of the design documentation submitted by the owner. This technical review, which may be undertaken either by the TA or by a private sector “Building Certifier” approved by the Building Industry Authority (BIA), is required to assure compliance of the building work with the performance based New ZealandBuilding Code. The Building Code’s requirements with respect to “Fire Safety” are covered in the following provisions:

- C1: Outbreak of Fire
- C2: Means of Escape
- C3: Spread of Fire

- C4: Structural Stability During Fire

and under requirements for “Safety of Users” provisions:

- F6: Lighting for Emergency
- F7: Warning Systems
- F8: Signs.

The BIA Approved Document is produced by the Building Industry Authority (BIA, 2000), and approved under BA(49) as complying with the New ZealandBuilding Code and, therefore, satisfying the purposes of the Act. A major revision of the Fire Documents was published in December 2000, with the changes to take effect from 1 June 2001. The relationship of the Approved Documents with the New Zealand Building Code is shown diagrammatically in Figure 15.1.

Any design based on the BIA Approved Documents is referred to as an “acceptable solution”. Other design solutions complying with the fire safety provisions of the Building Code, but not complying strictly with the Approved Document, are termed “alternative solutions”. The Approved Document C/AS1 Part 5 “Fire Resistace Ratings” makes specific reference to Fire Engineering Design as a recognised verification method in that fire engineering design must be used for determining fire resistance ratings in classes of occupancy with fire loads exceeding 1500MJ/m^2 (Fire Hazard Category 4).

Existing buildings

BA(64) specifies conditions under which an existing building might be considered dangerous to building occupants or neighbouring property by reason of an existing fire hazard and occupancy (if sufficient fire hazard exists), or if there is a change in fire hazard or a change of occupancy where:

- the building’s new use includes human occupation (with fire hazards becoming high or abnormal);
- the building's occupancy is residential or is a place of assembly, with fire hazards being high or abnormal;
- normal use involves storage, or processing of hazardous substances;
- life safety features or systems might not be maintained properly.

The New ZealandFire Service is recognised as the TA’s principle source of advice on matters concerning fire hazard in existing buildings, although the seeking of such advice is not mandatory on the TA. Given a situation of danger arising from a fire hazard in an existing building, the TA can:

- exclude people from the building;
- effect measures to secure public safety (at owner's expense);
- require the owner to remove, or reduce the danger and require further subsequent actions as specified by a District Court;
- apply for injunction from a District Court to prevent a breach of the Building Code.

It is notable, under BA 80(1)b, that:

> *“Every person commits an offence who uses any building, or permits other persons to use any building, for a use for which the building is not safe or sanitary, or has inadequate means of escape from fire.”*

and under BA 80(2)b:

> *“...is liable, on summary conviction, to a fine not exceeding $200,000 and, in the case of a continuing offence, to a further sum of $20,000 for every day, or part day, during which the offence has continued.”*

Alterations and changes of use in existing buildings

In general, the TA’s powers to enforce upgrading of the fire safety features of existing buildings is limited by BA(8). Exceptions include situations where an existing building is:

- subject to “alterations” under BA(38); or
- subject to a “change of use” under BA(46); or

- “dangerous” under BA(64); or
- “not safe” or has “inadequate means of escape from fire” under BA 70(1)(a) and 80(1)(b).

In cases of alteration or changes of use, the TA is only permitted to issue a Building Consent where it is satisfied that various fire safety (and other) features in the existing building will, after the alteration or in its new use, “comply with the Building Code as nearly as is reasonably practicable”, as if it were a new building. Note that the word “practicable” implies considerations of cost and benefit, as well as physical feasibility.

Potential upgrade categories in existing buildings which relate to fire safety include:
- means of escape from fire (BA(38) and (46));
- provision for protection of other property (BA(46)4);
- structural and fire rating behaviour (BA(46)2).

The term “means of escape from fire” is defined in the Building Act at BA(2) as:

> *“...continuous, unobstructed routes of travel from any part of a floor area of (a) building to a place of safety, and includes all active and passive protection features required to assist in protecting people from the affects of fire in the course of their escape.”*

Whilst the term “change of use” used in BA(46)2 is not defined in the Building Act, the meaning of the term in a fire engineering context may be inferred from the answer to the following question:

> *“Are there different (and increased) Building Code performance requirements for the building in its new use as compared to the requirements which applied in its original use?”*

If the answer to this question is “yes”, then the “change of use” provisions of BA(46)2 may be enforceable by the Territorial Authority. It is important, however, that such increases in Building Code requirements relating to the new use are quantifiable and relate to changes in measurable physical conditions, as referred to in the purposes and principles of the Building Act, i.e. BA(6).

In the area of fire safety, increased Building Code requirements within the code provisions C1-C4 and F6-F8 may arise from increases in fire hazard, e.g. increased fire load, fire severity or numbers of people at risk from fire.

Note, however, that the relationship between the causal factors driving the change of use and the building features required to be upgraded as a consequence under BA46 is indirect. For example, active and passive fire protection systems may need to be upgraded solely because a change of use has been generated from parts of the Building Code other than those relating to fire safety, e.g. requirements for earthquake strengthening, disabled access or solely because the building is being subdivided into separate titles under BA(46)4.

Consideration of the extent to which the fire safety (and other) features of a particular existing building will need to be upgraded will, in the final event, depend upon a range of factors, including:
- the existing building’s compliance (or noncompliance) with the Building Code;
- the reasonable practicality of the works concerned;
- the particular circumstances of the building in question;
- the cost of achieving compliance, when measured against the fire safety benefits received by carrying out the upgrading work.

Designers should also refer to BA(47) when considering the extent of upgrading of fire safety systems likely to be enforceable under BA(38) and (46).

Ongoing use of buildings

Under BA(44) the issue of compliance schedules is required to ensure the ongoing maintenance by the building owner of certain life safety systems and features in both new and existing buildings, but will not result in progressive upgrading of these systems solely to satisfy changes in the requirements of the Building Code. The annual building warrant of fitness scheme specified in BA(45) aims to ensure that such life safety systems continue to operate effectively for the intended life of the building, at least until such time that the building is altered or has a change of use.

There is a need for external agencies to monitor the effectiveness of this self-certified maintenance programme in the public interest. This is recognised in the Act under BA(26) and BA(44)2.

15.4 Fire Service Act 1975

Interface with Building Act 1991

The requirements of a fire safety system for a building as defined by the Building Act 1991 are to safeguard people from injury or illness caused by fire, prevent the spread of fire to adjacent properties and facilitate fire rescue operations. Note that not all property is included in this description as, for example, there are few property protection requirements for domestic housing.

In contrast, the Fire Service Act 1975 aims to protect life and property (i.e. all property).

The difference between protection of all property and protection of adjacent property is a fundamental difference in approach between the Fire Service Act and the Building Act.

Extracts from the New Zealand Fire Service Act 1975 are included in Appendix 2 of this Chapter.

The Building Act, via Clause 7(2), allows the requirements of the Fire Service Act to be acknowledged:

> *7. All building work to comply with the Building Code to the extent required by this Act:*
>
> *(2) Except as specifically provided to the contrary in any Act, no person in undertaking any building work shall be required to achieve performance criteria additional to or more restrictive in relation to that building work than the performance criteria specified in the Building Code.*

However, FSA(21)5 and FSA(21)6 state that:

> *21(5) Where a code of practice or standard is submitted pursuant to subsection (4) of this section for the Minister's approval, the Minister may approve that code of practice or standard.*
>
> *21(6) Notwithstanding the provisions of subsection (5) of this section, the Minister shall not approve any code of practice or standard, under that subsection, in relation to building matters if that code or standard purports to have the effect of requiring any building to achieve performance criteria additional to or more restrictive than those specified in the Building Act 1991 or in the Building Code.*

So, on the face of it, the Fire Service cannot impose more onerous requirements than those required by the Building Act 1991, or the Building Code.

Evacuation schemes

FSA 21A sets out specific buildings that may require evacuation schemes to be approved by the New Zealand Fire Service. The application of these evacuation requirements in the Fire Safety and Evacuation of Buildings Regulations 1992 reflect the suitability of fire safety systems installed in buildings to meet the nature of occupancy fire hazards and the needs of the building occupants. The installation of sprinkler systems, together with programmed evacuation alarms could, in some occupancies, provide some relief from full compliance with the evacuation requirements.

Water supply standards

The New Zealand Fire Service has produced a "Code of Practice for Fire Fighting Water Supplies" (effective from June 1992) in accordance with FSA17(91)(b) and 30(3). The New Zealand Fire Service can target the provision of inadequate water supplies to fire safety systems in specific buildings using the provisions of BA(64)(2)(e).

Access to buildings (for fire safety planning and investigation)

FS(29) authorises the Fire Service to access existing buildings for purposes of:

- advance planning for fire fighting, etc. or control of hazardous substances emergencies; and
- post incident investigations.

and requires the Fire Service to inform the TA if it believes the building does not comply with the relevant provisions of the Building Act 1991.

Early planning involvement

Given the overlaps in the legislation referred to earlier, it is prudent for designers to consult with the Fire Service at an early stage in the project to identify any particular consequential planning requirements for:

- evacuation;
- access to buildings; and
- fire safety systems.

This consultation, which should involve the building owner, may identify further requirements or requests by the owner for life safety and property protection on particular projects beyond those inherent in the Building Code.

15.5 Repairs to fire-damaged buildings

Under the previous model building bylaw provisions, i.e. NZS1900: Chapter5, 1988, clause 5.4, the TA retained a discretionary authority when existing buildings were subject to fire damage and the owner sought reinstatement in their original constructional form. Under the Building Act provisions, all fire reinstatement repairs must be considered as alterations under BA(38), taking into account the particular circumstances of the work, under BA(47) (h, i and k).

15.6 Fire Engineering Design Guide

This Fire Engineering Design Guide (FEDG) provides guidance to those wishing to carry out or review specific fire engineering designs to meet the requirements of the New Zealand Building Code. The status of the guide is that it can be used as a part of the "reasonable grounds" on which a designer offers and a TA accepts an alternative solution under BA(34)3.

As noted later in Section 15.7, users of the FEDG are:

(a) presumed to hold appropriate qualifications, and have academic training and experience in fire engineering work; and

(b) expected to refer to the various technical literature on fire engineering referred to in the guide (and elsewhere) in the course of their work.

15.7 Approved Persons

BA(53) requires the BIA to establish a register of Building Certifiers who may certify compliance of designs with the relevant provisions of the New ZealandBuilding Code. In the area of fire safety, these provisions are within clauses C1 - C4 and F6 - F8. Designs certified by Building Certifiers must be accepted by the TA without further review.

BA(12)2 requires that the BIA consult with the New ZealandFire Service Commission in respect of those functions, which include advice, approval and determinations relating to matters of fire safety and recognised fire engineering practice. This includes the appointment of Building Certifiers.

In addition, there is a need for appropriately qualified and experienced persons to:

- Undertake or review fire engineered designs in buildings in accordance with the New ZealandBuilding Code Fire Safety Provisions C1-C4;
- Inspect and maintain life safety systems and features identified in Compliance Schedules;
- Identify and report on the fire hazard conditions in buildings.

There is a need for recognition of "Professional Fire Engineering" as a separate technical discipline that can operate within the building control environment. This recognition should include the development of a regulatory framework for professional fire engineers to undertake their work, the establishment of centres of skill in technical knowledge and the setting of agreed standards of education and experience.

Due to the present "state of knowledge" in the fire engineering field it is recommended that:

- Except for trivial cases, all specific fire engineering designs submitted to TAs for technical approval should be subjected to "Peer Review" by professional fire engineers.
- The discretionary acceptance of Producer Statements solely from the designer under BA(33)(5) by TAs for specific fire engineering work without a corresponding peer-review statement should be discouraged (except for the more trivial design cases) until the field of knowledge is better established.

  This restriction is considered essential until the general public and the regulators have developed sufficient confidence in the fire engineering profession to accept self certified statements by those deemed competent to give them.

Any registers of professional fire engineers qualified to undertake fire engineering design work should:

- Be building industry oriented and appropriate to the need;
- Contain "checks and balances" (including appeal provisions);
- Be centralised rather than locally administered;
- Be subject to a code of ethics, including disciplinary procedures;
- Be widely recognised.

Qualification criteria for professional fire engineers are still to be established. However, these criteria are likely to recognise that:

- The supply of persons suitably qualified in fire engineering is insufficient to meet current demand.
- Some transitional provisions are necessary to allow new practitioners to gain the necessary advanced training in fire engineering prior to achieving full professional status.
- Advanced training in fire engineering needs to mix analytical design techniques with practical experience of real fires and fire fighting operations.

It is anticipated that this advanced training for professional fire engineers can be achieved using a two stage process which identifies:

- The "Fire Design Engineer" as a qualified person obtaining advanced training or experience in fire engineering; and
- The "Professional Fire Engineer" as the fully trained professional, whose capability has been assessed in terms of qualification, experience, and knowledge of the Building Code through a recognised peer review process.

Considering the above guidelines, the three recommended attributes for a "Professional Fire Engineer" are:

1. A specialist degree such as M.E.(Fire Engineering), or equivalent; and
2. Full membership of the Society of Fire Protection Engineers; and
3. Full membership of the Institution of Professional Engineers New Zealand

Attribute 1 provides the necessary technical background. Attribute 2 is recognition of that background and its application through a period of relevant responsible experience, as well as ensuring on-going contact with international developments in fire engineering. Attribute 3 ensures that the engineer belongs to a local professional body with a well established code of ethics, disciplinary procedures, and a scheme of recognition of continuing professional development.

The recommended transitional attributes for a “Fire Design Engineer” are either of the following:

1. A recognised specialist degree in fire engineering and graduate membership of the two professional organisations; or

2. A full member of both professional organisations but no specialist degree in fire engineering.

Option 1 applies to young professional fire engineers who are obtaining experience with on-the-job training and professional practice, whereas Option 2 applies to mature engineers who have moved into fire engineering from related disciplines.

15.8 Maintenance and inspection services

The Building Act under BA(44) requires building owners to provide evidence to the TAs of regular inspection and maintenance by Independent Qualified Persons (IQPs) as defined in BA(44)9 and who are registered with the TAs.

Such persons, either individually self employed, or as employees of private companies should be appropriately qualified to undertake the inspection and maintenance of the feature or system concerned and should be able to provide evidence of such to the building owner. Unlike Building Certifiers, the Act does not require BIA to approve or maintain a register of IQPs. The TAs are responsible for administering their local system by auditing 5% of IQPs per annum, but they are not empowered to charge fees to owners for such services.

BA(45) requires that the building owner shall supply the TA with an annual Warrant of Fitness to confirm that all life safety systems have been maintained in accordance with the compliance schedule for the previous 12 months. The Building Warrent of Fitness must be displayed within the building in the standard form prescribed by the Building Regulations.

When submitting a design, professional fire engineers should, to satisfy the Act, ensure that any system or provision included in the proposal for Building Consent has inspection and maintenance procedures either prescribed in a Standard or specifically prepared to facilitate annual Building Warrent of Fitness inspections and be a part of a maintenance manual. The Building Code Handbook (BIA 1992) includes proforma Compliance Schedules for all life safety systems requiring them to be inspected and maintained.

There is evidence from historical sprinkler and fire alarm performance records that this type of regime is capable of maintaining life safety features and systems fully operational throughout the lifetime of the building.

15.9 Summary

The regulatory framework established by the Building Act 1991, the New ZealandBuilding Code and the Fire Service Act 1975 establishes a positive environment for the work of the Professional Fire Engineer. This Fire Engineering Design Guide should provide a rational and nationally consistent basis for specific fire engineering design of buildings within this framework.

Appendix 1: Building Act 1991

6. Purposes and Principles

6(1) The purposes of this Act are to provide for:

(a) Necessary controls relating to building work and the use of buildings, and for ensuring that buildings are safe and sanitary and have means of escape from fire; and

(b) The coordination of those controls with other controls relating to building use and the management of natural and physical resources.

6(2) To achieve the purposes of this Act, particular regard shall be had to the need to:

(a) Safeguard people from possible injury, illness, or loss of amenity in the course of the use of any building, including the reasonable expectations of any person who is authorised by law to enter the building for the purpose of rescue operations and fire fighting in response to fire.

(b) Provide protection to limit the extent and effects of the spread of fire, particularly with regard to:

(i) Household units and other residential units (whether on the same land or on other property); and

(ii) Other property.

(c) Make provision in a building used for the storage or processing of significant quantities of hazardous substances to prevent significant adverse effects on the environment (whether within the immediate locality or otherwise) arising from an emergency involving fire within that building.

(d) Provide for the protection of other property from physical damage resulting from the construction, use, and demolition of any building.

(e) Provide, both to and within buildings to which section 25 of the Disabled Persons Community Welfare Act 1975 [or section 47A] applies, means of access and facilities that meet the requirements of that Act to ensure that reasonable and adequate provision is made for people with disabilities to enter and carry out normal activities and processes in those buildings.

(f) Facilitate the efficient use of energy, in the case of new buildings, during the intended life of those buildings.

6(3) In determining the extent to which the matters provided for in subsection (1) of this section shall be the subject of control, due regard shall be had to the national costs and benefits of any control, including (but not by way of limitation) safety, health, and environmental costs and benefits.

Amendments to Fire Service Act 1975, as incorporated in the Fourth Schedule of the Building Act 1991

21A. Evacuation schemes for public safety

(1) Subject to subsection (3) of this section, where any building is used as a place:

(a) Where 100 or more people are able to be present for different purposes or activities; or

(b) Where facilities for employment are provided for more than 10 people (whether self-employed or employed by 1 or more employers); or

(c) Where accommodation is provided for more than 5 people whether on an overnight, short-term, or long-term basis (other than 3 or less household units); or

(d) Which is used for any 2 or more of the purposes provided for in this subsection —

and the building is not sprinkler-protected, or, in the opinion of the National Commander, has an automatic sprinkler system that is inadequate to meet the nature of the fire hazard, the National Commander may require the owner of that building to make provision for a scheme which provides for evacuation from the scene of a fire to a place of safety outside the building.

(2) Notwithstanding the provisions of subsection (1) of this section but subject to subsection (3) of this section, where any building or part thereof is used as a place:

(a) Where 100 or more people can gather or assemble together in a common venue or place of assembly, whether for a commercial, social, cultural, religious, or any other purpose whatsoever; or

(b) Which is used in whole or in part for the storage or processing of hazardous substances; or

(c) In which early childcare facilities are provided (other than in a household unit); or

(d) In which specialised nursing, medical, or geriatric care is provided (other than in a household unit); or

(e) In which specialised care is provided for people with disabilities (other than in a household unit); or

(f) For the accommodation of people in lawful detention; or

(g) For any 2 or more of the purposes provided for in this subsection —

the National Commander may require the owner of that building to make provision for a scheme which —

(h) In the case of a building which is sprinkler-protected, provides for evacuation from the scene of a fire to some other place of safety (whether within or outside the building):

(i) In the case of a building which is not sprinkler-protected, provides for evacuation from the scene of a fire to a place of safety outside the building.

(3) For the purposes of subsections (1) and (2) of this section, the National Commander's requirements shall be as prescribed in regulations made under this Act, which regulations shall specify, with respect to sprinkler-protected buildings and non-sprinkler-protected buildings, such evacuation times and procedures as are necessary for safeguarding persons who are lawful occupants of the building or who are otherwise lawfully entitled to be in the building (whether as visitors or otherwise) including, in the case of buildings to which section 25 of the Disabled Persons Community Welfare Act 1975 [or section 47A of the Building Act 1991] applies, the evacuation of persons with disabilities.

(4) For the purposes of subsection (3) of this section, the requirements for such evacuation times and procedures as are necessary for safeguarding persons shall, in the case of the regulations, also be deemed to include, with respect to any sprinkler-protected building, the criteria that shall be applied by the National Commander in determining whether evacuation from the scene of a fire shall be to some other place within or outside the building.

(5) Where any owner fails, within the time required by the regulations, to prepare a scheme to the National Commander's requirements or otherwise refuses to prepare a scheme, or where a scheme that was previously approved becomes inoperative because of the failure of the owner to ensure the requirements of the scheme are fully maintained, the National Commander, on giving not less than 10 days written notice of his or her intention to do so to the owner of the building, may apply to the District Court for an order under subsection (6) of this section.

(6) If, after giving the National Commander and the owner of the building an opportunity to be heard, the District Court is satisfied that the owner of a building has failed to comply with subsection (5) of this section, the District Court may make an order requiring that the building be closed until the requirement for a scheme to be prepared or for a scheme to become operative, as the case may be, has been met.

(7) Where any building does not require a scheme in terms of subsection (1) or subsection (2) of this section but the owner considers that a scheme should nevertheless be approved, the owner shall notify the National Commander; and the provisions of this section, other than subsections (5) and (6), shall apply accordingly.

(8) Where any scheme is approved for the purposes of this section it shall be a requirement of that scheme that

(a) The appointment of building wardens and floor wardens be reviewed [at intervals of not more than 6 months]; and

(b) The duties of building wardens and floor wardens should be provided for in the scheme; and

(c) There be trial evacuations at prescribed intervals; and

(d) The means of escape from fire shall be monitored by the owner and properly maintained; and

(e) Special provision is made for the avoidance of panic on the part of members of the public who are lawfully in the building at the time the building is required to be evacuated; and

(f) Special provision is made for

(i) Young children, the elderly, the sick, and persons with disabilities, where the building or part of it is for their care; and

(ii) Those in lawful detention, where the building or part of it is for their detention.

(9) The National Commander may grant waivers from the requirement of any building to which subsections (1) and (2) of this section applies where, in the opinion of the National Commander, there are already other provisions which will ensure the safety of people within the building.

(10) Where any building for which a scheme is approved is altered or there is a change of use, the National Commander shall review the requirements for the scheme, and the provisions of subsections (1) to (9) of this section shall apply with the necessary modifications.

(11) For the purposes of subsection (l)(a) and subsection (2)(a) of this section, the question of whether a building can be categorised as coming within the scope of those provisions shall be determined in the light of the use to which the building is put, and the provisions of the building code in terms of the Building Act l991.

(12) For the purposes of this section any evacuation scheme approved pursuant to the Fire Safety (Evacuation of Buildings) Regulations 1970 and which is still an operative scheme shall be deemed to be a scheme approved under this section.

History

This section was inserted, as from l July 1992, by s 92(1) Building Act l991 (l991 No 150).

Subsection (3) was amended, as from 2 September 1996, by s4(a) Fire Service Amendment Act 1996 (1996 No 122) by inserting the words "or section 47A of the Building Act 1991".

Subsection (8)(a) was amended, as from 2 September 1996, by s 4(b) Fire Service Amendment Act 1996 (1996 No 122) by substituting the words "at intervals of not more than 6 months" for the words "at not less than 6-monthly intervals".

Appendix 2: Extracts from the New Zealand Fire Service Act 1975

17O. Specific responsibilities of National Commander — The National Commander shall:

(a) Make provision in every Fire District for the prevention of fire, the suppression and extinction of fires, and the safety of persons and property endangered by fire.

(b) Ensure that the Fire Service is maintained in a state of operational efficiency and conforms with the Act.

(c) Make provision for effective cooperation between all fire services, whether or not established under this Act.

(d) Make provision for cooperation between the Fire Service and territorial authorities and regional councils.

20. Commission to promote fire safety

(1) It shall be a matter of prime importance for the Commission to take an active and coordinating role in the promotion of fire safety in NewZealand.

(2) In so promoting fire safety, the Commission shall be concerned to:

(a) Reduce continually the incidence of fire and the attendant risk to life and property.

(b) Achieve unity and completeness of fire safety law and practice.

21. Functions of commission in relation to the promotion of fire safety

(1) The Commission shall seek to achieve coordination between territorial authorities, Government departments, the architectural profession, the engineering profession, the building industry, the Building Industry Authority, the Standards Association of NewZealand, the Building Research Association of NewZealand, and other bodies and organisations in matters relating to the promotion of fire safety, whether by making contributions to their expenses or otherwise.

(2) The functions of the Commission in relation to the promotion of fire safety shall include:

- (a) Establishing close and harmonious working relations with industry, commerce, Government departments, territorial authorities, and other bodies and organisations.
- (b) Seeking to ensure that knowledge affecting fire safety gained by the Commission is applied throughout the Community.
- (c) Stimulating and maintaining interest in fire safety by means of education and publicity through all communications media.
- (d) Publishing and disseminating fire safety literature.
- (e) Sponsoring, assisting, and conducting fire safety campaigns and fire safety courses (whether general or particular).
- (f) Research into methods and practices of fire safety, and making arrangements with any person, Government department, or body having appropriate facilities for the conduct of any such research.
- (g) Seeking continuously for new ways to reduce the incidence of fire and the risk to life from fire.

(3) The Commission may, after consultation with the Building Industry Authority, where appropriate, the Standards Association of NewZealand, or any association of territorial authorities, or any appropraite authorities, make recommendations to the Minister as to alterations of statutory responsibilities and reallocation of functions as between Government departments, territorial authorities, and other bodies, in respect of fire safety.

(4) Without limiting the generality of sub-section (3) of this section, the Commission may, after similar consultations, make recommendations to the Minister in respect of:

- (a) The issue of codes of practice or standards prescribing, in relation to proposed or existing buildings or additions or alterations to existing buildings
  - (i) Safeguards against fire;
  - (ii) Fire resisting construction and means of escape in the event of fire;
  - (iii) The protection of persons and property from the danger of fire or other emergency;
  - (iv) The installation and maintenance of hand-operated fire fighting equipment, riser mains for fire service use, fire detection systems, automatic sprinkler and other fixed fire extinguishing systems, and manual fire alarm systems.

(b) The fire safety provisions for any proposed building or for additions or alterations to any existing building.

(c) The packing, marking, handling, carriage, storage and use of hazardous materials.

(5) Where a code of practice or standard is submitted pursuant to sub-section (4) of this section for the Minister's approval, the Minister may approve that code of practice or standard.

(6) Notwithstanding the provisions of sub-section (5) of this section, the Minister shall not approve any code of practice or standard, under that sub-section, in relation to building matters if that code or standard purports to have the effect of requiring any building to achieve performance criteria additional to or more restrictive than those specified in the Building Act 1991 or in the building code.

29. Access to land and buildings (other than private dwellings) for pre-incident planning and post-incident investigation

(1) The Chief Fire Officer, the Deputy Chief Fire Officer, and any person authorised in writing by either of them shall have free access to all land and buildings (not including household units) at such times and under such conditions as are reasonable, having regard to any business carried on therein, in order to obtain information required for fire fighting planning purposes or hazardous substance emergency planning purposes (including the planned evacuation of persons from the premises and other matters relating to the protection of human life), if the Chief Fire Officer reasonably believes that in the event of any fire or hazardous substance emergency occurring a brigade may be called upon to enter that land or buildings.

(2) The provisions of subsection (1) of this section shall apply, with any necessary modifications, for the purposes of any post-incident investigation that may, from time to time, be required to be carried out to determine the cause of any fire or hazardous substance emergency.

(3) Reasonable notice shall be given of any proposed entry, and identification shall be shown on entry and at any subsequent time if requested.

(4) The provisions of this section shall not apply to any Crown land or building or any class or classes of Crown land or buildings that are, from time to time, specified by notice in the *Gazette* by the Minister or any land and buildings that are "premises of the mission" (as defined in the First Schedule to the Diplomatic Privileges and Immunities Act 1968).

(5) Where a person having access to land and buildings under this section believes that any building or site work does not comply with the Building Act 1991, that persons shall by notice in writing give to the appropriate territorial authority details of the respects in which the building or site work is believed not to comply.

(6) For the purposes of sub-section (5) of this section, the terms "building", "site work", and "territorial authority" have the meanings ascribed to them by the Building Act 1991.

Chapter 16
Regulatory Framework in Australia

16.1 Introduction

The framework for building regulations and fire safety in Australia is quite different from the situation in New Zealand.

In Australia, there is a federal system and 3 tiers of government which all play a role in fire safety provisions for buildings. These tiers are:

- Commonwealth (Federal) Government;
- State Government; and
- Local Government.

The objective of the regulatory framework is principally directed towards:

- life safety of occupants;
- protection of fire fighters during rescue and fire fighting; and
- protection of neighbouring (adjoining) property.

In addition, some of the fire brigade Acts and other legislation refer to the need to protect property and the environment.

16.2 Regulatory Framework

The three levels of Government are all important and involved in the ultimate process of controlling the levels of fire safety in buildings, transport infrastructure and industrial facilities. Australia has a federal system consisting of a broad national government which unifies the 6 states and 2 territories into the Commonwealth of Australia.

The Commonwealth Government is responsible for the development of the national "Building Code of Australia" (BCA) (ABCB, 1996). This contains the technical provisions for building design, including the Performance Requirements set out in the typical 5 level "Nordic hierarchy".

The legislation for government control of buildings and other structures is done at the individual state level. Each State and Territory has its own Building Act which calls up the BCA for the technical provisions and sets in place all the planning and building approval mechanisms, appeal processes, inspection procedures and associated regulations for new and existing buildings.

The implementation of the State or Territory legislation and regulation for an individual building occurs at local government level i.e., at each local council or municipality. Planning applications, submissions for building approvals and occupancy permits for individual projects are dealt with traditionally by local councils across Australia, with approvals given by local council building surveyors and inspectors. However, increasingly this statutory role is being undertaken by private building surveyors acting on behalf of councils and simply lodging documents with councils for record purposes.

There are other regulatory instruments at both Commonwealth and State level which can have an impact on building design and fire safety, often in a subtle or unclear manner until issues arise. Some examples are:

- The states' Occupational Health and Safety (OH&S) Acts which require fire safety for occupants in the work place to be provided as far as is "practicable" without specific performance requirements.
- The Commonwealth "Disability Discrimination Act" (DDA) which requires all people, particularly the

'disabled' to be considered and provided for in buildings with access and dignity. This Act has no defined provisions or measurable targets.

Finally, each State and Territory has a Fire Brigades Act which sets out the role and responsibilities of the Australian fire services to 'protect life and property' and in some States, also 'protect the environment'. These Acts set out the brigade's structure and operations, funding arrangements, reporting to Government, role and responsibilities, and other related matters.

16.3 Building Code of Australia

Since 1994 the Australian Building Codes Board (ABCB) has been responsible for the management, development and publication of the "Building Code of Australia (BCA)".

The ABCB has its secretariat in Canberra and allows state-based contributions to BCA development through its Building Code Committee (BCC). This committee consists of a number of representatives from each State and Territory to get a broad national industry input.

The 1996 edition of BCA was the first performance based version to include the 5 level hierarchy of:

- Objectives;
- Functional Statements;
- Performance Requirements;
- Building Solutions – Deemed-to-Satisfy or Alternative Solutions; and
- Assessment Methods.

The sections of the BCA and key aspects which are relevant to fire performance are as follows:

A	General Provisions	definition of terminology, acceptance methods, building classifications
B	Structure	none
C	Fire Resistance	fire protection of structural elements, fire separation, protection of openings
D	Access and Egress	exit locations and dimensions
E	Services and Equipment	fire fighting equipment, smoke management, lighting, signs, warning systems
F	Health and Amenity	none
G	Ancillary Provisions	atria, alpine areas, bushfire-prone areas
H	Special Use Buildings	theatres
I	Maintenance	maintenance of fire safety equipment

The BCA includes not only the Performance Requirements for each Chapter, but also contains the prescriptive, acceptable solutions which are "Deemed-to-Satisfy" the Performance Requirements. The document of course makes clear the opportunity to develop Alternative Solutions where they can be justified by fire engineering analysis or other methods to satisfy the Performance Requirements.

A feature of the BCA is a series of State Appendices for the Deemed-to-Satisfy provisions. Traditionally, in the prescriptive model codes for Australia, each State had its own major variations. While the number of these variations as set out in the BCA are now very significantly reduced compared with the past, they reflect the vast size of Australia, the differences in conditions based on geography and some hangovers from local thinking on each state's "special provisions".

The criteria in Section A0.9 for compliance with the Performance Requirements means that for any part or aspect of a building an acceptable design may consist of:

(a) Deemed-to-Satisfy provisions;

(b) one or more Alternative Solutions; or

(c) some combination of Deemed-to-Satisfy and Alternative Solutions.

Equally, the design solutions which meet the Performance Requirements may be satisfied by design solutions being:

(i) equivalent in level of safety to the Deemed-to-Satisfy provisions; or

(ii) other solutions which satisfy the Performance Requirements.

16.4 State Legislation and Regulation

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, such as the Environment Planning and Assessment Act (1979), in NSW, typically provides each State and Territory with control over:

- Planning provisions;
- Project approval procedures;
- Adoption of the 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, such as the Building Control Commission (BCC) in Victoria, also play a public and industry education role. In the case of Victoria's BCC, they collect a levy on all buildings which is used for research of fire safety and other building matters, some through the Fire Code Reform Centre.

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. For example in Victoria, there are two fire brigades:

- Metropolitan Fire Brigades Board (MFFB), covering most of metropolitan Melbourne; and
- Country Fire Authority (CFA), covering the urban fringes of Melbourne and all rural areas of Victoria.

By contrast, in Western Australia the fire brigades form part of the Fire and Emergency Services Authority (FESA) which operates under a broader emergency services Act.

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.

As indicated previously, there is a major legislative conflict between the Building Act and the Fire Brigade Act in most, if not all, States, over the issue of property protection. The BCA as called up in the Building Acts addresses fire spread between fire compartments, between buildings on the same site and to adjoining properties. However, it does not address the issue of fire spread within fire compartments, and the BCA uses the term 'to the degree necessary' in relation to fire spread under Section C. It could be inferred, and has been the approach on many large warehouse and food processing buildings, for example, that the owner may reduce fire safety provisions, e.g., delete sprinklers, if life safety and adjoining property is not threatened and the brigade has reasonable site access for fire fighting. This approach is encouraged in parts of the explanatory 'Guide to the BCA'.

On the other hand, the Fire Brigade Acts typically call for brigades to 'protect life and property', and in some cases 'the environment'. This is often interpreted by the brigades as a right to demand higher levels of fire protection when the owner and their insurer may feel this is not cost-effective.

This is further complicated nationally in that the role of the fire brigade in building approvals varies from State to

State. In Victoria, relevant building surveyors as certifying authorities for buildings only have to make a formal reference to the Fire Brigade if the Deemed-to-Satisfy provisions are not being strictly followed in the area of brigade access and fire fighting equipment, e.g. hydrants.

In some other states, the Fire Brigade role is more extensive, such as NSW where the Brigades have input on issues of sprinklers and smoke control where Alternative Solutions are proposed under the Performance Requirements. In Queensland, the Fire Brigade reviews the complete design approach.

Another parcel of legislation relating to fire safety controlled by State governments is that involved in managing 'Dangerous Goods', i.e. high hazard materials, particularly flammable liquids and gases. Again, the Dangerous Goods legislation in Victoria requires mandatory reference to the Fire Brigade if the required risk assessment shows other than minimal quantities of hazardous materials.

16.5 Building Approvals

For individual projects, building control is vested with local councils, and increasingly with private certifiers acting on their behalf. The control mechanisms are the usual steps as in most countries:

(i) planning permit;

(ii) building approval/permit; and

(iii) certificate of occupancy.

For a new building, or the upgrade, extension or reuse of an existing building, the application is made to a council or private certifier. They issue the requisite permits in order and organise the relevant inspections during construction and fitout.

The introduction of private certifiers in Australia varies state by state, with only Western Australia, South Australia and Tasmania yet to introduce and allow private certification. The usual reason given for introducing private certifiers is that it introduces a degree of healthy competition into the market place between private certifiers and council building surveyors.

In most States where private certification has been introduced, they now dominate the building certification process.

Two fundamental tenets of private certification are that:

(i) they act on behalf of the community as a watchdog of public standards; and

(ii) they do not participate in the "design process".

The legislative and regulatory provisions to implement these principles do differ in each state, with the legislation in NSW requiring the Principal Certifying Authority (PCA), who may be a private consulting building surveyor, to not be involved in the design process for a project.

All states have a process where the Relevant Building Surveyor or Principal Certifying Authority (PCA), as the certifier, may ask for "Compliance Certificates" for the design process and "Construction Certificates" for the completed building from consultants and builders. These are known by names such as Form 12 and 14 in Victoria, Form 10 in NSW and Form 15 in Queensland.

It is very important that those issuing such Certificates understand the legislation under which they are issued. For example, in NSW, a PCA may call for a "Compliance Certificate - Form 10" from the design fire engineer in support of the fire safety strategy and the Alternative Solutions, indicating which Performance Requirements have been addressed in a fire engineering report and how the Performance Requirements have been met. The design fire engineers might be tempted to issue the Form 10 themselves, but are prevented by the pecuniary interest and conflict of interest provisions of the NSW EP&A Act. A person with no connection with the design and no financial or other pecuniary interest must review the report and sign the Form 10 on which the PCA can then rely absolutely in relation to those Performance Requirements for the project.

The reason for this action is that the person signing the Form 10 is acting on behalf of the community in the public interest with no fear or favour as a result of a conflict of interest.

16.6 Registered Professionals

The registration of fire safety engineers and related professionals is another area which differs State by State. However, most States are considering registration of professionals and are in the process of amending their Building Acts accordingly.

The most developed system is in the State of Victoria where all involved in the building and construction industry must be 'Registered Building Practitioners (RBP)'. This requires fire safety engineers and consulting building surveyors to be registered annually. Evidence of professional recognised qualifications and experience must be provided together with evidence of a required level of professional indemnity (PI) insurance.

The process of professional recognised status in Victoria is generally demonstrated through membership on the National Professional Engineers Register (NPER) maintained by The Institution of Engineers, Australia in Canberra for the category of "Fire Safety Engineering".

In NSW, it is necessary to be registered to sign Form 10 'Compliance Certificates'. Under the NSW legislation, people registered under IEAust's NPER scheme or the alternative BSAP scheme are eligible to sign such certificates.

16.7 Australian/New Zealand Standards

The design of buildings and their fire safety systems is generally controlled by the BCA which, under the Deemed-to-Satisfy provisions, calls up a large number of Australian/New Zealand standards.

These include:

- AS1670 — Fire Detection and Alarm Systems
- AS2118 — Sprinkler Systems
- AS2220 — Emergency Warning and Intercommunications Systems
- AS1530.4 — Structural Fire Protection
- AS1530.3 — Early Fire Hazard Tests (for materials)
- AS2149 — Fire Hydrants

Compliance with these standards is no longer compulsory as they form part of the Deemed-to-Satisfy provisions and are generally not part of the Performance Requirements.

In theory, and sometimes in practice, automatic sprinklers are designed to NFPA 13 or Factory Mutual Standards, or fire detection systems are designed to NFPA 72.

As well, there are a number of areas where Australia and New Zealand do not have specific standards for particular types of buildings or systems, and other standards are used or referred to. Some examples are:

- NFPA 130 — Rail stations, tunnels
- NFPA 415 — Airport terminal buildings
- NFPA 409 — Aircraft hangars
- BS5588 Part 8 — Use of Lifts for Disabled Evacuation

16.8 Maintenance and Essential Services

Australia has a major series of Standards which cover maintenance of fire protection systems. These include the AS1851 Standards which set out the requirements for maintenance of sprinklers, fire detection and alarms and other related fire protection equipment.

Until recently, the responsibility for ensuring the maintenance of fire protection equipment was left in the hands of the building owner or operator. However, the advent of performance based fire engineering has highlighted the importance of key fire protection measures, including the availability of exits and control of fire loads as well as the fire protection equipment.

State legislation for so called ‘Essential Services’ is now appearing, requiring the fire safety engineer to identify all key fire safety systems in a building which relate to the Performance Requirements being considered. These are then often listed on the ‘Certificate of Occupancy’ as Essential Services requiring the owner to maintain those elements, components and systems to the maintenance standards listed on the Certificate of Occupancy.

16.9 Fire Engineering Guidelines

The general approach adopted by fire safety engineers in Australia for the development of fire engineered Alternative Solutions under the performance based BCA is to follow the ‘Fire Engineering Guidelines’ (FCRC, 1996). These were developed by the Fire Code Reform Centre (FCRC), a not-for-profit body responsible for co-ordinating fire research and developing technical tools, data and design methods for fire engineering throughout Australia.

The “Fire Engineering Guidelines” document is widely used and referenced in projects as it has the endorsement of:

- Australian Building Codes Board (ABCB), the organisation that produces the BCA;
- Australian Institution of Building Surveyors (AIBS), representing certifiers; and
- Australasian Fire Authorities Council (AFAC), body representing fire brigades in Australia and New Zealand.

The Fire Engineering Guidelines call for a consultative approach to design, close liaison as appropriate with authorities, and the development of an initial qualitative design report before detailed analysis is undertaken. This initial report, entitled the Fire Engineering Design Brief (FEDB), has proved effective in obtaining early identification of all key issues and effective communication and negotiation on design and approval issues.

The first edition of the Fire Engineering Guidelines was published in 1996 and a second edition is in preparation.

Notation

Symbol	Description	Units
α_h	horizontal openings ratio	
α_v	vertical openings ratio	
β	charring rate	mm/min
ε	emissivity	
λ	thermal conductivity	W/m K
ρ	density	kg/m^3
ρ_o	density of ambient air	kg/m^3
ρ_s	density of smoke	kg/m^3
σ	Stefan-Boltzmann constant	kW/m^2 K^4
Φ	configuration factor	
ϕ	strength reduction factor	
A	cross section area of beam	m^2, mm^2
A_d	door area	m^2
A_e	area of enclosing rectangle	m^2
A_f	floor area	m^2
A_h	area of horizontal roof openings	m^2
A_l	area for leakage at a door	m^2
A_o	area of openings within enclosing rectangle	m^2
A_t	area of total bounding surfaces (wall+floor+ceiling)	m^2
A_v	area of vertical window and door openings	m^2
a	depth of compression stress block in concrete	mm
B	width of boundary layer	m
b	breadth of beam	mm
b_v	vertical openings correction factor	
C	flow coefficient	
C_w	pressure co-efficient	
c	specific heat	J/kg K
c_v	cover to reinforcing steel	mm
D	distance of door knob	m
D	distance of notional radiator from window	m
D_o	occupant density	persons/m^2
d	thickness of insulation	m
d	depth of beam	mm
E	total energy available in fuel	MJ

Symbol	Description	Units
e_f	fire load energy density (per square metre of floor)	MJ/m^2
e_t	fire load energy density (per m^2 of bounding surfaces)	MJ/m^2
F	door opening force	N
F_a	actual flow	persons/min
F_{dc}	force to overcome door closer	N
F_f	facade factor	
F_s	specific flow	persons/min/m
f'_c	characteristic strength of concrete	MPa
f_y	yield stress	MPa
G	dead load	kN/m
G	length of going on stairs	m
g	acceleration of gravity	m/sec^2
H	height of firecell	m
H_p	heated perimeter of steel section	m
H_r	height of enclosing rectangle	m
h	height of window opening	m
h	overall height of beam	mm
h_a	nett calorific value of fuel at ambient moisture content	MJ/kg
h_n	nett calorific value of fuel when oven dry	MJ/kg
I_R	radiant heat intensity	kW/m^2
I_{Rm}	minimum ignition value of radiant heat intensity	kW/m^2
j	depth ration in concrete beam	
k	fire growth constant	$s(MW)^{.5}$
k_o	discharge coefficient	
k_1	radiation reduction factor	
k_c	proportion of fuel available to burn	
k_h	factor for height of building	
k_s	factor for sprinklers and columns	
k_t	travel speed factor	
$k_{y,T}$	strength reduction factor for steel	
L	span of beam	m
L_f	length of firecell	m
L_t	length of travel	m
M	mass of fuel	kg
$\dot{m}$	rate of burning	kg/sec
m_c	moisture content as percentage by weight	%
m_d	moisture content as percentage of oven dry weight	%
M_s	rate of production of smoke	kg/sec
N	number of storeys in a building	

Symbol	**Description**	**Units**
N_o	number of occupants	
P	flame projection from window	m
P_w	wind pressure	Pa
p	water pressure	kPa
ΔP	pressure difference	Pa
p	perimeter of fire	m
Q	flow through an orifice	l/min
Q	live load	kN/m
Q	rate of heat release	MW
Q_e	equivalent rate of heat release	MW
Q_{fo}	heat release rate at flashover	MW
Q_m	Maximum heat release rate	MW
Q_p	Peak heat release rate	MW
Q_v	ventilation-controlled heat release rate	MW
Q_w	cooling power of water	MW/(l/s)
q_f	heat release rate per square metre of floor area	MW/m^2
R	distance between radiating and emitting surfaces	m
R	height of stair riser	m
R_u	design strength	
r	radius	mm
r_f	load ratio on steel member	
S	speed of travel	m/min
T	temperature	˚C
T'	temperature	K
T'_f	flame temperature	K
T'_o	ambient temperature	K
T_1	limiting steel temperature	˚C
T_e	temperature of emitting surface (firecell temperature)	˚C
T_o	ambient temperature	˚C
T_r	temperature of receiving surface	˚C
t	time	min, seconds
t_a	time from detection until an alarm is sounded	min
t_b	duration of burning	min
t_d	time from ignition until detection of the fire	min
t_e	equivalent fire severity	min
t_{ev}	evacuation time	min
t_{ed}	design fire severity	min
t_i	time for investigating the fire	min
t_{lt}	time for conditions to become life threatening	min

Symbol	Description	Units
t_m	time for all the fuel to be burned	sec
t_o	time for occupants to respond to alarm	min
t_q	time for queuing	min
t_r	fire resistance period for structural element	min
t_s	safety margin	min
t_{ts}	time to pass through a stairway or door	min
t_t	travel time	min
t_1	time to reach peak burning rate	sec
t_2	time at end of steady burning	sec
V	wind velocity	m/sec
V_f	volumetric air flow	m^3/sec
V_w	water flow	l/sec
W	width of door	m
W_e	effective width of door or stair	m
W_f	width of firecell	m
W_r	width of enclosing rectangle	m
w	width of window opening	m
w_f	ventilation factor	
x	height ratio	
Y	distance between floor and smoke layer	m
y	width ratio	
Z	flame height above soffit	m
Z	elastic modulus of beam	mm^3

Appendix A
Code Requirements in New Zealand

This Appendix consists of the performance requirements of the New Zealand Building Code extracted directly from the Building Regulations 1992. Words in italics are defined terms in the Building Code (BIA, 1992). Proposals for minor amendments to the New Zealand Building Code are being considered at the time of publication.

Clause C1 — Outbreak of Fire

Objective

C1.1 The objective of this provision is to safeguard people from injury or illness caused by *fire*.

Functional Requirement

C1.2 In *buildings* fixed appliances using the controlled combustion of solid, liquid or gaseous fuel, shall be installed in a way which reduces the likelihood of *fire*.

Performance

C1.3.1 Fixed appliances shall be installed so as to avoid the accumulation of gases within the installation and in *building* spaces, where heat or ignition could cause uncontrolled combustion or explosion.

C1.3.2 Fixed appliances shall be installed in a manner that does not raise the temperature of any *building element* by heat transfer or concentration to a level that would adversely affect its physical or mechanical properties or function.

Clause C2 — Means of Escape

Objective

C2.1 The objective of this provision is to:

(a) Safeguard people from injury or illness from a *fire* while escaping to a *safe place*, and

(b) Facilitate *fire* rescue operations.

Functional Requirement

C2.2 *Buildings* shall be provided with *escape routes* which:

(a) Give people *adequate* time to reach a *safe place* without being overcome by the effects of *fire*, and

(b) Give fire service personnel *adequate* time to undertake rescue operations.

Performance

C2.3.1 The number of *open paths* available to each person escaping to an *exitway* or *final exit* shall be appropriate to:

(a) The *travel distance*,

(b) The number of occupants,

(c) The *fire hazard*, and

(d) The *fire safety systems* installed in the *firecell*.

C2.3.2 The number of *exitways* or *final exits* available to each person shall be appropriate to:

(a) The *open path travel distance*,

(b) The *building height*,

(c) The number of occupants,

(d) The *fire hazard*, and

(e) The *fire safety systems* installed in the *building*.

C2.3.3 *Escape routes* shall be:

(a) Of *adequate* size for the number of occupants,

(b) Free of obstruction in the direction of escape,

(c) Of length appropriate to the mobility of the people using them,

(d) Resistant to the spread of *fire* as required by Clause C3 "Spread of Fire",

(e) Easy to find as required by Clause F8 "Signs",

(f) Provided with *adequate* illumination as required by Clause F6 "Lighting for Emergency" and

(g) Easy and safe to use as required by Clause D1.3.3 "Access Routes".

Clause C3 — Spread of Fire

Objective

C3.1 The objective of this provision is to:

(a) Safeguard people from injury or illness when evacuating a *building* during *fire*,

(b) Provide protection to fire service personnel during fire fighting operations,

(c) Protect adjacent *household units* and *other property* from the effects of *fire*,

(d) Safeguard the environment from adverse effects of *fire*.

Functional Requirement

C3.2 *Buildings* shall be provided with safeguards against *fire* spread so that:

(a) Occupants have time to escape to a *safe place* without being overcome by the effects of *fire*,

(b) Firefighters may undertake rescue operations and protect property,

(c) Adjacent *household units* and *other property* are protected from damage, and

(d) Significant quantities of *hazardous substances* are not released to the environment during *fire*.

Limitations on Application

Requirement C3.2(d) applies only to *buildings* where significant quantities of *hazardous substances* are stored or processed.

Performance

C3.3.1 Interior surface finishes on walls, floors, ceilings and suspended *building elements*, shall resist the spread of *fire* and limit the generation of toxic gases, smoke and heat, to a degree appropriate to:

(a) The *travel distance*,

(b) The number of occupants,

(c) The *fire hazard,* and

(d) The active *fire safety systems* installed in the *building*.

C.3.3.2 *Fire separations* shall be provided within *buildings* to avoid the spread of *fire* and smoke to:

(a) Other *firecells,*

(b) Spaces intended for sleeping, and

(c) *Household units* within the same *building* or *adjacent buildings*.

Limitations on Application

Performance C3.3.2 shall not apply to *Detached Dwellings*, or within *household units* of *Multi-unit Dwellings*.

C.3.3.3 Fire separations shall:

(a) Where openings occur, be provided with *fire resisting closures* to maintain the *integrity* of the fire *separations* for an *adequate* time, and

(b) Where penetrations occur, maintain the fire *resistance rating* of the *fire separation.*

C3.3.4 *Concealed spaces* and cavities within *buildings* shall be sealed and subdivided where necessary to inhibit the unseen spread of *fire* and smoke.

Limitations on Application

Performance C3.3.4 shall not apply to *Detached Dwellings*.

C3.3.5 *External walls* and roofs shall have resistance to the spread of *fire*, appropriate to the *fire load* within the *building* and to the proximity of other *household units* and *other property*.

C3.3.6 Automatic fire suppression systems shall be installed where people would otherwise be:

(a) Unlikely to reach a safe place in *adequate* time because of the number of storeys in the *building*,

(b) Required to remain within the *building* without proceeding directly to a *final exit*, or where the *evacuation time* is excessive,

(c) Unlikely to reach a *safe place* due to confinement under institutional care because of mental or physical disability, illness or legal detention, and the *evacuation time* is excessive, or

(d) At high risk due to the *fire load* and *fire hazard* within the *building*.

C3.3.7 Air conditioning and mechanical ventilation systems shall be constructed to avoid circulation of smoke and *fire* between *firecells*.

C3.3.8 Where an automatic smoke control system is installed, it shall be constructed to:

(a) Avoid the spread of *fire* and smoke between *firecells*, and

(b) Protect *escape routes* from smoke until the occupants have reached a *safe place*.

C3.3.9 The *fire safety systems* installed shall facilitate the specific needs of fire service personnel to:

(a) Carry out rescue operations, and

(b) Control the spread of fire.

C3.3.10 Environmental protection systems shall ensure a low probability of *hazardous substances* being released to:

(a) Soils, vegetation or natural waters,

(b) The atmosphere, and

(c) *Sewers* or public *drains*.

Limitations on Application

Performance C3.3.10 applies only to *buildings* where significant quantities of *hazardous substances* are stored or processed.

Clause C4 — Structural Stability during Fire

Objective

C4.1 The objective of this provision is to:

(a) Safeguard people from injury due to loss of structural stability during *fire*, and

(b) Protect *household units* and *other property* from damage due to structural instability caused by *fire*.

Functional Requirement

C4.2 *Buildings* shall be constructed to maintain structural stability during *fire* to:

(a) Allow people *adequate* time to evacuate safely,

(b) Allow fire service personnel *adequate* time to undertake rescue and fire fighting operations, and

(c) Avoid collapse and consequential damage to adjacent *household units* or *other property*.

Performance

C4.3.1 Structural elements of *buildings* shall have *fire* resistance appropriate to the function of the elements, the *fire load*, the *fire intensity*, the *fire hazard*, the height of the *buildings* and the *fire* control facilities external to and within them.

C4.3.2 Structural elements shall have a *fire* resistance of no less than that of any element to which they provide support within the same *firecell*.

C4.3.3 Collapse of elements having lesser *fire* resistance shall not cause the consequential collapse of elements required to have a higher *fire* resistance.

Clause F6 — Lighting for Emergency

Objective

F6.1 The objective of this provision is to safeguard people from injury due to inadequate lighting being available during an emergency.

Functional Requirement

F6.2 *Buildings* shall be provided with *adequate* lighting within all *escape routes* in an emergency.

Limitations on Application

Requirement F6.2 shall not apply to *Detached Dwellings*, *household units* within *Multi-unit Dwellings*, *Outbuildings* or *Ancillary buildings*.

Performance

F6.3.1 An *illuminace* of 1 lux minimum shall be maintained at floor level throughout *buildings* for a period equal to 1.5 times the *evacuation time*.

Limitations on Application

Performance F6.3.1 shall not apply to spaces infrequently inhabited such as plant rooms, storage areas and service tunnels.

F6.3.2 Signs to indicate *escape routes* shall be provided as required by Clause F8 "Signs".

Clause F7 — Warning systems

Objective

F7.1 The objective of this provision is to safeguard people from injury or illness due to lack of awareness of an emergency.

Functional Requirement

F7.2 *Buildings* shall be provided with appropriate means of warning people to escape to a *safe place*.

Performance

F7.3 A warning system shall consist of a combined *fire* detection and warning system that will alert people in *adequate* time for them to reach a *safe place*.

Limitations on Application

Performance F7.3 shall not apply to *Detached Dwellings*, *Outbuildings* or *Ancillary buildings*.

Appendix B
Code Requirements in Australia

This Appendix consists of the performance requirements of the Building Code of Australia (1996), extracted directly from the Code (BCA, 1996).

Words in italics are defined within the BCA.

Section C: Fire Resistance

Fire Resistance

C01 The *Objective* of this Section is to

(a) safeguard people from illness or injury due to a fire in a building; and

(b) safeguard occupants from illness or injury while evacuating a building during a fire; and

(c) facilitate the activities of emergency services personnel; and

(d) avoid the spread of fire between buildings; and

(e) protect *other property* from physical damage caused by structural failure of a building as a result of fire.

Functional Statements

CF1 A building is to be constructed to maintain structural stability during fire to-

(a) allow occupants time to evacuate safely; and

(b) allow for *fire brigade* intervention; and

(c) avoid damage to *other* property.

CF2 A building is to be provided with safeguards to prevent fire spread-

(a) so that occupant's have time to evacuate safely without being overcome by the effects of fire; and

(b) to allow fire brigade intervention; and

(c) to sole-occupancy units providing sleeping accommodation; and

(d) to adjoining fire compartments; and

(e) between buildings.

Performance Requirements

CP1 A building must have elements which will, to the degree necessary, maintain structural stability during a fire appropriate to-

(a) the function or use of the building; and

(b) the *fire load*; and

(c) the potential *fire intensity*; and

(d) the *fire hazard*; and

(e) the height of the building; and

(f) its proximity to *other property*; and

(g) any active *fire safety system*s installed in the building; and

(h) the size of any *fire compartment*; and

(i) *fire brigade* intervention; and

(j) other elements they support; and

(k) the *evacuation time*.

CP2 A building must have elements which will, to the degree necessary, avoid the spread of fire

(a) to *exits*; and

(b) to *sole-occupancy unit*s and *public corridors*; and

Application: CP2(b) only applies to a Class 2 or 3 building or Class 4 part.

(c) between buildings; and

(d) in a building,

appropriate to -

i) the function or use of the building; and

ii) the *fire load*; and

iii) the potential *fire intensity*; and

iv) the *fire hazard*; and

v) the number of *storeys* in the building; and

vi) its proximity to *other property*; and

vii) any active *fire safety systems* installed in the building; and

viii) the size of any *fire compartment*; and

ix) *fire brigade* intervention; and

x) other elements they support; and

xi) the *evacuation time*.

CP3 A *patient care* of a Class 9a building must be protected from the spread of fire and smoke to allow sufficient time for the orderly evacuation of the building in an emergency.

CP4 A material and an assembly must, to the degree necessary, resist the spread of fire to limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to

(a) the *evacuation time*; and

(b) the number, mobility and other characteristics of occupants; and

(c) the function or use of the building; and

(d) any active *fire safety systems* installed in the building.

CP5 A concrete *external wall* that could collapse as a complete panel (eg. Tilt-up and pre-cast concrete) must be designed so that in the event of fire within the building the likelihood of outward collapse is avoided.

Limitation: CP5 does not apply to a building having more than two *storeys* above ground level.

CP6 A building must have elements, which will, to the degree necessary, avoid the spread of fire from service equipment having

(a) a high *fire hazard*; or

(b) a potential for explosion resulting from a *high fire hazard*.

CP7 A building must have elements, which will, to the degree necessary, avoid the spread of fire so that emergency equipment provided in a building will continue to operate for a period of time necessary to ensure that the intended function of the equipment is maintained during a fire.

CP8 Any building element provided to resist the spread of fire must be protected, to the degree necessary, so that an adequate level of performance is maintained

(a) where openings, construction joints and the like occur; and

(b) where penetrations occur for building services.

CP9 Access must be provided to and around a building, to the degree necessary, for *fire brigade* vehicles and personnel to facilitate *fire brigade* intervention appropriate to

(a) the function or use of the building; and

(b) the *fire load*; and

(c) the potential *fire intensity*; and

(d) the *fire hazard*; and

(e) any active *fire safety systems* installed in the building; and

(f) the size of any *fire compartment*.

Section D: Access and Egress

Objective

DO1 The *Objective* of this Section is to

(a) provide, as far as is reasonable, people with safe, equitable and dignified access to

i) a building; and

ii) the services and facilities within a building; and

(b) safeguard occupants from illness or injury while evacuating in an emergency.

Functional Statements

DF1 A building is to provide, as far as is reasonable

(a) safe; and

(b) equitable and dignified; and

(c) access for people to the services and facilities within.

Application: DF1(b), with respect to people with disabilities, only requires special provisions in

(a) a Class 3, 5, 6, 8 or 9 building; or

(b) a Class 7 building other than a Class 7 *carpark* associated with a Class 2 building; or

(c) a Class 10a building other than a Class 10a building associated with a Class 1 or 2 building or Class 4 part of a building.

DF2 A building is to be provided with means of evacuation which allow occupant time to evacuate safely without being overcome by the effects of an emergency.

Limitation: DF2 does not apply to the internal parts of a *sole-occupancy* unit in a Class 2 or 3 building or Class 4 part.

Performance Requirements

DP1 Access must be provided, to the degree necessary, to enable safe and equitable and dignified movement of people to and within a building.

Application: DP1(b), with respect to people with disabilities, only requires special provisions in-

(a) a Class 3, 5, 6, 8 or 9 building; or

(b) a Class 7 building other than a Class 7 *carpark* associated with a Class 2 building; or

(c) a Class 10a building other than a Class 10a building associated with a Class 1 or 2 building or Class 4 part of a building.

DP2 So that people can move safely to and within a building, it must have

(a) walking surfaces with safe gradients; and

(b) any doors installed to avoid the risk of occupants

i) having their egress impeded; or

ii) being trapped in the building; and

(c) any stairways and ramps with

i) slip-resistant walking surfaces
A. ramps; and
B. stairway treads or near the edge of the nosing; and

ii) suitable handrails where necessary to assist and provide stability to people using the stairway or ramp; and

iii) suitable landings to avoid undue fatigue; and

iv) landings where a door opens from or onto the stairway or ramp so that the door does not create an obstruction; and

v) in the case of a stairway, suitable safe passage in relation to the nature, volume and frequency of likely usage.

DP3 Where people could fall –

(a) 1 metre or more -

i) from a floor or roof or through an opening (other than through an openable window) in the external wall of a building; or

ii) due to a sudden change of level within or associated with a building; or

(b) 4 metres from a floor through an openable window, a barrier must be provided which must be-

(c) continuous and extend for the full extent of the hazard; and

(d) of a height to protect people from accidentally falling from the floor or roof or through the opening; and

(e) constructed to prevent people from falling through the barrier; and

(f) capable of restricting the passage of children; and

(g) of strength and rigidity to withstand -

i) the foreseeable impact of people; and

ii) where appropriate, the static pressure of people pressing against it.

Limitations: DP3 does not apply where such a barrier would be incompatible with the intended use of an area such as a stage, loading dock or the like.

DP3(d) does not apply to-

(a) *fire-isolated stairways*, *fire-isolated ramps*, and other areas used primarily for emergency purposes, excluding external stairways and external ramps; and

(b) Class 7 (other than *carparks*) and Class 8 buildings and parts of buildings containing those classes.

DP4 *Exits* must be provided from a building to allow occupants to evacuate safely, with their number, location and dimensions being appropriate to

(a) the travel distance; and

(b) the number, mobility and other characteristics of occupants; and

(c) the function or use of the building; and

(d) the height of the building; and

(e) whether the *exit* is from above or below ground level.

DP5 To protect evacuating occupants from a fire in the building *exits* must be fire isolated, to the degree necessary, appropriate to

(a) the number of *storeys* connected by the *exits*; and

(b) the *fire safety system* installed in the building; and

(c) the function or use of the building; and

(d) the number of *storeys* passed through by the *exits*; and

(e) *fire brigade* intervention.

DP6 So that occupants can safely evacuate the building, paths of travel to exits must have dimensions appropriate to

the number, mobility and other characteristics of occupants; and

the function or use of the building.

Limitation: DP6 does not apply to the internal parts of a *sole-occupancy unit* in a Class 2 or 3 building or Class 4 part of a building.

With respect to people with disabilities, DP6 does not apply to-

(a) a Class 2 building; or

(b) a Class 7 *carpark* associated with a Class 2 building.

DP7 Accessways must be provided, as far as is reasonable, to and within buildings which

(a) have features to enable people with disabilities to safely, equitably and with dignity

i) approach the building from the road boundary and from any carparking spaces associated with the building; and

ii) access work and public spaces, accommodation and facilities for personal hygiene; and

(b) are identified at appropriate locations and are easy to find; and

(c) enable a person in a wheelchair to manoeuvre.

Application: DP7 only applies to

(a) a Class 3, 4, 6, 8 or 9 building; or

(b) a Class 7 building other than a Class 7 *carpark* associated with a Class 2 building; or

(c) a Class 10 building other than a Class 10 building associated with a Class 2 building or Class 4 part of a building.

DP8 Carparking spaces for use by people with disabilities must be-

(a) provided, to the degree necessary, to give equitable access for carparking; and

(b) designated and easy to find.

Limitation: DP8 does not apply to a building where

(a) a parking service is provided; and

(b) direct access to any carparking spaces by the general public or occupants is not available.

DP9 An inbuilt communication system for entry, information, entertainment, or for the provision of a service, must be suitable for occupants who are hearing impaired.

Limitation: DP9 does not apply to

(a) a Class 2 building; or

(b) a Class 4 part of a building; or

(c) a Class 7 *carpark* associated with a Class 2 building; or

(d) an inbuilt communication system used only for emergency warning purposes.

Part E1: Fire Fighting Equipment

Objective

EO1 The *Objective* of this Part is to

(a) safeguard occupants from illness or injury while evacuating during a fire; and

(b) provide facilities for occupants and the *fire brigade* to undertake fire-fighting operations; and

(c) prevent the spread of fire between buildings.

Functional Statement

EF1.1 A building is to be provided with fire-fighting equipment to safeguard against fire spread-

(a) to allow occupants time to evacuate safely without being overcome by the effects of fire; and

(b) so that occupants may undertake initial attack on a fire; and

(c) so that the fire brigade have the necessary equipment to undertake search, rescue, and fire-fighting operations; and

(d) to other parts of the building; and

(e) between buildings.

Performance Requirements

EP1.1 A fire hose reel system must be installed to the degree necessary to allow occupants to safely undertake initial attack on a fire appropriate to

(a) the size of the *fire compartment*; and

(b) the function of use of the building; and

(c) any other *fire safety systems* installed in the building; and

(d) the *fire hazard*.

EP1.2 Fire extinguishers must be installed to the degree necessary to allow occupants to undertake initial attack on a fire appropriate to

(a) the function or use of the building; and

(b) any other *fire safety systems* installed in the building; and

(c) the *fire hazard*.

EP1.3 A hydrant system must be provided to the degree necessary to facilitate the needs of the *fire brigade* appropriate

(a) fire-fighting operations; and

(b) the *floor* area of the building; and

(c) the *fire hazard*.

Application: EP1.3 only applies to a building where a fire brigade is available to attend.

EP1.4 An automatic fire suppression system must be installed to the degree necessary to control the development and spread of fire appropriate to

(a) the size of the *fire compartment*; and

(b) the function or use of the building and

(c) the *fire hazard*; and

(d) the height of the building.

EP1.5 Suitable means of fire-fighting must be installed to a degree necessary in a building under construction to allow initial fire attack by construction workers and for the *fire brigade* to undertake attack on the fire appropriate to

(a) the *fire hazard*; and

(b) the height the building has reached during its construction.

EP1.6 Suitable facilities must be provided to a degree necessary in a building to co-ordinate *fire brigade* intervention during an emergency appropriate to

(a) the function or use of the building; and

(b) the floor area of the building; and

(c) the height of the building.

Part E2: Smoke Hazard and Management

Objective

EO2 The *Objective* of this Part is to

(a) safeguard occupants from illness or injury by warning them of a fire so that they may safely evacuate; and

(b) safeguard occupants from illness or injury while evacuating during a fire.

Functional Statement

EF2.1 A building is to be provided with safeguards so that-

(a) occupants are warned of a fire in the building so that they may safely evacuate; and

(b) occupants have time to safely evacuate before the environment in any *evacuation route* becomes untenable from the effects of fire.

Performance Requirements

EP2.1 In a building providing sleeping accommodation, occupants must be provided with *automatic* warning on the detection of smoke so they may evacuate in the event of a fire to a *safe place*.

Application: EP2.1 only applies to a Class 2, 3 or 9a building or Class 4 part.

EP2.2 (a) In the event of a fire in a building the conditions in any *evacuation route* must be maintained for the period of time occupants take to evacuate the part of the building so that

(i) the temperature will not endanger human life; and

(ii) the level of visibility will enable the *evacuation route* to be determined; and

(iii) the level of toxicity will not endanger human life.

(b) The period of time occupants take to evacuate referred to in (a) must be appropriate to

(i) the number, mobility and other characteristics of the occupants; and

(ii) the function or use of the building; and

(iii) the travel distance and other characteristics of the building; and

(iv) the *fire load*; and

(v) the potential *fire intensity*; and

(vi) the *fire hazard*; and

(vii) any active fire *safety systems* installed in the building; and

(viii) *fire brigade* intervention.

Limitation: EP2.2 does not apply to an *open-deck carpark* or *open spectator stand*.

Part E4: Emergency Lighting, Exit signs and Warning Systems

Objective

EO4 The *Objective* of this Part, is in an emergency, to safeguard occupants from injury by

(a) having adequate lighting; and

(b) having adequate identification of *exits* and paths of travel to *exits*; and

(c) being made aware of the emergency.

Functional Statement

EF4.1 A building is to be provided with

(a) adequate lighting upon failure of normal artificial lighting during an emergency; and

(b) adequate means

i) of warning occupants to evacuate; and

ii) to manage the evacuation process and

iii) to identify *exits* and paths of travel to an *exit*.

Performance Requirements

EP4.1 A level of illumination for safe evacuation in an emergency must be provided, to the degree necessary, appropriate to

(a) the function or use of the building; and

(b) the *floor area* of the building; and

(c) the distance of travel to an *exit*.

Limitation: EP4.1 does not apply to the internal parts of a *sole-occupancy unit* in a Class 2 or 3 building or Class 4 part of a building.

EP4.2 To facilitate evacuation, suitable signs or other means of identification must, to the degree necessary

(a) be provided to identify the location of *exits*; and

(b) guide occupants to *exits*; and

(c) be clearly visible to occupants; and

(d) operate in the event of a power failure of the main lighting system for sufficient time for occupants to safely evacuate.

EP4.3 To warn occupants of an emergency and assist evacuation of a building, an emergency warning and intercommunication system must be provided, to the degree necessary, appropriate to

(a) the *floor area* of the building; and

(b) the function or use of the building; and

(c) the height of the building.

Part I1: Equipment and Safety Installations

Objective

IO1 The *Objective* of this Part is to ensure that people are protected from illness, injury and loss of amenity throughout the life of the building.

Functional Statement

IF1.1 A building is to be adequately maintained to safeguard people from illness or injury and prevent the loss of amenity.

Performance Requirement

IP1.1 Equipment, installations and components essential to the safety of the people must be adequately maintained in such condition that will enable their proper performance.

Appendix C
Heat Release Rates

Tables C1 and C2 give heat release rates from selected experimental tests on typical items of furniture and warehouse goods carried out at NIST (NFPA, 1993).

Test No.	Description and mass of furniture item	Growth time k (sec)	Virtual time t_v (sec)	Peak heat release rate (MW)
Test 15	Metal wardrobe, 41.4 kg (total)	50	10	0.75
Test 18	Chair F33 (trial love seat), 39.2 kg	400	140	0.95
Test 19	Chair F21, 28.2 kg (initial)	175	110	0.35
Test 19	Chair F21, 28.2 kg (later)	50	190	2.0
Test 21	Metal wardrobe, 40.8 kg (total) (initial)	250	10	0.25
Test 21	Metal wardrobe, 40.8 kg (total) (average)	120	60	0.25
Test 21	Metal wardrobe, 40.8 kg (total) (later)	100	30	0.14
Test 22	Chair F24, 28.3 kg	350	400	0.70
Test 23	Chair F23, 31.2 kg	400	100	0.70
Test 24	Chair F22, 31.9 kg	2000	150	0.30
Test 25	Chair F26, 19.2 kg	200	90	0.80
Test 26	Chair F27, 29.0 kg	200	360	0.90
Test 27	Chair F29, 14.0 kg	100	70	1.85
Test 28	Chair F28, 29.2 kg	425	90	0.70
Test 29	Chair F25, 27.8 kg (initial)	100	100	2.0
Test 29	Chair F25, 27.8 kg (later)	60	175	0.70
Test 30	Chair F30, 25.2 kg	60	70	0.95
Test 31	Chair F31 (love seat), 39.6 kg	60	145	2.6
Test 37	Chair F31 (love seat), 40.4 kg	80	100	2.75
Test 38	Chair F32 (sofa), 51.5 kg	100	50	3.0
Test 39	12mm plywood wardrobe with fabrics, 68.5 kg	35	20	3.25
Test 40	12mm plywood wardrobe with fabrics, 68.3 kg	35	40	3.50
Test 41	3mm plywood wardrobe with fabrics, 36.0 kg	40	40	6.0
Test 42	3mm plywood wardrobe with fire-retardant interior finish (later growth)	30	100	5.0
Test 43	Repeat of 12mm plywood wardrobe, 67.6 kg	30	50	3.0
Test 44	3mm plywood wardrobe with fire-retardant latex paint, 37.3 kg	90	30	2.9
Test 45	Chair F21, 28.3 kg	100	120	2.1
Test 46	Chair F21, 28.3 kg	45	130	2.6
Test 47	Chair, adj. back metal frame, foam cushions, 20.8 kg	170	30	0.25
Test 48	Easy chair C07, 11.5 kg	175	90	0.95
Test 49	Easy chair F34, 15.7 kg	200	50	0.20
Test 50	Chair, metal frame, minimum cushion, 16.5 kg	200	120	3.0
Test 51	Chair, moulded fibreglass, no cushion, 5.3 kg	120	20	0.35
Test 52	Moulded plastic patient chair, 11.3 kg	275	2090	0.70
Test 53	Chair, metal frame, padded seat and back, 15.5 kg	350	50	0.28
Test 54	Love seat, metal frame, foam cushions, 27.3 kg	500	210	0.30
Test 56	Chair, wood frame, latex foam cushions, 11.2 kg	500	50	0.08
Test 57	Love seat, wood frame, foam cushions, 54.6 kg	350	500	1.0
Test 61	Wardrobe, 3/4-in. particle board, 120 kg	150	0	1.2
Test 62	Bookcase, plywood with aluminium frame, 30.4 kg	65	40	0.03
Test 64	Easy chair, moulded flexible urethane frame, 16.0 kg	1000	750	0.45
Test 66	Easy chair, 23.0 kg	76	3700	0.6
Test 67	Mattress and box-spring, 62.4 kg (initial)	1100	90	0.4
Test 67	Mattress and box-spring, 62.4 kg (later)	350	400	0.5

Note: The virtual time t_v is the time after ignition at which the burning item began to follow the t^2 fire. Prior to t_v the item may have smouldered but did not burn vigorously with an open flame.

Table C.1: Furniture heat release rate data obtained from furniture calorimeter tests

Warehouse materials	**Growth time k** (sec)	**Peak heat release rate density** (MW/m^2)
1. Wood pallets, stack, 0.45m high (6%-12% moisture)	150-310	1.2
2. Wood pallets, stack, 1.5m high (6%-12% moisture)	90-190	3.7
3. Wood pallets, stack, 3m high (6%-12% moisture)	80-110	6.8
4. Wood pallets, stack, 4.6m high (6%-12% moisture)	75-105	10.2
5. Mail bags, filled, stored 1.5m high	190	0.4
6. Cartons, compartmented, stacked 3m high	60	2.3
7. Paper, vertical rolls, stacked 6m high	15-28	
8. Cotton (also PE, PE/cot, acrylic/nylon/PE),	20-42	
9. Cartons on pallets, rack storage, 5-10m high	40-280	
10. Paper products, densely packed in cartons, rack storage, 6m high	470	
11. PE letter trays, filled, stacked 1.5m high on cart	190	8.5
12. PE trash barrels in cartons, stacked 4.6m high	55	2.8
13. FRP shower stalls in cartons, stacked 4.6m high	85	1.2
14. PE bottles, packed in item 6	85	6.2
15. PE bottles in cartons, stacked 4.6m high	75	1.9
16. PE pallets, stacked 1m high	130	
17. PE pallets, stacked 2-3m high	30-55	
18. PU mattress, single, horizontal	110	
19. PE insulation board, rigid foam, stacked 4.6m high	8	1.9
20. PS jars, packed in item 6	55	13.6
21. PS tubs nested in cartons, stacked 4.3m high	105	5.1
22. PS toy parts in cartons, stacked 4.6m high	110	2.0
23. PS insulation board, rigid, stacked 4.3m high	7	3.3
24. PVC bottles, packed in item 6	9	3.4
25. PP tubs, packed in item 6	10	4.4
26. PP and PE film in rolls, stacked 4.3m high	40	4.0
27. Distilled spirits in barrels, stacked 6m high	23-40	
28. Methyl alcohol		0.74
29. Gasoline		2.3
30. Kerosene		2.3
31. Diesel oil		2.0

Notes: The peak heat release rate per unit floor area are for fully involved combustibles, assuming 100% combustion efficiency.
PE = polyethylene
PS = polystyrene
PVC = polyvinyl chloride
PP = polypropylene
PU = polyurethane
FRP = fibreglass reinforced polyester

Table C.2: Heat release rate data for warehouse goods obtained from furniture calorimeter tests

Appendix D
Fire Load Energy Densities

This Appendix is extracted from CIB (1986). The table gives average fire load densities using data from Switzerland.

"The following values for *fire load densities* (only variable fire load densities) are taken from *Beilage 1: Brandschutztechnische Merkmale verschiedener Nutzungen und Lagerguter* and are defined as density per unit floor area (MJ/m^2).

Note that for the determination of the variable fire load of storage areas, the values given in the following table have to be multiplied by the height of storage in metres. Areas and aisles for transportation have been taken into consideration in an averaging manner.

The values are based on a large investigation carried out during the years 1967-1969 by a staff of 10-20 students under the guidance of the Swiss Fire Prevention Association for Industry and Trade (Brandverhutungsdienst fur Industrie und Gewerbe, Nuschelerstrasse 45, CH-8001 Zurich), with the financial support of the governmental civil defence organisation.

For each type of occupancy, storage and/or building, a minimum of 10-15 samples were analysed; normally, 20 or more samples were available. All values given in the following pages are average values. Unfortunately, it has been impossible to obtain the basic data sheets of this investigation. In order to estimate the corresponding standard deviations and the 80%-90%- and 95%-fractile values, the data from this source were compared with data given in references 1-5, 7-11. This comparison results in the following suggestions:

(a) For well-defined occupancies which are rather similar or with very limited differences in furniture and stored goods, e.g. dwellings, hotels, hospitals, offices and schools, the following estimates may suffice:

Coefficient of variation	=	30%-50% of the given average value
90%-fractile value	=	(1.35-1.65) x average value
80%-fractile value	=	(1.25-1.50) x average value
isolated peak values	=	2 x average value

(b) For occupancies which are dissimilar or with larger differences in furniture and stored goods, e.g. shopping centres, department stores and industrial occupancies, the following estimates are tentatively suggested:

Coefficient of variation	=	50%-80% of the given average value
90%-fractile value	=	(1.65-2.0) x average value
80%-fractile value	=	(1.45-1.75) x average value
isolated peak values	=	2.5 x average value

Type of occupancies	Fabrication (MJ/m²)	Storage (MJ/m²/m)
Academy	300	
Accumulator forwarding	800	
Accumulator mfg	400	800
Acetylene cylinder storage	700	
Acid plant	80	
Adhesive mfg	1000	3400
Administration	800	
Adsorbent plant for combustible vapours	>1700	
Aircraft hangar	200	
Airplane factory	200	
Aluminium mfg	40	
Aluminium processing	200	
Ammunition mfg	Special	
Animal food preparing, mfg	2000	3300
Antique shop	700	
Apparatus forwarding	700	
Apparatus mfg	400	
Apparatus repair	600	
Apparatus testing	200	
Arms mfg	300	
Arms sales	300	
Artificial flower mfg	300	200
Artificial leather mfg	1000	1700
Artificial leather processing	300	
Artificial silk mfg	300	1100
Artificial silk processing	210	
Artificial stone mfg	40	
Asylum	400	
Authority office	800	
Awning mfg	300	1000
Bag mfg (jute, paper, plastic)	500	
Bakery	200	
Bakery, sales	300	
Ball bearing mfg	200	
Bandage mfg	400	
Bank, counters	300	
Bank, offices	800	
Barrel mfg, wood	1000	800
Basement, dwellings	900	
Basketware mfg	300	200
Bed sheeting production	500	1000
Bedding plant	600	
Bedding shop	500	
Beer mfg (brewery)	80	
Beverage mfg, nonalcoholic	80	
Bicycle assembly	200	400
Biscuit factories	200	
Biscuit mfg	200	
Bitumen preparation	800	3400
Blind mfg, venetian	800	300
Blueprinting firm	400	
Boarding school	300	
Boat mfg	600	
Boiler house	200	
Bookbinding	1000	
Bookstore	1000	
Box mfg	1000	600
Brick plant, burning	40	
Brick plant, clay preparation	40	
Brick plant, drying kiln with metal grates	40	
Brick plant, drying kiln with wooden grates	1000	
Brick plant, drying room with metal grates	40	
Brick plant, drying room with wooden grates	400	
Brick plant, pressing	200	
Briquette factories	1600	
Broom mfg	700	400
Brush mfg	700	800
Butter mfg	700	4000
Cabinet making (without woodyard)	600	
Cable mfg	300	600
Cafe	400	
Camera mfg	300	
Candle mfg	1300	22400
Candy mfg	400	1500
Candy packing	800	
Candy shop	400	
Cane products mfg	400	200
Canteen	300	
Car accessory sales	300	
Car assembly plant	300	
Car body repairing	150	
Car paint shop	500	
Car repair shop	300	
Car seat cover shop	700	
Cardboard box mfg	800	2500
Cardboard mfg	300	4200
Cardboard products mfg	800	2500
Carpenter shed	700	
Carpet dyeing	500	
Carpet mfg	600	1700
Carpet store	800	
Cartwright's shop	500	
Cast iron foundry	400	800
Celluloid mfg	800	3400
Cement mfg	1000	
Cement plant	40	
Cement products mfg	80	
Cheese factory	120	
Cheese mfg (in boxes)	170	
Cheese store	100	
Chemical plants (rough average)	300	100
Chemist's shop	1000	
Children's home	400	
China mfg	200	
Chipboard finishing	800	
Chipboard pressing	100	
Chocolate factory, intermediate storage	6000	
Chocolate factory, packing	500	
Chocolate factory, tumbling treatment	1000	
Chocolate factory, all other specialities	500	

Type of occupancies	Fabrication (MJ/m²)	Storage (MJ/m²/m)
Church	200	
Cider mfg (without crate storage)	200	
Cigarette plant	3000	
Cinema	300	
Clay, preparing	50	
Cloakroom, metal wardrobe	80	
Cloakroom, wooden wardrobe	400	
Cloth mfg	400	
Clothing plant	500	
Clothing store	600	
Coal bunker	2500	
Coal cellar	10500	
Cocoa processing	800	
Coffee extract mfg	300	
Coffee roasting	400	
Cold storage	2000	
Composing room	400	
Concrete products mfg	100	
Condiment mfg	50	
Congress hall	600	
Contractors	500	
Cooking stove mfg	600	
Coopering	600	
Cordage plant	300	600
Cordage store	500	
Cork products mfg	500	800
Cosmetic mfg	300	500
Cotton mills	1200	
Cotton wool mfg	300	
Cover mfg	500	
Cutlery mfg (household)	200	
Cutting-up shop, leather, artificial leather	300	
Cutting-up shop, textiles	500	
Cutting-up shop, wood	700	
Dairy	200	
Data processing	400	
Decoration studio	1200	2000
Dental surgeon's laboratory	300	
Dentist's office	200	
Department store	400	
Distilling plant, combustible materials	200	
Distilling plant, incombustible materials	50	
Doctor's office	200	
Door mfg, wood	800	1800
Dressing, textiles	200	
Dressing, paper	700	
Dressmaking shop	300	
Dry-cell battery	400	600
Dry cleaning	300	
Dyeing plant	500	
Edible fat forwarding	900	
Edible fat mfg	1000	18900
Electric appliance mfg	400	
Electric appliance repair	500	
Electric motor mfg	300	
Electrical repair shop	600	
Electrical supply storage H< 3 m	1200	
Electro industry	600	
Electronic device mfg	400	
Electronic device repair	500	
Embroidery	300	
Etching plant glass/metal	200	
Exhibition hall, cars including decoration	200	
Exhibition hall, furniture including decoration	500	
Exhibition hall, machines including decoration	80	
Exhibition of paintings including decoration	200	
Explosive industry	4000	
Fertiliser mfg	200	200
Filling plant/barrels		
liquid filled and/or barrels incombustible	<200	
liquid filled and/or barrels combustible:		
Risk Class I	>3400	
Risk Class II	>3400	
Risk Class III	>3400	
Risk Class IV	>3400	
Risk Class V (if higher, take into consideration combustibility of barrels)	>1700	
Filling plant/small casks:		
liquid filled and casks incombustible	<200	
liquid filled and/or casks combustible:		
Risk Class I	<500	
Risk Class II	<500	
Risk Class III	<500	
Risk Class IV	<500	
Risk Class V (if higher, take into consideration combustibility of casks)	<500	
Finishing plant, paper	500	
Finishing plant, textile	300	
Fireworks mfg	Spez	2000
Flat	300	
Floor covering mfg	500	6000
Floor covering store	1000	
Flooring plaster mfg	600	
Flour products	800	
Flower sales	80	
Fluorescent tube mfg	300	
Foamed plastics fabrication	3000	2500
Foamed plastics processing	600	800
Food forwarding	1000	
Food store	700	
Forge	80	

Type of occupancies	Fabrication (MJ/m²)	Storage (MJ/m²/m)
Forwarding, appliances partly made of plastic	700	
Forwarding, beverage	300	
Forwarding, cardboard goods	600	
Forwarding, food	1000	
Forwarding, furniture	600	
Forwarding, glassware	700	
Forwarding, plastic products	1000	
Forwarding, printed matters	1700	
Forwarding, textiles	600	
Forwarding, tinware	200	
Forwarding, varnish, polish	1300	
Forwarding, woodware (small)	600	
Foundry (metal)	40	
Fur, sewing	400	
Fur store	200	
Furniture exhibition	500	
Furniture mfg (wood)	600	
Furniture polishing	500	
Furniture store	400	
Furrier	500	
Galvanic station	200	
Gambling place	150	
Glass blowing plant	200	
Glass factory	100	
Glass mfg	100	
Glass painting	300	
Glass processing	200	
Glassware mfg	200	
Glassware store	200	
Glazier's workshop	700	
Gold plating (of metals)	800	3400
Goldsmith's workshop	200	
Grainmill, without storage	400	13000
Gravestone carving	50	
Graphic workshop	1000	
Greengrocer's shop	200	
Hairdressing shop	300	
Hardening plant	400	
Hardware mfg	200	
Hardware store	300	
Hat mfg	500	
Hat store	500	
Heating equipment room, wood or coal-firing	300	
Heat sealing of plastics	800	
High-rise office building	800	
Homes	500	
Homes for aged	400	
Hosiery mfg	300	1000
Hospital	300	
Hotel	300	
Household appliances, mfg	300	200
Household appliances, sales	300	
Ice cream plant (including packaging)	100	
Incandescent lamp plant	40	
Injection moulded parts mfg (metal)	80	
Injection moulded parts mfg (plastic)	500	
Institution building	500	
Ironing	500	
Jewellery mfg	200	
Jewellery shop	300	
Joinery	700	
Joiners (machine room)	500	
Joiners (workbench)	700	
Jute, weaving	400	1300
Laboratory, bacteriological	200	
Laboratory, chemical	500	
Laboratory, electric, electronic	200	
Laboratory, metallurgical	200	
Laboratory, physics	200	
Lacquer forwarding	1000	
Lacquer mfg	500	2500
Large metal constructions	80	
Lathe shop	600	
Laundry	200	
Leather goods sales	700	
Leather product mfg	500	
Leather, tanning, dressing, etc	400	
Library	2000	2000
Lingerie mfg	400	
Liqueur mfg	400	800
Liquor mfg	500	800
Liquor store	700	
Loading ramp, including goods (rough average)	800	
Lumber room for miscellaneous goods	500	
Machinery mfg	200	
Match plant	300	800
Mattress mfg	500	500
Meat shop	50	
Mechanical workshop	200	
Metal goods mfg	200	
Metal grinding	80	
Metal working (general)	200	
Milk, condensed, evaporated mfg	200	9000
Milk, powdered, mfg	200	10500
Milling work, metal	200	
Mirror mfg	100	
Motion picture studio	300	
Motorcycle assembly	300	
Museum	300	
Musical instrument sales	281	
News stand	1300	
Nitrocellulose mfg	Spez	1100
Nuclear research	2100	
Nursery school	300	
Office, business	800	
Office, engineering	600	

Type of occupancies	Fabrication (MJ/m²)	Storage (MJ/m²/m)
Office furniture	700	
Office, machinery mfg	300	
Office machine sales	300	
Oilcloth mfg	700	1300
Oilcloth processing	700	2100
Optical instrument mfg	200	200
Packing, food	800	
Packing, incombustible goods	400	
Packing material, industry	1600	3000
Packing, printed matters	1700	
Packing, textiles	600	
Packing, all other combustible goods	600	
Paint and varnish, mfg	4200	
Paint and varnish, mixing plant	2000	
Paint and varnish shop	1000	
Painter's workshop	500	
Pain shop (cars, machines, etc)	200	
Paint shop (furniture, etc)	400	
Paper mfg	200	10000
Paper processing	800	1100
Parking building	200	
Parquetry mfg	2000	1200
Perambulator mfg	300	800
Perambulator shop	300	
Perfume sale	400	
Pharmaceutical mfg	300	800
Pharmaceuticals, packing	300	800
Pharmacy (including storage)	800	
Photographic laboratory	100	
Photographic store	300	
Photographic studio	300	
Picture frame mfg	300	
Plaster product mfg	80	
Plastic floor tile mfg	800	
Plastic mfg	2000	5900
Plastic processing	600	
Plastic products fabrication	600	
Plumber's workshop	100	
Plywood mfg	800	2900
Polish mfg	1700	
Post office	400	
Potato, flaked, mfg	200	
Pottery plant	200	
Power station	600	
Precious stone, cutting etc	80	
Precision instrument mfg		
(containing plastic parts)	200	
(without plastic parts)	100	
Precision mechanics plant	200	
Pressing, metal	100	
Pressing, plastics, leather, etc	400	
Preparation briquette production		
Printing, composing room	300	
Printing, ink mfg	700	3000
Printing, machine hall	400	
Printing office	1000	
Radio and TV mfg	400	
Radio and TV sales	500	
Radio studio	300	
Railway car mfg	200	
Railway station	800	
Railway workshop	800	
Record player mfg	300	200
Record repository, documents see also storage	4200	
Refrigerator mfg	1000	300
Relay mfg	400	
Repair shop, general	400	
Restaurant	300	
Retouching department	300	
Rubber goods mfg	600	5000
Rubber goods store	800	
Rubber processing	600	5000
Saddlery mfg	300	
Safe mfg	80	
Salad oil forwarding	900	
Salad oil mfg	1000	18900
Sawmill (without woodyard)	400	
Scale mfg	400	
School	300	
Scrap recovery	800	
Seedstore	600	
Sewing machine mfg	300	
Sewing machine store	300	
Sheet mfg	100	
Shoe factory, forwarding	600	
Shoe factory, mfg	500	
Shoe polish mfg	800	2100
Shoe repair with manufacture	700	
Shoe store	500	
Shutter mfg	1000	
Silk spinning (natural silk)	300	
Silk weaving (natural silk)	300	
Silverwares	400	
Ski mfg	400	1700
Slaughter house	40	
Soap mfg	200	4200
Soda mfg	40	
Soldering	300	
Solvent distillation	200	
Spinning mill, excluding garnetting	300	
Sporting goods store	800	
Spray painting, metal goods	300	
Spray painting, wood products	500	
Stationery store	700	
Steel furniture mfg	300	
Stereotype plate mfg	200	
Stone masonry	40	
Storeroom (workshop storerooms etc)	1200	
Synthetic fibre mfg	400	
Synthetic fibre processing	400	
Synthetic resin mfg	3400	4200
Tar-coated paper mfg	1700	
Tar preparation	800	
Telephone apparatus mfg	400	200

Type of occupancies	Fabrication (MJ/m²)	Storage (MJ/m²/m)
Telephone exchange	80	
Telephone exchange mfg	100	
Test room, electric appliances	200	
Test room, machinery	100	
Test room, textiles	300	
Theatre	300	
Tin can mfg	100	
Tinned goods mfg	40	
Tinware mfg	120	
Tire mfg	700	1800
Tobacco products mfg	200	2100
Tobacco shop	500	
Tool mfg	200	
Toy mfg (combustible)	100	
Toy mfg (incombustible)	200	
Toy store	500	
Tractor mfg	300	
Transformer mfg	300	
Transformer winding	600	
Travel agency	400	
Turnery (wood working)	500	
Turning section	200	
TV studio	300	
Twisting shop	250	
Umbrella mfg	300	400
Umbrellas store	300	
Underground garage, private	>200	
Underground garage, public	<200	
Upholstering plant	500	
Vacation home	500	
Varnishing, appliances	80	
Varnishing, paper	80	
Vegetable, dehydrating	1000	400
Vehicle mfg, assembly	400	
Veneering	500	2900
Veneer mfg	800	4200
Vinegar mfg	80	100
Vulcanising plant (without storage)	1000	
Waffle mfg	300	1700
Warping department	250	
Washing agent mfg	300	200
Washing machine mfg	300	40
Watch assembling	300	40
Watch mechanism mfg	40	
Watch repair shop	300	
Watch sales	300	
Water closets	~0	
Wax products forwarding	2100	
Wax products mfg	1300	2100
Weaving mill (without carpets)	300	
Welding shop (metal)	80	
Winding room	400	
Winding, textile fibres	600	
Window glass mfg	700	
Window mfg (wood)	800	
Wine cellar	20	
Wine merchant's shop	200	
Wire drawing	80	
Wire factory	800	
Wood carving	700	
Wood drying plant	800	
Wood grinding	200	
Wood pattern making shop	600	
Wood preserving plant	3000	
Youth hostel	300	

Appendix E
Section Factors for Steel Beams

This appendix provides section factors for standard hot-rolled Australian Universal Beams.

These tables give the dimensions and weight of each beam, but not the structural section properties which must be obtained from standard section property tables. The section factors have been calculated assuming that all sections are made from rectangular components, with no allowance for tapered flanges and root radii, and assuming that the protective insulation is in contact with the steel.

The tables do not include hollow sections, angles and channels. Section factors for these, and other sizes and shapes, can be easily calculated or can be obtained from manufacturer's literature.

The numbers in these tables have been obtained from The Heavy Engineering Research Association of New Zealand (HERA). The Australian Universal Beam data is from the "BHP Hot Rolled and Structural Steel Products" catalogue from BHP Steel, 1998.

The basic geometry for a hot rolled I-beam is shown in Figure F1.

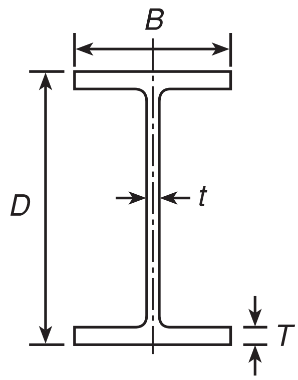
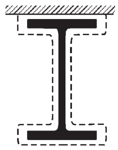
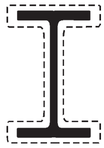
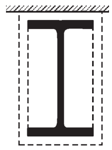
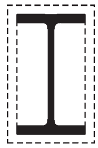


Figure F1: Geometry of hot rolled section

Australian Universal Beams and Universal Columns						Section factor							
						Contour				Hollow			
						3 Sides		4 Sides		3 Sides		4 Sides	
													
Size	Mass	Section depth	Section width	Thickness Flange	Thickness Web								
		D	B	T	t	H_p/A	Effective thickness	H_p/A	Effective thickness	H_p/A	Effective thickness	H_p/A	Effective thickness
	kg/m	mm	mm	mm	mm	m^{-1}	mm	m^{-1}	mm	m^{-1}	mm	m^{-1}	mm
610 UB	125	612	229	19.6	11.9	118	8.5	132	7.6	91	11.0	105	9.5
610 UB	113	607	228	17.3	11.2	129	7.7	145	6.9	99	10.1	115	8.7
610 UB	101	602	228	14.8	10.6	144	7.0	161	6.2	110	9.1	128	7.8
530 UB	92.4	533	209	15.6	10.2	142	7.1	159	6.3	108	9.3	126	8.0
530 UB	82.0	528	209	13.2	9.6	158	6.3	178	5.6	120	8.3	140	7.1
460 UB	82.1	460	191	16.0	9.9	140	7.1	158	6.3	106	9.5	124	8.1
460 UB	74.6	457	190	14.5	9.1	154	6.5	174	5.7	116	8.6	136	7.4
460 UB	67.1	454	190	12.7	8.5	170	5.9	192	5.2	128	7.8	150	6.7
410 UB	59.7	406	178	12.8	7.8	174	5.7	197	5.1	130	7.7	153	6.5
410 UB	53.7	403	178	10.9	7.6	192	5.2	218	4.6	143	7.0	169	5.9
360 UB	56.7	359	172	13.0	8.0	168	5.9	192	5.2	123	8.1	147	6.8
360 UB	50.7	356	171	11.5	7.3	187	5.3	214	4.7	136	7.3	163	6.1
360 UB	44.7	352	171	9.7	6.9	210	4.8	240	4.2	153	6.5	183	5.5
310 UB	46.2	307	166	11.8	6.7	185	5.4	213	4.7	132	7.6	160	6.3
310 UB	40.4	304	165	10.2	6.1	209	4.8	241	4.1	148	6.7	180	5.6
310 UB	32.0	298	149	8.0	5.5	253	4.0	289	3.5	183	5.5	219	4.6
250 UB	37.3	256	146	10.9	6.4	197	5.1	228	4.4	139	7.2	169	5.9
250 UB	31.4	252	146	8.6	6.1	232	4.3	268	3.7	162	6.2	199	5.0
250 UB	25.7	248	124	8.0	5.0	262	3.8	300	3.3	190	5.3	228	4.4
200 UB	29.8	207	134	9.6	6.3	210	4.8	245	4.1	143	7.0	179	5.6
200 UB	25.4	203	133	7.8	5.8	246	4.1	287	3.5	167	6.0	208	4.8
200 UB	22.3	202	133	7.0	5.0	276	3.6	323	3.1	187	5.3	233	4.3
200 UB	18.2	198	99	7.0	4.5	295	3.4	338	3.0	213	4.7	256	3.9
180 UB	22.2	179	90	10.0	6.0	218	4.6	250	4.0	159	6.3	191	5.2
180 UB	18.1	175	90	8.0	5.0	265	3.8	304	3.3	191	5.2	230	4.3
180 UB	16.1	173	90	7.0	4.5	298	3.4	342	2.9	214	4.7	258	3.9
150 UB	18.0	155	75	9.5	6.0	227	4.4	260	3.8	167	6.0	200	5.0
150 UB	14.0	150	75	7.0	5.0	289	3.5	331	3.0	211	4.7	253	4.0
310 UC	158	327	311	25.0	15.7	77	12.9	93	10.8	48	20.8	63	15.8
310 UC	137	321	309	21.7	13.8	88	11.4	106	9.5	54	18.4	72	13.9
310 UC	118	315	307	18.7	11.9	102	9.8	122	8.2	62	16.0	83	12.1
310 UC	96.8	308	305	15.4	9.9	122	8.2	146	6.8	74	13.5	99	10.1
250 UC	89.5	260	256	17.3	10.5	111	9.0	134	7.5	68	14.7	91	11.0
250 UC	72.9	254	254	14.2	8.6	134	7.4	162	6.2	82	12.2	109	9.2
200 UC	59.5	210	205	14.2	9.3	133	7.5	160	6.2	82	12.2	109	9.2
200 UC	52.2	206	204	12.5	8.0	151	6.6	182	5.5	92	10.8	123	8.1
200 UC	46.2	203	203	11.0	7.3	170	5.9	204	4.9	103	9.7	138	7.3
150 UC	37.2	162	154	11.5	8.1	163	6.1	195	5.1	101	9.9	134	7.5
150 UC	30.0	158	153	9.4	6.6	197	5.1	237	4.2	122	8.2	161	6.2
150 UC	23.4	152	152	6.8	6.1	251	4.0	302	3.3	153	6.5	204	4.9
100 UC	14.8	97	99	7.0	5.0	254	3.9	307	3.3	155	6.5	207	4.8

Note that for any section, the ratio of heated surface area to mass (m^2/tonne) can be obtained by dividing the H_p/A ratio by the density of steel (7.85 tonne/m^3).

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