Low-rise Office Construction
—A Guide to Fire Safety

Written by:
I. D. Bennetts, C. C. Goh, K. W. Poh

I. R. Thomas
Victoria University

Published by:
OneSteel - Market Mills
Ingal Street
Newcastle
NSW 2300, Australia.

First published, November 2000
Reprint edition, September 2006

DISCLAIMER

Low-rise Office Construction
—A Guide to Fire Safety

by

I. D. Bennetts, C. C. Goh, K. W. Poh

&

I. R. Thomas
Victoria University

published by
OneSteel
Market Mills

September 2006

contents

Abbreviations used:

ESA/M = The ratio of exposed surface area to mass per unit length (see Appendix E for ESA/M of steel sections).

FRL = Fire-resistance level—the grading periods in minutes determined in accordance with BCA Specification A2.3 [1] for the following criteria -
(a) *structural adequacy*; and
(b) *integrity*; and
(c) *insulation*,
and expressed in that order.
Note: A dash means that there is no requirement for that criteria. For example, -/-/- means there is no requirement for an FRL.

FSF = Fire-source feature— means-
(a) the far boundary of a road adjoining the allotment; or
(b) a side or rear boundary of the allotment; or
(c) and external wall of another building on the allotment which is not a Class 10 building.

Definition: **Bare steel** — steel members which have no fire-protective coating.

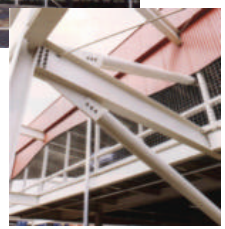
Introduction

Steel Construction

Steel construction utilises structural steel beams and columns in combination with composite floors and steel roof systems. Composite floors incorporate steel decking which acts as formwork for the concrete and also acts compositely with the hardened concrete to resist the floor loading. Such construction is cost-effective especially when fire protection is not required.








Steel construction offers other great advantages:

- greater usable floor space
- increased flexibility for future modifications
- smaller foundation loads and foundations
- greater speed of construction

Architects have long appreciated that the slenderness and long spanning capability of steel can be used to advantage in creating attractive commercial environments.

Low-rise Office Buildings

Due to these advantages steel construction has been chosen for numerous office buildings—particularly two storey buildings. This is because there are few *fire-resistance* requirements for these buildings and structural steel does not require fire protection—further improving the cost-competitiveness of steel construction. In addition, the steel structure can be expressed as an architectural feature.

Office buildings often have open-deck or sprinklered carparks below, further benefiting from the advantages of steel construction.

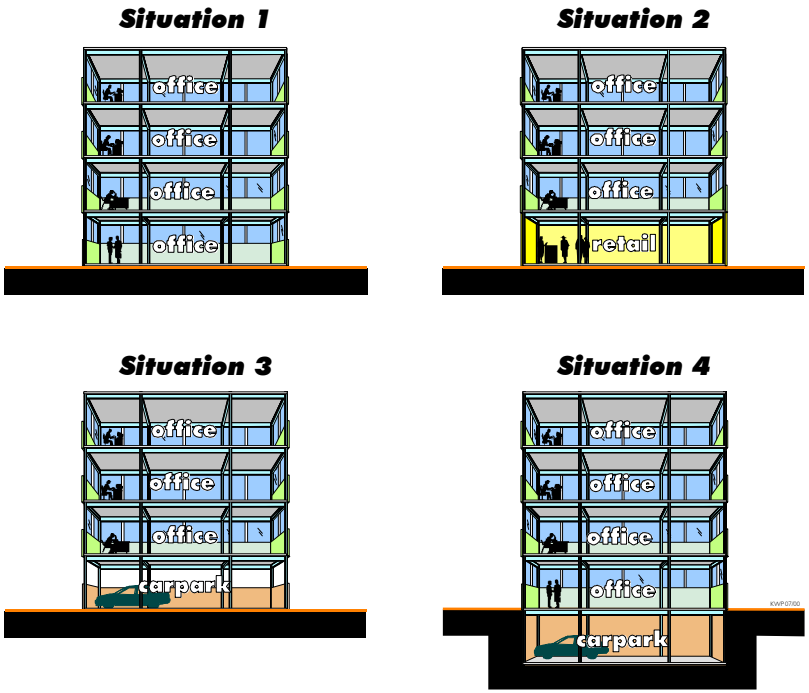
A number of three and four storey office buildings of larger floor area have also been constructed. In such cases the structural steel beams and columns have been protected to achieve the *fire-resistance* specified by the BCA [1].

It is noteworthy that the levels of *fire-resistance required* in a four storey building are identical to a seven storey building and that all of the other BCA requirements are also identical. More economical office and commercial construction would become a reality if the same levels of fire safety can be achieved with reduced *fire-resistance* levels.

it is increasingly common for the ground floor of an office building to be used for retail purposes in addition to the basement and sometimes ground floor levels being used for carparks.

This Publication

This publication considers low-rise office buildings having a maximum *rise in storeys* of 4 where the basement and/or ground floor may be carpark and the ground floor may be retail.



The BCA fire-safety objectives for a building can be achieved by:

- meeting the *deemed-to-satisfy* provisions, or
- an *Alternative Solution* which satisfies the Objectives and Performance Requirements of the BCA.

The publication presents some of the key BCA *deemed-to-satisfy* provisions for these buildings and a number of *Alternative Solutions* for more cost-effective construction.

The purpose of this publication is to:

- illustrate the current *deemed-to-satisfy* provisions for these buildings
- perform fire-safety evaluations
- present *Alternative Solutions*
- provide the basis for the *Alternative Solutions* presented

BCA Deemed-to-Satisfy Provisions

BCA Terms and Concepts

Central to an understanding of the BCA *deemed-to-satisfy* provisions and the justification of *Alternative Solutions*, is an understanding of some key terms and concepts used in the BCA, including:

- *rise in storeys*
- *effective height*
- Type of construction
- *fire compartments*
- types of *exits*
- travel distance
- *fire-resistance levels*

Aspects of the above terms and concepts are presented below prior to a more detailed presentation of the BCA *fire-resistance* requirements.

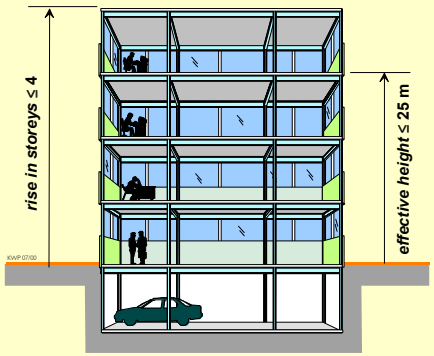
Rise in storeys and effective height

Clause C1.2(a) of the BCA defines *rise in storeys* as the greatest number of *storeys* above finished ground at any part of the *external walls* next to that part; or if part of the *external wall* is on the boundary of the allotment, above the natural ground at the relevant part of the boundary. A basement below natural ground is not considered as a *storey*.

Further descriptions of what constitutes a *storey* are given in clauses C1.2(b) - (d) of the BCA.

Clause A1.1 of the BCA defines the *effective height* as the height to the floor of the topmost *storey* from the floor of the lowest *storey* providing direct egress to a road or open space.

only buildings with a rise in storeys of 2, 3 and 4 are considered in this publication



Type of construction

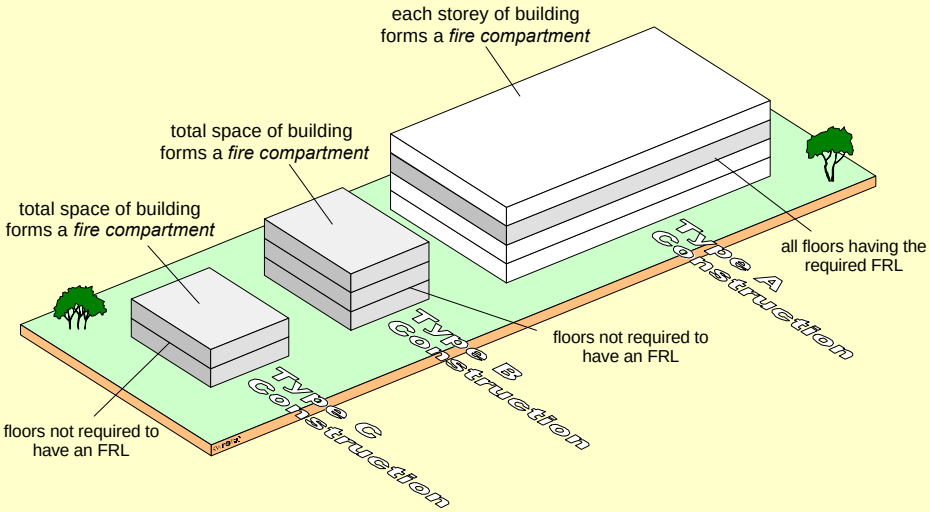
The BCA requires buildings (except for Classes 1 and 10) to be constructed according to Types A, B or C construction. Type A is the most *fire-resistant* form of construction whilst Type C is the least. The Type of construction applicable is determined on the basis of *rise in storeys* and *fire compartment* size.

Table C1.1 of the BCA summarises the Type of construction in relation to *rise in storeys*. This table is summarised here for Classes 5 (office), 6 (retail) and 7 (carpark) buildings.

Classes 5, 6 and 7 Buildings	***rise in storeys***		
	4 or more	3	2 or 1
Type of construction	A	B	C

Fire compartments

The definition of a *fire compartment* is given in clause A1.1 of the BCA. A *fire compartment* can be any part of a building separated from the remainder by barriers such as walls and/or floors having an appropriate FRL or resistance to the spread of fire with any openings adequately protected. Alternatively, if such barriers do not exist, it is the total space of the building.



Note: It is assumed that the maximum *floor area* of the *fire compartment* for each Type of construction is less than the allowable *floor area*.

The Type of construction required for a building depends not only on *rise in storeys* but on maximum *fire compartment* size. The maximum *floor area* of any *fire compartment* in relation to the Type of construction and the Class of building is given in the table below. Table C2.2 of the BCA also specifies the maximum *volume* of a *fire compartment* that needs to be satisfied for the Class of building and Type of construction considered. Since the typical floor-to-floor height for low-rise commercial buildings is around 4.0 m, it is the maximum *floor area* that governs, not maximum *volume*.

Classification	**Type of construction**		
	Type A	Type B	Type C
5 Office building	8,000 m²	5,500 m²	3,000 m²
6, 7 Retail and *carpark*	5,000 m²	3,500 m²	2,000 m²

Where there are buildings of mixed classifications, the *total allowable floor area* for buildings of Types B and C construction can be determined using an algorithm given in Reference [2]. By way of example, for a building of Type C construction with x% of the total *floor area* being Class 5 (office) occupancy, y% being Class 6 (retail) occupancy, and z% being Class 7 (carpark) occupancy, the total allowable *floor area* for this building is:

$$\text{Total allowable floor area} = \frac{x}{100} \times 3000 + \frac{y}{100} \times 2000 + \frac{z}{100} \times 2000$$

It should be noted that the *floor areas* of *open-deck* and sprinklered *carparks* are not required to be considered when determining the limiting *fire compartment* size (see clause C2.1 of the BCA).

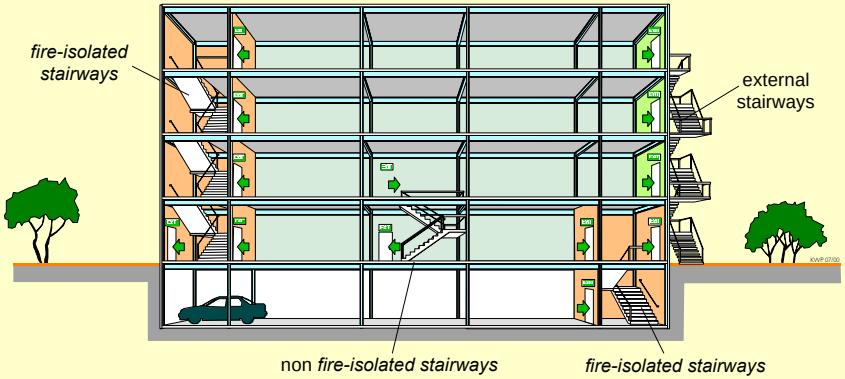
Exits

Exits must be provided from a building to allow occupants to evacuate safely; with the number, location and dimensions being appropriate to:

- the travel distance; and
- the number, mobility and other characteristics of occupants; and
- the function or use of the building; and
- the height of the building; and
- whether the *exit* is from above or below ground level.

Exits may be *required exits* or non-*required exits*. The number of *exits* required are given in clause D1.2 of the BCA. Non-*required exits* are generally provided to facilitate easy movement in and around the building. *Stairways*, either internal or external, are one form of *exit* which provides vertical movement of occupants inside the buildings. It is helpful to consider three types of *stairways*:

(i) *fire-isolated stairways* (internal)
(ii) non *fire-isolated stairways* (internal)
(iii) external stairways

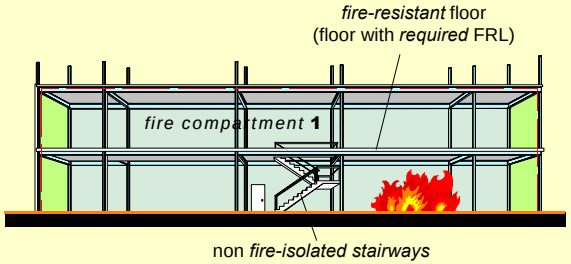


Clause A1.1 of the BCA defines a *fire-isolated stairway* as a *stairway* that is constructed within a *fire-resisting* shaft and includes the floor and roof or top enclosing structure. Further, in clause D1.3(b)(iii) of the BCA, every *required exit*, (in this case the *stairway*) must be *fire-isolated* unless it does not connect or pass through more than 2 consecutive *storeys* or 3 consecutive *storeys* if the building has a sprinkler system.

Clause D1.12(c) of the BCA stipulates that a non-*required* non *fire-isolated stairway* must not connect more than 2 *storeys* (non-sprinklered) or 3 *storeys* (sprinklered), provided that in each case, those *storeys* must be consecutive, and one of those *storeys* is situated at a level at which there is direct egress to a road or open space.

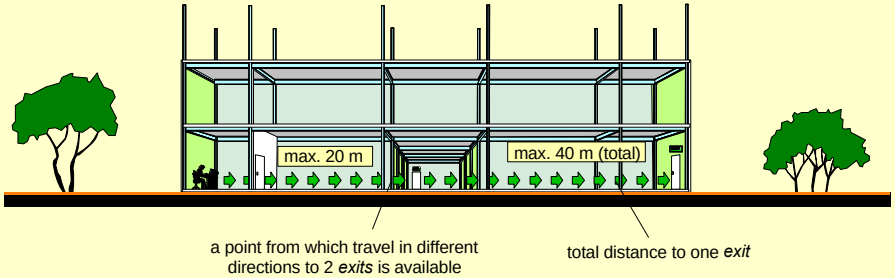
An external stairway may serve as a *required exit* for buildings with an *effective height* of not more than 25 m if the stairway is of *non-combustible* construction (see clause D1.8 of the BCA).

If a *fire-resistant* floor is penetrated by a non *fire-isolated stairway*, the two separate *fire compartments* become one *fire compartment*.

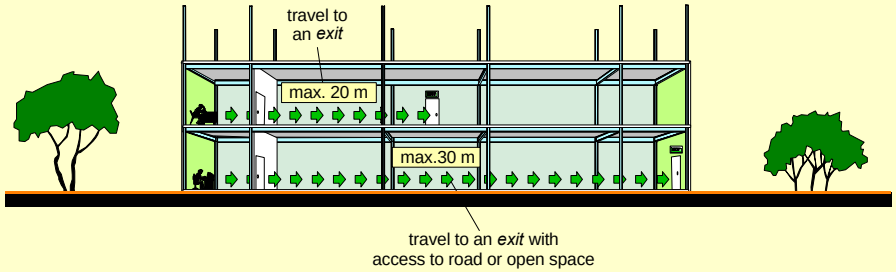


Travel distance

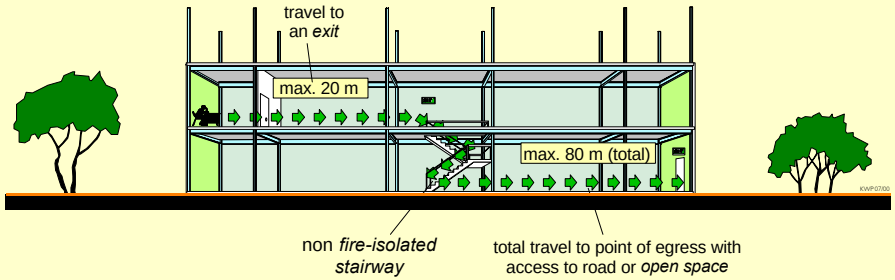
In many situations travel distance requirements will determine the number and location of *exits*. Clause D1.4(c) of the BCA states that no point on a floor must be more than 20 m from an *exit*, or a point from which travel in different directions to 2 *exits* is available, in which case the maximum distance to one of those *exits* must not exceed 40 m. Also, the distance between alternative *exits* must be not less than 9 m and not more than 60 m.



Should only one *exit* exist at a level of access to a road or *open space* (e.g. ground level) then the maximum travel distance may be 30 m.



In the case of a non *fire-isolated stairway*, the distance from any point on a floor to a point of egress to a road or *open space* must not exceed 80 m.



Fire-resistance levels

The term *fire-resistance level* (FRL) refers to the performance of a building element when tested to AS1530.4 [3]. This Standard specifies the gas temperature versus time relationship to be used in the test and other performance criteria. These are:

Fire-resistance

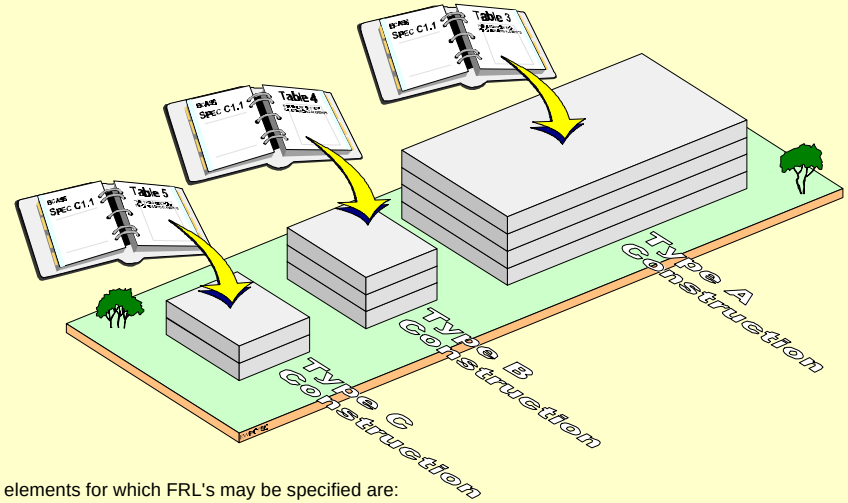
structural adequacy - the ability of the building element to support the imposed loads during a fire (applicable to all *loadbearing* elements), graded in minutes

integrity - the ability of the building element to prevent the development of cracks and fissures through which fire may spread (applicable to floors and walls required to provide a separating function), graded in minutes

insulation - the ability of the unexposed face of a separating element to remain sufficiently cool so that fire will not be initiated on the unexposed face of the element (applicable to floors and walls required to provide a separating function), graded in minutes

The BCA sets down the *required* FRL in terms of the above criteria, expressed in the above order. For example, 120/-/- means there is a 120 minutes FRL requirement for *structural adequacy*, and no requirement for *integrity* and *insulation*.

These requirements are specified according to the Type of construction *required* for the building elements, and are specified by Parts C1, C2 and C3 of the BCA. Tables 3, 4 and 5 of Specification C1.1 of the BCA set out many of the requirements for Types A, B and C construction although numerous concessions and additional requirements are given within that Specification and in other parts of the BCA.



Building elements for which FRL's may be specified are:

- common walls
- *external walls* (*loadbearing* and non-*loadbearing*)
- *internal walls* (*loadbearing* and non-*loadbearing*)
- floors (including beams)
- external columns
- internal columns
- iift and stair shafts
- service shafts
- roofs

A summary of the specific requirements relating to the building elements relevant to low-rise office construction is given in the later section "Building Elements - FRL's".

Overview of Provisions

The BCA provisions rely on *compartmentation* (assumed to limit the spread of fire and smoke, Section C), sufficient means of egress (Section D) and sufficient equipment to provide adequate warning and fire suppression (Section E). These provisions are now considered in more detail in relation to the buildings which are the focus of this publication.

As noted previously, for buildings of Types B and C construction, the *fire compartment* is represented by the *whole* building. This is because the floors in these buildings are not required to have an FRL. The *external walls* are required to have an FRL if they are within a certain distance from a *fire-source feature* and this is apparently aimed at preventing fire spread from (Types B and C construction) and to (Type B construction) adjacent buildings. It is only in the case of buildings of Type A construction that the floors are required to have an FRL and that each level is considered as a separate *fire compartment*.

Section D specifies the minimum number and type of *exits* to be provided. The number of *exits* required is generally dictated by limiting travel distances to the *exits*. For buildings with a *rise in storeys* of three or more, the exits stairs must be *fire-isolated*. This is achieved through the provision of shafts around the stairs having FRL's of 120/120/120 and 180/120/120 for office and retail levels, respectively. The doors to the stairs must be fire doors having an FRL of -/60/30.

Section E specifies the minimum requirements for hose reels, hydrants and fire extinguishers. Sprinklers are not required for these buildings except as a possible smoke management measure or if the level is a closed carpark with more than 40 cars.

Specific smoke management is required for these buildings when the *rise in storeys* is greater than 3 or greater than 2 if the *ground level* is retail or closed carpark. Four possibilities for smoke management are given: stair pressurisation, zone pressurisation (only if each level is a compartment), smoke detection and sprinklers. In the case of a closed carpark, a mechanical ventilation system must be provided.

Building Elements - FRL's

The FRL requirements for particular building elements are now presented for various low-rise building situations. The elements chosen are those which are relevant for the forms of construction being considered in this publication.

It should be noted that the FRL requirements for members are sometimes dependent on whether they are *exposed* to a *fire-source feature* and whether they are within a limiting distance. The meaning of the term *fire-source feature* and what constitutes *exposure* to a *fire-source feature* are now presented.

Fire-source feature

Fire-source feature (FSF) — means:

(a) the far boundary of a road adjoining the allotment; or
(b) a side or rear boundary of the allotment; or
(c) and external wall of another building on the allotment which is not a Class 10 building.

Exposure to fire-source feature

The BCA considers that an element is exposed to a *fire-source feature* if any horizontal straight line between that part and the FSF, or vertical projection of the feature, is not obstructed by another part of the building that—

(i) has an FRL of not less than 30/-/-, and
(ii) is neither transparent nor translucent.

Others details are given in clause 2.1 of Specification C1.1 of the BCA.

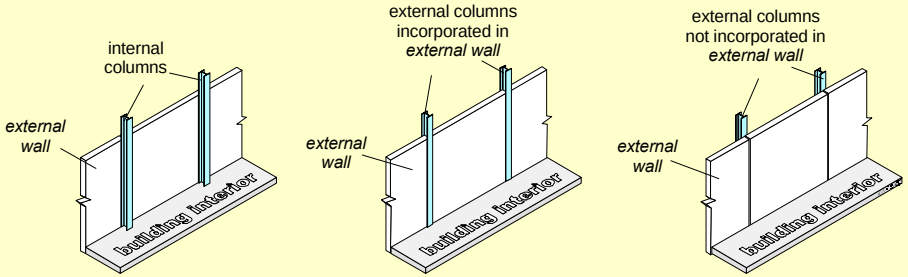
External walls

In BCA terminology, an *external wall* is one located at the outside of the building. This wall may be *loadbearing* or non-*loadbearing* (i.e. those which support only their own weight). Only the requirements for **non-*loadbearing* walls** are presented in the following pages as these are most commonly used in conjunction with the forms of construction being considered.

Non-*loadbearing external walls* are only required to have an FRL if they are within a limiting distance from a *fire-source feature*. Otherwise no FRL is required and the wall may incorporate glazing or other non *fire-resistant* cladding.

Columns

The BCA considers columns as internal, external or incorporated in an *external wall*. These three situations are illustrated below.



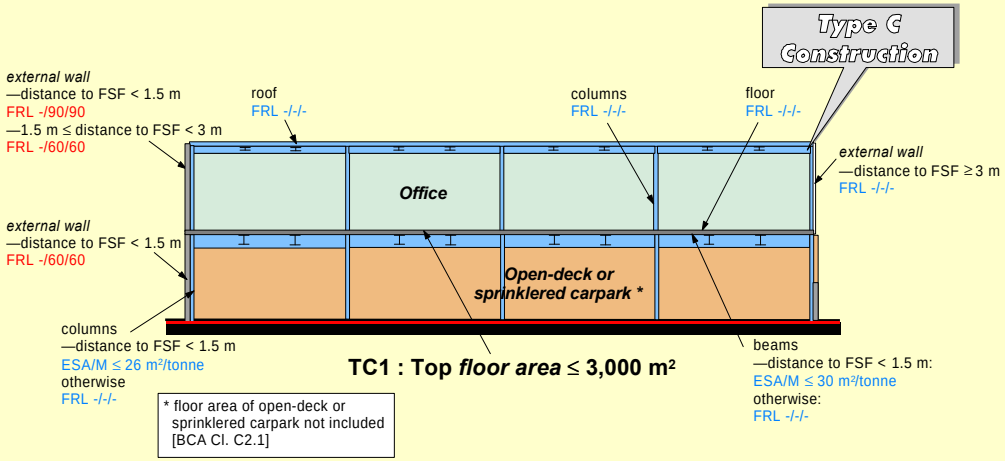
For the purpose of this publication all perimeter columns are considered as internal columns. This is because in low-rise commercial buildings, these columns are normally located at or inside the exterior facade.

Summary of FRL's

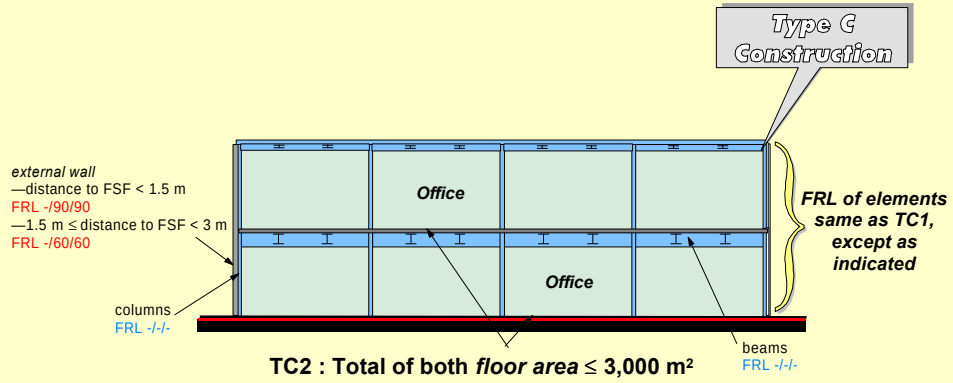
The following diagrams illustrate the FRL requirements for various elements in buildings which combine carpark, retail and office levels. These combinations are considered to correspond to the most likely practical situations.

Where elements are coloured blue, bare steel construction may be used.

Buildings with *rise in storey* = 2

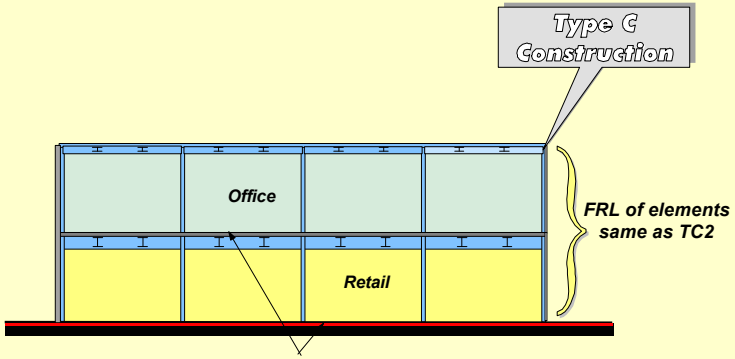


TC1 : Top *floor area* ≤ 3,000 m²

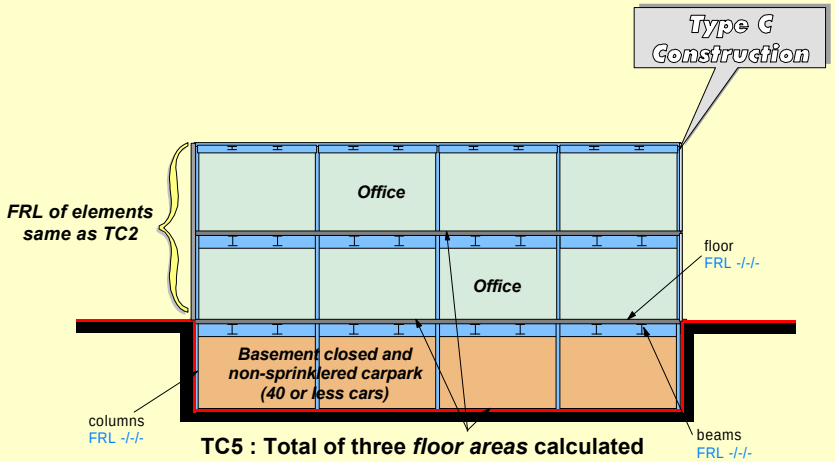


TC2 : Total of both *floor area* ≤ 3,000 m²

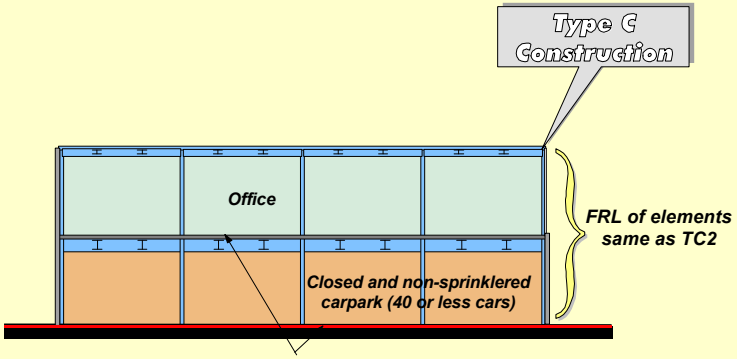
FRL's - Buildings with *rise in storey* = 2



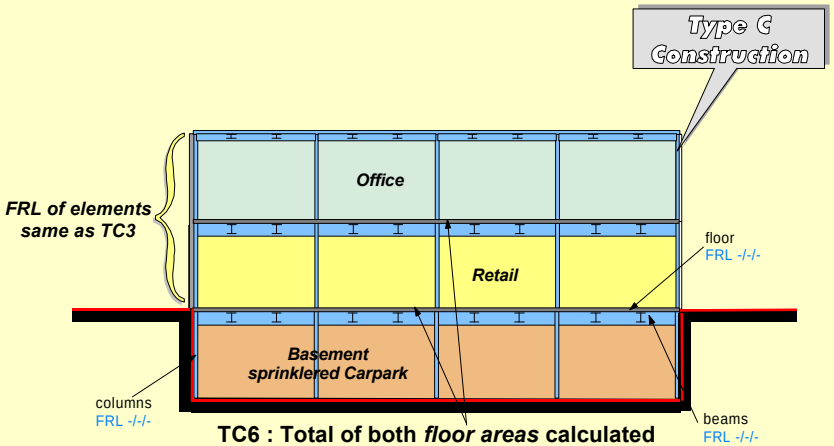
TC3 : Total of both *floor areas* calculated using method described in page 8



TC5 : Total of three *floor areas* calculated using method described in page 8

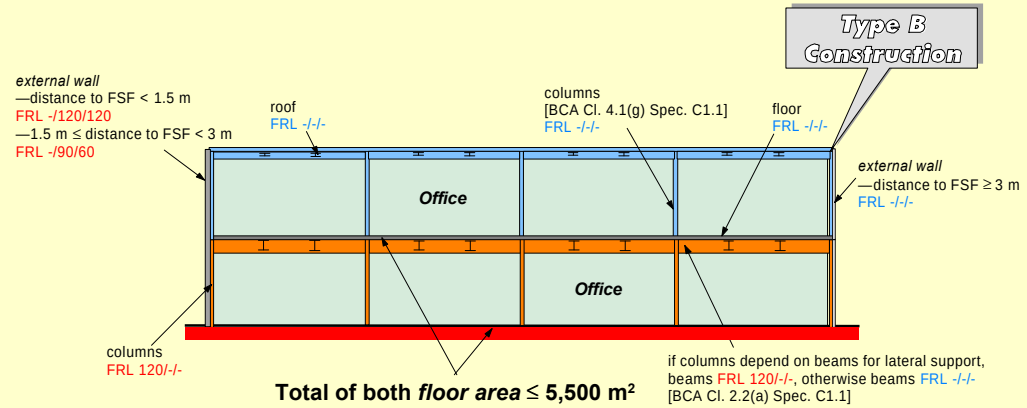


TC4 : Total of both *floor areas* calculated using method described in page 8

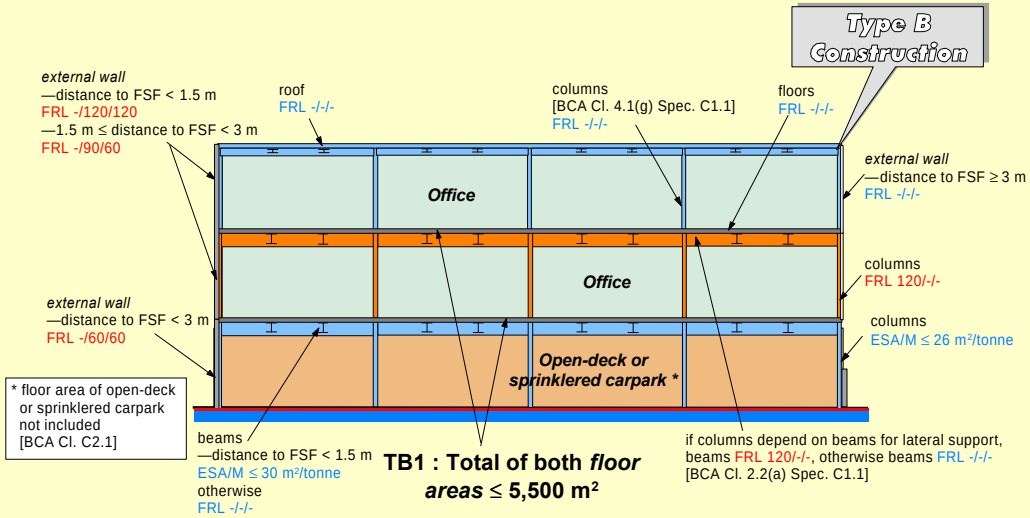


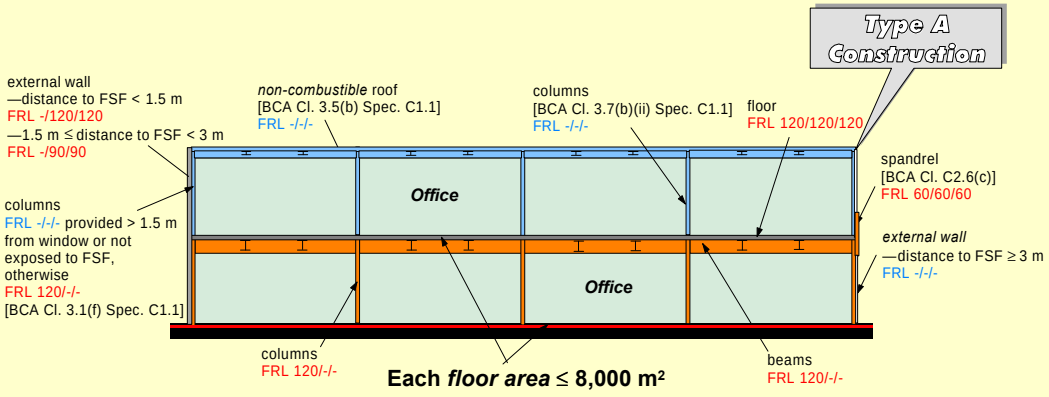
TC6 : Total of both *floor areas* calculated using method described in page 8

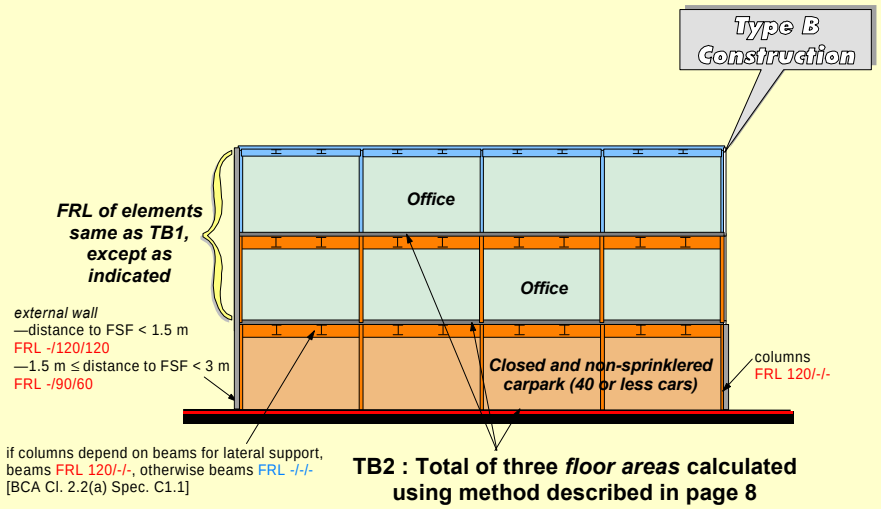
FRL's - Buildings with *rise in storey* = 2



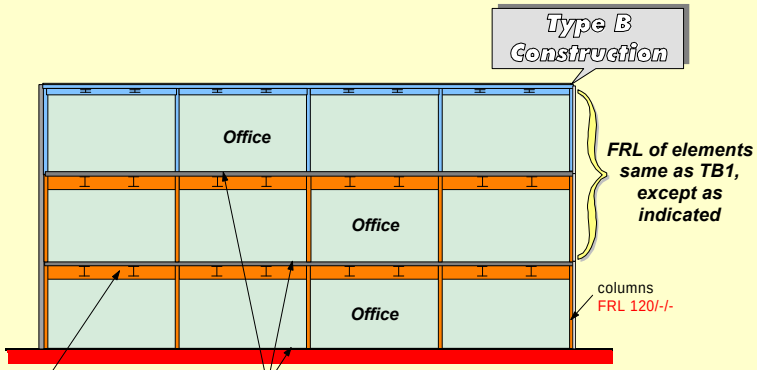
FRL's - Buildings with *rise in storey* = 3





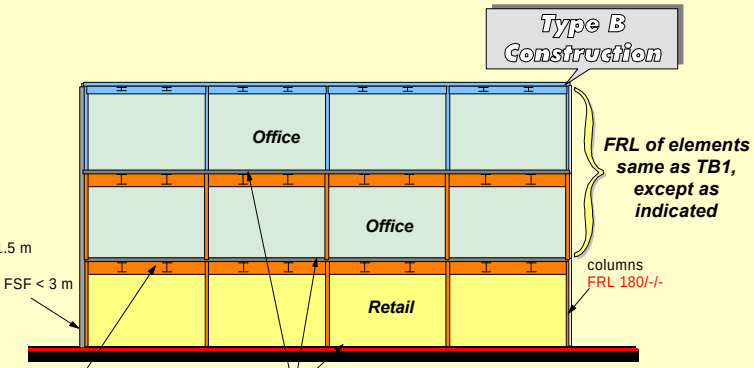


FRL's - Buildings with *rise in storey* = 3



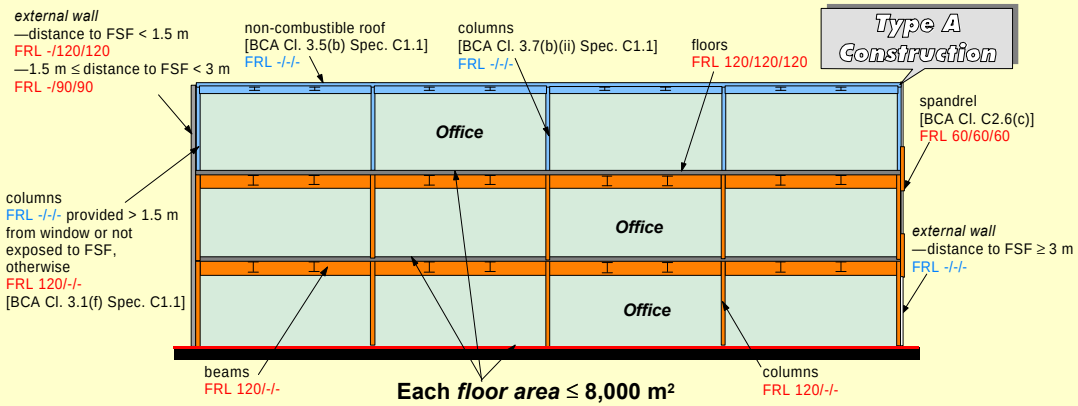
if columns depend on beams for lateral support, beams FRL 120/-/-, otherwise beams FRL -/-/-
[BCA Cl. 2.2(a) Spec. C1.1]

TB3 : Total of three *floor area* ≤ 5,500 m²

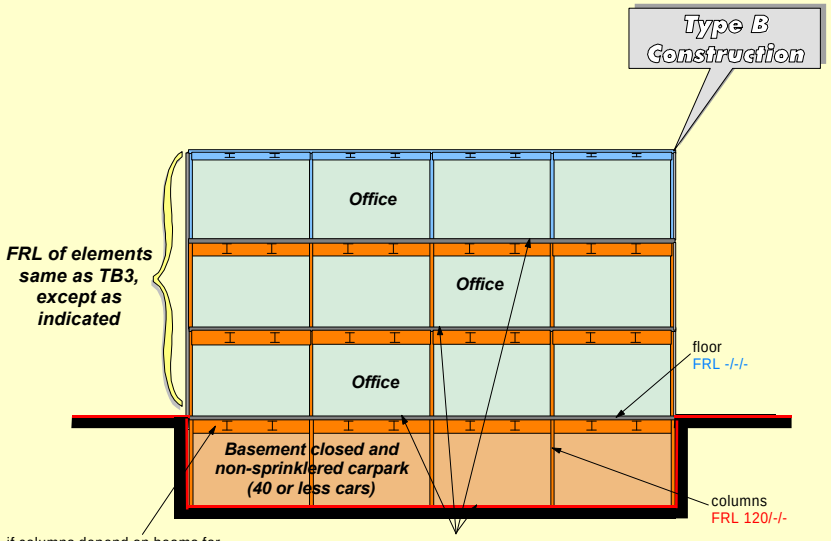


if columns depend on beams for lateral support, beams FRL 180/-/-, otherwise beams FRL -/-/-
[BCA Cl. 2.2(a) Spec. C1.1]

TB4 : Total of three *floor areas* calculated using method described in page 8

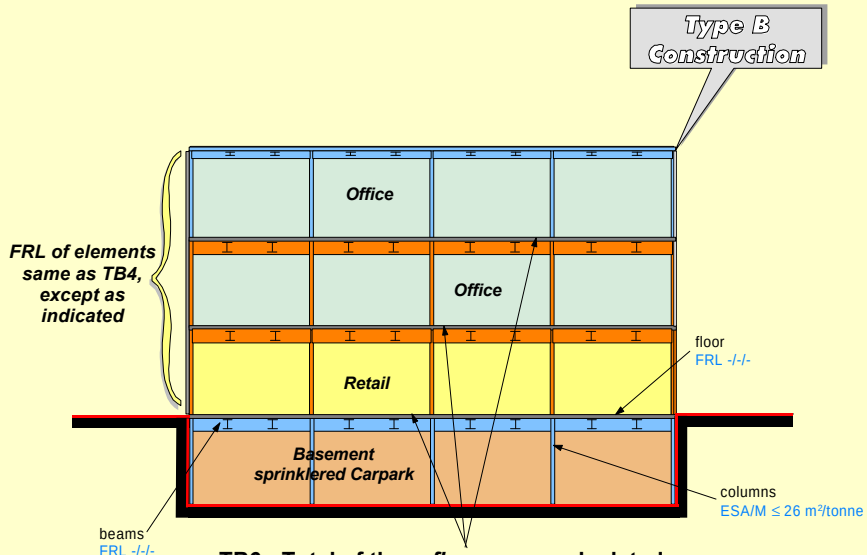


Each *floor area* ≤ 8,000 m²



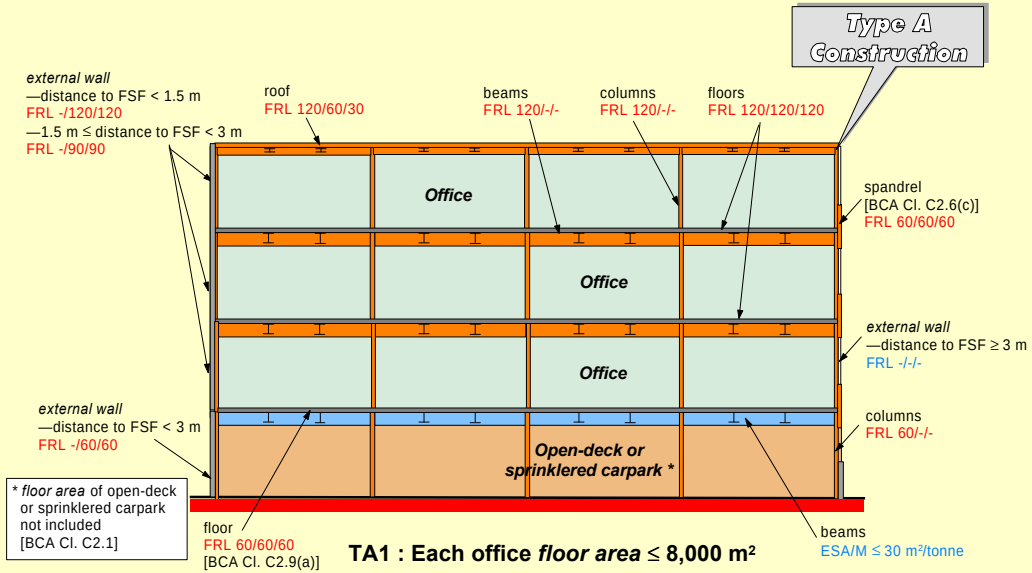
if columns depend on beams for lateral support, beams FRL 120/-/-, otherwise beams FRL -/-/-
[BCA Cl. 2.2(a) Spec. C1.1]

TB5 : Total of four *floor areas* calculated using method described in page 8

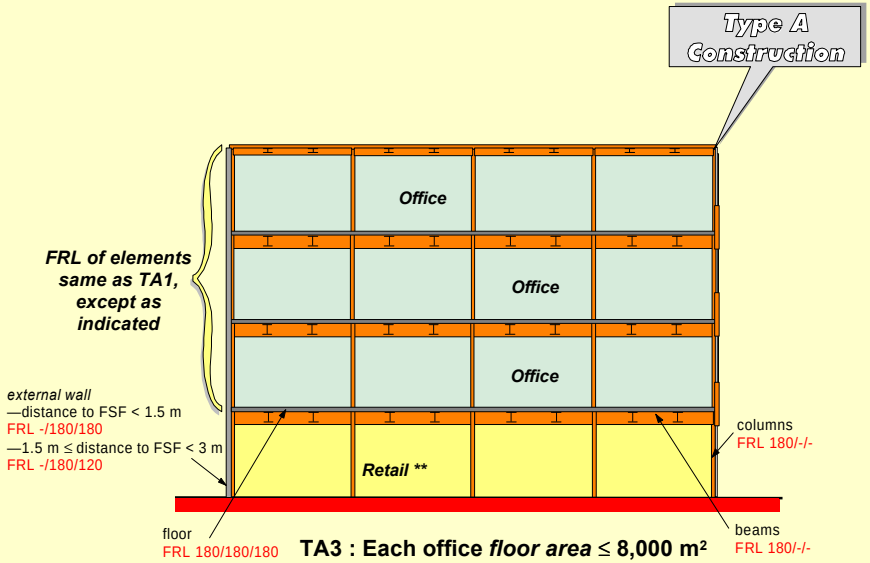


TB6 : Total of three *floor areas* calculated using method described in page 8

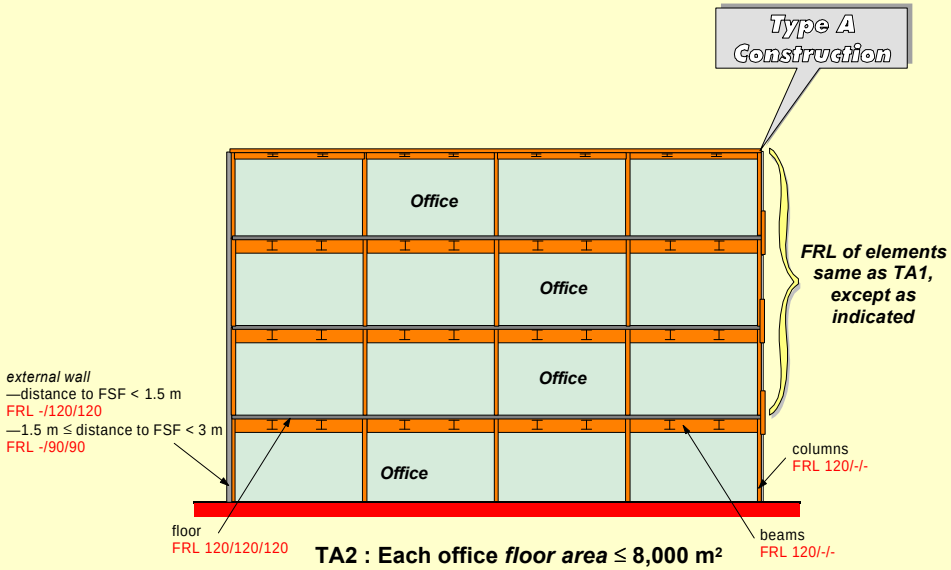
FRL's - Buildings with *rise in storey* = 4



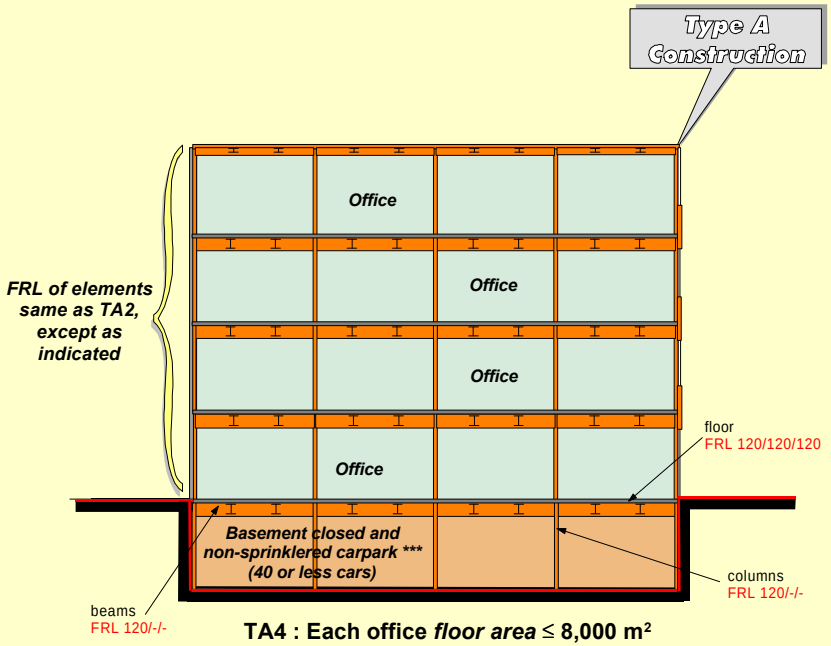
TA1 : Each office *floor area* ≤ 8,000 m²



TA3 : Each office *floor area* ≤ 8,000 m²
**** retail *floor area* ≤ 5,000 m²**

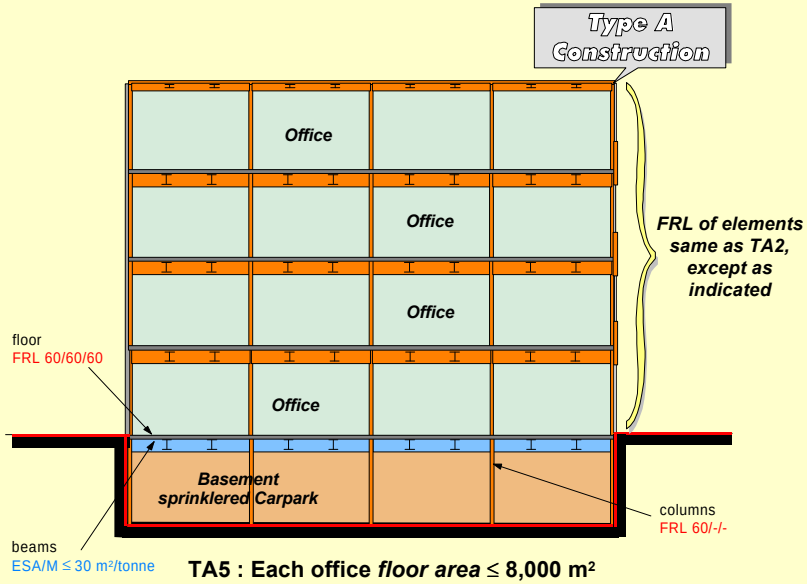


TA2 : Each office *floor area* ≤ 8,000 m²

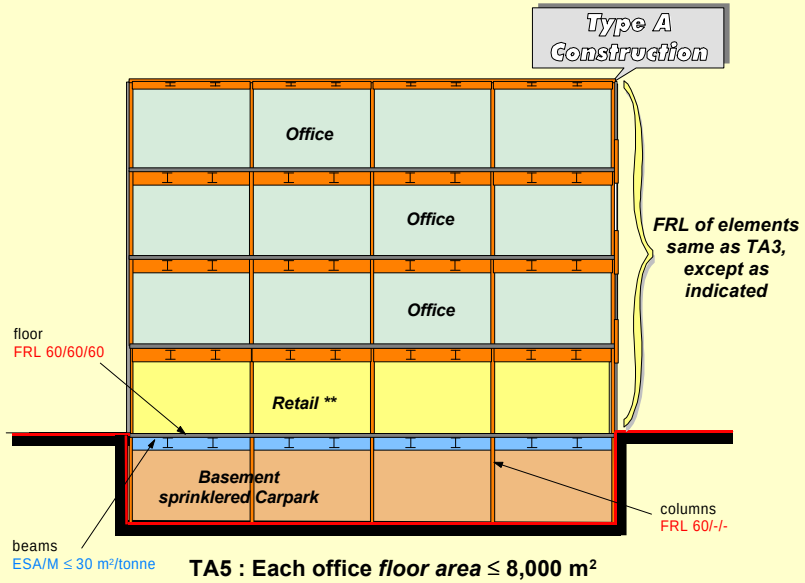


TA4 : Each office *floor area* ≤ 8,000 m²
***** basement carpark *floor area* ≤ 5,000 m²**

FRL's - Buildings with *rise in storey* = 4



TA5 : Each office *floor area* ≤ 8,000 m²



TA5 : Each office *floor area* ≤ 8,000 m²

**** retail *floor area* ≤ 5,000 m²**

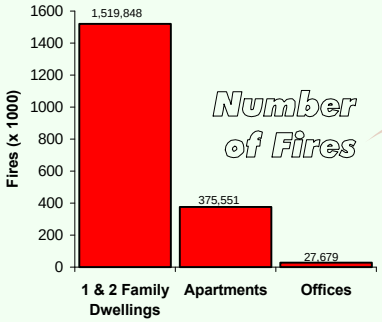
Fire-Safety Evaluation

PART 1: What can we learn from the fire record?

Introduction

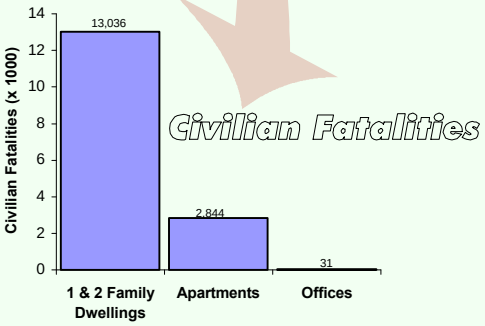
An understanding of the factors having an influence on the fire safety of building occupants can be obtained from existing statistical data. These data are vital because they give the best available picture of the situations in which occupant deaths have occurred and factors that have contributed to larger fires. This understanding can be used to provide a basis for evaluating the effectiveness of and need for various fire-safety systems.

The statistical data used in this publication were collected by US fire brigades for fires occurring between 1983 to 1991 [4]. These data have been chosen in preference to the much smaller available Australian database. Nevertheless, comparison of the two data sets indicates that similar trends are generally observable and thus the US data appears to be generally representative of the Australian situation.



In the USA between 1983 and 1991, there were 1,519,848 fires and 13,036 civilian fatalities in 1 & 2 family dwellings, and 375,551 fires and 2,844 civilian fatalities in apartment buildings. In contrast, there were just 27,679 fires and 31 civilian fatalities in office buildings.

Not only are there fewer deaths in office buildings but the fatality rate is an order of magnitude lower than for residential buildings (i.e. 8.5 per 1000 fires for 1 & 2 family dwellings compared with 1 per 1000 fires for offices).



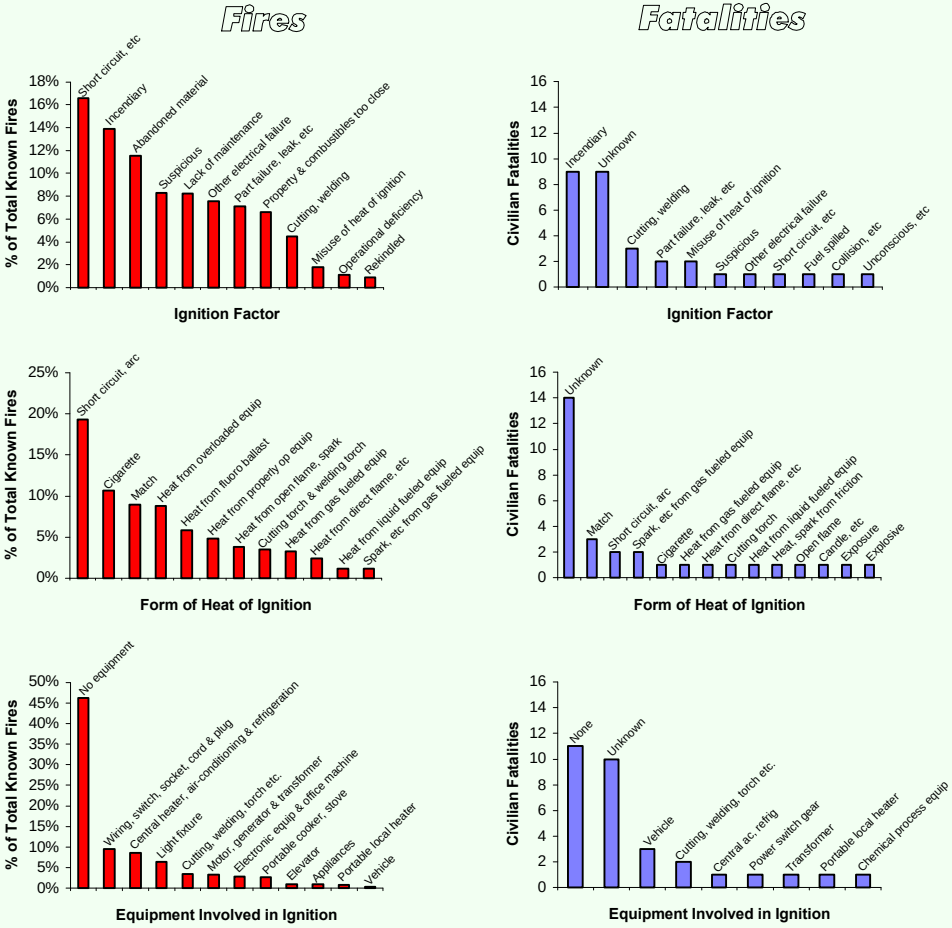
Fires in office buildings are infrequent compared with residential buildings. Fatalities in office building fires are even more infrequent.

How do fires start?

An understanding of how fires start can be obtained from the three parameters:

- ignition factor
- form of heat of ignition
- equipment involved in ignition

The Pareto charts given below plot both the percentage of total fires and the number of civilian fatalities for each of these parameters. Pareto charts plot the most significant factors to the left and the least significant to the right.

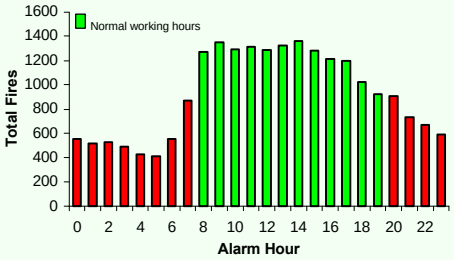


Thus:

- **most office building fires result from wiring and equipment,**
- **fatalities result from incendiary fires (and often involve liquid fuels)**

Why do fires spread?

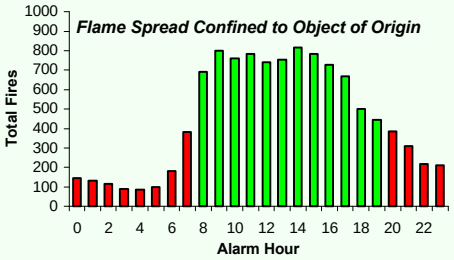
The total number of fires that occur on workdays (taken as Monday - Friday) are plotted versus alarm hour. Two thirds of all fires on workdays occur during normal working hours (taken as being between 8.00am and 7.00pm). This is to be expected since the presence of more people in buildings will lead to greater demands for electrical and mechanical services and an increase in the number of actions with some element of risk (e.g. smoking, use of electrical appliances, heaters, etc).

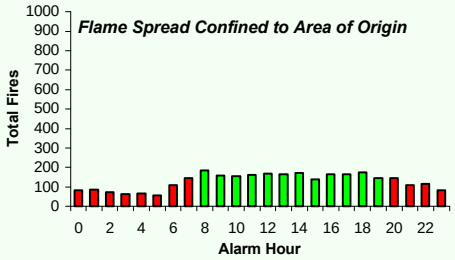


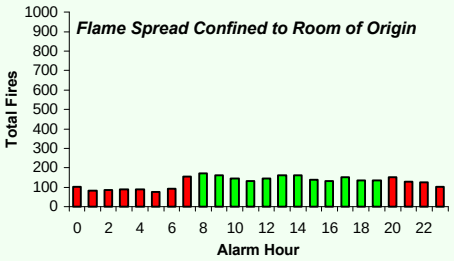
Fires during workdays

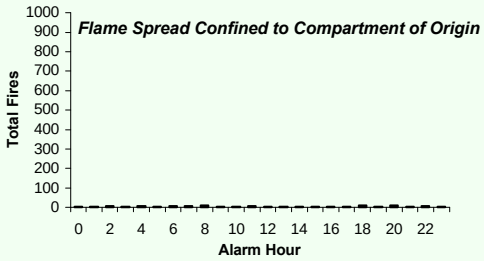
Normal working hours are taken as being between 8.00am and 7.00pm.

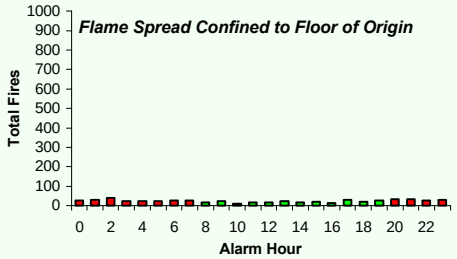
However, the majority of fires that occur during working hours do not spread far. This is illustrated by the following graphs:

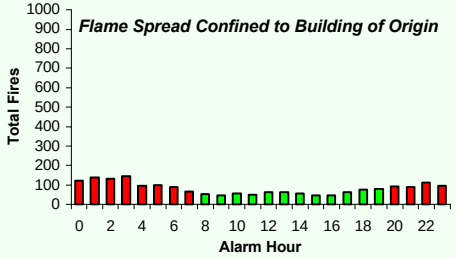


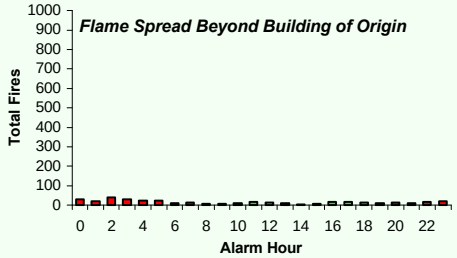






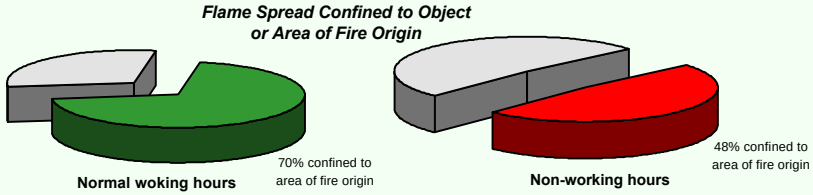




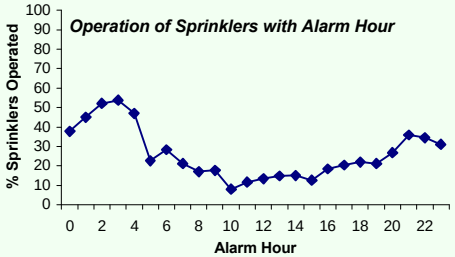


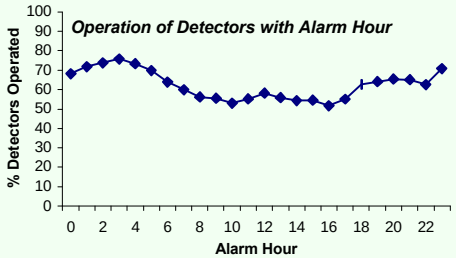
It is clear that the majority of fires that occur during normal working hours are small and are confined to the object of origin. There are actually fewer severe fires during normal working hours (see graphs of flame spread confined to floor of origin and building of origin). The reason for this is straightforward: having people in the building is a very effective fire safety system since the presence of people almost ensures that a fire start will be noticed and the fire dealt with before it gets large.

That the *absence of people* is the dominant factor in why fires spread is further illustrated by the pie chart showing the proportion of fires confined to the object or area of origin during non-working hours versus the proportion during normal working hours.



The fire statistics also note whether sprinklers and/or detectors operated during fires attended by the fire brigade. The graphs below show that the percentages of sprinklers and detectors operated are lower during normal working hours (i.e 8.00am to 7.00pm), with at least three times more, in the case of sprinklers, operating outside normal working hours. This reinforces the fact that it is the *presence of people* that is the dominant factor in controlling the fire growth and that most fires are dealt with when they are small.

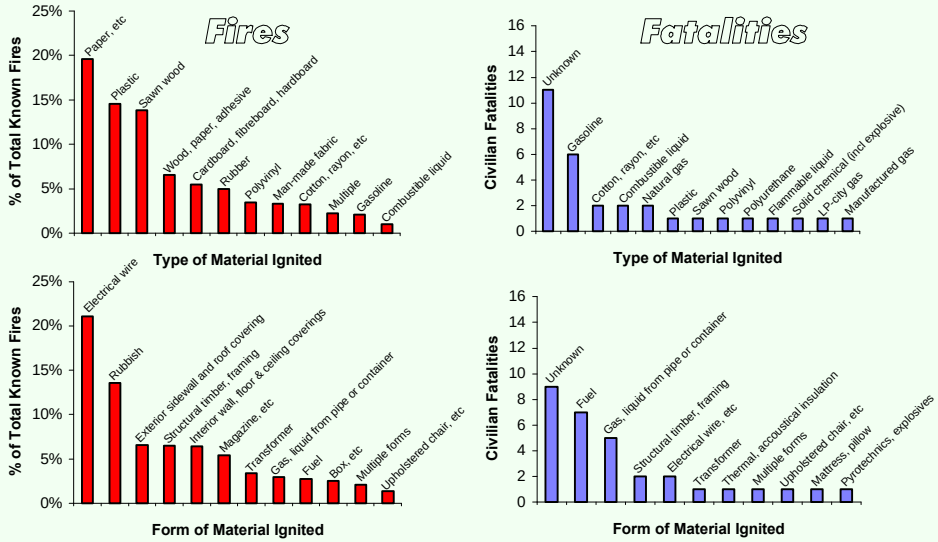




The number of fires increases greatly during occupied hours.
But the proportion (and number) of severe fires reduces dramatically.

Why do people die?

Following ignition, the material ignited can be related to two other parameters, i.e. *type of material ignited* and *form of material ignited*. Again Pareto charts are presented showing percentage of total fires and the number of civilian fatalities in relation to these parameters.



From 27,679 fires, there were 25 *single* fatalities, one *double* fatality and one *quadruple* fatality. Only one third of all fatalities occurring during normal working hours (8.00am to 7.00pm weekdays) although two thirds of all fires occurred during this time.

The information available on the victims is sparse, but of the 31 fatalities, at least 50% of the victims appear to have been intimately involved with the fire starts. In 42% of fires in which there were fatalities, liquid fuels appear to have been involved. Most of these are said to be incendiary or appear likely to be incendiary.

The above data can be use to estimate the risk level during normal working hours (during which the building is occupied, R_o) and the remaining hours (during which most office buildings are largely unoccupied, R_u). The number of occupants during unoccupied hours is assumed to be 1% of the total number of occupants (N) present during occupied hours. The risk level can be expressed as:

R = No. of fatalities / No. of fires / No. of occupants

Risk level during occupied hours:

$$R_o = \frac{1/3 \times 31}{2/3 \times 27679 \times N}$$

Risk level during unoccupied hours:

$$R_u = \frac{2/3 \times 31}{1/3 \times 27679 \times 0.01N}$$

Therefore, the comparative risk levels is: $\frac{R_o}{R_u} = \frac{1}{400}$

If the risk level during occupied hours was hypothetically assumed to be the same as that during unoccupied hours, we would expect to see 4,000 fatalities during occupied hours instead of the 10 fatalities that were recorded. Since the fire-safety systems in the building are the same during occupied and non-occupied hours, it appears that it must largely be the occupants themselves that have this dramatic influence on risk level.

Occupants have two contradictory effects their presence produces a greater number of fire starts (per unit time) but it also results in fire starts being less damaging than if they are not there. The second effect greatly outweights the first.

PART 2: What matters for fire-safety?

Part 1 has demonstrated that:

- the risk level for an occupant is very low during working hours compared with other times
- the presence of people who are awake and aware would appear to be the key factor in reducing risk

It follows that office buildings are safe for the occupants *primarily* due to the presence of a greater number of awake and aware people within the building.

Improving life safety

How can the level of life safety be further improved and which strategies will be most effective? Before considering the various ways that life safety might be achieved it is helpful to consider the following data for office buildings:

Fire size	Number of fires	Number of deaths	Relative rate of deaths per fire
small	9977	1	1
medium	4510	9	20
large	4218	20	47

The strong correlation between fire size and fatalities should be noted. It follows that two strategies are theoretically possible in attempting to improve the level of life safety:

- reduce the occurance of large fires
- design to better resist the effects of large fires

It is not clear that the second strategy is feasible or that it would be effective. The more severe the fire the greater the difficulty in designing against the effects. This is because the fire tends to control the situation and little is known about the effectiveness of fire-safety systems when subject to such fires. The uncertainty is very much greater.

The first strategy is therefore more appropriate. It can be achieved by reducing the number of fire starts and limiting the size of the fires.

Limiting fire starts

improved electrical equipment and practices

The statistical data demonstrated that the ignition of a substantial proportion of fires involved electrical equipment or wiring. It follows that improved and safer electrical wiring and equipment, and the use of residual current devices will reduce the number of fire starts.

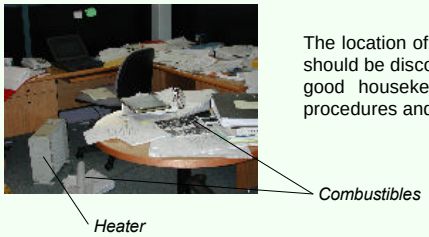
It is recommended that residual current devices be incorporated in buildings.

improved maintenance practices

Hot working (cutting and welding) is also something that contributes to fire ignition and associated fire starts can be reduced through the adoption of proper hot working procedures.

It is recommended that maintenance activities be undertaken in accordance with established procedures aimed at preventing the occurrence of a fire and be closely controlled and monitored.

housekeeping



The location of combustibles adjacent to potential heat sources should be discouraged. This can be achieved by the adoption of good housekeeping and facilitated through well developed procedures and monitoring.

Limiting the size of fire (helping the occupants)

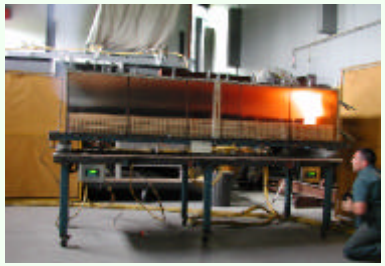
The more that a fire can be slowed down or limited, the more likely that it will be dealt with effectively and that occupants can respond in a reasonable manner.

limiting lining materials

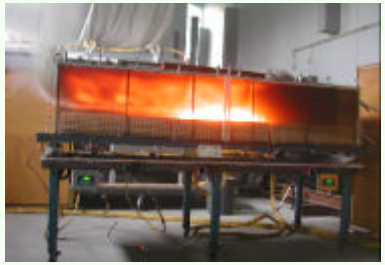
The ability of combustible surfaces to spread flames depends on:

- the characteristics of the surface materials
- the surface area presented to the fire
- the heat output and duration of burning
- the orientation of the surface in relation to the fire

Inclined or vertical surface orientation with the fire located below or adjacent to the surface at the lowest point will give rise to the fastest rate of spread. Simple tests conducted on a channel constructed of luan ply are shown here. For both tests the fire was associated with a small wood crib. In the first test, the fire spread up the entire height of the channel whereas in the second test, where the flames were constrained to remain on the interior surface only, flame spread was much more limited.



Two other tests have been conducted in a 1200mm x 600mm x 3000mm enclosure with a 450mm x 1200mm opening at one end and glazing along one side. Wood cribs were used as the fuel in both situations. In one case the ceiling of the enclosure was clad with plywood. The fire was started at the rear of the enclosure in both situations. The fire moved forward towards the opening along the top of the cribs until burning was established at the opening with little fuel being consumed. The presence of the plywood roof appeared to have little impact on the rate of movement towards the opening.



The above tests illustrate that certain materials, although combustible, may have little impact on the rate of fire spread in certain situations. More research is required to identify the circumstances under which the rate of spread will not be increased. In the interim period, combustible linings are not permitted for the Alternative Solutions presented in this publication.

housekeeping

Good housekeeping will limit the quantities of *combustibles* that are distributed in a scattered manner throughout an enclosure and this will reduce the likelihood of fire spread within an enclosure.

early fire fighting - facilities and training

The provision of fire fighting equipment and associated training will increase the likelihood of control of a developing fire. The current BCA provisions for extinguishers and/or hose reels are considered reasonable.

sprinklers

Many sprinklered fire tests have been conducted in order to study the efficacy of sprinklers in both individual and open-plan office situations. A description of these tests is given in Appendix A.

Office area set-up prior to test

Fire just prior to the operation of the sprinkler

Extent of damage after test

These tests demonstrated that a light hazard sprinkler system will be effective in rapidly reducing air temperatures and in preventing spread, even in situations where there is substantial shielding of the fire from the sprinkler.

The effectiveness of sprinklers in achieving a high level of life safety, in relation to other measures such as compartmentation, can be assessed from the statistical data mentioned in Part 1 for apartment and residential buildings. These are used as there are too few deaths in office or other commercial buildings to make meaningful statistical comparisons. The comparison is shown below where the relative impact on death rate is tabulated against the particular measure—protected construction (i.e. FRL), detectors, and sprinklers.

Sprinklers	Detectors in room of fire origin	Protected construction	Relative impact on death rate
7	7	7	1.0
7	7	3	0.78
7	3	7	0.78
3	7	7	0.34

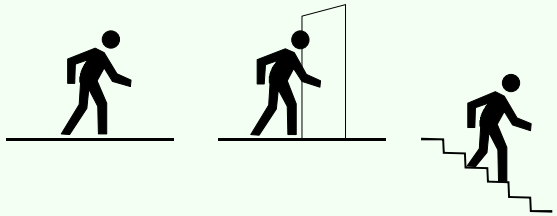
It can be seen that although fire-protected construction results in a reduction of the rate of deaths from 1.0 to 0.78 (a decrease of 22%), sprinklers by *themselves* result in a reduction of 1.0 to 0.34 (a decrease of 66%). Thus sprinklers are at least three times as effective in achieving the BCA life safety objectives compared with protected construction. Smoke detection within the room of fire origin has a similar effect to protected construction. Similar numbers are obtained if property loss is considered. The presence of sprinklers is seen as having a very positive impact on fire safety in comparison with either detection or compartmentation.

Limiting the spread of smoke

The spread of smoke into the stairs and upper levels will pose a threat to occupants in the stairs and other parts of the building. The question is: what requirements are really necessary? The answer depends on the time for evacuation via the stairs and the time to untenable conditions within the stairs.

How long will it take to evacuate?

The time for evacuation of occupants is essentially made up of two times—the time that it takes for the effected occupants to decide to evacuate (the pre-movement time) and the time for movement. The movement times have been calculated for various building situations using a more realistic estimate of population (16 m^2/person [5] compared with 10 m^2/person) and assuming that 90% of the floors are occupied as office space. It has also been assumed that only one of the two required stairs is tenable. The calculated times are given below:



Storeys	Movement time (*secs*)		
	1,250 m^2 in plan	1,500 m^2 in plan	1,850 m^2 in plan
2	121	142	171
3	223	263	321
4	324	385	472

It can be observed that the movement times are not large even for a building with a *rise in storeys* of 4.

How long will it take for the occupants to commence evacuation—remembering that we are considering low-rise office buildings?

The answer depends on the location of the occupants in relation to the fire. On the fire floor, it can be assumed that occupant evacuation will have commenced prior to the stage that a fire could be controlled by a fire extinguisher.

As far as occupants above the fire floor are concerned, warning of the presence of a fire will come from olfactory cues associated with the transport of the products of combustion via the air-handling system. The sense of "something burning" will most likely be noticed before the air-handling system shuts down due to the detection of smoke (should such a system be provided). The decision to evacuate these levels will result from:

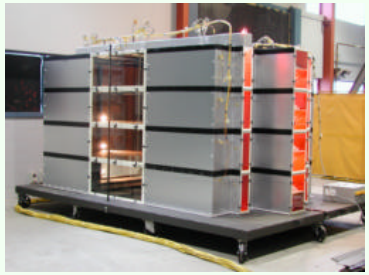
- investigation of the source of the burning smell
- direct communication from the fire or other levels
- detection and alarm (in the case of buildings where detection is provided)

In the absence of sprinklers, smoke detection is seen as increasing the awareness of the presence of a fire, especially in situations where the building is taller or where substantially different activities take place. Detection provides reinforcement to other cues and is recommended in office buildings with a *rise in storeys* of 4 or the *rise in storeys* is 3 where the ground level is retail.

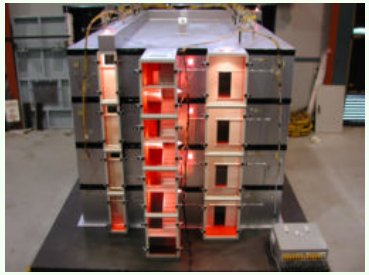
It is expected that evacuation of the other levels will commence within a few minutes of occupants evacuating the fire floor.

How long are the stairs likely to remain tenable?

This is critical since the occupants must evacuate before the stairs become untenable. In order to investigate such a question a model building was constructed at Victoria University of Technology. The building is a 1/7 scale of one quarter of a four storey building and incorporates service shafts, lift shafts and stairs.

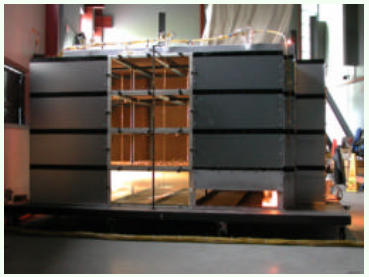


Smoke model building

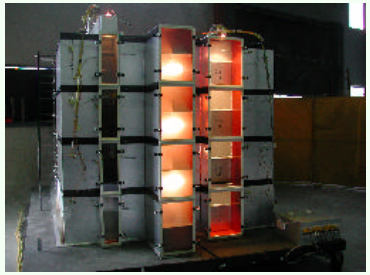


View of service shafts, lift shafts and stairs

Tests have been conducted to look at the flow of smoke into the stair shaft and through other parts of the building. The combination of small openings associated with the stairway door at the level of the fire and open stair doors above the fire will result in substantial smoke being pulled into the stairs. This can occur before the fire is large enough to break the external glazing and before there is even a rapid growth in fire severity.



Fire started at front end corner



Smoke in stair shaft

It is concluded that there is a window of opportunity for evacuation during the early stages of fire development.

The time for evacuation can be taken as 15 minutes from the time that a fire reaches the stage that it cannot be controlled by an extinguisher.

For buildings with a *rise in storeys* of more than 2 it is recommended that the construction around the stairs be designed to provide smoke separation for at least this period of time. The presence of a *fire-resistant* shaft will resist the spread of smoke into the stairs. However, gaps around the doors or particularly the doors on the level of fire origin being open, will limit the effectiveness of the shaft.

Limiting the spread of flame (outside the enclosure)

The best ways to limit the spread of flame *outside* the enclosure of origin are to reduce the number of fire starts and limit the size of the fire.

However, the presence of composite or concrete floors when supported by bare steel construction will offer substantial fire separation to the levels above the fire level and levels of performance beyond that required for evacuation of the occupants. The reader is referred to Appendix B for a discussion of this matter.

Improving fire brigade safety

The best ways to improve brigade fire safety are to reduce the number of fire starts and limit the size of the fire.

It is noted that since these buildings are low-rise construction, major fire fighting can be conducted from outside. Access via the stairs is possible but these may become untenable due to smoke during the early stages of a major fire. Nevertheless, for many of the *Alternative Solutions* proposed in this publication, the stairs are required to be surrounded by a *fire-resistant* shaft and the building to be designed such that outwards collapse is not possible.

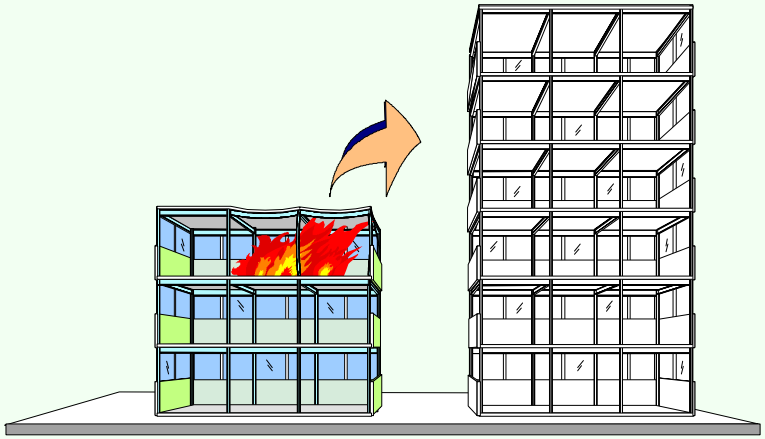
The *maximum floor areas* of the proposed *Alternative Solutions* are also limited, as the duration of a fire, other factors being equal, is directly dependent on the *floor area* of the building.

Reducing fire spread between buildings

The best ways to reduce fire spread between buildings are to reduce the number of fire starts and limit the size of the fire.

The prevention of spread to an adjacent building can be also achieved by limiting the distance to a *fire-source feature*, having limited openings, or having *external walls* which can sufficiently contain the fire and limit radiation. This does not require *external walls* to remain vertical but that the walls continue to remain attached to the supporting frame and substantially intact. This is further discussed in Appendix C as well as the FRL *required* for *external walls* to provide a sufficient barrier to radiation.

In theory, fire could also spread from the roof to an adjacent building. However, if the roof is constructed such that significant flaming from or through the roof to outside does not occur, then the radiation from the roof can be shown to be very limited compared with that associated with an opening.



There are principally two reasons for this:

- the temperature of an intact roof membrane is much lower than that of flames from an opening
- the configuration factor associated with radiation from the roof to an adjacent building is much lower than that associated with flames from an opening

This matter is further considered in Appendix D.

Reducing damage to adjacent buildings

The best ways to reduce the likelihood of damage to adjacent buildings are to reduce the number of fire starts and limit the size of the fire.

In addition, the *Alternative Solutions* proposed in this document are required to be designed such that:

- outwards collapse of the building is not possible
- connections between *external wall* panels and the supporting frame be designed such that outwards collapse of the panels is not possible

Alternative Solutions

Alternative Solutions

BCA objectives and performance requirements

Alternative Solutions must satisfy the BCA fire-safety objectives and the relevant performance requirements. The fire-safety objectives can be summarised as follows:

- The building shall be designed to allow safe evacuation of the occupants.
- The building shall be designed so as not to put the fire brigade at risk in the exercise of their duty.
- The building shall be designed to avoid the spread of fire to other buildings.
- The building shall be designed to avoid damage to other buildings.

The performance requirements that are applicable are CP1 - CP2, CP4 - CP9, DP1 - DP8, EP1.1 - EP1.6, EP2.2, EP3.1, EP3.3 and EP3.4.

The proposed *Alternative Solutions* have been derived on the basis of the arguments presented in Part 2. The *Alternative Solutions* are considered so as to satisfy these objectives and performance requirements.

Recommendations

The following recommendations are given in order to further improve the level of fire-safety in office buildings:

Improved maintenance practices

Maintenance within the building should be undertaken by suitably qualified persons to established procedures particularly with regard to hot working (grinding, welding and cutting). Such procedures should require maintenance staff to notify occupants before commencing work and to be equipped with insulation blankets and portable extinguishers. Hot working should not be undertaken in the vicinity of combustibles unless these combustibles have been adequately protected. Isolation of smoke detectors should be temporary and these should be re-instated after completion of work.

Housekeeping audits

Regular audits should be undertaken to check that:

- use of portable heaters and electrical devices is safe with respect to type of device and location
- combustibles are not stored near potential heat sources
- combustibles are not stored in exit paths, near or in stairs
- doors to emergency stairs are not chocked open
- levels of combustibles are reasonable and storage is ordered with use made of cabinets or shelving
- any other housekeeping matter that is related to fire safety

Detailed requirements - specification

Relevant BCA clauses

In this specification it is convenient to refer to the BCA *deemed-to-satisfy* provisions that are applicable. These are listed below. In certain cases the clauses are applicable with modification and the appropriate modifications are given. In the BCA clauses noted below, the expressions:

"is *required* to have an FRL", or
"*required* to be fire-resisting", or
"*required* FRL", or
"FRL *required* by",

or any similar expression, should be taken as referring to the level of fire resistance, if any, required by this Specification.

The term *fire compartment* should be understood as referring to any part of a building separated from the remainder by barriers to fire such as walls and/or floors having the fire resistance required by this Specification and with any openings protected in accordance with this Specification.

Subject to the above definitions, Sections A, B, F and I of the BCA apply as do the following clauses of the *deemed-to-satisfy* provisions of Section C:

- Part C1: clauses C1.2, C1.8, C1.10, C1.11, C1.12
- Part C2: clauses C2.5(d), C2.11, C2.13, and

  C2.6 with "which is *required* to be of Type A construction" replaced by "has a *rise in storeys* of 4".

  C2.7(a)(ii), (b) prescribed by this Specification; and "*Deemed-to-Satisfy Provisions* of Part C3" with "provisions of"; and "*Deemed-to-Satisfy Provisions* of Sections C, D and E" replaced by "requirement of this Specification".

  C2.10 modified to read "must be separated from the remainder of the building by enclosure in a shaft which is required to have the FRL prescribed by this Specification; and openings for lift landing doors and services are protected in accordance with the requirements of this Specification."; delete (a)-(c).

  C2.12 with "*required* by Specification C1.1" replaced by "required by this Specification"; replace "120" by "60".

  C2-13 with "120" replaced by "60"

- Part C3: clauses C3.1, C3.2, C3.4, C3.8, C3.9, C3.10, C3.16 and

  C3.12 replace "In a building of Type A construction" with "In a building with a *rise in storeys* of 4"; and "Specification C1.1" with "this Specification".

  C3.13 with replace "In a building of Type A construction" with "In a building with a *rise in storeys* of 4"

  C3.15 replace "*required* by Specification C1.1" replaced by "required by this Specification"

Specification C1.1:

- Clause 2.1 except for reference to Clause 2.2.
- Clause 2.7

Section D: All clauses apply except for clause D1.9(b)

Section E: All clauses apply except for clause E1.8; paragraph 11 in Spec E1.5; and Spec E1.8

Other requirements

Applicable to all Alternative Solutions

(1) Buildings shall incorporate residual current devices.

(2) Occupant fire awareness and fire-fighting training shall be undertaken in accordance with documented procedures. This is required in any case as part of the OH&S legal requirements relating to duty of care in providing a safe place of work.

(3) Fire-safety systems including detection systems, sprinkler systems, portable extinguishers, doors to stairs shall be maintained in accordance with AS1851 [6]. This is also required by Section I of the BCA and the OH&S legal requirements relating to duty of care in providing a safe place of work.

(4) Where stairs are required to be within a *fire-resisting* shaft, the only openings into the stair shaft shall be associated with doors.

(5) The following elements are required to be constructed of *non-combustible* materials in accordance with clause C1.12 of the BCA:

- ceilings
- roof
- floors
- external wall
- common walls
- flooring and framing of lift pits
- internal walls required to be fire-resisting
- loadbearing fire wall
- lining of internal walls
- lift and service shafts - if the shaft connects more than two storeys.

(6) Open-deck or sprinklered carpark levels shall be designed in accordance with the solutions given in Reference [7].

(7) Fire-resistance levels for the various building elements are given in Tables 1-4. These are illustrated for particular elements of construction in the next part of this section.

Applicable to all non-sprinklered Alternative Solutions

(8) The plan area of each floor shall be limited to 1,850 m^2.

(9) Partially-open carpark level (≤ 40 cars)—cars shall not be more than 30 m from a wall which has an opening across its entire width. The height of the opening should be at least 75% of the floor-to-floor height.

(10) The building frame shall be designed so as not to collapse outwards when subject to a fire within the building.

(11) Connections between the building frame and any *external wall* panels shall be designed so as to prevent outwards collapse of the panels in the event of deformation of the supporting frame.

(12) Where *common walls* and *fire walls* are required these shall be supported on both sides of the wall to maintain lateral support in the event of a fire on either side of the wall.

(13) The roof shall be reinforced concrete or steel. In the case of a steel roof the minimum base metal thickness shall be 0.42 mm. The sheeting shall be screw-fixed to the steel purlins at the spacing required for resistance to wind loading in that particular situation.

Tables of fire-resistance requirements

Table 1: *Rise in storeys = 2 (Non-sprinklered buildings)*

Building Elements	Basement Carpark	Closed carpark (Level 1)	Partially open carpark (Level 1)	Retail level (Level 1 if exists)	Office level
	Fire-resistance requirements (FRL or ESA/M)				
Wall					
(a) external wall					
(i) less than 3m from fire-source feature to which it is exposed					
loadbearing		90/90/90	90/90/90	90/90/90	90/90/90
non-loadbearing		-/90/90	-/90/90	-/90/90	-/90/90
(ii) 3m or more from a fire-source feature to which it is exposed		-	-	-	-
(b) internal wall - loadbearing	60/60/60	60/60/60	60/60/60	60/60/60	60/60/60
Common Walls and Fire Walls	90/90/90	90/90/90	90/90/90	90/90/90	90/90/90
Lift and Stair shaft	-	-	-	-	-
Service Shaft	-	-	-	-	-
Beams					
basement	≤ 30 m^2/tonne				
level 1		≤ 30 m^2/tonne	≤ 30 m^2/tonne	≤ 30 m^2/tonne	≤ 30 m^2/tonne
Columns					
basement	30/-/-				
level 1		≤ 26 m^2/tonne	≤ 26 m^2/tonne	≤ 26 m^2/tonne	≤ 26 m^2/tonne
level 2					
Floor Slab					
basement	60/60/60				
other levels		*	*	*	*
Roof (including beams)					-

Table 2: *Rise in storeys = 3 (Non-sprinklered buildings)*

Building Elements	Basement Carpark	Closed carpark (Level 1)	Partially open carpark (Level 1)	Retail level (Level 1 if exists)	Office level
	Fire-resistance requirements (FRL or ESA/M)				
Wall					
(a) external wall					
(i) less than 3m from fire-source feature to which it is exposed					
loadbearing		90/90/90	90/90/90	90/90/90	90/90/90
non-loadbearing		-/90/90	-/90/90	-/90/90	-/90/90
(ii) 3m or more from a fire-source feature to which it is exposed		-	-	-	-
(b) internal wall - loadbearing		60/60/60	60/60/60	60/60/60	60/60/60
Common Walls and Fire Walls	90/90/90	90/90/90	90/90/90	90/90/90	90/90/90
Lift and Stair shaft	60/60/60	60/60/60	60/60/60	60/60/60	60/60/60
Service Shaft	-	-	-	-	-
Beams					
basement	30/-/-				
level 1		≤ 30 m^2/tonne	≤ 30 m^2/tonne	≤ 30 m^2/tonne	≤ 30 m^2/tonne
Columns					
basement	30/-/-				
level 1		30/-/-	≤ 10 m^2/tonne	30/-/- or #	30/-/- or #
levels 2 - 3					-
Floor Slab					
basement	60/60/60				
other levels		60/60/60	*	*	*
Roof (including beams)					-

* Use of composite or concrete floor construction where beams are in continuous contact with a concrete floor slab.

\# Protection of column with 16 mm fire-resistant plasterboard (or equivalent) up to bottom flange of beam.

Table 3: *Rise in storeys = 4 (Non-sprinklered buildings)*

Building Elements	Basement Carpark	Closed carpark (Level 1)	Partially open carpark (Level 1)	Retail level (Level 1 if exists)	Office level
Fire-resistance requirements (FRL or ESA/M)					
Wall					
(a) external wall					
(i) less than 3m from fire-source feature to which it is exposed					
loadbearing		90/90/90	90/90/90	90/90/90	90/90/90
non-loadbearing		-/90/90	-/90/90	-/90/90	-/90/90
(ii) 3m or more from a fire-source feature to which it is exposed		-	-	-	-
(b) internal wall - loadbearing	60/60/60	60/60/60	60/60/60	60/60/60	60/60/60
Common Walls and Fire Walls	90/90/90	90/90/90	90/90/90	90/90/90	90/90/90
Lift and Stair shaft	60/60/60	60/60/60	60/60/60	60/60/60	60/60/60
Service Shaft	60/60/60	60/60/60	60/60/60	60/60/60	60/60/60
Beams					
basement	30/-/-				
level 1		30/-/-	≤ 30 m^2/tonne	≤ 30 m^2/tonne	≤ 30 m^2/tonne
Columns					
basement	60/-/-				
level 1		30/-/-	≤ 10 m^2/tonne	30/-/- or #	30/-/- or #
level 2					30/-/- or #
levels 3 - 4					-
Floor Slab					
basement	60/60/60				
other levels		60/60/60	60/60/60	60/60/60	60/60/60
Roof (including beams)					-

Table 4: *Rise in storeys £ 4 (Sprinklered buildings)*

Building Elements	Basement Carpark	Closed carpark (Level 1)	Partially open carpark (Level 1)	Retail level (Level 1 if exists)	Office level
Fire-resistance requirements (FRL or ESA/M)					
Wall					
(a) external wall					
(i) less than 3m from fire-source feature to which it is exposed					
loadbearing		90/90/90	90/90/90	90/90/90	90/90/90
non-loadbearing		-/90/90	-/90/90	-/90/90	-/90/90
(ii) 3m or more from a fire-source feature to which it is exposed		-	-	-	-
(b) internal wall - loadbearing		60/60/60	60/60/60	60/60/60	60/60/60
Common Walls and Fire Walls	90/90/90	90/90/90	90/90/90	90/90/90	90/90/90
Lift and Stair shaft	60/60/60	60/60/60	60/60/60	60/60/60	60/60/60
Service Shaft	-	-	-	-	-
Beams					
basement	≤ 30 m^2/tonne				
level 1		≤ 30 m^2/tonne	≤ 30 m^2/tonne		
Columns					
basement	≤ 26 m^2/tonne				
level 1		≤ 26 m^2/tonne	≤ 26 m^2/tonne	≤ 26 m^2/tonne	≤ 26 m^2/tonne
levels 2 - 4					-
Floor Slab					
basement	60/60/60				
other levels		60/60/60	*	*	*
Roof (including beams)					-

* Use of composite or concrete floor construction where beams are in continuous contact with a concrete floor slab.

\# Protection of column with 16 mm fire-resistant plasterboard (or equivalent) up to bottom flange of beam.

Explanatory notes on Tables

Tables 1 - 3 (non-sprinklered buildings)

It will be noted that different fire resistances have been specified for the various levels with those for the lower levels increasing with the *rise in storeys*. This is because:

(a) the consequences of failure of the upper levels are less significant than the lower levels. Consequently lower fire resistances are required for the upper levels.

(b) the evacuation time increases with *rise in storeys.*

It will also be noted that different levels of performance are specified for different building elements. There are several reasons for this:

(i) Higher levels of performance are generally specified for fire-resisting stair shafts (required for *rise in storeys* of greater than 2). This is because stair shafts are the only paths for evacuation. Note also the requirements of clause D2.2 of the BCA.

(ii) Floor slabs when required to have a fire resistance are specified as requiring an FRL of 60/60/60 only because this is the minimum practical level able to be achieved by a composite or concrete floor. It is not because this level of fire resistance is necessary.

(iii) Columns have more stringent requirements than beams. This is because the failure of a column will have greater consequence than sagging of a beam.

(iv) The FRL's specified for *external walls* within a limiting distance from a *fire-source feature* are chosen so as to provide a radiation barrier between buildings.

(v) The values of exposed surface area-to-mass ratio (ESA/M) specified for beams is given so as to reflect the size of members used in tests and in real fire situations where bare steel beams have continued to support the floors well beyond the time required for evacuation. The limited fire severity has also been taken into account for office and retail levels.

(vi) Similarly, the exposed surface area-to-mass ratios specified for columns are given so as to maintain stability until beyond the time for evacuation. In some situations bare steel columns may not give sufficient fire resistance and a protection system or a corresponding FRL is specified.

Table 4 (sprinklered buildings)

In this case, the presence of sprinklers is considered to remove the need for any fire resistance requirements other than for stairs and walls.

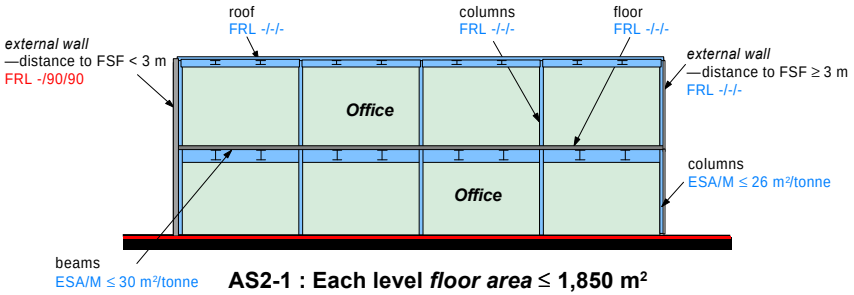
Summary of fire-resistance requirements

The following diagrams illustrate the fire-resistance requirements for various elements in buildings which combine carpark, retail and office levels. These combinations are considered to correspond to the most likely practical situations.

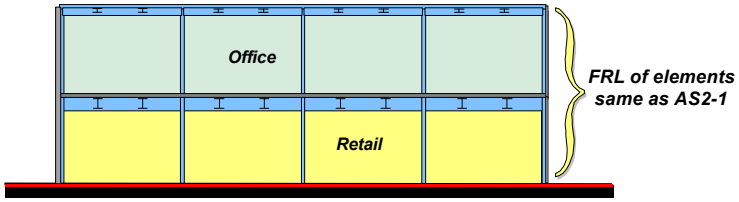
Where elements are coloured blue, bare steel construction may be used.

Buildings with *rise in storey* = 2

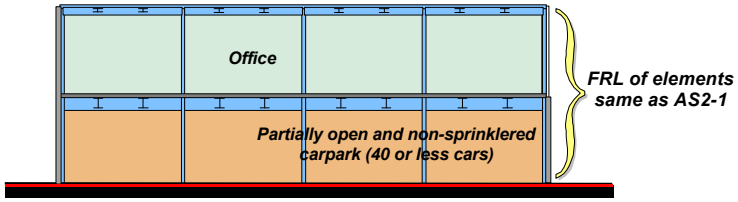
Non-sprinklered Buildings



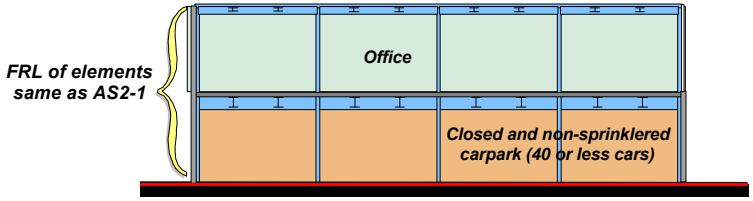
AS2-1 : Each level *floor area* ≤ 1,850 m²



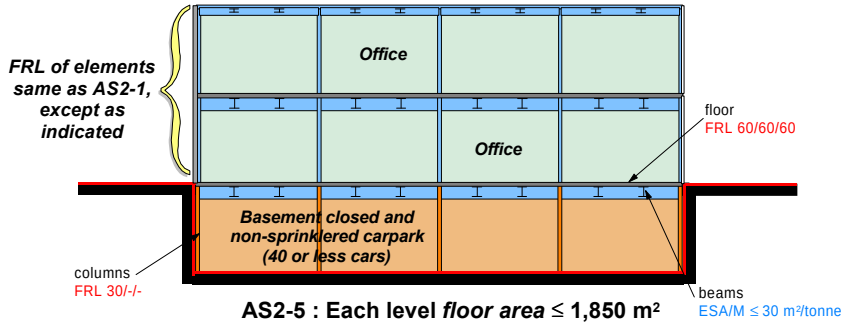
AS2-2 : Each level *floor area* ≤ 1,850 m²



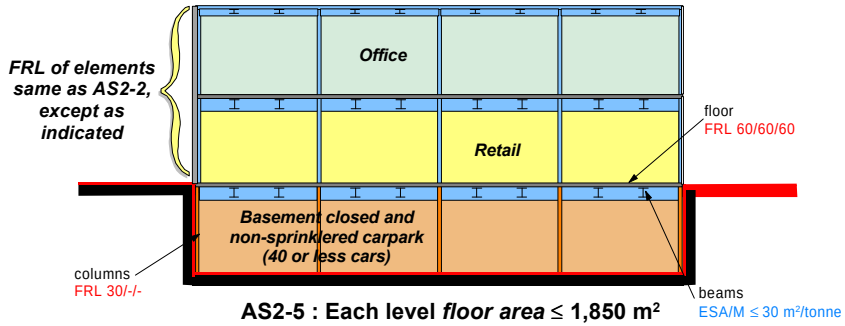
AS2-3 : Each level *floor area* ≤ 1,850 m²



AS2-4 : Each level *floor area* ≤ 1,850 m²



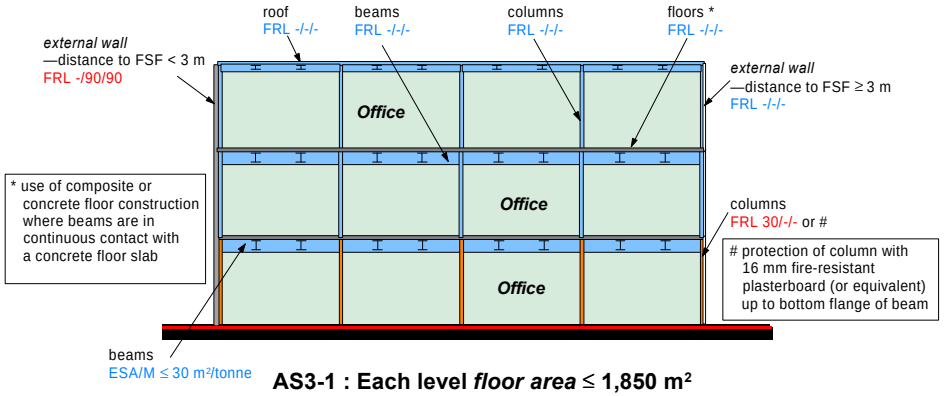
AS2-5 : Each level *floor area* ≤ 1,850 m²



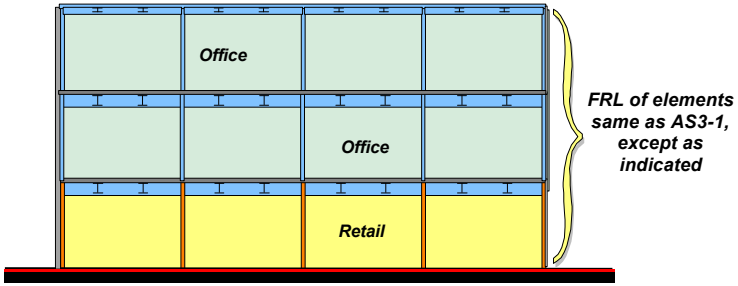
AS2-5 : Each level *floor area* ≤ 1,850 m²

Buildings with *rise in storeys* = 3

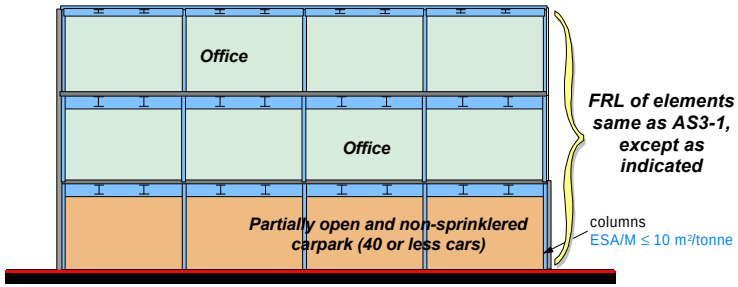
Non-sprinklered Buildings



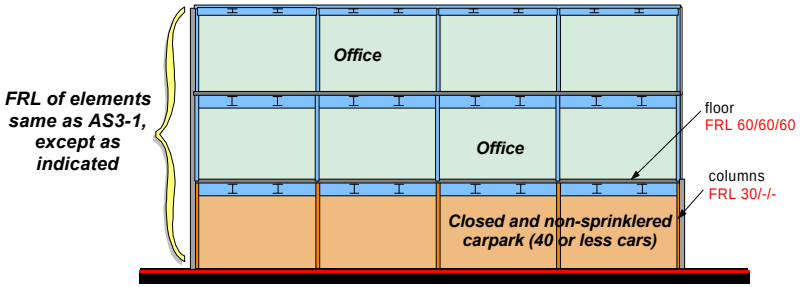
AS3-1 : Each level *floor area* ≤ 1,850 m²



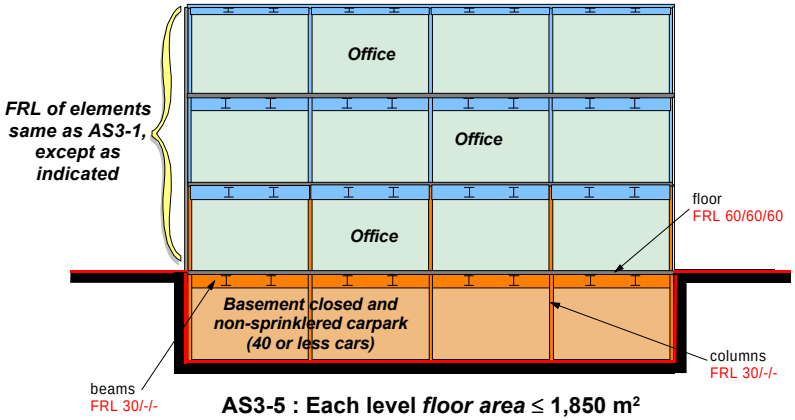
AS3-2 : Each level *floor area* ≤ 1,850 m²



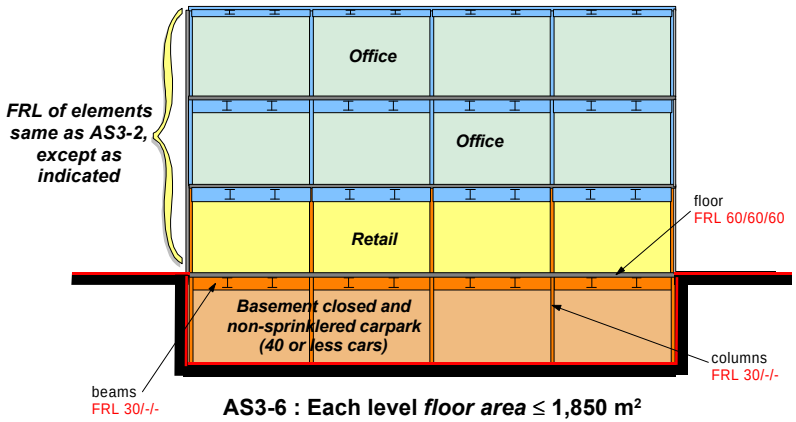
AS3-3 : Each level *floor area* ≤ 1,850 m²



AS3-4 : Each level *floor area* ≤ 1,850 m²



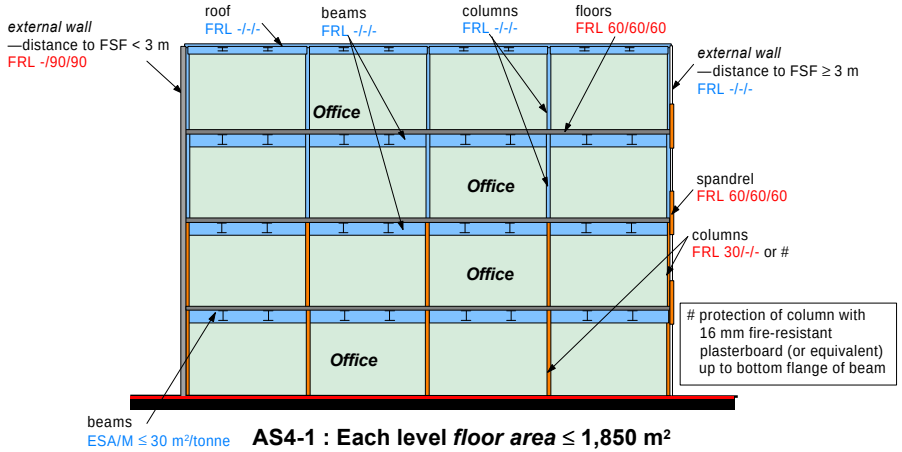
AS3-5 : Each level *floor area* ≤ 1,850 m²



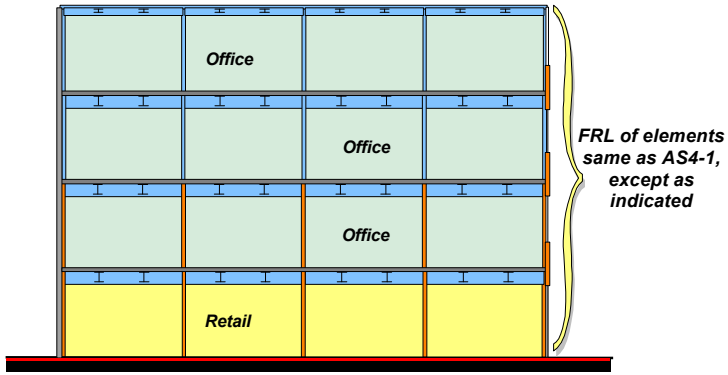
AS3-6 : Each level *floor area* ≤ 1,850 m²

Buildings with *rise in storeys* = 4

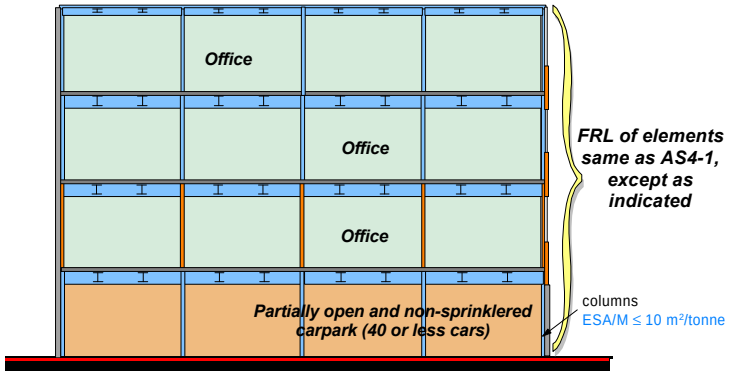
Non-sprinklered Buildings



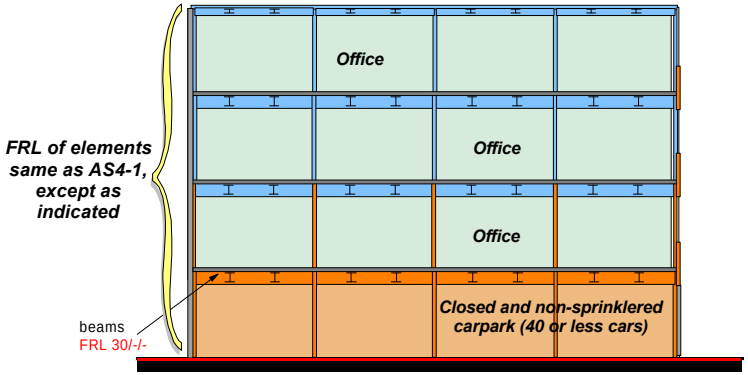
AS4-1 : Each level *floor area* ≤ 1,850 m²



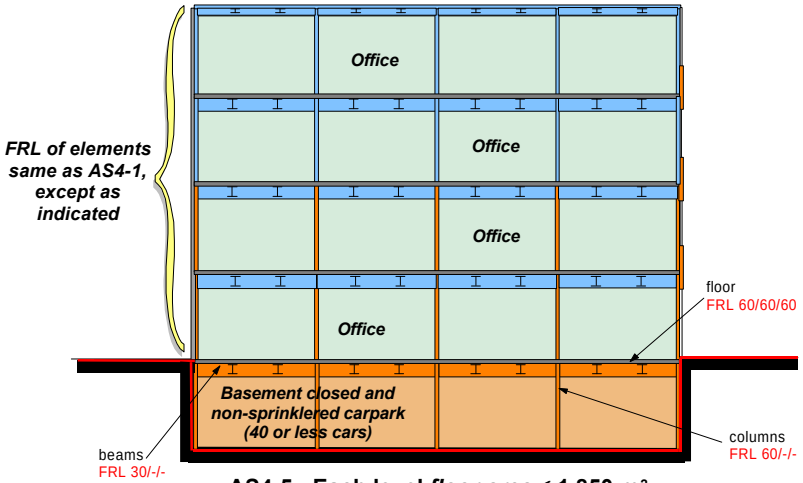
AS4-2 : Each level *floor area* ≤ 1,850 m²



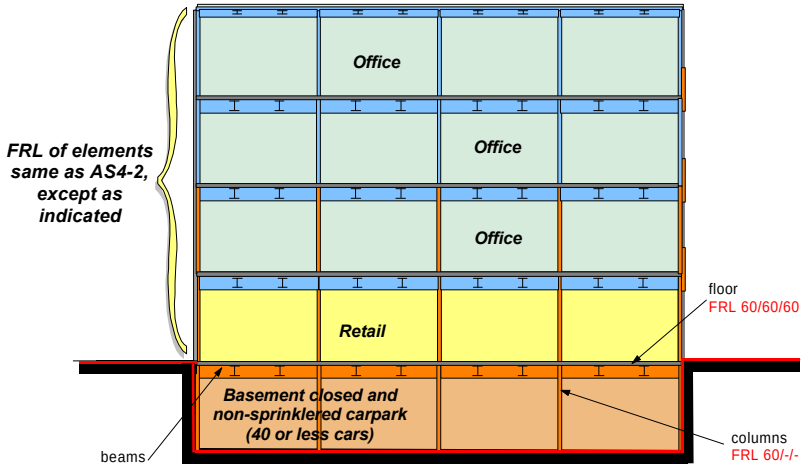
AS4-3 : Each level *floor area* ≤ 1,850 m²



AS4-4 : Each level *floor area* ≤ 1,850 m²



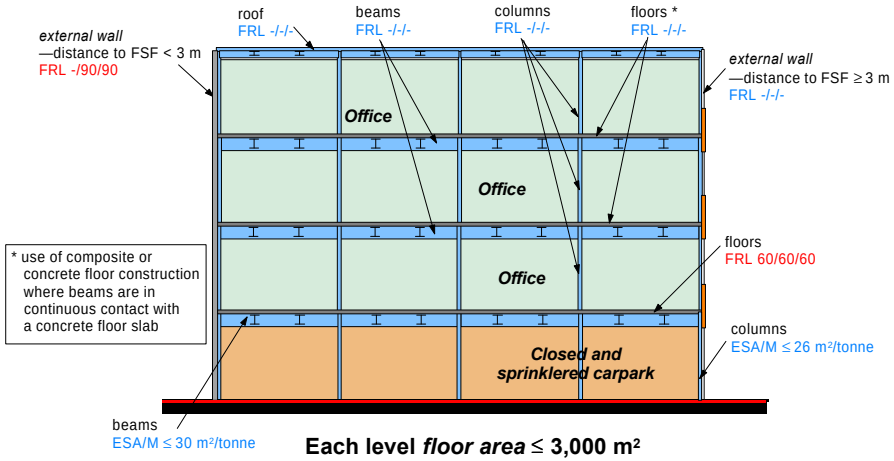
AS4-5 : Each level *floor area* ≤ 1,850 m²



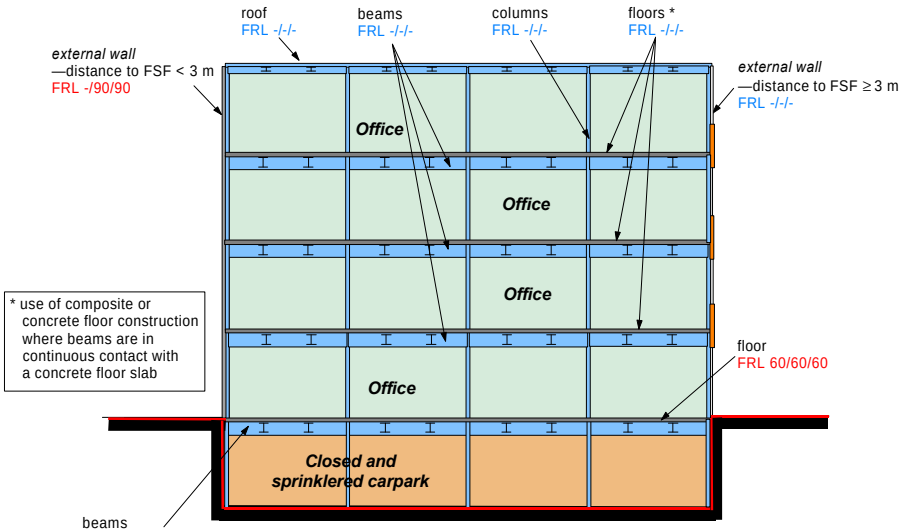
AS4-6 : Each level *floor area* ≤ 1,850 m²

Buildings with *rise in storeys* ≤ 4

Sprinklered Buildings



Each level *floor area* ≤ 3,000 m²



Each level *floor area* ≤ 3,000 m²

Comparison with BCA deemed-to-satisfy provisions

Non-combustible construction

Comparing the *deemed-to-satisfy* provisions with the *Alternative Solutions*, the latter require the following additional elements to be *non-combustible*:

- ceilings
- roofs
- floors
- linings of internal walls

Allowable floor areas

All other things being equal, the duration of a fire is a function of the total fire load and therefore the total *floor area*. The *floor areas* permitted for the *Alternative Solutions* are well below those permitted for Type A construction. Some comparisons are given below:

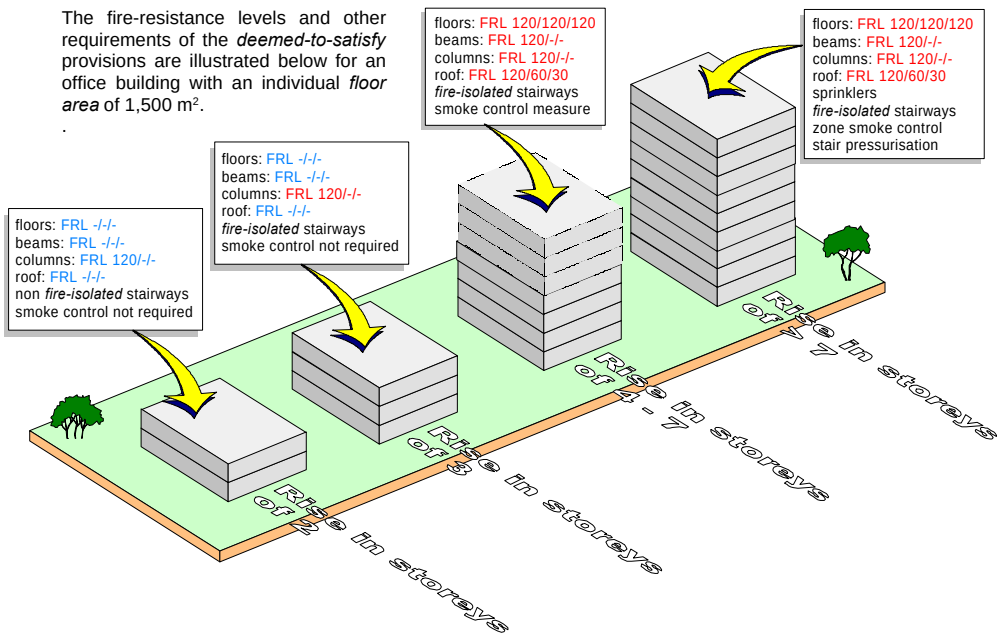
Situation	BCA Provisions (non-sprinklered)	Alternative Solution (non-sprinklered)	Alternative Solution (sprinklered)
3 storey office	Type B: 1,833 m² per floor	1,850 m² per floor	3,000 m² per floor
4 storey office	Type A: 8,000 m² per floor	1,850 m² per floor	3,000 m² per floor

Fire-resistance and other requirements

Non-sprinklered buildings - BCA deemed-to-satisfy provisions

The fire-resistance levels and other requirements of the *deemed-to-satisfy* provisions are illustrated below for an office building with an individual *floor area* of 1,500 m².

.



It will be noted that in the BCA:

(a) *Rise in storeys* ≤ 4
There are no FRL requirements for floors in buildings with a *rise in storeys* of 3 or less (subject to the total *floor area*); yet for buildings with a *rise in storeys* of 4, a ***high fire-resistance*** level is specified. This is difficult to justify since the additional time required to evacuate the taller building is a few minutes. Furthermore, a building with a *rise in storeys* of 4 is required to have a form of smoke control which will normally be provided in the form of smoke detection.

(b) 4 ≤ *Rise in storeys* **<** 8
The requirements for buildings having a *rise in storeys* of 4 are the same as those required for buildings with *rise in storeys* above 4. At a *rise in storeys* of 8 (i.e. effective height of > 25 m) sprinklers, zone smoke control and stair pressurisation are required. Once again, the taller buildings take longer to evacuate and there are more occupants at risk. It is difficult to justify the requirements being the same for *all* buildings with a *rise in storeys* of 4 or greater.

The *Alternative Solutions*, on the other hand, are designed on the basis of the required performances. The requirements are also tailored to the *rise in storeys* and allow for the fact that taller buildings will take longer to evacuate. Basements are seen as being the most critical level and more stringent requirements are given.

Sprinklered buildings

Building Solutions satisfying all of the BCA *deemed-to-satisfy* provisions get few "concessions" for the addition of sprinklers. Edge spandrels are not required and the roof is not required to have an FRL.

On the other hand, the *Alternative Solutions* recognise the demonstrated value of sprinklers compared with *compartmentation* in achieving the fire-safety objectives and performance requirements of the BCA. The fire-resistance requirements are therefore further reduced.
.

References

[1] "Building Code of Australia 1996", Volume 1—Class 2 to Class 9 Buildings, Australian Building Code Board, 1996.

[2] "Guide to the BCA", Class 2 to Class 9 Buildings, Australian Building Code Board, 1998.

[3] AS1530.4—1997, "Methods for Fire Tests on Building Materials, Components and Structures Part 4: Fire-Resistance Tests of Elements of Building Construction", Standards Australia, 1997.

[4] National Fire Incident Reporting System, Federal Emergency Management Agency, "Fires in Offices", 1983-1991, USA.

[5] Pauls, J., "Movement of People", The SFPE Handbook of Fire Protection Engineering, 2nd Edition, Section 3/Chapter 13, 1995.

[6] AS1851, *Relevant Parts*, Standards Australia.

[7] Bennetts, I. D., Poh, K. W., and Thomas, I. R., "Economical Carparks—A Guide to Fire Safety", BHP Steel, Marketing—Construction and Engineering, March 1999.

[8] Bennetts, I. D., Thomas, I. R., and Lewins, R. R., "Capita Facade Fire Tests", BHP Melbourne Research Laboratories Report Number MRL/PS65/88/001, May 1998.

[9] Thomas, I. R., Bennetts, I. D., Dayawansa, P. H., Proe, D. J., and Lewins, R. R., "Fire Tests of the 140 William Street Office Building", BHP Melbourne Research Laboratories Report Number BHPR/ENG/R/92/043/SG2C, February 1992.

[10] Proe, D. J., and Bennetts, I. D., "Six Fire Tests in a Large Sprinklered-Protected Open-Plan Office", BHP Melbourne Research Laboratories Report Number BHPR/SM/R/010, May 1997.

[11] AS2118—1995, "Automatic Fire Sprinkler Systems", Standards Australia, 1995.

[12] Thomas, I. R., Bennetts, I. D., Proe, D. J., Lewins, R. R., and Almand, K. H., "Fire in Offices", BHP Melbourne Research Laboratories Report Number MRL/PS69/89/005, August 1989.

[13] Proe, D. J., and Bennetts, I. D., "Real Fire Test in 380 Collins Street Office Enclosure", BHP Melbourne Research Laboratories Report Number BHPR/PPA/R/94/051/SG021A, September 1994.

[14] Proe, D. J., and Bennetts, I. D., "Timber Crib Fire Test for Comparison of Ceiling Tiles", BHP Melbourne Research Laboratories Report Number BHPR/PPA/R/94/085/SG021A, October 1994.

[15] Kirby, B. R., "Large Scale Fire Tests: the British Steel European Collaborative Research Programme on the BRE 8-Storey Frame", Fire Safety Science—Proceedings of the Fifth International Symposium, March 1997.

[16] Meyer, J., "Fires in Department Stores over the Last few Decades", Journal des Sapeurs—Pompiers, No. 10, pp 255 - 259, 1967.

[17] "Toy Factory Fire in Thailand Kills 188 Workers", NFPA Journal, January/February 1994.

Acknowledgment

The authors wish to thank Mr N. Bowen of the Australian Building Codes Board for reviewing an early draft of the BCA requirements. The assistance of Mr D. Verghese in preparation of the publication is also gratefully acknowledged.

Appendix A:
Sprinklered Office Fire Tests

The ability of sprinklers to limit fire spread and growth is well understood. In the context of office buildings, tests have been conducted to study the efficacy of sprinklers in individual offices and open-plan areas. These tests are now described.

Four tests [8] were conducted in two nominally identical offices to look at the resulting fire size and its effect on an adjacent glass façade. The offices were directly adjacent to the façade, furnished as typical offices and having a plan dimensions of 3 m x 3 m. Two tests were conducted in each office. In three of the tests, fast response sprinkler heads were used, whereas in the fourth test, a normal response head was used. The fire in each test was started close to the glass façade in a waste paper basket located so as to spread fire to an adjacent desk chair. The ceiling height in the office was 2.7 m and the sprinkler pendants were mounted in the ceiling. The ceiling was a tiled mineral fibre system supported by a lightweight steel framing system. In all tests, the sprinklers activated within 30 - 180 seconds and the fire was rapidly extinguished. The temperature above the ceiling remained close to ambient.

View inside office prior to test

Ignition

General test layout

Fire just prior to the operation of the sprinkler

Extent of damage after Test

Tests 1 and 2 of the "140 William Street" fire tests [9] were conducted, respectively, in a small office and an open plan area. In these tests, normal response heads were provided at ceiling level. The ceiling consisted of plaster tiles supported by lightweight steel framing system. The sprinkler heads were spaced at an extra-light hazard spacing and the fires started in waste paper baskets directly adjacent to work stations. The arrangement of combustibles was designed to enhance the spread and growth of the fire. In Test 1, the fire developed until a sprinkler activated at 7 minutes at which time, the fire was rapidly extinguished. The smoke detector in the return air plenum, located some distance from the office, activated 40 seconds later.

Test 1 office set-up

Fire just prior to the operation of the sprinkler

Extent of damage after Test 1

In Test 2, four sprinkler heads activated after about 6 minutes and 18 seconds which was 40 seconds later than the time for activation of the smoke detector in the return air plenum. There was no measurable rise in temperature for the steel beams above the ceiling. The air temperature above the work stations reduced rapidly once the sprinklers activated, dropping to less than 50°C after about 60 seconds.

Test 2 open-plan area set-up

Fire just prior to the operation of the sprinkler

Extent of damage after Test 2

Six fire tests were conducted in an open-plan office set-up [10] to evaluate the response and suppression capability of sprinklers. Various sprinkler heads and ceiling mounted smoke detectors were tested as was the effect of water pressure and flow at the sprinkler head. The spacing of sprinkler heads corresponded to an extra-light hazard system such that in most tests there was 3.25 m from the ignition site to an active sprinkler head location. The smoke detectors were located at the same position as the sprinklers. The various set-ups were organised so as to maximise the effect of shielding and the pressure at the heads was controlled to correspond to the minimum pressure at a sprinkler head envisaged by AS2118 [11]. Despite the reduction of pressure to simulate conservative design assumptions regarding pressure, the sprinklers had no difficulty in containing the fire.

View of open-plan office set-up

In all cases the fire was rapidly extinguished above the desk resulting in a rapid drop of air temperature. Fast response sprinklers were found to operate significantly faster that normal response with a difference in activation time of about 3 mins for the situations tested. The air temperatures experienced in these tests would have resulted in a rise in temperature of the structural steel members above the ceiling of only several degrees.

Open-plan office area prior to test

Fire just prior to the operation of the sprinkler

Extent of damage after test

The above fire tests demonstrate that sprinklers are a very effective way of containing and reducing the severity of a growing fire. Rapid reduction of air temperatures occurs upon sprinkler activation even in situations where there is substantial shielding. Negligible rise in steel temperatures can be assumed for sprinklered fires.

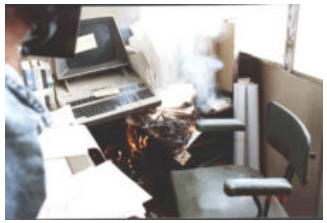
Appendix B:
Non-sprinklered Office Fires

The behaviour in fire of composite or concrete floors in combination with bare steel construction, has been studied experimentally using full-scale fire tests. Aspects of these tests are now described.

Office test structure

An office test was conducted in 1989 [12]. The office was 4 m x 4 m in plan and constructed above a carpark. The contents were estimated as giving a fire load density of 45 kg/m^2.

View inside office prior to test



Ignition of fire in office

The ceiling consisted of lightweight mineral fibre tiles supported by a steel framing system. The opening at the front of the enclosure was covered by clear plastic sheeting to simulate the presence of a window. The fire was started in a wastepaper basket and eventually spread to the adjacent stair and desk.

The fire built in intensity until after 25 minutes the plastic sheeting melted and the enclosure erupted in flames. The air temperatures reached 1100°C whilst the maximum steel beam (ESA/M = 29.3 m^2/tonne) temperature reached was 390°C.

Flames emerging from office

Interior of office after test

Tests 3 and 4 of the "140 William Street" fire test program [9] saw much larger scale tests conducted in a test structure simulating part of a floor of the building. This building was the subject of a refurbishment program and tests were undertaken to look at fire severity in non-sprinklered situations. The tested area was 12 m x 12 m and was occupied by representative office furniture with a fire load density of greater than 50 kg/m^2. A smoke detector was located in the return air duct and the air-handling system continued to operate until this smoke detector activated. A plaster tile ceiling was incorporated at a height of 2760 mm from the floor.

"140 William St" test structure

In the tests the air temperature varied substantially across the tested area. A temperature of 1200°C was momentarily obtained at one location but this dropped rapidly. The temperatures varied markedly throughout the enclosure at different stages of the test. In this regard it is interesting to note from video footage of the tests, that at one time during Test 4, flames gushed from one set of openings (where the windows had broken); but on the other side where the windows were still intact, there appeared to be no burning in the rear of the enclosure. The average cross-sectional temperature of the steel beam reached a maximum of 530°C well below the limiting temperature for a simply supported steel beam of about 600°C.

.

Fire through much of the building

Extent of material consumed after fire

Structure not damaged after test

The "140 William Street" tests were followed by another office test [13], this time conducted in an 8.35 m x 3.37 m enclosure which was glazed on two sides. Once again the ceiling consisted of suspended plaster tiles and steel beams (360UB45) were suspended above the ceiling (ESA/M = 26.6 m^2/tonne). The ceiling height was 2.7 m.

"380 Collins St" test structure

View inside office prior to test

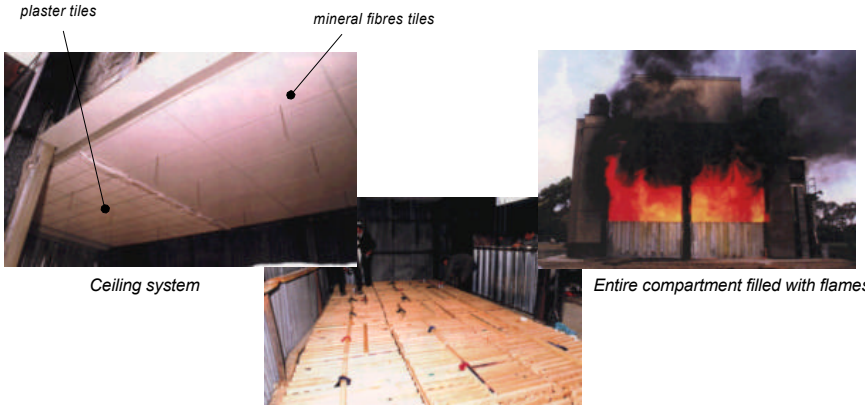
The test was started by initiating a fire in a waste paper basket with the door closed. The door had to be re-opened to keep the fire alight. At 12 minutes a window broke and at 13 minutes the door was shut for the last time. From 13 minutes the fire built steadily and more glass fell. At 30 minutes, a window on the other side of the enclosure broke and a rapid escalation of burning occurred.

At 36 minutes the fire severity dropped noticeably. The air temperatures varied considerably throughout the enclosure with gradients of more than 400°C. The maximum air temperature reached 1163°C whilst the steel beams reached just over 400°C and a column reached a temperature of just over 700°C. The ceiling offered some shielding for the steel beams.

Intense fire during test

Ceiling after test

A later test was conducted in the same test enclosure to look at the effect of ceilings [14]. In this case, two types of tiled ceilings were used: plaster tile and mineral fibre with each system occupying one half of the enclosure. For this test, short sections of 360UB45 and 530UB82 (ESA/M = 19.9 m^2/tonne) were positioned below the concrete slab. The combustibles were wood cribs and sufficient cribs were incorporated to give a fire load density of 46 kg/m^2. The front of the enclosure was open to the air and all of the cribs were ignited at once. Fire growth and development were therefore rapid (reaching 800°C inside 5 minutes). The air temperature peaked at 1000°C after 8 minutes but then began to decline to reach 400°C after a further 22 minutes. The maximum cross-section temperature reached 530°C after 17 minutes for the 530UB82 section whilst for the 360UB45 section, reached similar temperatures. The tiles fell out after about 11 minutes from the time of ignition.



Ceiling system

Entire compartment filled with flames

Timber cribs in place ready for test

An office fire test was conducted in the 8 storey building at Cardington in the United Kingdom [15]. The beams associated with this building were representative of those likely to be found in a typical office building (ESA/M = 24.2 - 37.3 m^2/tonne). The beams were composite with the floor slab. The columns in the fire storey were protected. The test enclosure measured 18 m width and 10 m depth and was fitted out with office furniture and wood cribs to give an average fire load density of 46 kg/m^2. No ceilings were present. The height of openings along the front of the enclosure was 2 m. The floors in the building were loaded to simulate the floor loading likely to be present in the event of a fire. The onset of extensive burning was achieved after about 10 minutes (there being no glass in the windows and fires being started simultaneously) and the fire burnt for more than 60 minutes with air temperatures reaching a maximum of 1150°C at one location. It is estimated that the maximum HRR reached 58 MW. Extensive floor deformation was noted but collapse did not occur.

Cardington fire test

Floor system after test

The temperatures achieved for individual steel beams indicated that failure would have occurred if these members had been tested as isolated members. The fact that this did not happen illustrates that the behaviour of a building structure in fire will often be significantly better than the behaviour of the most effected isolated member.

The above findings are reflected by observations made during major fires in bare steel-framed buildings. For example, in the case of the fire in the five storey L'Innovation retail complex in Belgium in 1967 [16], the fire was initiated on the second level which was constructed from bare steel construction as were other parts of the building. The spread of fire was rapid due to openings through the floors and the presence of combustible ceilings and the entire building complex was noted as being apparently "engulfed in flame" by the time that the fire brigade arrived. The building collapsed about two hours after arrival of the brigade.

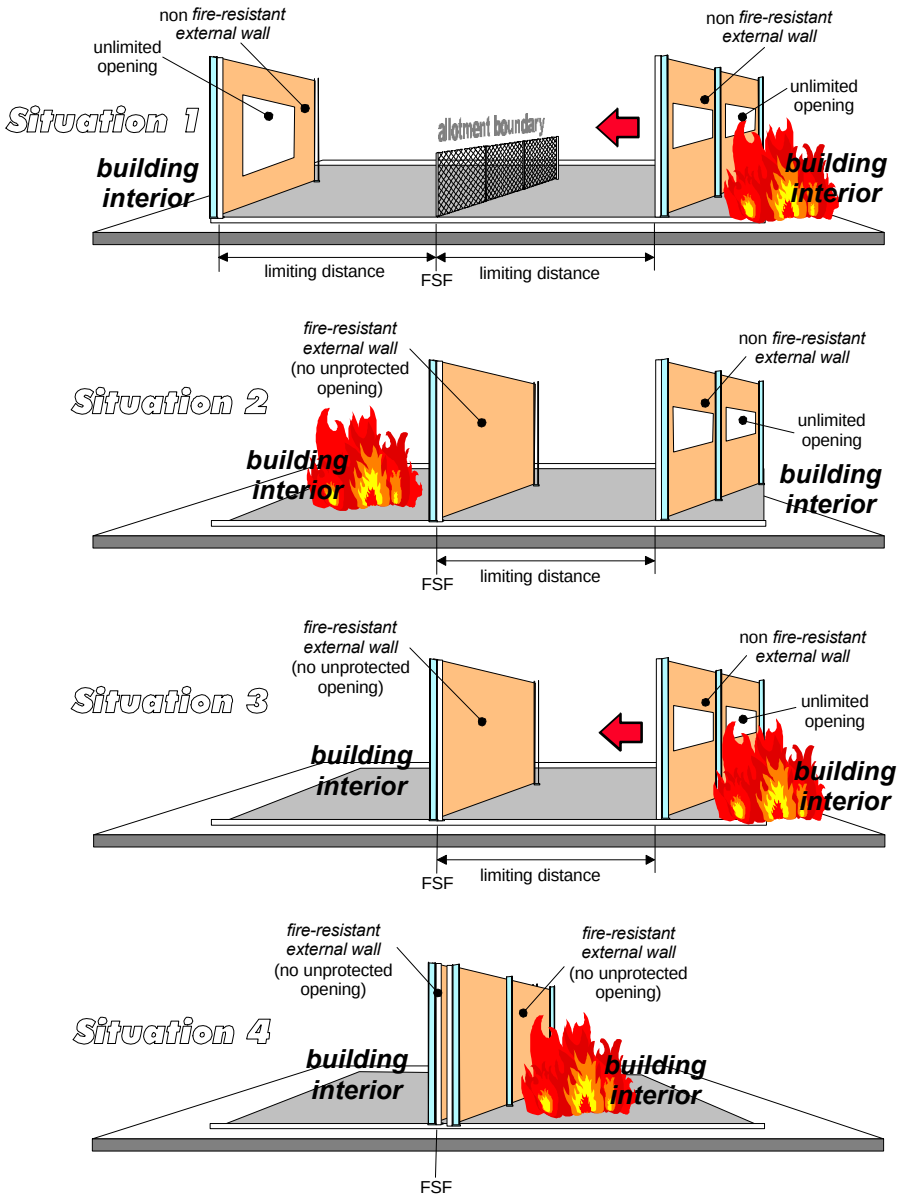
In 1993 a very serious fire destroyed a toy factory in Thailand [17]. This building was a four storey steel-framed construction with voids and open stairs connecting all levels. None of the steel members were fire protected. Being a toy factory the fire load level was very high (compared with office buildings) as was the potential for rapid fire spread. The plan area of each level of the building was 2275 m^2.

The fire in the building was extremely fierce. The fire started at 4:00pm on the first floor (i.e. the lowest floor) and was well and truly noted. Security guards were unsuccessful in extinguishing the fire. The brigade was called at 4:21pm with two more calls at 4:30pm. The first fire apparatus arrived at 4:40pm. It was at this point that the building (Building 1) was stated as showing sign of distress but collapse of the building did not occur until 5:14pm. The building hung together for more than 40 minutes from the time of ignition despite the presence of a fast spreading and intense fire.

The structural behaviour of buildings in fire is much better than that which might be expected for isolated members. Furthermore, a fire does not affect all parts of the level of a building at the one time. It is concluded that concrete or composite floors where supported by bare steel construction similar to that described above will offer levels of performance beyond that required for evacuation of the occupants. However, the protection of columns in the lower levels of the building is recommended in certain situations.

Appendix C:
Barriers to Fire Spread - Walls

Fire spread between building is mostly associated with radiation heat transfer. It follows that fire spread may be limited through provision of sufficient separation between buildings and/or *external wall* construction designed to resist heat radiation. Four limiting situations are now considered:



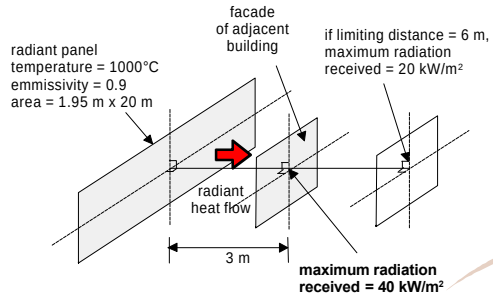
Situation 1 relies on having a sufficient spacing between buildings. What spacing is acceptable? The BCA *deemed-to-satisfy* provisions suggest that 6 m is an acceptable distance at which unrestricted openings in adjacent *external walls* are acceptable. This separation distance appears to be justified by the fact that lateral fire spread between buildings, in the event of a fire within one of the buildings, is a rare occurrence. This distance is therefore accepted as appropriate. It also corresponds to aspects of CV1 of the BCA which specifies a radiation of 20 kW/m² at a spacing of 6m between buildings, the latter value of radiation being commonly accepted as the value at which non-piloted ignition occurs.

Situation 2 relies on "containing" the fire sufficiently to prevent higher levels of radiation reaching the openings of the adjacent building. The *external wall* of the building of fire origin should be designed to resist the fire severity relevant to that building. It is not necessary for the wall barrier to remain vertical but only for it to block the majority of radiation.

Situation 3 relies on the combination of distance and the presence of a wall barrier at the receiving building. The wall is exposed to radiation from outside and will be supported by a structure that is not affected by the fire.

Situation 4 has one wall that "contains" the fire and another which "resists" any radiation. The internal fire situation will govern in the case of both walls as there will be little, if any, radiation from a fire in the adjacent building.

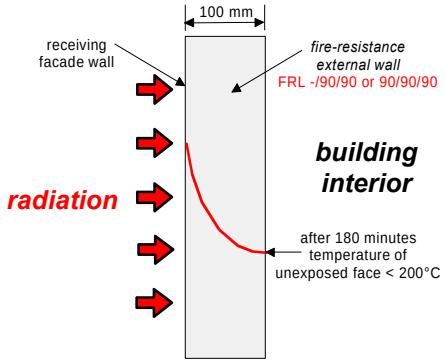
What level of FRL is appropriate?



Radiation heat transfer to adjacent building

It follows that an *external wall*, if within a limiting distance (taken as 3 m) from a *fire-source feature* must be designed to resist both an internal and an external fire. The resistance to an *internal* fire is achieved by specifying an FRL appropriate to the potential fire severity. This is commonly taken as 120/120/120. What level of *fire-resistance* is necessary to resist the radiation effects from an *external* fire?

The *required* level has been determined by considering a concrete wall with an FRL of 90/90/90 (100 mm in thickness) when exposed as in Situation 3 to the specified level of radiation (40 kW/m²) for a period of 180 minutes—this period being considered as a conservative upper limit for exposure time. Heat transfer analysis shows that the unexposed temperature of the wall will be less than 200°C after this time. It is concluded that an FRL of 90/90/90 is more than adequate with respect to exposure to external radiation.



Temperature across thickness of wall

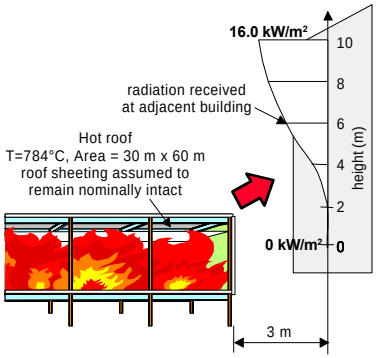
It follows that an FRL of 90/90/90 or -/90/90 for loadbearing and non-loadbearing external walls is appropriate to cover all possible adjacent building situations.

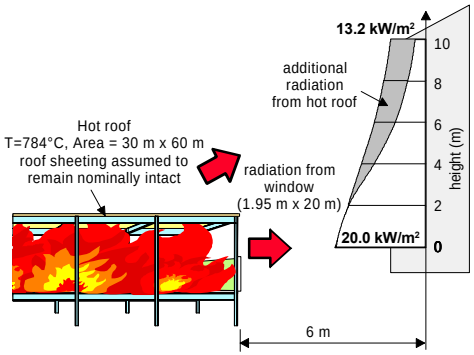
Appendix D:
Barriers to Fire Spread - Roof

Not only can fire spread due to the radiation from the vertical openings in an *external wall* of a building but also due to radiation from the roof. However, in this document, steel or concrete roofs only are considered, with the steel roofs designed so that they will essentially contain the flames. It will be demonstrated that such roof construction will not result in fire spread to adjacent buildings.

This situations have been analysed as shown below.

The first situation is where the building of fire origin is located at the *fire-source feature* and must therefore have an *external wall* with the appropriate FRL. No openings are permitted in this wall. The adjacent building is located 3 m from the *fire-source feature* and is therefore exposed essentially to radiation from the roof. The maximum radiation is 16 kW/m² which occurs 8 m above the roof assuming that there is no overhang and that the *external wall* does not extend beyond the top of the roof. If the wall extends above the roof this will further reduce the radiation. Note that the radiation level is less than 20 kW/m².





The second situation is where the building of fire origin and the adjacent building are both 3 m from the *fire-source feature*. Accordingly the *external walls* of both buildings are not required to be *fire resisting* and as a result radiation is emitted from both the *external wall* and the roof. The resultant radiation remains below the limiting value of 20 kW/m² which occurs directly adjacent to the wall opening.

The above levels of radiation are based on the assumption that the roof remains relatively intact.

This can be assumed to be the case provided the roof is of steel or concrete construction. In the case of a steel roof the sheeting must be screw fixed to supporting members.

steel roof after fire

It follows therefore, that subject to roof being of steel or concrete construction as required in this document, there is no justification for the roof to have a *fire-resistance level.*

Appendix E:
ESA/M of Steel Sections (m²/tonne)

BEAMS
(3-side exposure to fire)

welded-plate sections

section	ESA/M
1200WB455	8.51
423	9.10
392	9.79
342	10.4
317	11.1
278	12.1
249	12.6
1000WB322	10.0
296	10.8
258	11.8
215	13.4
900WB282	10.7
257	10.7
218	13.0
175	15.3
800WB192	13.1
168	14.5
146	16.5
122	18.9
700WB173	13.0
150	14.3
130	16.3
115	18.4

section	ESA/M
500WC440	5.41
414	5.78
383	6.21
340	7.30
290	8.51
267	9.22
228	10.7
400WC361	5.48
328	6.11
303	6.56
270	7.34
212	9.25
181	10.7
144	13.4
350WC280	6.08
258	6.54
230	7.30
197	8.49

hot-rolled sections

section	ESA/M
610UB125	14.9
113	16.3
101	18.1
530UB 92.4	17.8
82.0	19.9
460UB 82.1	17.7
74.6	19.4
67.1	21.4
410UB 59.7	21.9
53.7	24.1
360UB 56.7	21.1
50.7	23.4
44.7	26.3
310UB 46.2	23.2
40.4	26.2
250UB 37.3	24.7
31.4	29.0
200UB 29.8	26.3
180UB 22.2	27.1
150UB 18.0	28.3

section	ESA/M
310UC158	9.66
137	11.0
118	12.7
97	15.3
250UC 89.5	13.9
72.9	16.8
200UC 59.5	16.8
52.2	18.9
46.2	21.2
150UC 37.2	20.3
30.0	24.6

COLUMNS
(4-side exposure to fire)

welded-plate sections

section	ESA/M
1200WB455	9.61
423	10.3
392	11.1
342	11.5
317	12.4
278	13.3
249	13.7
1000WB322	11.2
296	12.1
258	13.1
215	14.8
900WB282	12.1
257	13.3
218	14.6
175	17.0
800WB192	14.7
168	16.1
146	18.4
122	20.9
700WB173	14.5
150	16.0
130	18.3
115	20.6

section	ESA/M
500WC440	6.55
414	6.99
383	7.52
340	8.77
290	10.2
267	11.1
228	12.9
400WC361	6.59
328	7.33
303	7.88
270	8.22
212	11.1
181	13.0
144	16.1
350WC280	7.33
258	7.89
230	8.82
197	10.3

hollow sections

section	ESA/M
457.0×12.7CHS	10.3
9.5CHS	13.7
6.4CHS	20.2
406.4×12.7CHS	10.4
9.5CHS	13.7
6.4CHS	20.2
355.6×12.7CHS	10.4
9.5CHS	13.8
6.4CHS	20.3
323.9×12.7CHS	10.4
9.5CHS	13.8
6.4CHS	20.3
273.1×9.3CHS	14.2
6.4CHS	20.4
4.8CHS	27.0
219.1×8.2CHS	16.1
6.4CHS	20.5
4.8CHS	27.1
168.3×7.1CHS	18.7
6.4CHS	20.7
4.8CHS	27.3
114.3×6CHS	22.4
4.8CHS	27.7
88.9×5.5CHS	24.7
4.8CHS	28.1

section	ESA/M
250×250×9.0SHS	14.6
6.0SHS	21.7
200×200×9.0SHS	14.7
6.0SHS	21.8
5.0SHS	26.0
150×150×9.0SHS	14.9
6.0SHS	22.0
5.0SHS	26.2
125×125×9.0SHS	15.1
6.0SHS	22.1
5.0SHS	26.3
100×100×9.0SHS	15.4
6.0SHS	22.4
5.0SHS	26.6
89×89×6.0SHS	22.5
5.0SHS	26.7
75×75×6.0SHS	22.8
5.0SHS	27.0

hot-rolled sections

section	ESA/M
610UB125	16.7
113	18.3
101	20.3
530UB 92.4	20.0
82.0	22.4
460UB 82.1	20.0
74.6	21.9
67.1	24.2
410UB 59.7	24.8
53.7	27.4
360UB 56.7	24.1
50.7	26.8
310UB 46.2	26.8
250UB 37.3	28.6

section	ESA/M
310UC158	11.6
137	13.3
118	15.3
96.8	18.4
250UC 89.5	16.8
72.9	20.3
200UC 59.5	20.2
52.2	22.8
46.2	25.6
150UC 37.2	24.4
30.0	29.7