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The Fire Safety Design of Apartment Buildings

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THE FIRE SAFETY DESIGN OF APARTMENT BUILDINGS

A research project report

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Abstract

In Australia and New Zealand, residential buildings have the highest number of fire fatalities each year, compared to any other occupancy type. The majority of these fatalities occur in single family dwellings, but a proportion of these fatalities occur in apartment buildings. Apartment building fires also have the potential to be high fatality fires, due to greater occupant numbers and more complex egress paths.

With the movement away from prescriptive building codes, building fire safety design can become more efficient and effective. This should ultimately result in equivalent or better fire safety for occupants, and economical savings with respect to the building codes.

The objective of this research report is to discuss the primary issues concerning apartment buildings and to provide a guidance matrix for the fire safety design of apartment buildings, that comprehensively integrates all aspects of fire safety. The fire safety design matrix is presented as a three by two matrix, which recommends minimum fire safety measures based on building height, sprinkler protection and the building emergency plan. The selection of fire safety measures is based on providing multiple levels of protection for the occupants, and addressing the primary characteristics of different apartment buildings.

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Nomenclature

ABCB – Australian Building Codes Board

AHJ – Authority Having Jurisdiction

ASET – Available Safe Egress Time

BCA – Building Code of Australia

BIA – Building Industry Authority (New Zealand)

BSI – British Standards Institution

CO – carbon monoxide

EWIS – Emergency Warning and Intercommunications System

FEG – Fire Engineering Guidelines (Australia)

FRR – Fire Resistance Rating

HVAC – Heating Ventilation and Air Conditioning

NFIRS – National Fire Incident Reporting System (United States)

NFPA – National Fire Protection Association (United States)

NZ – New Zealand

NZBC – New Zealand Building Code

NZFS – New Zealand Fire Service

RSET – Required Safe Egress Time

UK – United Kingdom

US – United States of America

A_f – area of fire cell floor (m^2)

A_h – area of horizontal openings in roof (m^2)

A_v – area of vertical windows and door openings (m^2)

c – specific heat (J/kgK)

e_f – fire load (MJ/m^2)

H – height of fire cell (m)

J – number of lifts

k_b – conversion factor ($min.m^{2.3}/MJ$)

m – number of round trips

t_a – time for lift evacuation start up (s)

t_e – equivalent fire severity

t_o – travel time from lift lobby to outside (s)

$t_{r,j}$ – time for round trip (s)

w_f – ventilation factor

α_h – horizontal opening area ratio (A_h/A_f)

α_v – vertical opening area ratio (A_v/A_f)

η – lift inefficiency

λ - thermal conductivity (W/mK)

ρ - density (kg/m^3)

1 INTRODUCTION

Each year, fires in residential buildings cause the greatest number of fatalities of any occupancy type. In the United States, over 80% of all fire deaths occur in residential occupancies, and approximately 20% of these fatalities occur in apartment buildings (FEMA et al, 1999). In Australia and New Zealand approximately 60% of fire deaths occur in residential buildings (King, 1997 and NZFS, 1999). In addition to fatalities in apartment buildings, occupants can also suffer injuries from heat and smoke during evacuation. Therefore by improving the fire safety of apartment buildings the number of injuries and fatalities can be reduced.

Fires in apartment buildings pose numerous challenges to fire engineers. The potential combinations of a large number of occupants, demographic diversity, numerous ignition sources, high fuel loads and sleeping occupants create several issues that can be difficult to resolve. These issues need to be reconciled with the building codes, fire safety design and cost constraints of the project.

The progression towards performance based building codes is resulting in the movement away from prescriptive code requirements, increasing the flexibility in apartment building fire safety design. This increased flexibility provides the opportunity to realise greater efficiencies and effectiveness in fire safety design.

The objective of this research report is to discuss the primary issues concerning apartment buildings, and to provide a guidance matrix for the fire safety design of apartment buildings that comprehensively integrates all aspects of fire safety. The fire safety design matrix is presented as a three by two matrix that considers building height, sprinkler protection and evacuation strategy as the primary variables. The matrix provides recommended fire safety measures in relation to these variables, resulting in a high level of fire protection for the occupants.

Figure 1 represents the eight primary elements of a fire safety strategy that should be considered in a fire-engineered design, and the inter-relationships between those elements. The emergency plan, building and egress characteristics, occupant characteristics, fire, fire safety systems and fire brigade intervention will all have a direct impact on the fire safety design of apartment buildings. The inter-relationship between elements also needs to be considered, as design trade-offs are possible and the interaction of elements can influence the effectiveness of the design.

The training and education aspect, of Figure 1, encompasses all of the elements. This is to represent the importance of occupant training and education in all areas of fire safety. It is important that occupants to know the options available to them, and the appropriate actions to take in a fire.

The inspection and maintenance aspect (see Figure 1) covers the building and egress characteristics and the fire safety systems. It is important that these elements are regularly checked to ensure reliability and that they function as designed.

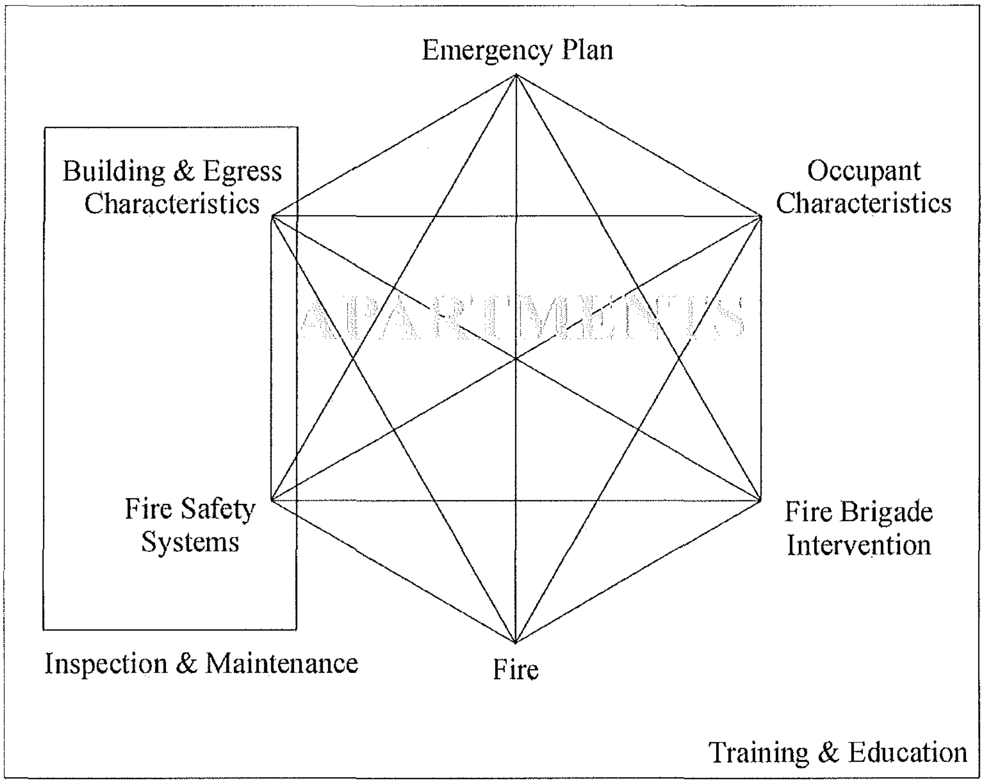


Figure 1 – Inter-relationship of fire safety elements

This research project will focus on the development of a fire safety design matrix and the discussion of the eight elements in Figure 1 for new apartment buildings. Each of the eight elements will be discussed, focusing on areas that are not extensively covered in the Australian and New Zealand building codes and standards.

1.1 Design Objectives

The performance requirements of the Building Code of Australian (BCA, 1996) and the Acceptable Solutions to the New Zealand Building Code (NZBC) (BIA, 1991) are concerned with the protection of life safety and adjacent properties. Secondary considerations are the protection of fire fighters and property protection.

This research project will focus on the life safety protection of building occupants. Property protection will not be considered unless it affects the life safety of the building occupants. The level of property protection in buildings is a matter for the building owner and their insurers and not a concern of the regulations (Beck et al, 1992).

The protection of fire fighters has been considered directly in the fire safety matrix if they are an important aspect of the design. Fire brigades are generally well equipped and trained to handle fires with the use of breathing apparatus, protective clothing and hose reels. Fire fighters also have experience and training, and they have the ability to decide when to enter a building and when to leave.

2 APARTMENT BUILDINGS

Apartment buildings are identified as structures containing three or more living units with independent cooking and bathroom facilities, whether designated as apartment houses, tenements, condominiums, or garden apartments (Bush, 1991). Apartments differ from multi-unit residential occupancies that are not considered homes (such as hostels and boarding homes), by the provision of individual cooking facilities, the number of sleeping rooms and the less transient nature of the occupants (Bush, 1991).

The BCA (ABCB, 1996) classifies apartments as Class 2 buildings, "A building containing two or more sole occupancy units each being a separate dwelling". Similar buildings can be classified as Class 3 buildings, but these differ to Class 2 buildings by having short-term residents.

The Acceptable Solutions to the NZBC (BIA, 1991), classify apartment buildings as Purpose Group SR. The SR purpose group includes "attached and multi-unit residential dwellings".

Essentially these definitions are generally the same, therefore apartment buildings will be defined as a structure containing self contained multi-unit residential units, with non-transient occupants.

Apartment buildings can also be attached to, or a part of, other building types, for example retail or office buildings. This research report will assume that apartments buildings are separate buildings by being either independent buildings or adequately fire separated. Therefore the inter-relationships between multiple classification buildings will not be considered.

2.1 Design Issues

A combination of several fire safety issues make apartment buildings unique compared to other buildings. Some of the main issues are sleeping occupants, numerous ignition sources, high fuel loads, demographic and cultural diversity, protection of escaping occupants and high populations.

One the main reasons for the high number of fatalities in residential buildings is sleeping occupants. When occupants are sleeping, there are problems in alerting them and motivating them to move. This can result in long pre-movement times or occupants not even attempting to evacuate.

In sleeping occupancies there is also the risk of smouldering fires. Smouldering fires can produce large amounts of carbon monoxide (CO), which is extremely toxic and can result in incapacitation in low doses.

Residential occupancies generally have numerous sources of ignition. For example: heaters, cigarettes, candles, cooking facilities, electrical appliances and electrical wiring. Residential units can also be untidy which can exacerbate the risk of ignition. Another source of ignition is children, who are known to play with matches and start fires.

High fuel loads from polyurethane furniture, plastics and other synthetic materials in modern residential buildings contribute to large fast growing fires. Fast growth fires reduce the time occupants have to evacuate safely and the time available for occupants to control or extinguish a fire.

Apartment buildings will also contain a broad range of demographic and cultural groups. This diversity can have an affect on the egress provisions and fire safety systems provided in the building. Some cultural groups regularly burn incense, which are a potential fire hazard. Occupant age is another factor that should be considered in building design. It is well known that young children and elderly occupants are at a high-risk (Tremblay, 1994, 1995).

In general, occupants in an apartment building will have similar socio-economic backgrounds. This is due to the property and rental value of the building governing occupant characteristics. Occupants in low socio-economic groups are also at higher risk of dying in fires (Tremblay, 1994). The main reasons for this are: unconventional heating, cooking and lighting methods (use of candles); apartment security measures (bars on windows preventing egress), buildings being over crowded and poor maintenance of the building (Tremblay, 1993 and 1994)

The protection of escaping occupants is another issue that needs to be considered in the design. Occupants should be protected in escape paths from fire and smoke, for the duration of the incident, to ensure the risk of injury and death is minimised.

High occupant load in apartment buildings is an issue, due to the potentially high number of fatalities that could occur in a fire. Large numbers of occupants can also result in longer escape times due to queuing and variable pre-movement times.

3 RESIDENTIAL FIRE STATISTICS

This section presents residential fire statistics for New Zealand, Australia and the United States. The statistics have been obtained from the latest available published data and they provide an indication of the trends in residential fires.

It is difficult to compare the statistics from the different countries directly. This is mainly due to different occupancy type definitions and different means of collecting the data. The statistics have only been used for a general comparison, and to provide an idea of the scale and relative importance of fires in apartment buildings.

3.1 New Zealand

Table 1 – New Zealand residential property fires

	1995/96	1996/97	1997/98	1998/99
Single house	5379	5617	7264	6427
1 or 2 units	274	324	286	227
2 or more units	275	353	371	345
Total	5928	6294	7921	6999
% fires in 1 and 2 or more units	9.3%	10.8%	8.3%	8.2%

(Table 4-4, 1995-1998 Emergency Incident Statistics (NZFS, 1999, 2000))

Table 2 – New Zealand fire fatalities

Property type	1995/96	1996/97	1997/98	1998/99
Health care and detention	0	6	1	1
Residential	25	35	29	25
Miscellaneous	7	11	17	16
Total	32	52	47	42
% residential	78%	67%	61%	60%

(Table 46, 1995-1998 Emergency Incident Statistics (NZFS, 1999, 2000))

3.2 Australia

Table 3 – Australian residential property fires

	1989-93*	1993-94
Structural fires	58, 793	19,181
Residential fires	35, 176	11,980
Apartment fires	5,606	1,547
% apartment fires of residential fires	15.9%	12.9%

(Australian National Fire Statistics 1993-1994 (King, 1997), *Dowling and Ramsay (1997) – Table 12)

Table 4 – Australian fire fatalities

	1989-93*	1993-94
Fatalities	-	124
Residential fatalities	244	64
Apartment fatalities	38	6
% residential	-	51.6%

(Australian National Fire Statistics 1993-1994 (King, 1997), *Dowling and Ramsay (1997) – Table 12)

Limited data was available on Australian building fires, and the latest published data was for 1993-94.

3.3 United States

Table 5 –United States residential property fires

	1993	1994	1995	1996
Residential fires	470,000	451,000	425,500	428,000
Apartment fires	100,000	97,000	94,000	93,000
Other residential fires	12,000	13,000	11,500	11,000
% apartment fires (excluding other residential)	22%	22%	23%	22%

(Figure 33, 57 and 65 – Fire in the United States 1987-1996 (FEMA, National Fire Data Centre and United Stated Fire Administration, 1999))

Note: "Residential Fires" includes homes, apartments, hotels, motels, residential hotels, dormitories and halfway houses. It does not include institutions (ie prisons, hospital, elderly homes and juvenile detention facilities and care facilities).

"Other Residential Fires" includes rooming houses, dormitories, halfway houses, motels, hotels and miscellaneous unclassified residential unclassified properties.

Table 6 – United States residential fires fatalities

	1993	1994	1995	1996
Residential fires	3,825	3,465	3,695	4,080
Apartment fires	685	640	605	565
Other residential fire	105	40	55	45
% apartment (excluding other residential)	18%	19%	17%	14%

(Figure 33, 57 and 65 – Fire in the United States 1987-1996 (FEMA, National Fire Data Centre and United Stated Fire Administration, 1999))

Table 7 – United States fire fatalities

	1993	1994	1995	1996
Fire deaths	4,635	4,275	4,585	4,990
Residential Fires	3,825	3,465	3,695	4,080
Other residential fires	105	40	55	45
% residential (excluding other residential)	80%	80%	79%	81%

(Figure 14, 33 and 65 – Fire in the United States 1987-1996 (FEMA, National Fire Data Centre and United Stated Fire Administration, 1999))

3.4 Discussion

The statistics in this section show the majority of fatal fires occur in residential properties. In the United States over 80% of all fire deaths occur in residential occupancies and approximately 20% of these fatalities occur in apartment buildings.

In Australia and New Zealand the percentage of deaths in residential properties is approximately 60% of fire deaths. Most of the fire fatalities occur in single family dwellings or homes and hence they are the highest risk group. The second highest risk residential group is apartment buildings. In New Zealand between 1991 and 1998, 85.7% (114/133) of residential fatal fires occurred in single family dwellings, 11.3% (15/133) of fatal fires occurred in apartment buildings and the remaining fatal fire occurred in temporary dwellings (Duncanson et al, 2000).

The high proportion of fire fatalities in residential buildings is an area of concern for fire engineers and general public. The number of deaths indicates that to reduce fire fatalities, more resources need to be allocated to residential property protection. The allocation of additional resources to fire protection will provide numerous, direct and indirect benefits to society.

Beever and Britton (1999) have estimated the costs per life saved, for various fire safety measures in Australian residential buildings.

- The cost per life saved for a sprinkler system installed and maintained to the Australian Standard is between $30 and $60 million
- The cost per life saved for a sprinkler system supplied by a domestic plumbing system is approximately $2 million
- The cost per life saved for battery powered smoke detectors installed in hallways will be less than the likely savings accrued through injury and property loss reductions. Therefore battery-powered smoke detectors are the most cost effective solution.
- Mains powered smoke detectors have a cost per life saved of approximately $350,000
- Introducing flammability legislation for upholstered furniture will have a cost per life saved of approximately $10 and $30 million

The total cost of fire protection in buildings in Australia is estimated at 0.72% of Gross Domestic Product (GDP) or $2 billion dollars each year (Beck et al, 1992). This includes direct (0.23% GDP) and indirect (0.03% GDP) fire losses, expenditure on fire fighting (0.20% GDP) and expenditure on fire protection (0.26% GDP) (Beck et al, 1992).

4 ARE CURRENT FIRE SAFETY MEASURES IN APARTMENT BUILDINGS ADEQUATE?

Fire safety in apartment buildings requires the protection of occupants in the apartment of fire origin, occupants escaping and occupants who remain in their apartments. The fire protection of these groups requires the consideration of different issues and fire safety measures.

Fire safety in apartment buildings is generally concerned with the life safety of the occupants outside the apartment of fire origin. This is predominantly due to the difficulties in protecting the occupants in the apartment of origin unless sprinkler protection is provided. If a fire occurs in an apartment the occupants will either be alerted by a detection device or by the fire. If the occupants do not leave the apartment, there is a possibility that they may become a fatality. Therefore, the most effective method of protecting occupants in the apartment of fire origin, if they do not evacuate or are unable to evacuate, is by a sprinkler system.

The obvious question that needs to be addressed is: are current fire safety measure adequate for the protection of occupants outside the apartment of fire origin?

4.1 Fatalities

To determine the effectiveness of current fire safety measures in apartment buildings, an analysis of fatalities and injuries in apartment buildings is required. Brennan (1999a) analysed US fire data to determine the proportion of fatalities that occurred in the room of origin or corridors. Brennan (1999a) concluded that the number of fatalities due to occupants escaping is small and the reason why this group receives so much attention is due to the media and the emotive response of people seeing occupants trapped as they are attempting to escape. The small proportion of fatalities occurring while occupants are escaping indicates the apartment of origin is the main concern and not escaping occupants. However, the analysis by Brennan (1999a) did not consider injuries and stress caused by occupants escaping in a fire.

The statistics for the location of the victims at fire ignition, from NFPA data for 1993-97, are; 74% were intimate with the fire, 20% were on the same floor and 6% were in other locations (Proulx, 2000). These statistics suggest that the occupants closest to the fire at ignition are at most risk. However, the location of the victims are unknown, therefore it is difficult to determine how many died in the unit of origin or in their attempt to escape.

Generally, fatalities in apartment buildings occur in the apartment or room of fire origin. Brennan's (1999a) analysis of US NFIRS (National Fire Incident Reporting System) fire statistics over a 10 year period (1983-1993 excluding 1986) found the number of fatalities outside the room of origin was approximately 308 people with a maximum of 478 (48 per year). The maximum value was estimated to include some proportion of the unknown category in data. The total number of fatalities in apartments was 3,126 people. Therefore it is estimated that 15% of the fatalities are due to occupants attempting to escape.

One of the problems with Brennan's (1999a) analysis is that the data does not specifically address fatalities outside the room of origin. Brennan (1999a) states the data could include occupants who are still in their apartment and have made a move to escape, and people who have escaped through unorthodox escape routes, such as windows. Due to accurate data not being available, Brennan (1999a) has had to make assumptions on the number of people being outside their apartments and attempting to escape. Even though assumptions have been made, Brennan (1999a) seems to have made a conservative assumption of the number occupants attempting to escape and it is possible that less than 478 fatalities occurred during the escape attempts.

The statistics also do not show whether occupants were escaping from a place of relative safety or because conditions in their unit were becoming untenable. If fatalities occurred while occupants were moving from a place of relative safety, then an argument could be made for the use of a non-evacuation strategy.

The catastrophic fire statistics, in the United States (see Appendix A), indicate that residential fires, where five or more fatalities occur, involve fatalities where occupants are escaping or attempting to escape.

4.2 Injuries

The number of injuries sustained during evacuation of apartment buildings is difficult to assess from the current statistics. The fire safety systems of an apartment building should not only protect the occupants from death, but also from injury. There have been numerous cases where occupants have escaped through heat and smoke resulting in injury. For example, in the 25-storey apartment fire in Ottawa, Canada all occupants above the fire floor who attempted to evacuate encountered smoke. Four evacuees suffered smoke inhalation and two people suffered heart attacks (Proulx, 1999).

The NFPA estimates that 19,300 people were injured in residential fires in 1996, and of these injuries 5,175 occurred in apartment buildings (Karter, 1997). In Australia, between 1989-1993, 2,165 fire injuries occurred in residential buildings (Dowling and Ramsay, 1997). However, the number of injuries due evacuation is not known.

Brennan (1999a) states that the problem of smoke in escape paths is not just the risk of death, but also injury. Injuries can be sustained as occupants evacuate through smoke and fire, by using unorthodox escape routes, poor escape route design and from poor lighting. As delays in evacuation occur, occupants have an increased risk of being exposed to the fire and fire products (Brennan, 1999a). Therefore, inadequate fire safety design can result in occupants evacuating through smoke filled corridors resulting in injuries.

4.3 Discussion

An assessment of whether current fire safety measures are adequate in apartment buildings requires the determination of what is an acceptable risk to life, and what is an acceptable number of fatalities and injuries in the event of a fire. Obviously, zero fatalities would be the most ideal situation, but currently this is unachievable and uneconomical.

In determining the number of fatalities that occur in the room of fire origin, or due to occupants attempting to escape, an important distinction needs to be made between whether occupants are escaping:

- Due to fire or fire products penetrating their unit (movement from danger) (Brennan, 1999a)
- From units in which conditions are currently not dangerous but are perceived to be dangerous or become dangerous (movement from potential danger) (Brennan, 1999a)
- From a unit in which conditions are not dangerous and are not likely to become dangerous (evacuation in response to emergency procedures) (Brennan, 1999a)

These distinctions are important, as they determine whether a fatality was primarily caused by the emergency procedures or due to other factors. If high proportions of apartment building fatalities are caused by the emergency procedures, then there is a strong argument for change, but if the fatalities are caused by other factors the emergency procedures may be adequate.

Brennan (1999a) believes that fatalities during egress is not a significant concern, but more an emotive reaction to scenes of people dying whilst attempting to escape, and very few fatalities actually occur in egress paths. However, it is argued that improved fire safety design and emergency strategies could reduce the number of fatalities and injuries in the event of a fire.

The difficulty in determining whether resource allocation to fire protection is adequate, is that it depends on the "value" of human life and the "acceptable" level of risk (Lo, 1995). In general, fire safety performance is based on a relative assessment against previous year's statistics. If the trend in the number of fatalities continues to decrease, society seems to accept this as being successful.

Another method of assessment is through bench marking. The New Zealand Fire Service (NZFS) evaluates its performance by bench marking target indicators, for example in the 1998-1999 Incident Investigation Summaries three key target goals were set for 2001. These were to decrease the number of house fires by 25%, reduce house fire fatalities by 50% and to reduce mean property loss by 30% (NZFS, 2000).

Society seems to accept the level of safety that current fire safety has provided (Beck et al, 1992). Therefore any "alternative designs" to the prescriptive requirements should at least maintain the present level of safety.

5 OCCUPANT CHARACTERISTICS

Occupants in apartment buildings consist of people from diverse cultural, socio-economic, educational, demographic and religious backgrounds. This diversity in backgrounds can result in different behaviours and actions in the event of a fire and different sources of ignition. For example some religious and cultural practices involve the lighting of incense.

In many cases apartment buildings will have occupants of similar income levels and socio-economic backgrounds, due to the similar rent and the apartment values. This could be an important risk factor, as it has been demonstrated that some socio-economic groups have a higher risk to dying in fires. For example, low-income groups have a relatively higher risk (Fahy and Tremblay, 1991).

In the design of apartment buildings consideration needs to be given for disabled occupants, young children and elderly people. In a fire, these people will be most at risk due to mobility limitations and they will be more likely to be injured or die (Proulx, 1995). In New Zealand between 1991 and 1996, 14.2% of residential fatalities were children under the age of 5 and 26.5% of fatalities were people over 65 years old (Duncanson et al, 2000). In the US the death rate of children under 5 is twice the national average and the death rate of people over 65 is three times the national average (Conley and Fahy, 1994).

In standard housing, in Canada, approximately 20% of the residents are people with some sort of movement, perception or cognitive limitations (Proulx 1995). In addition to this, 15.5% of the population has some sort of disability and in 1992, 11.8% of the population was over the age of 65 (Proulx et al, 1994).

Males are also more likely to be killed in a fire, with a death rate that is 40% higher than females (Conley and Fahy, 1994). The two main reasons for this are, males are more likely to participate in risky behaviour (ie fire fighting and rescue) and males are more likely to be under the influence of alcohol and drugs (Conley and Fahy, 1994).

In the timing of evacuation drills by Proulx and McQueen (1994), they found that gender, age and occupant limitations did not have a significant impact on the total evacuation time in non crowded buildings. Occupants who had limitations or were over 65 years of age and children between 2 and 5 years old, generally moved slower, but this did not have major impact on the evacuation time (Proulx and McQueen, 1994). Another finding by Proulx and

McQueen, (1994), is that, occupants tended to evacuate in groups and used the most central stairwell, located in their familiar path of travel to exit the building, or stairwell that led to a familiar area.

5.1 Occupant Location

In the event of a fire, occupants can be located in three general locations. Each of these locations will have different variables and issues that need to be designed for. The three possible occupant locations are:

(i) Occupants in the apartment of fire origin

(ii) Occupants on the floor of fire origin

(iii) Occupants remote from the floor of fire origin

Casualties in the compartment of fire origin are usually characterised by negligence and/or social problems (Proulx, 2000). Casualties in other locations are characterised by multiple system failures and/or victims attempting to evacuate (Proulx, 2000).

5.1.1 Occupants in the apartment of fire origin

Occupants in the unit of fire origin are in the highest risk group, and it is the location where most apartment fatalities occur (Brennan, 1999a). The characteristics and design issues that need to be considered for these occupants are:

- Occupants could be sleeping or under the influence of alcohol
- Occupants will most likely be alerted by the fire or a detection system
- Occupants are usually familiar with the building and exit routes
- If the occupants are not alerted, there is a high probability that they may not be able to escape (ie exits could be blocked or they could be overcome by smoke and toxic products).
- There can be a high fuel load in apartments
- There are numerous ignition sources in apartments

According to some estimates, at least 10% of all fire victims are under the influence of alcohol or other drugs, with 20-64 year olds being twice as impaired as the general population (Meacham, 1999). A 1970s study in Maryland (US) found that, 70% of the fire victims between the age of 30 and 60 were legally intoxicated (Meacham, 1999). Males are also more susceptible to being under the influence of drugs and dying in a fire. A study by Conley and Fahy (1994) has shown that 12.5% of male fatalities, and 4.8% female fatalities can be attributed to alcohol and drugs.

It is estimated that 50% of the fire victims in apartment buildings are located close to the fire (Hall, 1994). Therefore victims in apartment buildings may not have a chance to escape even if a smoke detectors are present (Hall, 1994).

5.1.2 Occupants on the floor of fire origin

The risk to occupants on the floor of fire origin depends primarily on two factors. Firstly whether the door to the apartment of fire origin is left open, and secondly the fire resistance rating between the apartments. The amount of smoke that enters the corridor depends heavily on whether the apartment doors are open or closed.

- If fire and smoke is confined to the apartment of origin then the corridors will remain tenable and occupants should have sufficient time to escape.
- If fire and smoke enters the escape paths then occupants on the fire floor are at risk of injury or death as they attempt to escape.
- If a fire occurs in the escape paths or common areas then the occupants would probably be exposed to fire and/or smoke as they escape.

Occupants may be alerted by a central alarm, other occupants, the fire brigade or other visual and audible fire cues.

5.1.3 Occupants remote from the floor of fire origin

Occupants below the fire floor are usually safe and will not be exposed to smoke or fire. The major potential hazard for these occupants is if mechanical systems are not properly designed and smoke can be circulated to lower floors.

Occupants above the fire floor are at risk from internal and external fire spread and smoke spread through the building. Smoke can spread via mechanical systems and vertical shafts in the building. If the door to the apartment of fire origin is closed then smoke spread will be limited.

The amount of smoke spread into exit paths will determine how long these occupants will have to evacuate. If a fire occurs in the escape paths then all occupants above the fire floor will be at risk. In the NFPA Catastrophic Fires (see Appendix A), arson fires in stair shafts have resulted in occupants being trapped and unable to escape.

Occupants remote from the fire floor may be alerted by the central alarm, other occupants, the fire brigade or other fire cues.

6 FIRE SAFETY MEASURES

This section will discuss some of the fire safety measures available to a fire engineer for the design of apartment buildings. This section focuses on the performance of the fire safety measure and areas that are not well covered in codes and standards.

6.1 Detection

The detection system's primary function is to detect a fire, activate the alarm and activate other fire safety measures. Smoke detectors and heat detectors are the most common detection systems installed in apartment buildings. Smoke detectors generally have a faster activation time and are an important device for alerting occupants in the event of smouldering and flaming fires.

Smoke detectors in residential properties are one of the most cost-effective fire protection measures available. Between 1986 and 1995, in US residential properties, the deaths per 100 fires were 0.57 and 1.04 with detectors present and without detectors present respectively (Aherns, 1998). Therefore smoke detectors reduced the risk of dying in a residential home fire by 45%. However, it should be noted that in apartment fires, smoke detectors only reduce the risk of dying by 14% (Aherns, 1998 and Hall, 1994). This could be attributed to higher occupant numbers, longer escape distances and alarms being ignored due to activation caused by another residents. In the US, the 8% of homes that do not have smoke detectors account for 50% of reported residential fires (Hall, 1994).

In a study of risk factors associated with residential fires, Runyan et al (1992) found that 77% of fatal fires and 50% of non fatal fires occurred in houses with no smoke detectors. The assessment of risk factors showed that smoke detectors were beneficial in almost every instance (Runyan et al, 1992).

The main problem with smoke detectors is nuisance alarms. Nuisance alarms are the primary cause of why smoke detectors are deactivated and why occupants do not automatically assume a fire, if a detector activates (Aherns, 1998). An NFPA survey found that when a smoke detector activated, only 7% of occupants first reaction was that there was a fire and they should get out (Aherns, 1998).

To eliminate nuisance alarms, smoke detectors need to be placed correctly, or photoelectric detectors should be used (Aherns, 1998). Another possibility is to use analogue detectors and adjust their sensitivity to suit the application.

In the event of a smouldering fire smoke detectors may be the only effective fire safety measure. Smouldering fires would not activate a sprinkler system and passive protection may be defeated by open doors.

There are numerous types of detection systems available for fire engineers to specify. The detection system in apartment buildings will generally have a combination of the following components: smoke detectors, heat detectors, sprinklers and manual call points.

Some guidelines for detectors are:

- Provide heat detectors in kitchens
- Avoid smoke detectors near bathrooms and kitchens
- Provide smoke detectors in bedrooms
- Provide hardwired detectors in apartments linked to local alarms
- Provide hardwired detectors in corridors linked to alarms in apartments and alarms in general areas
- Provide local alarms in apartments

Current analogue addressable detection systems can provide numerous advantages over a conventional system. However, these advantages need to be assessed with the cost of the system. Some of the advantages of an analogue addressable system are:

- Individual detectors can be identified
- The status of the detectors can be identified
- The detector sensitivity can be set and adjusted
- Heat and smoke detectors can be interchanged with some systems
- The location of the activated detectors can be identified at the panel

The estimated reliability of smoke detectors in residential buildings is 77.8% and the estimated reliability in apartment buildings is 69.3% (Bukowski et al 1999).

Manual call points can provide a back up to the automatic detection system in apartment buildings. Manual call points should be located near the exits of the building or at the entrance of protected escape paths so occupants can activate them as they exit the building. The location of manual call points is usually provided in the relevant standards.

6.2 Alarm System

The objective of the alarm system is to alert occupants in the event of a fire. The alarm could be could be a simple system involving bells or sounders or it could be a more complex emergency warning and intercommunications system (EWIS).

Proulx and Fahy (1997) found that an alarm in itself is not an informative indication of a fire and occupants will tend to ignore or deny the signal. On hearing an alarm, occupants will not move immediately, but will investigate why the alarm activated. The study by Proulx and Fahy (1997) found that an alarm with good audibility significantly reduces the time delay to start evacuation. A separate study by Proulx et al (1994), again found the time to start evacuation is highly dependent on the ability of occupants to hear the alarm. The decision to evacuate will also depend on the occupant's familiarity with the alarm (Meacham, 1999). Without drills or training, occupants will not be familiar with the alarm.

The audible warning system should have a sound pressure level that exceeds the maximum background sound level by a minimum of 5dBA (Bukowski, 1996). The sound pressure should not be less than 60dBA and not more than 100dBA. In buildings providing accommodation the minimum sound should be 70-75dBA at the bed head (Meacham, 1999).

Alarms placed inside apartments are more efficient to alert occupants of a fire, as opposed to an alarm in the corridors or stairs (Proulx, 1995). This conclusion further reinforced by Sultan and Halliwell (1990) who studied sound levels in apartment buildings and concluded that for alarms to be effective they need to be installed in the apartments. To achieve a 75dBA at the bed head and not exceed 100dBA in other areas, alarms need to be placed in apartment units (Sultan and Halliwell, 1990).

In a study on whether sleeping occupants are alerted by a 60dBA sound pressure level, Bruck and Horasan (1995) found 87% of people were awoken by smoke alarms, awoke within one minute of initiation of the smoke alarm. In addition to this, 20% of all subjects did not wake up to the sound of the smoke alarm. A further study by Bruck (1998) found that children (6-17 yrs old) are unlikely to be alerted by an alarm and 85% of the sample children did not reliably awaken.

A study by Brennan (1999) of 150 fatal fires found, three quarters of those asleep and half of those awake did not move from the room in which they were originally located. Brennan (1999) suggests that the people asleep succumbed to the products of fire without waking or before they could take action. One of the main conclusions by Brennan (1999) is that many fatalities could have been avoided if occupants received an early warning from the detection and alarm system.

In the study by Proulx (1995) of evacuation drills, 25% of occupants could not hear the alarm located in the corridor. This resulted in delays in evacuation and occupants beginning their evacuation when the fire brigade knocked on their door. In addition to this, Proulx (1995) concluded that in some cases alarms placed in corridors or stairs can be counter productive as it prevents the exchange of verbal information, and mobility impaired people in lobbies, have to endure the alarm.

Occupant reaction to an alarm system is a function of the alarm type. Proulx and Sime (1991) found that the most effective alarm system was a directive alarm (public address system) or a directive alarm with staff assistance. The most ineffective system is an alarm with bells only (Canter, 1990). When occupants hear alarm bells, without any further instructions, they wait for further information before evacuating, resulting in delayed evacuation. The conclusion of Proulx and Sime (1991) is that greater evacuation efficiency can be achieved if occupants are provided with an informative alarm system.

Another example of the ineffectiveness of uninformative alarms was in the 25-storey, 296 unit, high-rise apartment fire in Ottawa, Canada. In this fire only 4% of the occupants initiated evacuation based on the building alarm (Proulx, 1998). This fire again showed that occupants treat the sounding of alarms as a signal to wait for further information and not to evacuate (Proulx, 1998).

The nature of the information provided to occupants is also important. The information needs to be clear, simple, consistent and from a reliable source (Proulx and Sime, 1991). This will ensure occupants have confidence in the system and react as instructed. Clear, up to date, accurate information can reduce the time for occupants to authenticate the situation and make decisions (Saunders, 1997).

Complicated or unique emergency strategies may require an Emergency Warning and Intercommunication System (EWIS). This will enhance the effectiveness of the alarm system and reduce the chance of confusion.

A potential problem for alarm system is occupants who have hearing impairments. If occupants cannot hear the alarm or instructions, they probably will not react in accordance with the emergency procedures or instructions and be put at risk. In this situation, the safety of occupants can be enhanced by: having other occupants provide assistance, installing alarm lights in apartments and through education and training, to ensure the occupant knows how to react if they see smoke or fire.

6.3 Sprinkler Protection

Sprinkler protection in apartment buildings has an exemplary record in Australia and New Zealand. Between 1886 and 1986 there have been no fatalities in sprinkler protected apartment buildings (Marryatt, 1988). In the US there have been some fatalities in sprinkler protected apartment buildings, but the level of life safety provided by sprinklers are well in excess of any other active fire safety measure. A properly installed sprinkler system is the most effective device for protecting and safeguarding against loss of life and property (Cote, 1997).

Table 8 – Fatalities in sprinkler protected apartment buildings US 1996

Sprinkler Protected Apartments	1994 US	1996 US	Australia and NZ (1886-1986)
Fires	2,222	2,258	33
Deaths	4	3	0

(Figure 61 – Fire in the United States 1987-1996, Figure 62 – FEMA et al, 1999 and Marryatt, 1988)

The conclusion that can be drawn from the above figures is that sprinklers are extremely effective. In the US, Australia and New Zealand the fatalities in sprinkler protected apartment buildings are minimal, and can be considered to be almost 100% effective. In fully sprinkler protected residential buildings the NFPA has no record of a fire killing more than two people (Hall, 1993). Hall (1993) estimates that a sprinkler protection reduces property loss in apartment buildings by 40% and the chance of death in a fire by 55%. The combination of sprinklers and smoke detectors in homes will reduce the chance of death in a fire by approximately 82% (Hall, 1993).

Marryatt (1998) has quoted sprinklers as being 99.5% reliable, however this applies to occupancies where inspection, maintenance and testing activities were well documented. The study by Bukowski et al (1999), found that the overall reliability of sprinklers is approximately 94.6%. Based on a 1959 study, Bukowski et al (1999) estimate the reliability of residential sprinklers to be 96.6%. However, this value is based on limited residential sprinkler data that may not apply to contemporary sprinkler systems.

Some of the concerns in estimating the reliability of residential sprinklers are: permitted area coverage, poor water supplies, no remote alarm and low levels of maintenance (Bukowski et al, 1999). These concerns are more applicable to single family dwellings and not necessarily apartment buildings. Sprinkler systems installed in residential buildings to the Australian and New Zealand Standards have to meet the coverage, water supply and maintenance requirements of the Standard.

Sprinkler protection will not necessarily eliminate all fire fatalities and certain types of fires are likely to produce casualties. For example people intimate with the fire (ie people close to the fire), smouldering fires and fast flaming fire in non-sprinkler protected areas could still result in casualties (Hall, 1993).

The Building Code of Australia's prescriptive requirements, specifies sprinkler protection for all apartment buildings with an effective height greater then 25m (ABCB, 1996). The 25m height is partly based on the fire brigade's ability to rescue occupants externally using ladders. Therefore, as the ability of the fire brigade to rescue occupants is limited, an increase in the level of fire protection is required, thus sprinklers are specified.

The Acceptable Solutions to the NZBC (BIA, 1991) require sprinkler protection in SR Purpose Group buildings greater than 34m. For intermediate floors different requirements apply.

6.4 Smoke Control

Smoke control in buildings can be in the form of dilution (smoke extraction), airflow, pressurisation, buoyancy and compartmentation (Klote and Milke, 1992). Depending on the building characteristics and architectural features of the building, any of these systems, or a combination of these systems, can be used to control smoke in the event of a fire.

The Building Code of Australia's (ABCB, 1996) prescriptive requirements specify fire isolated exits in apartment buildings greater than 25m to be pressurised. The Acceptable Solutions to the NZBC (BIA, 1991) only require smoke control in apartment buildings (SR purpose group) when intermediate floors are present.

The most common forms of smoke control in apartment buildings are pressurisation of corridors and/or stair shaft.

A study of smoke control reliability by Zhao (1998) found:

- Zoned smoke control systems have a reliability of between 52% and 62% for a building between 5 and 20 storeys.
- The reliability of a stair pressurisation system is approximately 90%

Zhao (1998) determined the reliability for stair pressurisation and zoned smoke control systems from a fault tree analysis. Two conclusions from Zhao's (1998) study are that maintenance has a significant influence on the reliability of the system and dampers are the most unreliable component of the system. To improve the reliability of the system, the most effective solutions would be to decrease the maintenance period and/or install dampers with greater reliability.

In the Carlyle Apartment fire (Taylor, 1975), a fire in one of the apartments burnt out the apartment and the door to the corridor. Due to the corridor being effectively pressurised, the effects of fire and smoke into the corridor were minimised. The corridor pressurisation was stated to be so effective that occupants were able to walk past the apartment and observe what was burning inside. From this fire, and further experiments, Taylor (1975) concluded that:

- Positive pressurised corridors, using a "make up" air system, can contain a fire within a unit if:
    - The system is properly balanced and
    - The fire occurs above the neutral plane
- With pressurised corridors the following are essential:
    - Stairwells should be at a higher pressure than corridors
    - Corridor construction should be non-combustible
    - Exhaust system should be non-combustible
    - All access doors to corridors should have self-closers
    - Each fire compartment should have exterior windows and vents

In this study, Taylor (1975) also believes that "sprinklers would be of dubious value in a properly pressurised corridor".

7 FIRE BRIGADE INTERVENTION

In most fire engineered buildings, intervention of the fire brigade is not usually considered. The fire brigade provides the last line of attack on a fire, and usually the last opportunity to find and rescue occupants. The intervention of the fire brigade is highly dependent on them receiving an alarm or notification of a fire.

The role of the fire brigade is important in an apartment fire as they can:

- Fight, suppress and extinguish the fire
- Perform search and rescue operations
- Externally rescue occupants
- Control evacuation via the EWIS system or lifts
- Perform first aid
- Reassure occupants

For the fire brigade to perform their jobs properly they require:

- Adequate site access
- Adequate water supplies
- Suitably located fire system control centres and indicator panels
- Controls for lifts
- Protection from structural failure for an appropriate length of time

The Australian and New Zealand building codes and standards provide design criteria for the above requirements. Successful fire brigade intervention can be achieved with pre-planning, early alarm, rapid response and the provision of sufficient labour and equipment to deal with the hazard (Beck et al, 1992).

The time for the fire brigade to arrive and extinguish the fire is influenced by the following components:

- Time to detection of fire. Either by automatic systems or people (Buchanan, 1996).
- Time to notification of fire brigade (Buchanan, 1996).
- Fire brigade travel time (Buchanan, 1996).
- Access and search time for all floors (Buchanan, 1996).
- Fire brigade setup time
- Fire attack time (Buchanan, 1996).

The Fire Engineering Guidelines (FCRC, 1996) contains a "Fire Brigade Communication and Response" model which provides guidance on assessing the response of the fire brigade. The following fire brigade times are 95th percentile times taken from the FEG (FCRC, 1996).

Table 9 – Times for fire brigade arrival and set up

	Time (minutes)	
Environment	Arrival	Set up
City	10	20
Country	20	15

In a non-evacuation strategy, the fire brigade maybe relied upon to suppress and extinguish the fire. Therefore notification and arrival times are crucial.

The arrival of the fire brigade may also be crucial in an emergency strategy where they are required to communicate with the occupants or assist the evacuation. If communication with occupants is vital to the emergency strategy, appropriately trained wardens should take charge prior to the arrival of the fire brigade.

The intervention of the fire brigade needs to be negotiated with the approval authority or Authority Having Jurisdiction (AHJ) and fire brigade. The times for intervention need to be agreed upon by all relevant stakeholders.

The activities of the fire brigade can be aided through sensible designs and architecture. For example, location of hydrants, hose reels and fire indicator panels should be designed such that they assist the operations of the fire brigade.

Some of the problems faced by the fire brigade during a fire are: fighting the fire whilst assisting the evacuation, access to the fire floor being restricted with evacuating occupants and reduced effectiveness due to fatigue after climbing stairs.

8 BUILDING AND EGRESS CHARACTERISTICS

The building and egress characteristics are two of the most influential variables on the evacuation strategy and fire safety measures provided in a building. The primary building and egress characteristics that influence the fire safety design are:

- Building height
- Number of exits
- Exit widths
- Egress distance
- Building construction and passive protection
- Refuge floors and/or refuge areas
- Lifts

8.1 Building Height

In Australia and New Zealand the building height is major determinant of the fire safety systems. When buildings are greater than 25m in effective height, there is a significant increase in the prescriptive requirements specified by the Building Code of Australia.

The 25m building height limit is partly based on the limits of ladder access, and the ability of the fire brigade to rescue occupants and fight the fire externally. In Australian buildings greater than 25m, the prescriptive requirements require the buildings to be sprinkler protected and to have pressurised escape paths.

The fire safety matrix presented in this report considers three building heights, with the height limits being based on the BCA and the Acceptable Solutions to the NZBC. It should be noted that the guidelines presented in the matrix do not strictly apply to these limits, and it is the responsibility of the fire engineer and approval authority to determine if an adequate level of safety has been achieved.

The building height limits that have been considered are:

- Buildings less than 3 storeys. These buildings are characterised by unprotected escape paths and travel distances generally meeting code requirements. The buildings have short travel distances and external rescue is generally possible.
- Buildings greater than 3 storeys, less than 25m high. These buildings are characterised by having protected stairs, lifts and external rescue being possible
- Buildings greater than 25m high. These buildings are characterised by having protected stairs, lifts, relatively long travel distances and limited external rescue options.

8.2 Number of Exits, Exit Width and Egress Distance

The Building Code of Australia and the Acceptable Solutions to the NZBC comprehensively cover the number of exits, minimum exit widths and maximum egress distances for apartment buildings. If the egress characteristics of a building are not fire engineered from first principles, then it is recommended that the code requirements be used as default values.

The following is a summary of the Building Code of Australia (ABCB, 1996) and the Acceptable Solutions to the NZBC (BIA, 1991) requirements. The summary applies to Class 2 buildings (BCA) and SR Purpose Group buildings (Acceptable Solutions to NZBC).

8.2.1 Acceptable Solutions to NZBC

Prescriptive egress requirements for SR purpose groups.

Table 10 – Number of escape routes

	Minimum number of escape routes
Up to 100 beds	2
Over 100 beds	2 plus 1 for every 100 beds, or part thereof over 100.

(Table 1 – Acceptable Solutions C2/AS1)

Table 11 – Width of escape routes

	Minimum width	
	Horizontal travel	Vertical travel
Based on activity	850 mm	1000 mm
Based on occupant load	7 mm/person	9 mm/person

(Table 2 – Acceptable Solutions C2/AS1)

Table 12 – Egress distance

Dead end open path	Total open path	Protected path
24m	60m	60m

(Table 3 – Acceptable Solutions C2/AS1)

The Acceptable Solutions to the NZBC maximum egress distances are for SR purpose groups. The open path distance is calculated from the furthermost point inside the apartment. Open path lengths and horizontal safe path lengths can be increased by:

- 15% where heat detectors are installed
- 50% where sprinklers are installed
- 100% where smoke detectors are installed
- 100% where the occupant density does not exceed 0.05 people/m^2

8.2.2 Building Code of Australia

The clauses for the number of exits, exit-travel distances and the dimensions of exit paths, extracted from the BCA, are located in Appendix B.

In summary:

- All buildings require at least one exit. Buildings over 25m high require two exits. The maximum allowable exit travel distance may govern the number of exits.

- The maximum travel distance from a sole-occupancy unit is 6m, to a point where travel in different directions to two exits is available. The maximum distance between alternative exits is 45m.

- The minimum width of an exit is 1.0m or 1.8m in a passageway. The minimum width of the exit increases when occupant numbers are in excess of 100 on a storey.

8.3 Building Construction and Passive Protection

All apartment buildings will have a fire resistance rating for building structure and fire barriers. This fire resistance can either be determined from the relevant Building Code or through a fire engineering analysis.

Passive protection is one of the most important elements in the prevention of fire spread and limiting fire size. By breaking up the building into vertical and horizontal compartments, the fuel is broken down into smaller units that will reduce the potential fire size. Passive protection is also essential in preventing and limiting smoke spread through the building.

In the context of this report, the main objective for passive protection is to limit the fire and smoke to the apartment of fire origin or at least the floor of fire origin. This will reduce the threat to other occupants in the building, and provide enough time for them escape, or for the fire brigade to suppress the fire.

The compartment and structural fire resistance rating of an apartment can be determined from the time equivalence formula. By using this method, an apartment should be designed to contain a fire until complete burn out. This should therefore ensure the fire does not spread beyond the apartment of origin.

Eurocode (1993) time equivalence formula (taken from Buchanan, 1994):

$t_e = e_f \, k_b \, w_f$ (equation 1)

t_e = equivalent fire severity

e_f = fire load (MJ/m^2) ~ 300-500 MJ/m^2 for apartments (Buchanan, 1996)

k_b = conversion factor ($min.m^{2.3}/MJ$)

w_f = ventilation factor

Table 13 - k_b values

$(\lambda\rho c)^{1/2}$ [$J/m^2Ks^{1/2}$]	Typical construction	k_b [min $m^{2.3}$ /MJ]
< 720	Insulating material	0.090
720 to 2500	Concrete or Plasterboard	0.055
> 2500	Thin steel	0.045

λ - Thermal conductivity (W/mK)

ρ - Density (kg/m^3)

c – Specific heat (J/kgK)

Ventilation Factor

$$w_f = \left(\frac{6.0}{H}\right)^{0.3}\left[0.62 + \frac{90(0.4-\alpha_v)^4}{1+b_v\alpha_h}\right] > 0.5$$ (equation 2)

$$\alpha_v = A_v / A_f$$ (equation 3)

$$\alpha_h = A_h / A_f$$ (equation 4)

$$b_v = 12.5(1+10\alpha_v - \alpha_v^2)$$ (equation 5)

A_v – area of vertical windows and door openings (m^2)

A_f – area of firecell floor (m^2)

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

H – height of fire cell (m)

Fire separation and compartmentation relies on doors, walls, floors, ceilings, glazing, smoke dampers and construction units (Bukowski et al, 1999). For effective passive protection these factors need to be inspected, tested and maintained regularly. It is recommended that self-closers be used on doors that open into common areas, to prevent fire and smoke spread from apartments to common areas or escape paths.

There is very little literature on the reliability of passive protection (Bukowski et al, 1999). A survey of experts has estimated the reliability of passive protection to be 95% for construction with no openings, and 90% for construction with openings and with self-closers (FCRC, 1996). Similarly, a Delphi group study in the UK estimated the reliability of masonry and gypsum construction to have a reliability of 81% and 69% respectively (Bukowski et al, 1999).

The fire safety matrix makes a distinction between low and high passive protection. This distinction is used to demonstrate different relative levels of safety between an occupant in an adjacent apartment and one who is in a corridor. If an occupant is in a corridor, at a minimum, they will have one wall and one door (assuming it is closed or has a self-closer) separating them from the fire. If the occupant remains in their room they will have two walls and two doors (assuming it is closed or has a self-closer) separating them from the fire and hence a higher level of protection. The door from the apartment of fire origin door could be either open or closed, which increases the risk to occupants in the corridor and hence the term low protection is used.

8.4 Stair Requirements

In an emergency, the primary means of egress in multi-storey occupancies are stairs. Different building codes have different requirements for the number of stairs and the width of stairs (Refer Section 8.2 and Appendix B).

The Building Code of Australia (ABCB, 1996) requires apartment buildings (Class 3) to have at least one exit from every storey and two exits where the building exceeds 25m. However, the maximum travel distances from the door of an apartment permitted by the prescriptive requirements are:

- 6m to an exit, or a point from which travel in different directions to two exits is available, or
- 20m from a single exit serving the storey at the level of egress to a road or open space.

Therefore, even though two exits are required in apartment buildings greater than 25m high, in many cases to meet travel distances specified by the BCA, two stairs will be necessary.

The minimum number of exits, in the Acceptable Solutions to the NZBC (BIA, 1991), are based on the number of beds (ie the occupant load) in the apartment building. For apartments with less than 100 beds two exits are required. For apartments with over 100 beds two exits are required, plus an additional exit for every 100 beds or part thereof greater than 100.

The objective of two stairs is to provide an alternative means of egress if one exit is blocked. Having multiple stair shafts can also reduce egress distances and allow occupants to change egress routes depending on the conditions.

The three main factors building codes use to determine if two or more stairs are required, are the number of occupants, the number of floors and the characteristics of the occupants. Some of the additional areas that should be considered in determining the stair requirements are:

- Fire brigade utilisation and rescue operations
- Sprinkler protection
- Fire resistance rating of exit paths
- Smoke control systems in the exit paths
- Emergency plan

To determine the relative effectiveness of a single stair, Hagiwara et al (1997) have proposed a probabilistic model based on the expected number of occupants unable to escape. The model provides a basis for evaluating a single stair against the building code based on:

- The probability of a fire occurrence in the room
- The probability the fire develops into a hazardous fire
- The probability the door is left open
- The efficiency of rescue by the fire brigade
- The degree of protection of the escape route

Single stair buildings are permitted in the UK provided certain conditions are met. Clause 3.18 of Approved Document B (Department of the Environment, Transport and the Regions, 2000) states:

3.18 Every dwelling should have access to alternative escape routes so that a person confronted by the effects of an outbreak of fire in another dwelling can turn away from it and make safe escape.

However, a single escape route from dwelling entrance door is acceptable if either:

(a) the dwelling is separated from the common stair and:

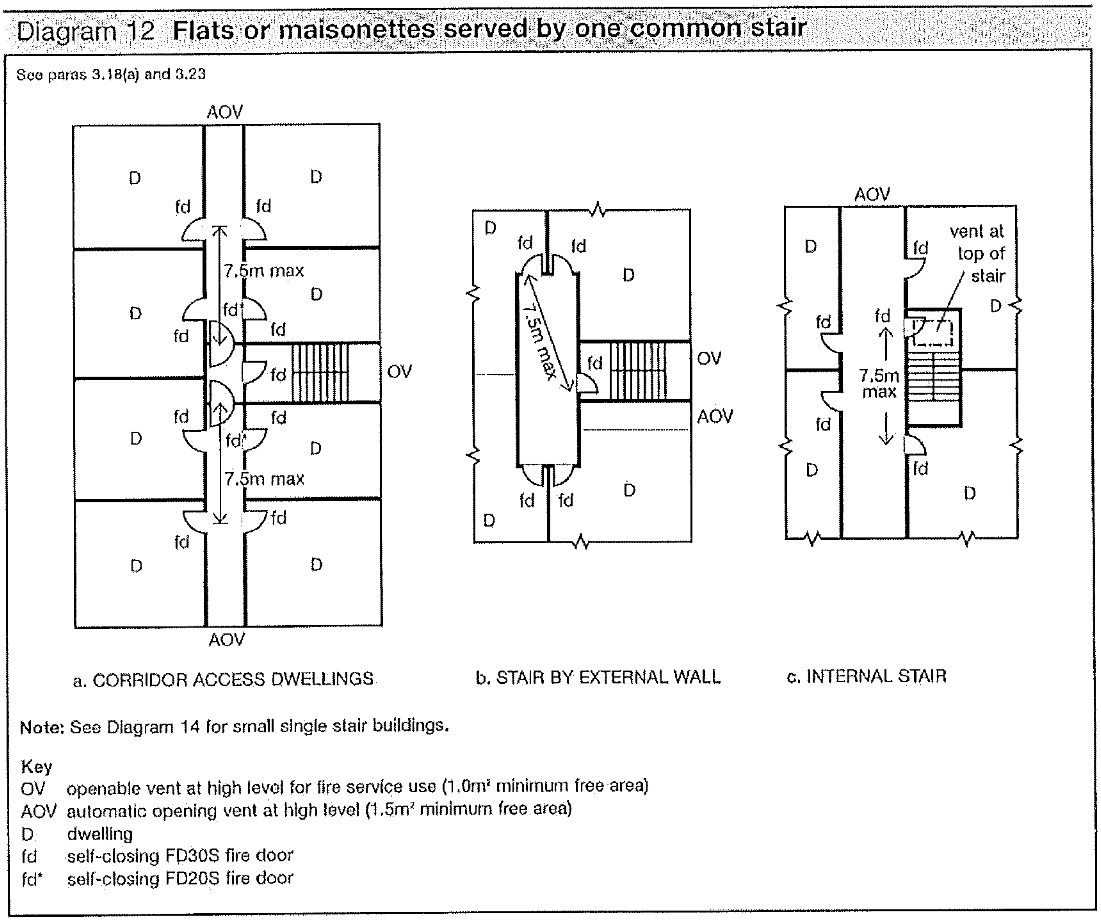
(i) every dwelling is separated from the common stair by a protected lobby or common corridor (see diagram 12), and

(ii) the travel distance limitations in Table, on escape in one direction only, are observed;

Effectively, this means that the required number of stairs is not a function of the building height, provided travel distances and other building requirements are met. Therefore, it is possible to have tall single stair apartment buildings. Figure 2 shows the maximum travel distances and stair requirements of Approved Document B (Department of the Environment, Transport and the Regions, 2000).

Some of the important requirements for single stair buildings is the provision of openable vents and/or automatic opening vents in the stairs and the corridors. These vents provide a means of venting the stairs of smoke, for both occupants and fire brigade.

Figure 2 – Approved Document B single stair building requirements



(Department of the Environment, Transport and the Regions, 2000)

8.5 Refuge Floors and Areas

Refuge floors and areas provide rest locations for escaping occupants, a safe area for both disabled and able-bodied occupants and a staging area for the fire brigade. The BCA and the Acceptable Solutions to the NZBC do not prescribe refuge floors, however they are prescribed in the Hong Kong building code (Lo and Will, 1997). In a fire engineered apartment building refuge floors may be justifiable if the building was an ultra high-rise building, with excessive travel distance via stairs.

Refuge areas are more commonly used in Australia and New Zealand to provide safe areas for disabled occupants. In apartment buildings a common emergency strategy is for disabled occupants is to remain in their apartments until assistance arrives.

8.5.1 Refuge floors

The Building Code of Australia and the Acceptable Solutions to the NZBC do not specify refuge floors for apartment buildings. However, they are prescriptive requirements for high-rise buildings in the Hong Kong Code of Practice (Lo and Will, 1997).

The Hong Kong Code of Practice specifies that refuge floors should be in all buildings above 25 storeys, at intervals of not less 20 storeys and not more than 25 storeys (Lo and Will, 1997). The basis for the number of storeys is travel distance and the estimated fatigue of the occupants (Lo and Will, 1997).

The functions of refuge floors (Lo and Will, 1997) are to:

- Act as a relief area for the evacuees in a fire situation
- Act as a sub-base for fire fighting purposes
- Act as a command point for the rescue personnel to assist the evacuation of the building
- Provide a place for disabled or partially disabled occupants to wait for assistance before being evacuated
- Allow occupants to move to an alternative staircase
- Allow smoke separation at the refuge level in the stair case

Lo and Will (1997) also state that refuge floors can psychologically assist occupants under escape conditions. Refuge floors can psychologically relieve occupants by:

- Reassuring them that the height of escape is not too onerous
- Providing an area for cognitive and decision control
- Seeing the presence of fire brigade personnel

Refuge floors can also be used as a safe area where lifts are controlled and co-ordinated for egress. Passenger lifts not used on the fire floor can be used at the refuge floor to evacuate occupants (Lo and Will, 1997). High-rise buildings are usually broken up into low-rise, mid-rise and high-rise sections, with lifts that serve each section separately. To assist in rescue operations, lifts that do not serve the fire floor can be used for rescue and mobilisation of fire brigade personnel and equipment.

The arguments against refuge floors (Lo and Will, 1997) are that:

- They provide an additional cost to the building owner in terms of building cost and non-utilised space
- It can be difficult to maintain and enforce the use of refuge floors
- There are already protected escape routes
- Unless people have difficulty in escaping they are unlikely to remain on the refuge floor

For residential buildings, Lo and Will (1997) believe that refuge floors may be necessary to provide an area of safety if conditions become untenable due to long pre-movement times.

Another approach to using refuge floors is to reduce the effective height of high-rise buildings (Teh, 1994). Since the height is directly proportional to egress time, the provision of adequately protected refuge areas can reduce the effective building height. Therefore once occupants have reached a refuge floor they can be considered to be safe. To achieve this Teh (1994) proposes the following requirements:

- Additional provisions to prevent smoke infiltration (smoke stopping of all vertical shafts)
- All lifts connecting to the refuge floor to be accessible through smoke lobbies
- The refuge floor must be accessible at all times and capable of accommodating the projected number of people
- A substantial part of the refuge floor is to be natural vented or capable of being naturally vented (ideally the refuge area should be a part of an external area)
- The design and layout of exit stairs should discharge occupants into the refuge floor before they proceed further down

- Pressurisation of exit stairs can be separated into vertical zones to avoid failures of the system affecting the whole stair

Refuge floors in apartment buildings may assist the evacuation of occupants, but requirements of refuge floors need to be assessed against: other fire safety measures, the cost of a refuge floor and the emergency strategy. With the provision of sprinklers, compartmentation and smoke control, the need for a refuge floor in apartment buildings is questionable. Apartment buildings are generally fire separated between individual units, at each floor level and between escape paths. The areas that are fire separated from each other could be designed as refuge areas reducing the need for an entire refuge floor. Occupants also have option to remain in their apartments, where they have access to fresh air from windows.

The cost of a refuge floor also needs to be considered in conjunction with the cost of other fire safety systems. The opportunity cost of a refuge floor is the: loss of rental space, loss of real estate and cost of maintaining the floor. These cost could easily outweigh the cost of a sprinkler system that may provide a higher level protection.

In high-rise buildings fires, where smoke control systems have failed, a refuge floor with adequate natural cross ventilation, could have assisted occupant egress. The World Trade Centre bombing (Fahy and Proulx, 1996) and the MGM Grand fire (NFPA, 1982a) are two possible cases where injury and fatalities may have been avoided, if the occupants were able to get to a refuge floor with adequate ventilation. In these two fires, exits were compromised by smoke and occupants were evacuating through poor conditions.

In ultra high-rise buildings, defined as greater than 40 storeys (Lo and Will, 1997), refuge floors could be of some assistance for disabled, elderly and other occupants who need assistance to evacuate. However, these occupants may be better served through refuge areas on each floor or by the occupants remaining in their apartments. Lo and Will (1997) argue that refuge areas do not have the same psychological benefits for the escaping occupants, as a refuge floor, and therefore are not as effective.

8.5.2 Refuge areas

The Acceptable Solutions to the NZBC (BIA, 1991) require refuge areas in apartment buildings greater than 58m high with intermediate floors. These refuge areas are to be located at intervals of no greater than 3 floors in the vertical safe paths, be at least 800mm wide and have an area of no less than $2m^2$. Guidance on refuge areas is also provided in British Standard BS5588 - Part 8, 1998 (BSI, 1988).

The NFPA Life Safety Code (Cote, 1997) requires people with severe mobility impairment to have at least two means of accessible egress. One method to achieve this is through the provision of a compliant refuge area.

Some of the problems of refuge areas or staging areas are:

- The effectiveness of refuge areas is highly dependent on the design details. Some of details that need to be considered are fire exposure, reliability of the smoke control system, outside wind and temperature condition. Without pressurisation all refuge areas can be subject to lethal failure (Nelson, 1993 and Klote, 1993).
- In many cases, the people needing the refuge areas may be unable to reach the area before their pathways become untenable (Nelson, 1993 and Klote, 1993)
- The organisation and human behaviour problems involved with refuge areas are more complex (Nelson, 1993 and Klote, 1993).
- The operation of a sprinkler system eliminates the life threat to all occupants and can provide superior protection for people with disabilities as compared to a refuge area. (Nelson, 1993 and Klote, 1993)

Klote (1993) found pressurisation of refuge areas could be significantly influenced by, opening and closing of doors, window breakage and external wind pressures. Generally, refuge areas can be effectively pressurised by a direct pressurisation system or an indirect pressurisation system using lift shafts. But an indirect pressurisation system using the stairwell may not be effective or appropriate (Klote, 1993).

8.6 Lifts

The use of lifts or elevators for emergencies is not a new concept, but they are typically only used with fire brigade assistance. In general, occupants are told not to use lifts in a fire. However, the fire brigade has often used lifts to rescue people and mobilise equipment. Lifts have also been used in hospitals to move non-ambulatory patients.

The use of lifts for fire fighting and assisting rescue operations provides an efficient means of moving people and equipment. This is particularly important in high-rise buildings, where moving equipment takes time and uses valuable resources. An example of this was the First Interstate Bank, where lifts were not used, and a fire on the 12^{th} floor required 100 men to carry equipment up the stairs (Degenkolb, 1991).

The BCA requires buildings with an effective height greater then 25m to have one or more lifts, fitted as an emergency lift (Performance Requirement EP3.2, BCA, 1996). This is to facilitate the activities of the fire brigade and other emergency service personnel. In addition to this, stretcher facilities must be provided in at least one of those emergency lifts, or in a non emergency lift where the effective building height is greater than 12m.

The British Standard BS 5588 – Part 8 1988 (BSI, 1988), provides guidance on the use of lifts for evacuation of disabled people. BS 5588 Part 8 provides guidance on the design of lifts used for evacuations as well as the management of evacuation lifts, and examples of fire plan strategies in buildings with evacuation lifts.

The some of the problems with the use of lifts for egress are:

- Pressurisation of shafts is not necessarily effective for smoke control (Klote et al, 1993)
- Lift components can be affected by heat, smoke and water (Klote et al, 1993)
- Power failure (Klote et al, 1993)
- Potential of lifts opening onto the fire floor
- The evacuation needs to be controlled and co-ordinated and the number of occupants entering the lift needs to be regulated
- Lift shafts can act as chimneys exposing occupants to heat and smoke.
- Occupants have been told for the last 20 years not to use lifts in a fire (Klote et al, 1993)
- Pressure differentials in lift shafts can vary with building geometry and at different floors (Klote, 1983)

- Lift microprocessor controls are very sensitive to heat (Semple, 1993)
- Fire brigade shutting off the power can be a problem. Batteries will only run for a limited length of time (Semple, 1993).
- Malfunctions in an emergency could lead to litigation (Semple, 1993).
- There is limited opportunity for rescue of people trapped between floors (Pauls et al, 1991)

The some of the other reasons why lifts are unsafe stated in the ASME Elevator Code and Handbook A17.1 (Cote, 1997) are:

- Occupants may push a button and waste valuable time waiting for a lift that may not arrive
- Lifts can not start until the car and hoistway (lift shaft) doors are closed. Overcrowding may prevent these doors from closing
- A lift occupant could press the incorrect button
- Normal functioning of lifts such as high or low call reversal may occur at the fire floor

The NFPA Life Safety Code (Cote, 1997) does not recognise lifts as a typical means of escape, but it does allow their use under certain circumstances. If a lift complies with Section 7-4 of the Code, it is permitted as a second means of egress, provided:

- The building and surrounding structure is protected throughout by an automatic sprinkler system
- The building is subject to an occupancy of no more than 90 people
- Primary egress discharges directly to the outside
- There are no high hazard content areas in the building or attached structures
- 100% of the egress capacity shall be provided independent of the lifts
- An evacuation plan is implemented specifically including the lift

The most immediate application for the use of lifts, in the evacuation of apartment buildings, is for the evacuation of disabled and elderly occupants and the evacuation of low occupancy high-rise apartments.

The escape times for lift egress can be calculated from the following formula (Klote et al, 1993)

$$t_e = t_a + t_o + \frac{(1+\eta)}{J}\sum_{j=1}^{m} t_{r,j} \qquad \text{(equation 6)}$$

$t_{r,j}$ – time for round trip (s)

t_a – time for elevator evacuation start up (s)

t_o – travel time from elevator lobby to the outside (s)

J – number of elevators

η – elevator inefficiency

m – number of round trips

Klote et al (1993) found that the use of lifts for egress decreases building evacuation times by between 10 and 50%. Greater evacuation efficiency occurs as the height of the building increases. The time-savings are a result of using a combination of lifts and stairs for evacuation. A similar result was found by Andersson and Wadensten (2000), in their simulations of the One Canada Square building at Canary Wharf in London, where they found that lifts improved the evacuation procedures in the building.

The following are 13 criteria for safe lift egress design proposed by Chapman (1994)

1. The building be fully sprinkler protected
2. Lift shafts should be pressurised
3. Lift lobbies on all floors should be enclosed
4. Lift lobbies should be pressurised
5. Lift and lobby pressurisation intakes should be in a smoke free location
6. All lift lobbies should be protected by smoke detectors

7. Lift systems should be made water resistant
8. When a power failure occurs all lifts should return to their designated level
9. All lifts should be able to be operated from a designated emergency power generator
10. All lift lobbies should have access to a pressurised stair, without the occupants having to pass through a fire area
11. All lift cars should have a means of two way communication
12. All lift lobbies should have a means of two way communication
13. A program specifying the priority of lift response during a fire should be developed.

For lifts to be effective in evacuations, some other design concepts that should be considered are:

- Smoke and fire separation of lift machine room and lift shaft (Klote, 1993, Klote et al, 1995, Levin and Groner, 1994)
- Analogue addressable detection system linked to lift control to prevent lift stopping on fire floors and to prioritise floors for evacuation (Klote et al, 1995, Levin and Groner, 1994)
- Automatically recall lift if a fault is detected (Klote, 1993, Klote et al, 1995, Levin and Groner, 1994)
- Wardens or security staff to direct evacuations, reassure occupants and prioritise who uses the lifts, and also to control occupant numbers in the lifts (Klote et al, 1995, Levin and Groner, 1994)
- Provide a system to prevent the lift stopping on floors where heat is detected, or providing fire rated lobbies on all floors (Klote et al, 1995, Levin and Groner, 1994)

- Higher levels of protection for lift system, if building is non sprinkler protected (Klote et al, 1995)

- Load weighting device, so lift bypasses all other calls when fully loaded (Fox,1991)

- Lifts connected to alarm panel and sent to the top floor in an emergency and only responding to calls in the down direction (Fox, 1991)

- Have machine room close to ground level, therefore if occupants are trapped in the lift the time to access machine room is reduced (Gatfield, 1991).

- Reduce lobby sizes to prevent storage of combustible materials. BS5588 Part 5 limits the lift lobby to between 5-20m^2 (Gatfield, 1991)

In some cases occupants may prefer to use lifts, instead of stairs, for egress due to the physical exertion of walking down several flights of stairs (Klote et al 1993). In the Forest Lane fire, 40% of the respondents said they used the lifts (Proulx et al, 1995). This included people who were assisted by rescue personnel and occupants who were not successful.

Occupants also prefer to use entry points as exit points due to familiarity. Therefore, as lifts are the main point of entry for the occupants, they will be familiar with them and may prefer to use them as an exit (Klote et al, 1993).

Another factor affecting whether people will show a propensity to use lifts in emergencies is the perceived reliability of the lifts (Levin and Groner, 1994). If lifts are shown to be reliable and have very few breakdowns, occupants will be more confident of using them in an emergency.

In a high-rise apartment building fire in Hiroshima (Sekizawa et al, 1999), the use of lifts by occupants for evacuation increased with the storey height. In total, 54% of the occupants who escaped used lifts. 44% of these occupants said they used the lifts for means of escape because they use them every day, and 29% thought they were safer (Sekizawa et al, 1999). One of the reasons for this is that the occupants may not be aware of the emergency procedure not to use lifts in a fire. The study also showed that more occupants above the 6th floor used the lifts as opposed to stairs and all occupants between the 18th and 20th floor used the lifts (Sekizawa et al, 1999).

One of the problems with installing an emergency lift system is the education and training of occupants in the use of the system (Levin and Groner, 1994). To ensure the effectiveness of the system, occupants need to be educated about the safety features of the system, and be trained in the appropriate use of the system.

It is currently feasible to design an emergency lift system for a low number of people (Klote et al, 1995). Therefore a lift emergency system would be most beneficial for the evacuation of disabled occupants from office buildings and all occupants in luxury apartment buildings, due to low occupancy numbers (Klote et al, 1995). However, the use of lifts for large numbers of people is not practical at this time, due to the required complexity of the system (Klote et al, 1995). Evacuation via lifts should only be an option for occupants who can not use the stairs, otherwise lifts will be delayed for the people who are most in need (Pauls et al, 1991). If possible, people who require assistance should have their needs incorporated into the emergency plan (Pauls et al, 1991).

9 FIRE

In residential buildings there are numerous sources of fire ignition. In New Zealand for the 3 year period between 1995 and 1998, the three main locations of residential fires were: 25% occurred in the kitchen, 16% occurred in the lounge and 13% occurred in the bedroom. The main ignition sources were cooking facilities, careless disposal of cigarettes, careless disposal of ash and embers and heat sources too close to combustibles (NZFS, 1999).

A more detailed study by Duncanson et al (2000) found, between 1991 and 1998, 25.2% of residential fires started in the kitchen, 16.0% started in the lounge room and 12.5% started in the bedroom. Of the fatal residential fires, 26.3% started in the bedroom, 18.8% started in the kitchen and 13.5% started in the lounge or living area (Duncanson et al, 2000).

In Australia (1989-90) 33% of fires in 1 and 2 family dwellings (Class 1 buildings) occurred in the kitchen, 13.6% occurred in the lounge room and 13.6% occurred in sleeping rooms (Beever et al, 1999). Dowling and Ramsay (1997) found that cooking and kitchen fires are the most common, but fires involving upholstered furniture caused more deaths and damage. The most hazardous fire scenarios are fires started by smoker's material on soft furnishings in lounge rooms and sleeping areas (Dowling and Ramsay, 1997).

In the US, 33% of fatal apartment fires were found to have started in the bedroom (Hall, 1994). Once again the leading cause of fire death in the US is smoking materials, which accounted for 25% of residential fire deaths (Conley and Fahy, 1994).

The fire characteristics can have a significant influence on the fire safety systems and life safety of occupants. The fire size and growth rate will affect the activation time of safety systems and the time to conditions being untenable. The development stages of the fire will influence the fire safety design and emergency strategy of the occupants. Smouldering fires and fully developed fires will require different fire safety strategies. Flashover is another critical stage in the fire's development, and enclosure effects of the compartment can result in large amounts of toxic products being produced.

The prevention of fire spread is an important design objective for designers and building codes. By preventing the spread of fire, tenable conditions will be maintained for a longer period of time. In addition to this, the damage to property will be reduced and the intervention of the fire brigade can be more effective.

9.1 Internal Fire Spread

In any apartment building one of the primary design objectives is the prevention of fire spread outside the unit of origin. This objective can be met with passive barriers and/or the installation of a sprinkler system.

Fire in corridors and escape paths also has to be prevented from spreading. This can be achieved by having non-combustible linings and the absence of combustible products in these areas. The flammability, flame spread and smoke development indices of corridors and public spaces should be based on the relevant codes and standards. Ensuring combustible products are not present in the escape paths and public areas will also reduce the chance of ignition and fire in those areas.

9.2 External Fire Spread

Limiting external fire spread is another objective of the BCA and the Acceptable Solutions to the NZBC. The risk of vertical fire spread can be reduced with the proper design of spandrels and balconies, and horizontal fire spread can be prevented with adequate separation distances between buildings and limiting the size of unprotected openings.

The prescriptive requirements of the BCA and the Acceptable Solutions to the NZBC have been extracted in Appendix C. In summary, the BCA specifies a minimum spandrel height of 900mm or a minimum horizontal projection of 1100mm. The Acceptable Solutions to the NZBC specify a minimum vertical spandrel of 2.5m or a horizontal spandrel of at least 600mm.

The prescriptive requirements of the Acceptable Solutions to the NZBC are based on Oleszkiewicz's (1991) study of spandrels and horizontal projections. Oleszkiewicz (1991) found that horizontal projections are extremely effective in protecting the above windows from flames, but for a spandrel to be equally effective they would need to be an impractical height. A 600mm horizontal projection reduced the exposure to an upper opening by 60% and a 1m projection reduced the exposure by 85% (Oleszkiewicz, 1991). A vertical spandrel of 2.5m reduced the exposure by 50% to an upper opening (Oleszkiewicz, 1991).

The chance of fire spread via unprotected openings can be reduced by limiting the radiant heat flux to an object to 12.5 kW/m^2 for cellulose material, and 10.0 kW/m^2 for plastics, exposed to piloted ignition (Buchanan, 1994). For non-piloted ignition the radiant heat flux for ignition is higher. The radiation intensity from an opening can be determined from fire engineering calculations or Approved Document B recommends a design radiation intensity level of 84 kW/m^2 from an unprotected opening (Department of Environment, Transport and the Regions, 2000).

In a non-evacuation emergency strategy, the prevention of fire spread is particularly important. A non-evacuation strategy requires occupants not in the unit of fire origin to remain in their apartments awaiting further instructions or fire brigade assistance. If a fire is unable to be contained in the unit of origin or adjacent corridor then these occupants will be put at risk.

10 TRAINING AND EDUCATION

Training and education of building occupants is an essential aspect of fire safety that is often overlooked. Many fire fatalities are the result of poor decision making and occupants being unaware of the consequences of their actions (see Appendix A). In numerous cases, fire fatalities have occurred, or the situation was exacerbated, by occupants not closing doors, disabling self-closers and removing batteries from smoke detectors. Training and education in the emergency plan and fire safety could reduce the number of these fatalities. In the Forest Lane fire, 22% of the occupants thought it is a good idea to try and exit to the roof (Proulx et al, 1995). However, in almost all cases roof access doors are locked.

Another area of training that would be of benefit is the training in the prevention of fires (Canter, 1990). This could reduce the number of fires and indirectly increase the level of life safety. Occupants can also be trained in the use of first aid fire fighting equipment (hose reels, extinguishers). This will enable occupants to use them effectively, and know when to retreat or evacuate the building.

Training and education is also reinforced by Fahy and Proulx (1996), who noted that during the World Trade Centre bombing, occupants continued to egress through worsening smoke condiditons. Fahy and Proulx (1996) state that occupants need some level of training and education if they are to react safely to a fire in a building.

People need to be aware of:

- The emergency strategy of the building (evacuation, non-evacuation, staged evacuation)
- The hazards of fire (smoke, heat, flames, carbon monoxide)
- The fire safety measure in the building (sprinklers, smoke detectors, hose reels, extinguishes, manual call points)
- The consequences of actions (closing doors, disabling smoke detectors, blocking escape paths, locking doors, breaking windows, leaving late)
- What options and alternatives are or are not available in the event of a fire (for example refuge areas, roof access and lobbies)

- Techniques to minimise risk in either an evacuation or defend in place emergency strategy

The decisions of people in a fire are their own responsibility, fire service personnel and fire engineers can not decide if, or when, a person should evacuate, or stay in place and seek refuge. The only person who can make this decision is the occupant faced with the smoke, heat and fire. Therefore, to assist occupants in making the correct decisions they need to be educated about fire, fire safety and the consequences of the actions they take.

To assist occupants in making decision, the NFPA recommends the following steps for high-rise residential buildings and hotels (Siegel-McKelvey, 1999). This type of information should be provided to all occupants to assist them in decision making in the event of a fire.

In general...

- Familiarise yourself with buildings alarm system and evacuation plan.
- Count the number of doors between you unit and the nearest exit (to aid evacuation in the dark).
- If you discover a fire, sound the alarm and call the fire brigade.
- If the fire is in your unit leave the area closing all doors behind you.
- If smoke is entering your unit or the hallway, you must decide to leave or stay. If you leave, be alert to changing conditions and regularly re-evaluate your situation. If you know the fire is well below you, stay put.
- If you encounter smoke or flames use an alternative escape route.

If you stay...

- Remain calm and take actions to protect yourself.
- If possible go to a room with an outside window or balcony.
- Close all doors between you and the fire and use tape and wet towels to cover vents and seal around doors.

- Call the fire brigade and tell them exactly where you are.

- If possible open the window, be prepared to close it if smoke comes in. Do not break windows.

- Be patient. The evacuation of high-rise buildings can take hours.

The NFPA Life Safety Code requires that emergency instructions be available and given to each resident of high-rise apartment buildings (Wolf, 1999). This practice should be applied to other buildings and include evacuation drills and fire safety education. One of Proulx et al's (1994) conclusions, in the study mixed abilities evacuations, is that improved life safety for occupants can be achieved with annual evacuation drills to ensure occupants, recognise the fire alarm, know different means of egress and know the general fire emergency procedure.

Training in emergency procedures makes occupants aware that there can be problems with safe evacuation (Hallberg, 1988). Hallberg (1988) believes the training exercise should involve elements of realism. For example, blocking of exits and/or lighting being turned off. Evaluation and documentation of training exercises can also provide information on deficiencies and areas requiring improvement.

For effective fire drills, Canter (1990) has listed the following important considerations:

- Establish that appropriate individuals understand the conditions under which first aid fire fighting or building evacuation is to be carried out.

- The signal for an evacuation is taken as being clearly and unambiguously an indication that the building should be evacuated

- All communications with building users are clear an unambiguous, giving direct instructions that are understood and followed

- The routes to be taken for evacuation, and any phased sequence, are clearly understood and followed by the building users

- The communication between critical members of the organisation and the utilisation of a chain of command are shown to be effective

- Any particular difficulties in evacuation, of special groups or particular individuals, are identified

- Knowledge of location and appropriate use of fire fighting equipment is established

- Clear and effective feedback is given to all those involved in the drill as to how it was carried out and what consequences there are for actions in any future emergency.

11 INSPECTION AND MAINTENANCE

Inspection and maintenance is an important aspect of fire safety to ensure the reliability and effectiveness of fire safety measures. If fire safety measures are not regularly inspected and maintained, the reliability of the systems decrease, and in the event of a fire they may not function as designed.

In New Zealand, building compliance schedules specify maintenance and inspection periods for fire safety systems. In Australia, the maintenance and inspection of fire safety measures varies according to each state's legislation. All buildings should have a maintenance schedule, and log-books that include any essential fire safety measures specified in the fire engineering design.

Inspection of passive protection in buildings is just as important as the inspection of active systems. Passive protection plays an important role in containing the fire and smoke, and protecting the escape paths for the occupants and fire brigade. Building changes or renovations that penetrate or alter passive barriers may need to be fire stopped and should be checked or approved by a fire engineer.

One of the major problems in apartment buildings, is obtaining access to individual apartments for inspections and maintenance. Because each apartment is an individual unit, the co-ordination of inspections can be difficult and time consuming. Occupants may also feel that inspections are an invasion of privacy and may be reluctant to allow inspections.

In some cases, the need for individual inspections of apartments may be reduced through the practical design of the fire safety systems. For example, an analogue addressable smoke detector system could be used to check detectors at the panel, rather than in each individual unit. Hard-wired smoke detectors could also be used, to reduce the problems of batteries being removed or going flat.

The inspection and maintenance of common areas and escape paths, to ensure they are free from combustible materials, is another area of high importance. Through good housekeeping, the likelihood of ignition and fire spread can be reduced.

12 EMERGENCY STRATEGY

The emergency strategy in any building is as important as the active and passive fire safety measures. In the event of a fire, occupants need to be informed or have some knowledge of what to do and the correct actions to take in different situations.

Historically the term "Evacuation Strategy" or "Evacuation Scheme" has been used for the building emergency strategy. The use of these terms implies occupants should evacuate the building in an emergency, whereas in some cases remaining in the apartment may be a safer alternative. The evacuation of apartment buildings may also be impractical due to the size of the building and the abilities of the occupants. Therefore it is suggested that the term "emergency strategy", "emergency scheme" or "emergency plan" should be adopted to reflect the different alternatives available to occupants in the event of an emergency.

Changes in the emergency strategy of a building can result in potential problems with implementation and execution of the strategy. Some of the potential problems are:

- Changing the mindset of the occupants
- Ensuring occupants react as planned
- Confusion in the event of an emergency
- Education and training of occupants
- Notifying new occupants

An important aspect to changing the mindset of occupants is communication, education and training. In some cases the natural mindset of occupants could be congruent with the emergency strategy. For example, occupants may prefer to remain in their apartments as it is a place of familiarity and it is generally perceived to be a relatively secure environment.

In any emergency strategy, the simpler the strategy the less likely chance of confusion and unforeseen occupant behaviour. Where possible, an emergency information system should be included as a fire safety measure to provide instructions, information and reassurances to occupants. Proulx and Sime (1991) found that the occupant response in an evacuation was far more effective when an information system was used.

All emergency schemes are dependent on passive and active fire systems to ensure occupants have an adequate level of life safety in an emergency. Failure of active and passive system can compromise the emergency strategy and occupants may need to react to situations that are unplanned. Adequate training and education is essential to prepare occupants for any unforeseen situations.

12.1 Evacuation

In an emergency, occupants are usually trained to evacuate the building as soon as possible. In general, this concept has been effective in providing adequate life safety for the occupants, but in some cases this is not always the best strategy (Proulx, 2000).

The main advantage of an evacuation strategy is that people are safe once they have evacuated. The failure of passive and active systems or fire and smoke spread from the unit of origin does not reduce their life safety. The fire brigade also has to only assist those occupants remaining in the building who are unable to escape and need assistance.

Evacuation strategies are usually simple and easy to understand. Occupants simply have to leave the building as soon as possible after hearing the alarm. Generally there are only problems in this strategy when smoke and fire spread affect the egress routes.

The fire safety systems of buildings are usually designed to protect occupants using an evacuation strategy. This requires occupants to be protected during egress as well as in their apartments. Due to unpredictable pre-movement times, the time that occupants require protection can be significant.

The following are some of the main reasons why occupant evacuation in apartment buildings may not be the best strategy:

- Exposure to fire and fire products. Occupants may have to egress through smoke, resulting in death and injury.
- Occupants will continue to move through smoke resulting in injury and possibly death
- Fire and flashover can occur in escape paths

- Pre-movement times in apartment buildings are unpredictable. Leaving late could result in injury and death. Occupants may not even hear the alarm or wake up.
- Finite tenability time. Design for safety based on Available Safe Egress Time (ASET) > Required Safe Egress Time (RSET) can result in fatalities if the ASET is insufficient.
- Disabled and elderly occupants are more at risk
- Evacuation can be impractical in high-rise buildings
- Occupants do not always evacuate

12.1.1 Exposure to fire and fire products

During an evacuation, occupants on and above the fire floor may be exposed to the fire or fire products. The level of this exposure will depend to a great extent, on the actions of the occupant in the unit of origin. If the door is left open, fire may spread into the corridor and smoke will most likely spread into the corridor. The fire safety measures and the extent of combustible materials in the corridor will determine the extent of the fire and smoke spread. Once occupants are exposed to fire and fire products they are at risk to injury or death.

Smoke is one of the main contributors to fatalities in fire. An example of this is the MGM Grand (85 fatalities) where all 61 victims in the high-rise area died from smoke inhalation and asphyxiation. The other victims located in the casino and other areas died of asphyxiation, burns and carbon monoxide (CO) poisoning. Of the 61 victims in the high-rise, 25 were found in rooms, 22 in corridors, 9 in stairways and 5 in lifts (NFPA, 1982a). Another case is the Rockefeller Park Towers Fire (Bell, 1983b), where five people were killed by smoke inhalation and by being trapped in their apartments. The failure of the occupant in the unit of origin to close the apartment door was a significant factor in the fatalities and injuries (further cases can be seen in Appendix A).

The possibility of smoke being present in the escape path is increased by fire fighters and occupants opening doors, and by fire fighters using the stairs as a staging area. Without effective pressurisation these actions can allow smoke to enter the corridors and stair shafts.

Fire hydrants are often located in the stair shafts to provide a safe staging area for fire fighters. Therefore, as the fire fighters attack the fire, the door has to remain open and smoke can flow into the stair shaft, exacerbating smoke spread throughout the building. In the Polo Club Condominium Fire (Harvey, 1992/93), a significant amount of smoke was spread throughout the building as fire fighters fought the fire.

Leakage around doors and from vents can also allow smoke to spread to the egress paths or into the rooms of other occupants. It is extremely important that penetrations in smoke and fire barriers are protected by fire dampers, or are adequately fire stopped.

Occupants escaping the unit of origin will have to open a door to escape. This will allow some smoke to enter the corridor on the fire floor. If the escaping occupant does not close this door, a significant amount of smoke can enter the escape path. In the Baptist Towers Home for the Senior Citizens fire (Willey, 1973), the unit of fire origin door was left open and it resulted in the death of 9 people on the floor of fire origin (7^{th} floor). A tenth victim rescued from the 10^{th} floor died six days later. Similarly in the Rockefeller Park Towers Fire (Bell, 1983b), the door was left open resulting in five casualties.

As occupants escape the fire floor they will open the doors to the stair shafts and other smoke control doors. This can also allow smoke to enter stair shafts and egress paths. If self-closers are not present on doors, open doors will make the smoke spread worse.

In some cases the effects of smoke spread can be minimised by a pressurisation or extraction system. Smoke can also be controlled with baffles, and smoke production can be reduced by a sprinkler system.

12.1.2 Evacuation through smoke

Case studies have shown that occupants will evacuate through untenable conditions and continue to evacuate through conditions that are becoming untenable. In the World Trade Centre Bombing and resulting fire, over 1,000 people were treated for injuries sustained from the evacuation and explosion (Fahy and Proulx, 1996). The results of the occupant surveys showed between 94% and 70% (Towers 1 and 2 respectively) of the occupants moved though smoke and three quarters of those occupants who moved through smoke turned back (Fahy and Proulx, 1996). The study of the World Trade Centre bombing highlighted the fact that people will egress through smoke and keep moving even if conditions deteriorated (Fahy and Proulx, 1996). Many evacuees also thought they were heading straight into the fire and yet they kept going, even though the smoke got thicker (Fahy and Proulx, 1996).

In many fire cases, smoke forces occupants to turn back as conditions deteriorate. In the Ottowa apartment fire (Proulx 1999) 25% of occupants who attempted to escape had to return to their apartment, and 21% had to seek refuge in a neighbour's apartment. Four evacuees had to be treated for smoke inhalation and two people suffered heart attacks (one of them died later).

Another example is a fire in a 21 storey apartment building in Canada (Pauls, 1999). The fire began on the 7^{th} floor and caused the exit stairways and corridors to fill with smoke. A family in a 21^{st} floor apartment attempted to evacuate and encountered heavy smoke on the 15^{th} floor. The family retreated back up the stairs, and sought refuge at the top of the stairs where the door to the roof was locked. The father attempted to find help on the 21^{st} floor and had to find refuge in an apartment. The mother and child trapped in the stairwell died from smoke inhalation. In this situation the family should probably have stayed in their apartment and waited for assistance, rather than try to evacuate through the smoke logged stairs.

Bryan (1992) found that the decision to move through smoke is based on the recollection of the distance to the exit and the ability to estimate the travel distance required. Secondary variables are, occupant perception of the severity of smoke and the presence of heat (Bryan, 1992). Occupants have been known to travel distances of up to 20m with visibility of less than 4m (Bryan, 1992). In the experimental study by Janse et al (1998), able-bodied occupants, in a corridor with a visibility of 25m, were able to walk without breathing for 20 seconds and travel at least 30m.

12.1.3 Flashover and fire in escape paths

A threat to occupant life safety is fire in the escape paths. Fires in corridors and stairwells have often resulted in exits being blocked and occupants being trapped (refer Appendix A). In a New York apartment building in 1990, an arsonist lit a fire in the stairwell, trapping five occupants (Fahy and Tremblay, 1991). There have been numerous cases where arson fires in exit ways have trapped occupants (refer to Appendix A), but fire can also spread from the unit of origin resulting in the same problem.

Another potential threat is that corridors can flashover. Flashover can occur if there is enough combustible material or lining in the corridor and from un-burnt gasses spilling into the corridor (Quintiere, 1974). In the Dorothy Mae apartments (Dektar, 1983, Bell, 1983a) many of the 24 victims were killed when the fire flashed-over down the second and third floor hallways. One investigator stated that if the victims had stayed in their rooms they would still be alive (Dektar, 1983).

12.1.4 Pre-movement time

The pre-movement time of occupants is one of the most unpredictable variables of human behaviour and one of the most important variables in fire engineering. In apartment buildings the pre-movement time of occupants can vary significantly, depending on when or if the occupants are alerted and decide to evacuate. Due to the large variation in the pre-movement time of occupants, the pre-movement time can be greater than the movement time and it is usually a significant portion of the total evacuation time.

Some of the occupant response time (or pre-movement time) principles summarised by Sime (1996) are:

1. Deaths in large scale fires attributed to panic are more likely to be caused by delays in information
2. Fire alarm sirens can not always be relied upon to prompt people to move immediately to safety
3. The pre-movement time is just as important as the movement time
4. Movement in the early stages of a fire is characterised by activities such as investigation, not escape
5. As long as the exit is not seriously obstructed, people will move to a familiar exit even if it is further away
6. Individuals often move towards and with groups, and maintain proximity to people to whom they have emotional ties
7. Fire exits are not always noticed and may not overcome difficulties in way-finding

8. People are often prepared to move through smoke

9. People's ability to move towards exits may vary considerably

People closer to the fire or on the fire floor are likely to receive visual and olfactory cues and therefore have shorter pre-movement times. Occupants can also be warned by other occupants or receive more accurate information, again resulting in a shorter pre-movement times.

In a study by Proulx and Fahy (1997) of five buildings, they found the delay to start evacuation was a function of the type of occupancy, the occupant's characteristics and the fire safety features in the building. The results of residential evacuation drills (Proulx and Fahy, 1997) found that the average time to start evacuation was between 2:30 min and 9:40 min for mid-rise buildings and between 2:50 min and 5:20 min for high-rise buildings. However in the Forest Lane Fire (mid-rise 30 storey), the occupants who evacuated within the first hour had an average time to start evacuation of 10:30 min (Proulx and Fahy, 1997). 48% of occupants attempted to escape in the first hour, and only 35% of them were successful (Proulx and Fahy, 1997). The time delay before starting evacuation in actual fires is often longer compared to fire drills (Proulx and Fahy, 1997). This is due to the greater ambiguity of the cues received by the occupants. Evacuation drills also do not consider occupants seeking refuge for communication, or relief from contaminants, or way finding being complicated by smoke and the seeking of psychological support (Bryan, 1999).

In some cases occupants may not immediately react to the alarm, and if they are sleeping or under the influence of alcohol they may not even wake up (Refer to Section 6.2). On hearing a building alarm, occupants tend to treat it as a signal to wait for more information (Proulx, 1999) and therefore long pre-movement times result.

Numerous models have been developed to predict the pre-movement time of occupants. Sime's (1996) and the FEG (FCRC, 1996) model use a weighted scoring system based on occupant characteristics to derive a pre-movement efficiency weighting factor. This factor is then multiplied by baseline pre-movement times for various alarm and information system types. Other Models have been developed by Proulx and the NRCC and by MacLennan et al (1999).

Pre-movement models can provide reasonable estimates of occupant pre-movement times, but it is impossible to generalise individual behaviours and characteristics. Taking a relatively small sample of data and applying it to the general population is a rough approximation and does not consider variables like: group dynamics, education, sex, intelligence, physical abilities, cultural background, socio-economic status, toxins, perceived value of life and the interdependencies of these variables.

It has already been shown that males and females act very differently in a fire (Bryan, 1995). In general males, are more likely to engage in fire fighting and high risk activities, whereas females will assist others and call for help (Canter, 1990).

The longer occupants take to start evacuation, the higher risk of injury and death from fire and smoke. Intuitively, the longer the delay, the larger the fire, the greater the amount of smoke that will be produced, and the more time smoke will have to enter exitways. In many cases, fatalities and injuries have occurred when occupants have commenced evacuation late and encountered smoke in escape paths. An example of this is the Forest Lane Fire (Proulx and Fahy, 1997) where none of occupants above the fire floor, who attempted to evacuate after the first half-hour, were successful. This indicates that conditions after this time had deteriorated and occupants risked injury if they attempted to evacuate.

Pre-movement times can also be increased if the building has a history of false alarms and minor fires. In the high-rise apartment in Hiroshima, it is hypothesised that the history of minor fires resulted in relatively long pre-movement times (Sekizawa et al, 1999). Occupant perceptions were influenced by the history of minor fires and many occupants assumed the fire would be suppressed at an early stage and the threat was only minor (Sekizawa et al, 1999).

12.1.5 Finite tenability time

In many cases the fire-engineering design of buildings is usually based on a comparison of the Available Safe Egress Time (ASET) and the Required Safe Egress Time (RSET). If the ASET is greater than the RSET time with an adequate safety margin, the egress design of the building is considered safe.

However, this only provides a limited time for tenable conditions based on the designer's assumptions of fire growth rate, fire size, fire spread, smoke production, smoke spread and the behaviour of the occupants. If the ASET is exceeded occupants can be escaping through untenable conditions.

12.1.5.1 ASET

The ASET is usually determined from the time it takes to reach predetermined untenable conditions. The Fire Engineering Design Guide (Buchanan, 1996) and the Fire Engineering Guidelines (FCRC, 1996) provide recommended tenability limits for toxicity, heat, radiation, smoke optical density and smoke layer height.

The tenability conditions are usually assessed through fire and smoke modelling. Therefore the assumptions made in the model, and the modelling software or equations, can have a significant impact on the available safe egress time. The ASET value may also need to consider different fire scenarios in conjunction with different occupant locations and characteristics.

12.1.5.2 RSET

Attempting to predict the human behaviour of the occupants complicates the calculation of the RSET. The RSET can be considered to consist of the following components: alarm time, pre-movement time and movement time.

- Alarm time can be predicted from fire modelling and correlations for the activation of active systems. This does not assess whether occupants hear the alarm.
- Movement times are relatively easy to predict by using travel and flow speeds or "ball bearing" models.
- Pre-movement times are difficult to predict, as occupant behaviour of individuals or in-groups can vary significantly. Therefore the prediction of the RSET becomes extremely difficult.

In the prediction of the ASET and RSET values, there is the potential for an extremely large range of variation. This will affect the evacuation safety margin, and the likelihood that occupants will escape safely and without injury.

If fire brigade intervention is considered, rescue of occupants may occur after the tenability limits have been reached. The fire brigade is able to rescue occupants with breathing apparatus, and they have the ability to control the fire and externally rescue occupants.

12.1.6 Disabled and elderly are more at risk

An evacuation strategy increases the risk of injury to disabled and elderly occupants in apartment buildings. This is primarily due to: delays in evacuation, slower movement times and the limited ability of these people to travel down stairs. In addition to the higher risks to the elderly and disabled, occupants assisting these people can be placed at risk due to increased delays in evacuation.

A study of residential fires by Sekizawa (1991) found that people 65 years and older accounted for 47.8% of residential fire deaths. The risk of death in a residential fire for handicapped people is 5 times higher than the average population, and the risk for a person greater than 65 years of age and bedridden is 41 times higher than the average population (Sekizawa, 1991). In New Zealand between 1991 and 1996, 26.5% of the residential fire deaths consisted of people greater than 65 years of age (Duncanson et al, 2000).

12.1.7 Evacuation can be impractical in high-rise buildings

In high-rise buildings evacuation is not always practical. This is due to:

- Large numbers of people, resulting in long escape times. Large numbers of people can cause queues in exitways and congestion in stairs. Therefore, overall escape times can increase.
- Long egress distances for disabled and elderly occupants can increase their risk to injury from fire and smoke as well as travel via stairs.
- In the event of a power failure, limited lighting and failure of smoke control systems can put evacuating occupants at risk to injury.
- In a small fire or sprinkler controlled fire, the evacuation of a whole building usually would not be necessary.

- Disruption of fire brigade operations. The fire brigade generally use exitways for staging areas and to move equipment. Occupants in the stairs can disrupt these operations and conversely the fire brigade can slow the egress of occupants.

- Some occupants are not at risk. Occupants below the fire floor and high above the fire floor may not be at risk in a fire. Therefore the evacuation of these people is not necessarily required.

- Delays and long evacuation time can increase the risk to occupants. The taller the building, the longer occupants are in exit-ways and the more likely they can be exposed to fire or fire products. If smoke is not contained on the fire floor it can spread through vertical shafts and exit ways.

12.1.8 Occupants do not always evacuate

In many cases occupants have not evacuated on alarm, and have only begun to evacuate when told to do so by the fire brigade. An apartment building fire case study by Brennan (1997), found that fewer than 50% of occupants evacuated the building. In a Hiroshima apartment building fire, 12% of occupants stayed in their apartments and did not evacuate (Sekizawa et al, 1999).

Another case was the Ambleside apartment fire, where 17% of respondents decided to remain in their apartments despite instructions from the intercommunication system (Proulx, 1999). The reason for their decision was smoke, and the fact that they could not manage the stairs or they thought it safer to stay in their apartments (Proulx, 1999). Of the remaining 83% who attempted to escape, 46% had to return to their apartment or seek refuge in another apartment (Proulx, 1999). After the fire, 48% of the occupants stated that in a future fire they would act differently and many of them said they would stay in their apartments and disregard the voice communication instructions (Proulx, 1999).

With proper compartmentation and fire safety measures, occupants who remain in their apartments are probably not at high risk. However, if the fire spreads or is not controlled then they may be at risk and have no means of escape.

12.2 Non-Evacuation

The concept of non-evacuation in an emergency is not new, and to some extent it is already practised in some buildings. Hospitals, for example, may evacuate parts of the building, but unless patients are in immediate danger they will probably remain in their rooms. A non-evacuation strategy is sometimes called defend in place, or protect in place.

In 1985, MacDonald (1985) presented a paper with the conclusion that, in a fire resistive compartmented building, occupants are safer if they stay in their units, and the majority of people die trying to evacuate. MacDonald (1985) based his conclusions on 14 high-rise building fires (apartments and hotels) and found that, out of 160 fatalities, 117 died attempting to evacuate and 36 died by not evacuating (the location and decision of the remaining victims was indeterminate).

Another advocate of non-evacuation in high-rise buildings is Proulx (2000), who at the May 2000 NFPA conference stated "In high-rise buildings, unless the fire is in your compartment, all occupants should stay where they are, doing protect-in-place activities, waiting for instructions". Proulx (1999) also stated that at some stage of fire development, it is probably safer to instruct occupants to stay in their apartments unless they are in immediate danger.

The emergence of non-evacuation strategy has developed from deaths and injury occurring due to occupants evacuating through untenable or poor conditions. If occupants remain in their rooms they may avoid evacuating though smoke filled corridors and stair shafts. In addition to this, the behaviour of occupants to fire alarms indicates a non-evacuation strategy maybe appropriate. Occupants do not respond well to fire alarms (Proulx, 2000), and they have been shown to wait for further information rather than evacuating immediately (Proulx and Fahy, 1997).

If the building is fully sprinkler protected, the required fire rating between the compartments can be reduced. Sprinklers have an exemplary record in apartment buildings, and they provide one of the highest possible levels of protection. A sprinkler protected building and non-evacuation strategy could be extremely effective (MacDonald, 1985).

The concept of non-evacuation in apartment buildings is based on each apartment being a separate fire compartment. This restricts the fire spread from the unit of origin into other compartments in the building, and provides a safe place for occupants in their own units, to wait for assistance.

In a non-evacuation strategy, the occupants not in the room of fire origin remain in place, being protected by passive protection and/or active systems. Occupants are in a secure and familiar place and can take measures to increase their safety. For example, occupants can:

- Open windows for fresh air or move to balconies
- Prevent smoke ingress with masking tape and wet towels
- Communicate with the fire brigade (if telecommunications are unaffected)

The advantages of non-evacuation in compartmented fire resistive buildings presented by MacDonald (1985) are:

- The probability of survival is greater. It is not possible to guarantee that everyone will survive, but MacDonald (1985) concluded that the chance of survival is greater if evacuation is not attempted.
- Uniform handling of all occupants. Handicapped and non-ambulatory occupants have the same consistent emergency strategy.
- Rooms offer more features for defence.
    - Doors provide some smoke protection
    - Towels, bedding etc can be used to seal penetrations.
    - Windows can be opened
    - The telephone can be used for communication
- If you enter the corridor you could encounter the following problems
    - Fire and combustibles in the corridor could cause a flashover
    - There may be smoke in the corridor and stairs
    - It is possible to be locked out

  - Occupants can be locked in stair shafts
  - Egress distances can be long

- Closed doors may restrict the flow of smoke. Because smoke travels with the flow of air, not opening doors reduces the airflow and therefore the smoke spread can be inhibited.

- Stair pressurisation could fail with the opening of doors and fire fighters using the stairs as staging areas.

- Uniform reaction of occupants irrespective of pre-movement and alarm time.

- Eliminates decisions based on inaccurate information. Occupant decision making often depends on what other occupants see, think or do, which may not be accurate, resulting in poor decisions.

- Evacuation of high-rise buildings is not always practical and the time it takes to evacuate high-rise buildings can be significant. In a high-rise building, not all occupants have the same level of risk, therefore the evacuation needs to be prioritised. If there is no co-ordination of the evacuation and everyone evacuates on alarm, then queuing and flow problems may occur.

- The fire brigade's role will change. The fire brigade can focus on fighting the fire. There is less of a need to assist evacuating occupants, unless they are in immediate danger. The stairs would be clear for the fire brigade to use. The response time of the fire brigade may not be as crucial, due to occupants not evacuating through smoke. The fire service response has to also ensure the fire does not spread to other compartments.

- There are no problems evacuating people using limited staff or wardens. Generally this will apply to hotels and care facilities where the number of night shift staff can be limited, and the staff is an integral part of the evacuation scheme.

- Occupants or wardens are not put at risk trying to ensure everyone has evacuated, or assisting occupants evacuating.

- In some cases it may be simpler to use a non-evacuation strategy in existing buildings, rather than upgrading the active systems.

Non-evacuation is not necessarily the answer to the fire safety problem of predicting human behaviour. A non-evacuation strategy eliminates some of the variables in human behaviour, but it can still result in serious problems. Some of the problems with non-evacuation are:

- If fire is unable to be controlled a greater number of occupants are at risk
- Compartmentation and the maintenance of passive fire protection is crucial to life safety (fire resistance ratings, smoke seals, fire doors and self-closers)
- Occupants need to be familiar with the strategy, and be trained and educated. Changing occupant's mindset could be a problem.
- External vertical fire spread needs to be prevented
- There is increased responsibility on the fire brigade to control and extinguish the fire

The conditions and building characteristics that Proulx (2000) believes necessary for a non-evacuation strategy are:

- High-rise building (over 6-storey)
- Non-combustible construction
- Central alarm system
- Voice communication system

In addition to these essential conditions, HVAC, pressurisation, sprinklers, balconies, doors with self-closers can also be provided (Proulx, 2000).

12.2.1 Case study

There is currently insufficient data available to determine if non-evacuation is more effective than an evacuation strategy. MacDonald (1985) demonstrated that a higher number of fatalities occurred in an evacuation strategy, but this was based on a small number of high fatality cases. The cases that were selected by MacDonald (1985) would tend to favour a non-evacuation emergency strategy. This is because high fatality fires usually have evacuation casualties.

Casualties can occur in the unit of fire origin, escape paths and in other apartments. The unit of fire origin usually has a low number of occupants relative to the total occupancy of the building. Therefore, in a high fatality fire many of the victims would not be from the unit of origin. In addition to this, in a compartmented building, a fire would usually produce untenable conditions in the room of origin and the exit paths (depending on whether the doors are left open). Therefore if fatalities occur, they will occur in these areas. As the room of origin usually has a small number of occupants, a high fatality fire would thus result in many of the victims being in the escape paths.

High fatality fires are usually the result of multiple system and/or process failures, and usually can not be attributed solely to the evacuation strategy. It is easy in hindsight to say that if the occupants had stayed in their rooms they would have survived, but the conditions inside the rooms are not known, and the failure of other systems may have put them at risk.

If information is available on the location of casualties, it can be inferred what evacuation decision was made. However this would not differentiate between occupants who evacuated from a safe place or occupants who evacuated because were forced to by fire or smoke. These are two fundamentally different concepts (Brennan, 1999).

MacDonald's (1985) analysis also does not necessarily represent all building types and modern fire safety measures. New technology, changes to building codes, improved fire fighting techniques, fire safety research and regular maintenance have improved fire safety, and therefore reduced the risk of high fatality fires in new apartment buildings.

To determine if non-evacuation is more effective than evacuation, the number of occupants that survive using an evacuation strategy needs to be analysed, to determine if the probability of survival is increased by not evacuating. Information on the number of injuries due to evacuation could also support the case for non-evacuation, but again the data is limited.

In Appendix A, there are some summaries of fatal residential fires cases. These fires have been reported in journals and usually have multiple fatalities. Therefore there is high probability that some deaths would have occurred in the escape paths.

12.2.2 Case summary discussion

The fire case summaries in Appendix A, is by no means a comprehensive analysis of apartment fires. However the following trends and conclusion can be inferred from the cases:

- Occupants on the level of fire origin or above the level of fire origin are most at risk. There are very few fatalities below the level of fire origin.
- Catastrophic fires are generally the result of system failure(s) or arson. The failure of compartmentation and smoke detectors are a primary contributor to the fatalities.
- Fatalities are caused by poor decision making. Occupants have attempted to remove burning sofas, thereby blocking escape paths and contributing to the fire and smoke spread.
- Arson is a primary contributor to fatalities, especially where fires have been lit in stairways. In 1997 arson was the major cause of catastrophic fires (Tremblay and Fahy, 1998).
- Doors play a significant role in controlling fire and smoke spread. In many cases, if self-closers had not been de-activated, or if occupants had not opened their door, they may have survived.
- The ignition source of many of the catastrophic fires is cigarettes. The other major causes of fires are heaters and electrical faults.
- The occupants at highest risk are children. A large proportion of the victims in catastrophic apartment fires are children. Another high-risk group is occupants who are intoxicated.
- Occupants in board and care facilities are also a high-risk group. These occupants are usually mentally or physically disabled which affects their judgement and evacuation time.
- Fire in corridors and stairs are extremely dangerous.

12.3 Staged Evacuation

A staged evacuation emergency strategy involves prioritising the evacuation of the building, with respect to the occupants who are most at risk. Staged evacuation is an "in-between" strategy, combining elements of full evacuation and non-evacuation. In general high-rise buildings would benefit most from a staged evacuation strategy, because occupants remote from the fire may not be at risk and may not even have to evacuate.

General concepts for staged evacuation:

- Compartmentation between floors needs to be maintained and two compartments on each floor is recommended (Sherry, 1983). The simplest way to achieve this is with a fire separation of the corridor into two of more compartments.
- An emergency warning and information system (EWIS) should be provided. This provides a means of directing the evacuation, communicating with the occupants and reassuring the occupants.
- On alarm, the EWIS system will evacuate the fire floor and floors above (using a pre-recorded message). On arrival, the fire brigade can co-ordinate the remainder of the evacuation.
- Manual call points should not be connected to the EWIS. If a call point is activated that is not on the fire floor, the evacuation priority of the floors could be erroneous.
- The detection system in the apartments and corridors should be used to activate the EWIS. An analogue addressable system can be used to identify the fire location.
- Provisions will need to be made to minimise false alarms. Cross zoning the detection system, and sensitivity setting of the detectors, can be used to minimise the chance of false alarms.

A staged evacuation strategy maybe more expensive due to a more costly alarm and detection system. As the complexity of the emergency strategy increases, so does the level of technology required to control the evacuation and inform the occupants.

Some of the problems with a staged evacuation or zone evacuation system are:

- Compartmentation of floors is required (Sherry, 1983). Occupants waiting to evacuate need to be protected either in their apartments or in lobbies.
- A voice alarm system and pre-recorded messages are required (Sherry, 1983). Problems can occur if an unforeseen scenario arises or the fire spreads. An automated system will only be able to cope with a limited number of situations and unique fire circumstances could defeat the system.
- The alarm system must be thoroughly tested (Sherry, 1983), to ensure it operates correctly for all credible fire scenarios.
- The evacuation scheme must be understood by all occupants (Sherry, 1983). Education and training of occupants will ensure they know how to react and follow the instructions. Information about system limitations and fire safety is also important to ensure occupants know how to react if the system fails.
- Complexity (Sherry, 1983). The simpler the system the less chance of system failure and confusion for occupants.
- The alarm needs to be audible to all occupants. It is important that voice instructions are clear and able to be understood by occupants. This may require speakers in each apartment.

The buildings in which staged evacuation systems may be appropriate depend on the building characteristics and the fire safety measures. Sherry (1983) recommends buildings greater than 14 storeys, and/or occupied by more than 1000 people, would benefit from a staged evacuation scheme.

13 FIRE SAFETY MATRIX

The objective of this fire safety matrix is to provide a guide for the fire engineering design of apartment buildings. The matrix is only intended for guidance and an appropriately qualified fire safety engineer should verify the final design.

The three main fire scenarios that should be considered in the design of apartment buildings are: a smouldering fire in an apartment, a flaming fire in an apartment and a fire in common spaces (ie stairs and corridors).

Irrespective of the building and occupant characteristics, some minimal fire safety measures should be implemented in all apartments. The following is a list of essential fire safety measures that should be provided in all apartment buildings:

- Smoke detectors
- Heating, ventilation and air conditioning (HVAC) system to shut down on fire alarm
- A 30-minute minimum fire resistance between apartments, vertical shafts and floors.

13.1 Emergency strategy

Brief descriptions of the emergency strategy, or emergency plans used in the matrix are provided below.

- Evacuation – on alarm all occupants evacuate the building.
- Non evacuation – occupants in the room of fire origin evacuate the building. Other occupants remain in their rooms, waiting for fire brigade assistance and advice, and carry out protect-in-place activities.
- Staged evacuation – occupants in the room of fire origin and on the fire floor evacuate first. The remaining occupants are directed to evacuate automatically in the following sequence until the fire brigade intervenes. Occupants immediately

above the fire floor evacuate after those on the fire floor, followed by the floors above. Occupants on levels below the fire floor are evacuated last.

Fire brigade intervention can alter the sequence of evacuation, or halt the evacuation in response to current conditions or any changes.

13.2 Occupants at risk

For the three fire scenarios and the three emergency strategies, the following matrix outlines the occupants that are most at risk.

	Smouldering fire	Apartment fire	Public area fire
Evacuation	• Apartment of fire origin	• Apartment of fire origin • Floor of fire origin • Evacuating occupants above fire floor	• Floor of fire origin • Evacuating occupants above fire floor
Non-Evacuation	• Apartment of fire origin	• Apartment of fire origin	• Floor of fire origin
Staged Evacuation	• Apartment of fire origin	• Apartment of fire origin • Floor of fire origin • Evacuating occupants above fire floor	• Floor of fire origin • Evacuating occupants above fire floor

13.3 Matrix variables

The fire safety design of apartment buildings consists of numerous variables and interdependencies. These variables have to be considered concurrently to provide the most effective design.

The selection of fire safety measures in many cases results in a trade-off between various alternatives. For example, sprinkler protection can permit a reduction in fire resistance rating required for buildings and may allow extended travel distances. These trade-offs and interrelationships between fire safety measures need to be considered to obtain the most efficient and effective fire safety design.

Table 14 lists some of the fire safety measures that should be considered for apartment buildings. The variables presented are not a comprehensive list, and other fire safety measures may be more appropriate for more complex designs.

Table 14 – Matrix variables

Variables	Sub-variables	Comments
Building and egress characteristics	• **Building characteristics** Building height Multiple occupancies or purpose groups Floor area No. of apartments Security bars	Usually governed by architectural and project constraints. The options assume each floor of the building is a separate fire compartment and the vertical shafts are separate fire compartments.
	• **Egress characteristics** Number of stairs Emergency lifts Protected paths Travel distances Exit widths Emergency lighting and signs	All doors opening into escape paths should have self-closers.
	• **Passive protection** Fire resistance ratings Self-closers on doors Smoke seals on doors Smoke doors in corridors Smoke and fire dampers Fire rated escape paths Low passive protection High passive protection	Low and high protection is to distinguish between occupants who are escaping and those who remain in their unit. Occupants outside their room will be partially protected or have a lower level of protection.
	• **Refuge areas** Refuge floors Refuge areas	Refuge areas should be provided for the disabled or they should be instructed to remain in their apartment. This needs to be incorporated into the building's emergency plan.
Fire Safety Systems	• **Detection** Smoke detectors Heat Detectors Analogue addressable system Central/local detectors Manual call points	Smoke detectors should be provided in all apartments. Hard-wired detectors are preferred.
	• **Alarm** Sounders Emergency warning and intercommunication system (EWIS) Connection to fire brigade	The alarm system will be more effective if located in apartments. Sound levels achieving a minimum of 75 dB at bed head with doors closed.

	Fire indicator panels Mimic panels • **Suppression** Sprinkler protection Fire extinguishers Fire hose reels Fire hydrants • **Smoke Control** Extraction HVAC shut down Compartmentation Pressurisation Zoned smoke control	Sprinklers provide the highest level of property and life safety protection Fire extinguishers and fire hose reels should be provided to Building Code requirements. Smoke control compartmentation includes smoke lobbies and corridor smoke barriers. Pressurisation systems should not activate on detection of a fire in the area to be pressurised area. This is to prevent smoke spread.
Emergency plan	Evacuation Non-evacuation Staged evacuation	
Inspection and Maintenance	Frequency of testing and checking of active and passive systems Maintenance of escape paths and keeping them of combustibles	Regular maintenance to relevant Standards and Building Codes
Training and Education	Frequency of fire drills Fire safety briefings Pamphlets and literature Simulate realistic conditions ie use theatrical smoke and reduced lighting	Fire safety training and emergency plan training Building wardens
Occupant characteristics	Age Mental and physical ability/mobility Education Cultural background	
Fire brigade intervention	Alarm time (connection to the fire brigade) Time to reach apartment Time to set up and access floor Time to fight fire/search and rescue Communication with occupants Water availability	

Fire	Internal fire spread External fire spread Fire growth rate Fire development stages Fire size Flashover Enclosure effects	Internal fire spread includes linings and combustible materials. External fire spread includes spandrels, balconies and separation distances.

13.4 Buildings greater than 25m

The fire safety matrix for buildings greater than 25m high is presented in Table 15. The matrix provides the recommended fire safety measures for apartment buildings with respect to sprinkler protection and the emergency strategy. The matrix provides a simple method of determining some of the minimum fire safety requirements of an apartment building. It can also be used to evaluate which type of emergency strategy would be most effective, or when sprinklers would be beneficial given certain building conditions. The justification of the recommended fire safety measures is provided in Section 14.1.

Table 15 – Fire safety matrix: buildings greater than 25m

	Sprinkler Protected	Non-sprinkler protected
Evacuation	• FRR 30 • Refuge areas • Pressurised stairs • Self-closers and smoke seals on apartment and escape path doors • Connection to the fire brigade	• FRR 60 • Connection to fire brigade • Emergency lifts • Stair and lift lobbies • Refuge areas (pressurised) • Self-closers and smoke seals on apartment and escape path doors • EWIS • Zoned smoke control with stair and corridor pressurisation • Additional egress routes (pressurised)
Non-evacuation	• FRR 60 • Self-closers and smoke seals on apartment and escape path doors • Connection to fire brigade	• FRR 90 • Connection to fire brigade • Emergency lifts • Lift and stair lobbies • EWIS • Self-closers and smoke seals on apartment and escape path doors • Stair pressurisation
Staged evacuation	• FRR 60 • Cross zoned detection • Connection to fire brigade • Refuge areas • Pressurised stairs • EWIS • Self-closers and smoke seals on apartment and escape path doors	• FRR 90 • Cross zoned detection • Connection to fire brigade • Refuge areas (pressurised) • Emergency lifts • Lift and stair lobbies • EWIS • Self-closers and smoke seals on apartment and escape path doors • Zoned smoke control with stair and corridor pressurisation

The fire safety measures listed in the above matrix are designed to provide at least two levels of protection for the occupants. As the building height increases, the number of fire protection measures also increases to provide additional levels of protection and maintain the level of safety for the occupants.

Table 16 summarises the occupants who are most at risk and the levels of fire safety provided by the above fire safety matrix. Table 17 provides the cell key for identifying the designated cells in Table 16. This key remains the same for all cases presented.

Table 16 – Levels of fire safety (buildings greater than 25m)

Cell	Occupants most at risk	Levels of fire safety
1	• In apartment of fire origin • On floor of fire origin	Sprinklers, low passive protection, pressurised stairs, fire brigade
2	• In apartment of fire origin • On floor of fire origin • All occupants escaping	High passive protection, short travel distances to protected exit paths, zoned smoke control, fire brigade
3	• In apartment of fire origin	Sprinklers, passive protection, fire brigade
4	• In apartment of fire origin • On floor of fire origin	High passive protection, fire brigade.
5	• In apartment of fire origin • On floor of fire origin	Sprinklers, high or low passive protection (depends on occupant location), pressurised stairs, fire brigade
6	• In apartment of fire origin • On floor of fire origin • Occupants evacuating	High or low passive protection (depends on occupant location), zoned smoke control, fire brigade.

Table 17 – Cell key

	Sprinkler Protected	Non-sprinkler protected
Evacuation	1	2
Non-evacuation	3	4
Staged evacuation	5	6

13.5 Buildings greater than three storeys and less than 25m

The fire safety matrix for buildings greater than three stories and less than 25m high is presented in Table 18. The justification of the recommended fire safety measures is provided in Section 14.2.

Table 18 – Fire safety matrix: buildings greater than three storeys and less than 25m

	Sprinkler Protected	Non-sprinkler protected
Evacuation	• FRR 30 • Refuge areas in stair shaft • Self-closers and smoke seals on escape path doors	• FRR 60 • Refuge areas for disabled in stairs • Stair smoke lobbies • Self-closers and smoke seals on apartment and escape path doors
Non-evacuation	• FRR 60 • Connection to fire brigade • Self-closers and smoke seals on apartment and escape path doors	• FRR 90 • Connection to fire brigade • Self-closers and smoke seals on apartment and escape path doors
Staged evacuation	• FRR 60 • Connection to fire brigade • Refuge areas in stair shaft • EWIS • Self-closers and smoke seals on apartment and escape path doors	• FRR 90 • Connection to fire brigade • Refuge areas in stair shaft • Stair smoke lobbies • EWIS • Self-closers and smoke seals on apartment and escape path doors

Table 19 – Levels of fire safety (buildings greater than three storeys and less than 25m)

Cell	Occupants at risk	Levels of fire safety
1	• In apartment of fire origin • On floor of fire origin	Sprinklers, low passive protection, fire brigade
2	• In apartment of fire origin • On floor of fire origin • All occupants escaping	Low passive protection, smoke lobbies, fire brigade
3	• In apartment of fire origin	Sprinklers, high passive protection, fire brigade
4	• In apartment of fire origin • On floor of fire origin	High passive protection, fire brigade.
5	• In apartment of fire origin • On floor of fire origin	Sprinklers, high or low passive protection (depends on occupant location), fire brigade
6	• In apartment of fire origin • On floor of fire origin • Occupants escaping	High or low passive protection (depends on occupant location), fire brigade.

13.6 Buildings less than three storeys

The fire safety matrix for buildings less than three stories is presented in Table 20. The justification of the recommended fire safety measures is provided in Section 14.3.

Table 20 – Fire safety matrix: buildings less than three storeys

	Sprinkler Protected	Non-sprinkler protected
Evacuation	• FRR 30 • Disabled occupants above ground floor remain in apartment	• FRR 60 • Self-closers and smoke seals on apartment and escape path doors
Non-evacuation	• FRR 60 • Connection to fire brigade • Self-closers and smoke seals on apartment and escape path doors	• FRR 90 • Connection to fire brigade • Self-closers and smoke seals on apartment and escape path doors
Staged evacuation	• FRR 60 • Self-closers and smoke seals on apartment and escape path doors • EWIS • Connection to fire brigade • Disabled occupants above ground floor remain in apartment	• FRR 90 • Self-closers and smoke seals on apartment and escape path doors • EWIS • Connection to fire brigade

Table 21 – Levels of fire safety (buildings less than three storeys)

Cell	Occupants at risk	Levels of fire safety
1	• In apartment of fire origin • On floor of fire origin	Sprinklers, low passive protection, fire brigade
2	• In apartment of fire origin • On floor of fire origin • All occupants escaping	Low passive protection, smoke lobbies, fire brigade
3	• In apartment of fire origin	Sprinklers, high passive protection, fire brigade
4	• In apartment of fire origin • On floor of fire origin	High passive protection, fire brigade.
5	• In apartment of fire origin • On floor of fire origin	Sprinklers, high or low passive protection (depends on occupant location), fire brigade
6	• In apartment of fire origin • On floor of fire origin • Occupants escaping	High or low passive protection (depends on occupant location), fire brigade.

14 DISCUSSION OF FIRE SAFETY MATRIX

The fire safety matrix considers the building height, sprinkler protection and the emergency strategy as the primary variables. This is due to the high influence that the interactions of these variables have on other fire safety measures. In addition to this, the fire engineer can specify the emergency strategy and sprinkler protection for the building that will provide flexibility to the matrix. Therefore once the extent of these three variables has been determined the remaining fire safety systems can be selected to suit the building.

The objective of the fire safety recommendations is to address key issues that result from a given set of building characteristics, while providing multiple levels of protection for occupants in the event of a fire. This provides a backup or redundancy in the design in the event of one part of the system failing. For example, if the sprinkler system fails the occupants will be protected with passive protection and smoke control systems.

The following sections discuss the three building height limits with respect to the fire safety measures that have been recommended. The staged evacuation strategy has not been discussed separately as it is a combination of the other two strategies and the same fundamental principles apply.

14.1 Buildings greater than 25m in height.

Once buildings exceed 25m in height, the ability of the fire brigade to rescue occupants externally becomes limited. Therefore, a higher level of fire safety needs to be provided to the stairs and escape paths. Emergency lifts are also considered an option to provide rapid access for the fire brigade and egress for disabled occupants.

As buildings become taller the level of fire protection needs to increase. This is due to:

- Further travel distances, resulting in a higher chance of exposure to fire and fire products, and longer exposure time.
- The reduced ability of the fire brigade to rescue people externally
- The increased time for the fire brigade to reach upper levels
- More occupants, resulting in a higher risk of injury and deaths

- There is a greater variability in occupant abilities and human behaviour, due to the greater number of occupants

- There are more sources of ignition and fire

14.1.1 Evacuation in buildings greater than 25m

An evacuation strategy relies on the protection of egress paths, as well as the protection of occupants in their apartments before evacuation. The protection of egress paths is critical to ensure occupants are not evacuating through untenable conditions. In buildings greater than 25m high, egress distances can be considerable and therefore, the time occupants spend in escape paths can be significant.

In a sprinkler protected building, protection is provided by:

1. The sprinkler system. The sprinklers will activate and extinguish or control the fire, reducing the threat to occupants.

2. Compartmentation and mechanical systems. Rooms, corridors and stair shafts are recommended to have a FRR of at least 30 minutes. This will contain the fire in the room of origin and protect occupants before and during egress. Self-closers provided on doors are to ensure the fire does not spread to the corridor. The stairs are to be pressurised to limit smoke spread, provide a partial safe egress paths and provide a smoke free area for the fire brigade.

3. The final level of protection is the fire brigade. The fire brigade's role would be to assist any remaining occupants and extinguish the fire. A connection to the fire brigade will be provided to achieve a faster response.

In a non-sprinkler protected building the systems of protection are 2 and 3, as listed above, however the following other fire safety measures will be introduced to increase the level of protection:

1. An increased FRR to 60 minutes minimum. This is to provide additional time for occupant evacuation and fire brigade intervention. If occupants choose to stay in their apartments the increased FRR will provide a higher level of protection.

2. Connection to the fire brigade. To ensure a faster response by the brigade to a fire.

3. Emergency lifts to aid egress and fire brigade access

4. Zoned smoke control system. This is to ensure smoke spread through the building is minimised. This should include stair and corridor pressurisation to reduce the chance of smoke spread into the escape paths.

5. Lift and stair lobbies to provide an additional barrier against smoke and an area where occupants can wait for lifts or further instructions. These areas can be used as refuge areas or other pressurised refuge areas should be provided.

6. Emergency warning and intercommunication system. This will allow occupants to communicate with the fire brigade and inform them if assistance is required.

7. Additional protected stairs or reduced travel distances, as a trade-off for the limited ability of the fire brigade to externally rescue occupants.

14.1.2 Non-evacuation in buildings greater than 25m

A non-evacuation strategy relies on the protection of the occupants in their apartments. There is a greater reliance on the fire brigade to extinguish the fire and assist occupants, if evacuation is necessary, during and after the fire is extinguished.

In a sprinkler protected building, protection is provided by:

1. The sprinkler system.

2. Compartmentation and mechanical systems. The rooms are recommended to have a FRR of at least 60 minutes and to protect the occupants. The fire resistance rating should be designed so complete burn out of the apartment will not result in further fire spread. Self-closers and smoke seals should be provided on all doors opening into corridors. This is to contain the fire in the apartment of origin and reduce smoke spread to other apartments. In theory, there will be at least two doors with smoke seals between the fire and occupants.

3. The final level of protection is the fire brigade. The building alarm should be connected to the fire brigade to reduce the response time.

In a non-sprinkler protected building the systems of protection are 2 and 3, as listed above, however the following other fire safety measures will be introduced to increase the level of protection:

1. Increase FRR to 90 minutes (minimum). This is to ensure complete burnout occurs before further fire spread.

2. Emergency lifts to aid egress and fire brigade access

3. Lift and stair lobbies to provide protection for the fire brigade, or areas of refuge if occupants choose to escape.

4. Stair pressurisation to provide a smoke free path for the fire brigade

5. Emergency warning and intercommunication system. This will allow occupants to communicate with the fire brigade and inform them of any assistance that is required. It will also provide a means for the fire brigade to instruct the occupants.

14.2 Buildings greater than three storeys and less than 25m

Buildings that are greater than three storeys and less than 25m, have different fire safety issues than buildings greater than 25m. The most notable of these is the fire brigade is able to rescue occupants and fight the fire externally, provided adequate access is provided and a window exists. The travel distances are also reduced, decreasing the time for occupants to evacuate and the fire brigade to reach the fire.

The transfer of information may also increase, as occupants are relatively closer together. This increases their ability to communicate with other occupants and to perceive visual and audible cues.

14.2.1 Evacuation in buildings greater than three storeys and less than 25m

This emergency strategy relies on the protection of the egress paths as well as the protection of the occupants in their compartments before they evacuate. The protection of the egress paths is critical to ensure occupants are not evacuating through untenable conditions. Egress travel distances are less and therefore, the duration of occupant exposure to smoke is reduced.

In a sprinkler protected building, protection is provided by:

1. The sprinkler system.

2. Compartmentation and mechanical systems. The apartments, corridors and stair shafts are recommended to have a FRR of at least 30 minutes. This will protect occupants before and during egress. Self-closers and smoke seals should be provided on all escape path doors.

3. The final level of protection is the fire brigade.

In a non-sprinkler protected building the levels of protection are 2 and 3, however the following other fire safety measures will be introduced to increase the level of protection:

1. Increase FRR to at least 60 minutes to allow the complete burn out of the apartment without fire spread into the corridors or adjacent rooms.

2. Self-closers on doors to contain the fire and smoke spread.

3. Refuge areas in stairs for disabled occupants.

4. Stair lobbies to provide two smoke and fire barriers for occupants in the stair refuge areas.

14.2.2 Non evacuation in buildings greater than three storeys and less than 25m

A non-evacuation strategy relies on protection of occupants in their apartments. There is a greater reliance on the fire brigade to extinguish the fire and assist in the evacuation after the fire is extinguished. The fire brigade can rescue occupants externally via ladders and fight the fire externally.

In a sprinkler protected building the levels of protection are:

1. The sprinkler system.

2. Compartmentation and mechanical systems. The rooms will have a recommended FRR of at least 60 minutes to protect the occupants. The fire resistance rating should be designed so that the complete burn out of the apartment will not result in further fire spread. Self-closers and smoke seals should be provided on all doors. This is to contain the fire in the apartment of origin and reduce smoke spread into other apartments.

3. The final level of protection is the fire brigade. The building alarm will be connected to the fire brigade to reduce the fire brigade response time.

In a non-sprinkler protected building the levels of protection are 2 and 3, as listed above, however the following other fire safety measures will be introduced to increase the level of protection:

1. The fire resistance rating will be increased to at least 90 minutes. This will ensure the complete burnout of the apartment can occur without further fire spread.

14.3 Buildings less than three storeys

Buildings less than three storeys are generally the maximum size of a building without lifts. The egress distances in these buildings would typically be within the building code's maximum allowable travel distances, and may not require fire rated stair shafts.

The relatively short travel distances result in short movement times, and a fast response from the fire brigade on the arrival. If necessary, occupants could also use unconventional escape routes, for example garden ladders or climbing down balconies. The fire brigade can also rescue occupants externally via ladder and fight the fire externally.

The lack of lifts in buildings of this size may limit the number of mobility impaired occupants that would be present. In general, mobility impaired occupants would be located on the ground floor, where they would be able to escape directly to safety. If disabled occupants are present, it is recommended that they remain in their apartments and wait for rescue. Therefore, they would use a non-evacuation strategy.

14.3.1 Evacuation in buildings less than three storeys

This emergency strategy relies on occupants escaping quickly. Without fire rated stair shafts the occupants have to travel a relatively short unprotected distance to make final escape. Occupants also need to be protected in their apartments before they attempt to escape.

In a sprinkler protected building the levels of protection are:

1. The sprinkler system.
2. Compartmentation and mechanical systems. The apartments are recommended to have a FRR of at least 30 minutes to protect the occupants before and during their egress. There should also be a FRR of 30 minutes in the corridors and stairs, if egress distance is in excess of the building code's prescriptive requirements.
3. The final level of protection is the fire brigade.

In a non-sprinkler protected building the levels of protection are 2 and 3, as listed above, however the following other fire safety measures will be introduced to increase the level of protection:

1. The FRR will be increased to at least 60 minutes. This will ensure the fire does not spread further than the apartment of origin.
2. Self-closers and smoke seals will be provided on all doors. This is to contain the fire in the apartment of origin and reduce smoke spread into other apartments.
3. A connection to the fire brigade will be provided to achieve a faster response.

14.3.2 Non-evacuation in buildings less than three storeys

A non-evacuation strategy relies on the protection of occupants in their apartments. For buildings less than 3 storeys the fire brigade can rescue occupants externally via ladders and fight the fire externally.

In a sprinkler protected building the levels of protection are:

1. The sprinkler system.

2. Compartmentation and mechanical systems. The rooms are recommended to have a FRR of at least 60 minutes and to protect the occupants. The fire resistance rating will be designed so that the complete burn out of the apartment will not result in further fire spread. Self-closers and smoke seals will be provided on all doors. This is to contain the fire in the apartment of origin and reduce smoke spread into other apartments.

3. The final level of protection is the fire brigade. The building will be connected to the fire brigade to reduce the time for fire brigade arrival.

In a non-sprinkler protected building the levels of protection are 2 and 3, however the following other fire safety measures will be introduced to increase the level of protection:

1. The fire resistance rating will be increased to a minimum of 90 minutes to ensure the fire does not spread further than the apartment of origin.

14.4 Risk and Reliability

The assessment of the absolute risk to life safety to apartment building occupants is an extremely difficult task. The numerous scenarios, variables, limited data and changes in the risk to life safety during a fire incident, makes an assessment of occupant risk very difficult. Each of the eight elements in Figure 1 will have an impact on the risk to life safety and this level of risk will change during a fire incident. For example occupants on level of fire origin will have a relatively high risk, but if they move below the level of fire origin their risk to life safety will decrease.

An assessment of the relative risk to life safety is a more feasible option, but again the numerous variables and limited data makes this difficult. Previous research by Beck and Yung (1990) used a risk assessment model to assess the expected risk to life and fire cost expectations of apartment buildings relative to the building code.

An assessment of the relative life safety is simpler, and in some cases intuitive. In many instances, a qualitative relative risk assessment can be made. For example, given the same building, sprinkler protection would be safer than no sprinkler protection. However, a relative assessment of life safety becomes more complex if different fire safety systems are assessed against each other. For example, is a building with a FRR 60 safer than a building with a FRR 30 and pressurisation?

The absolute risk to life safety in the matrix cells is expected to different and they have not been designed to provide an equivalent level of safety for all occupants. Intuitively, it can been seen that occupants in a three storey sprinkler protected building would have a relatively higher level of life safety than occupants in a thirty storey sprinkler protected building irrespective of the other fire safety measures. Both buildings can be designed to be safe, but they may not have an equivalent level of risk to life safety.

The reliability of fire safety measures is another important aspect that needs to be considered in a quantitative risk assessment. Previous sections in this report, contain reliability values for some of the fire safety measures. This data has been included to provide an indication of the reliability of the fire safety measures and their failure modes.

Reliability data for some systems is available, but this is pretty limited and there is no correlations between the risk to life safety and the reliability of a system. For example a stair pressurisation system may work as designed, but fatalities could still occur. Some other difficult problems are questions such as, does a 60 minute FRR provide a higher level of safety than a 30 minute FRR and is a 30 minute fire rated wall more reliable than a 60 minute wall?

Information on the reliability of a fire safety measure is not enough to determine the risk to life safety of the occupants. The reliability data needs to be assessed in conjunction with the ability of the fire safety measures to protect occupants to provide some sort of measure of effectiveness.

The effectiveness of sprinklers and smoke detectors has been estimated in a study by NIST. The study found that in home fires:

- The introduction of smoke detectors will reduce death rates by 52%. If sprinkler protection was introduced after the smoke detectors, the death rate would be reduced by a further 30%, resulting a total reduction in the death rate of 82% (Hall, 1993).

- If sprinklers were introduced first the death rate would be reduced by 69%. Adding smoke detectors would reduce the death rate by a further 13%, resulting a total reduction in the death rate of 82% (Hall, 1993).

- Sprinklers do not operate properly 8% of the time and smoke detectors do not operate properly 15% of the time (Hall, 1993).

- Detectors are non-operational 32% of the time when a fire occurs (Hall, 1993).

This information of this type would be very useful in a quantitative risk assessment, however for other fire safety measures it is not readily available. In addition to this, it is difficult to assess the contribution of an individual fire safety measure to the safety of occupants. The safety of occupants is usually provided through the combination and interaction of different fire safety measures. Therefore the assessment of the contribution to life safety from individual safety measures is difficult without the consideration of these interdependencies.

Another problem is that some fire safety measures provide protection indirectly. For example sprinkler protection would provide direct protection, but smoke detectors will provide indirect protection. Direct protection can be defined as the fire safety measures that can directly affect the fire or products of combustion.

The limited information and data available makes it difficult to assess the matrix quantitatively. A relative risk assessment of the matrix with respect to the building code would be the next logical stage, but the statistics on the effectiveness of the fire safety systems is limited. Reliability data is relatively easy to determine, but data on the ability of a fire safety measure or a combination of measures to increase life safety is difficult to determine.

Some of the problems with a quantitative risk assessment are:

- Limited data
- Assessment of matrix variables
    - Fire safety systems. Assessment of reliability and effectiveness of fire safety systems.
    - Fire. Assessment of fire growth, spread, production of toxic products.
    - Building characteristics. Level of safety provided by architectural characteristics, number of stairs, egress path widths, travel distances.
    - Occupant characteristics. Assessment of occupant characteristics, human behaviour, physical and mental abilities.
    - Training and Education. Decision making ability of occupants.
    - Maintenance and inspections. Assess the frequency and effectiveness of maintenance program.
    - Fire brigade intervention. Assessment of response time of fire brigade and time to extinguish or control the fire.
- Assessment of interdependencies and interrelationships between matrix variables. For example, the fire size is related to the ability of sprinklers to control the fire.
- Changes to the risk to life safety during a fire. Occupant behaviour, occupant location, occupant characteristics, fire characteristics, fire safety measures and fire brigade intervention can all change as the situation evolves. Therefore the level of risk faced by occupants also changes.

To avoid the inherent difficulties in quantitative risk assessment, the fire safety design matrix is based on providing multiple levels of protection for the occupants. Therefore, if one of the fire safety measures fails, there is at least one other mechanism to provide protection. In addition to this, fire safety training is essential to educate occupants on what to do in the event of a fire, and how to maximise their chances of survival.

15 CONCLUSIONS

Performance based building codes provide an opportunity to increase the level of fire safety in apartment buildings. However, to realise this objective, and maximise the effectiveness of fire safety measures, an integrated fire safety design is required. Guidance on the integration of fire safety measures has been provided, in this project, through the fire safety design matrix and recommended minimum fire safety requirements. This provides a tool for engineers that can be used to ensure the fundamental design issues are considered, and improvements in the fire safety design of apartment buildings are achieved.

The key conclusions of this research report are summarised below.

- A fire safety design matrix has been developed to provide a design guide for apartment buildings. The matrix considers sprinkler protection, building height and the emergency scheme as the primary variables, and recommends minimum fire safety measures that address the fundamental design issues in apartment buildings.

- In some circumstances non-evacuation may be an appropriate emergency strategy. For certain building characteristics and fire safety measures, the benefits of a non-evacuation strategy appear to outweigh the advantages of an evacuation strategy.

- Lifts are an option for occupant egress. Careful consideration needs to given to the design and operation of fire lifts, as well as occupant training and education.

- Fire brigade intervention should be considered in the fire safety design. The fire brigade has an essential role in assisting the evacuation and suppressing the fire. The fire brigade is also the final level of protection, for occupants, in the event of a multiple system failure.

- There is limited statistical data on the effectiveness of fire safety measures and the interdependencies between measures. To perform a quantitative risk assessment more data is required on the impact to life safety of various fire safety measures.

Statistical fire data for Australia is limited. The collection and analysis of fire statistics is extremely important, to determine if current fire safety measures are effective, and areas where improvements can be made. The publishing of fire statistics should be continued to provide valuable information for designers and researchers.

There should be higher level of detail provided in the collected fire data. To establish the viability of a non-evacuation strategy, information is required on the locations of victims and their assumed actions. Details of injuries in fires could also provide valuable information on the effectiveness of different emergency strategies.

- The fire case summaries have shown that well-known problems are still causing fatalities. Doors being left open, the disabling of smoke detectors, ineffective alarm systems and incorrect disposal of smoking materials have resulted in numerous fire deaths.

- The case summaries have also shown that education and training are extremely important aspects of fire safety. A number of fatalities could have been prevented if occupants acted appropriately.

  Training and education should be provided in the emergency strategy, use of first aid fire equipment and fire safety.

16 REFERENCES

ABCB (Australian Building Codes Board), 1996, Building Code of Australia (BCA), Australia.

Aherns, M., 1998, "Batteries Not Included", NFPA Journal, May/June 1998.pg 99-109.

Andersson, C. and Wadensten, K., 2000, Elevator Evacuation of a High-rise Building, Ove Arup and Partners.

Beck, V. R., Thomas, I. R., Ramsay, G. C., MacLennan, H., Lacey, R., Johnson, P. and Eaton., 1992, "Risk Assessment and the Design of Fire Safety Systems in Buildings", Fire Hazard and Risk Assessment, ASTM STP 1150, Macelo M. Hirschler Ed., pg 209-223.

Beck, V. R. and Yung, D., 1990, "A Cost Effective Risk Assessment Model For Evaluating Fire Safety and Protection In Canadian Apartment Buildings", Journal of Fire Protection Engineering, vol 2, no. 3, pg 65-74.

Beever, P. and Britton, M., 1999, Research into the Cost Effective Fire Safety Measures for Residential Buildings, Building Control Commission, Melbourne. Centre for Environmental Safety and Risk Engineering, Victoria University of Technology.

Bell, J. R, 1983a, "24 Die in Los Angeles Residential Apartment Building Fire", Fire Journal, 77, (3), pg 43-46.

Bell, J. R, 1983b, "Five Die in Rockefeller Park Towers Fire, Cleveland Ohio", Fire Journal, 77, March, pg 63-65.

BIA (Building Industry Authority), 1991, Acceptable Solutions C1 – C4, Standards New Zealand, 181-187 Victoria Street, Wellington.

Brennan, P., 1997, "Timing Human Response in Real Fires", Fire Safety Science, Proceedings of the 5th International Symposium, pg 807-818.

Brennan, P., 1999a, "Successful Evacuation in Smoke: Good Luck, Good Health or Good Management?", Interflam 1999, Proceedings from the 8th International Fire Science and Engineering Conference, pg 697-706.

Brennan, P., 1999, "Victims and Survivors in Fatal Residential Building Fires", Fire and Materials, Vol 23, pg 305-310.

Bruck, D., 1998, Arousal from Sleep with a Smoke Detector in Children and Adults, FCRC Project 4, Technical Report FCRC-TR 98-04, Fire Code Reform Centre.

Bruck, D., Horasan, M., 1995, "Non-arousal and Non-action of Normal Sleepers in Response to a Smoke Detector Alarm", Fire Safety Journal, vol 25, pg 125-139.

Bryan, J. L., 1999, "Human Behaviour in Fire: The Development and Maturity of a Scholarly Study Area", Fire and Materials, Vol 23, pg 249-253.

BSI, 1998, Fire Precautions in the Design and Construction of Buildings – Part 8. Code of Practice for Means of Escape for Disabled People, BS 5588 Part 8.

Buchanan, A. H., 1994, Fire Engineering Design Guide, Centre of Advanced Engineering University of Canterbury.

Bukowski, R. W. and O'Laughlin, 1996, Fire Alarm Signalling Systems, Ch 7, NFPA, USA.

Bukowski, R. W., Budnick, E. K. and Schemel, C. F., 1999, "Estimates of the Operational Reliability of Fire Protection Systems", International Conference on Fire Research and Engineering (ICFRE3), 3rd Proceedings, SFPE, NIST and IAFSS, October 4-8, 1999, Chicago, pg 87-89.

Bush, K., 1991, "Apartment Buildings", NFPA Fire Protection Handbook, 17th Edition, NFPA, pg 8/122-8/127.

Canter, D., 1990, Fires and Human Behaviour, 2nd Edition, David Fulton Publishers London.

Chapman, E. F., 1993, "13 Criteria for Safe Elevator Design", NFPA Journal, May/June 1993, pg 51.

Conley, C. J. and Fahy, R. F., 1994, "Who Dies in Fires in the United States", NFPA Journal, May/June, pg 99-106.

Cote, B., Klem, T. and Wall, W. P., 1984, "Five Die at Texas Ramada Inn", Fire Journal, March 1984, pg 55-65.

Cote, R., 1997, NFPA – Life Safety Code Handbook, NFPA, USA

De Vita, A. W a V. D., 1988, "Fatal Fire on East 50th: building size and conditions complicated operations, but occupants who stayed in their apartments remained safe" WNYF, No. 1 2-7.

Degenkolb, J., 1991, "Elevator Use During a Building Fire", ASME Symposium on Fire and Elevators, Baltimore, MD, Feb 19-20, 1991, American Society of Mechanical Engineers, New York, NY, pg 76-79.

Dektar, C., 1983, "24 Killed in apartment fire", Fire Eng 136, (1) 44-45.

Demers P, January 1980, "Familiar Problems Causes 10 Deaths in Hotel Fire" Fire Journal, National Fire Protection Association, pg 52-56.

Department of the Environment, Transport and the Regions, 2000, Approved Document B, The Building Regulations 1991 – Fire Safety, Department of the Environment, Transport and the Regions, Eland House, Bressenden Place, London.

Dowling, V. P., and Ramsay, G. C., 1997,"Building Fire Scenarios-Some Fire Incident Statistics", Fire Safety Science, Proceedings of the 5th International Symposium, pg 643-654.

Duncanson, M., Woodward, A., Reid, P. and Langley, J., 2000, "Unintentional House Fire Deaths in New Zealand 1991-1998", New Zealand Public Health Report, vol 7 no. 7/8, July/August 2000, pg 31-34.

Fahy, R. F. and Proulx, G., 1995, "Collective Common Sense: A Study of the Human Behaviour During the World Trade Centre Evacuation", NFPA Journal, March/April, pg 59-67.

Fahy, R. F. and Proulx, G., 1996, "A Study of Occupant Behaviour During the World Trade Centre Evacuation", Interflam 1996, Proceedings of the 7th International Fire Science and Engineering Conference. pg 793-802.

Fahy, R. F. and Sapochetti, J. I., 1999, "Human Behaviour Modelling As A Part of An Engineering Design", Interflam 1999, Proceedings from the 8th International Fire Science and Engineering Conference, pg 747-756.

Fahy, R. F. and Tremblay, K.J., 1991, "Catastrophic Fires of 1990", NFPA Journal, Sept/Oct 1991, pg 60-73.

FEMA, National Fire Data Centre and United Stated Fire Administration, 1999, Fire in The United States 1987 – 1996, 7th Edition, US Fire Administration, South Seaton Avenue, Maryland.

FCRC, 1996, Fire Engineering Guidelines, First Edition, Fire Code Reform Centre, March 1996.

FEMA - Federal Emergency Management Agency, 1997, Fire in the United States 1985-1994, 9th Edition, US Fire Administration, Federal Emergency Management Agency, Maryland, 21727.

FEMA - Federal Emergency Management Agency, 1999, Fire in the United States 1987-1996, 11th Edition, US Fire Administration, Federal Emergency Management Agency, Maryland, 21727.

Fox, C. C., 1991, "Handicapped Use of Elevators", ASME Symposium on Fire and Elevators, Baltimore, MD, Feb 19-20, 1991, American Society of Mechanical Engineers, New York, NY, pg 80-82.

Gatfield, A, J., 1991, "Elevators and Fire: Designing For Fire Safety", ASME Symposium on Fire and Elevators, Baltimore, MD, Feb 19-20, 1991, American Society of Mechanical Engineers, New York, NY, pg 95-107.

Gaudet, R, July 1967, "Dormitory Fire Kills Nine" Fire Journal, National Fire Protection Association, pg 5-9.

Hall, J. R., 1993, "The US Experience with Sprinklers: Who has Them? How Well Do They Work?", NFPA Journal, Nov/Dec, pg 44-55.

Hall, J. R., 1994, "The US Experience with Smoke Detectors: Who has Them? How Well Do They Work? When Don't They Work?", NFPA Journal, Sept/Oct, pg 36-46.

Hallberg, G., 1988, "Evacuation of Buildings – Practice Makes Safety", Fire Safety Science – Proceedings of the 2nd International Symposium, pg 531-540.

Harvey, C. S., 1992 "The Polo Club Condominium fire, Denver, Colorado", Journal of Applied Fire Science, 2 no. 1, 85-96.

Janse, E. W., Van De Leur, P. H. E. and Van Oerle, N. J., 1998, "Evacuation From Smoke Filled Corridors", Human Behaviour in Fire, Proceedings of the First International Symposium, pg 639-648.

Juillerat, E, (July 1981) "Prevention and Planning Avert Hotel Disaster in Evanston, Illinois" NFPA Quarterly, National Fire Protection Association, pg 52-56.

Karter, M. J. Jr., 1997, "U.S. Fire Loss – 1996", NFPA Journal, September/October, pg 76-83.

King, M., 1997, Australian National Fire Incident Statistics 1993-1994, CSIRO Australia.

Klem, T., 1987, "97 Die in Arson Fire at Dupont Plaza Hotel", Fire Journal, May/June 1987, pg 74-83.

Klote, J. H and Milke J. A. Design of Smoke Management Systems. ASHRAE, 1992.

Klote, J. H., 1983, "Elevators as a Means of Egress", ASHRAE Transactions, Part 1B, Vol. 89, Pg 362-378.

Klote, J. H., 1993, Design of Smoke Control Systems for Areas of Refuge, NIST, NISTIR-5132, March 1993.

Klote, J. H., Deal, S. P., Levin, B. M., Groner, N. E. and Donoghue, E. A., 1993, Workshop on Elevator use During Fires, NIST, NISTR 4993.

Klote, J. H., Levin, B. M. and Groner, N. E., 1995, "Emergency Elevator Systems" ASME 2nd Symposium on Elevators, Fire and Accessibility, Baltimore, MD, Feb 19-21, 1995, American Society of Mechanical Engineers, New York, NY, pg 131-149.

Levin, B. M. and Groner, N. E., 1994, Human Factors Considerations For The Potential Use of Elevators For Fire Evacuations of FAA Air Traffic Control Towers, NIST, NIST-GCR-94-656.

Lo, S. M. and Will, B. F., 1997, "A View to the Requirement of Designated Refuge Floors in High- rise Buildings in Hong Kong", Fire Safety Science, Proceedings of the 5th International Symposium, pg 737-745.

Lo, S. M., 1995, "Fire Safety Design in Buildings of Hong Kong: A Preliminary View", Asia Pacific Building and Construction Management Journal, vol 1, pg 41-50.

MacDonald, J. M., 1985, "Non Evacuation In Compartment Fire Resistive Building Can Save Lives and Makes Sense", Proceedings of the International Conference on Building Use and Safety Technology, pg 169-174.

MacLennan, H. A., Regan, M. A., and Ware, R, 1999, "An Engineering Model for the Estimation of Occupant Premovement and or Response Time and the Probability of their Occurrence", Fire and Materials, Vol 23, pg 225-263.

Marryatt, H. W., 1988, Fire - A Century of Automatic Sprinkler Protection, Australia and New Zealand 1886-1986, Australian Fire Protection Association, Melbourne Victoria.

Meacham, B. J., 1999, "Integrating Human Factors Issues into Engineered Fire Safety Design", Fire and Materials, Vol 23, pg 273-279.

Millar, A. L. and Tremblay, K.J., 1992, "342 Die in Catastrophic Fires in 1991", NFPA Journal, July/Aug 1992, pg 62-73.

Nelson, H. E., 1993, "Fire Modeling Assessment of Areas of Refuge Intended to Provide Safety for Persons with Mobility Limitations", Interflam 1993, Proceedings of the 6th Fire Safety Science Engineering Management Proceedings, pg161-170.

New Zealand Fire Service (NZFS), 1999, 1995-1998 Emergency Incident Statistics, New Zealand fire Service, Wellington, New Zealand.

New Zealand Fire Service (NZFS), 2000, 1998-1999 Incident Investigation Summaries, New Zealand fire Service, Wellington, New Zealand.

NFPA, 1981, "Inn on the Park Hotel Fire" Fire Journal, National Fire Protection Association (May 1981), pg 46-47.

NFPA, 1982a, "Fire at The MGM Grand" Fire Journal, National Fire Protection Association (January, 1982), pg 19-37.

NFPA, 1982, "Investigation Report on the Las Vegas Hilton Hotel Fire", Fire Journal, NFPA, January 1982, pg 52-63.

NFPA, 1995, NFPA Fire Investigations Summary – Dormitory Fire, Oct 25, 1995, NFPA Fire Investigations Department.

NFPA, 1997, NFPA Fire Investigations Summary – Harveys Lake Board and Care Fire, May 13, 1997, NFPA Fire Investigations Department.

NFPA, 1998, NFPA Fire Investigations Summary - Arlington WA Board and Care, April 27, 1998, NFPA Fire Investigations Department.

NFPA, 1999, NFPA Fire Investigations Summary – Apartment Building Fire, Nov 13, 1997, NFPA Fire Investigations Department.

NFPA, 2000, "Board and Care Facility Fire, Detroit Michigan, June 2, 1982",NFPA, Online available http://www.nfpa.org/Research/summaries/detroit.html, 21 August 2000.

NFPA, 2000a, "Ste. Genevieve, Quebec Board and Care Facility Fire Investigations", NFPA, Online available http://www.nfpa.org/Research/summaries/genevieve.html, 21 August 2000.

NFPA, 2000b, "Fraternity House Fire, Berkeley, California, Sept 1990", NFPA, Online available http://www.nfpa.org/Research/summaries/berkeley.html, 21 August 2000.

NFPA, 2000c, "Hotel Fire, Chicago, March 1993", NFPA, Online available http://www.nfpa.org/Research/summaries/chicago.html, 21 August 2000.

Oleszkiewicz, I., 1991, "Vertical Separation of Windows Using Spandrel Walls and Horizontal Projections", Fire Technology, November 1991, pg 334-340.

Pauls, J., 1999, "A Personal Perspective on Research, Consulting and Codes/Standards Development in Fire-related Human Behaviour, 1969-1999, With and Emphasis on Space and Time factors", Fire and Materials, Vol 23, pg 265-272.

Pauls, J., Gatfield, A. J. and Juillet, E. 1991, "Elevator Use and for Egress: The Human Factors Problems and Prospects", ASME Symposium on Fire and Elevators, Baltimore, MD, Feb 19-20, 1991, American Society of Mechanical Engineers, New York, NY, pg 63-75.

Proulx, G. and Sime, J. D., 1991, "To Prevent Panic in an Underground Emergency: Why Not Tell People the Truth?", Fire Safety Science – Proceedings of the 3rd International Symposium, pg 843-852.

Proulx, G., 1995, "Evacuation Timing in Apartment Buildings", Fire Safety Journal, vol 24, pg 229-246.

Proulx, G., 1996, "Critical Factors in High-rise Evacuations", Fire Prevention, July/August, 1996, pg 24-27.

Proulx, G., 1998, "The Impact of Voice Communication Messages During a Residential Highrise Fire", Human Behaviour in Fire, Proceedings of the First International Symposium, pg 265-274.

Proulx, G., 1999, "Occupant Response During a Residential Highrise Fire" Fire and Materials, Vol 23, pg 317-323.

Proulx, G., 2000, "Is it Wise to Evacuate During a Highrise Fire?" Presentation, NFPA Conference, Denver, May 2000.

Proulx, G., and Fahy, R., 1997, "The Time Delay to Start Evacuation: Review of Five Case Studies", Fire Safety Science, Proceedings of the 5th International Symposium, pg783-794.

Proulx, G., Latour, J., and MacLaurin, J., 1994, IR#661, Housing Evacuation of Mixed Abilities Occupants, NRC-CNRC, National Research Council of Canada.

Proulx, G., Latour, J., MacLaurin, J., Pinau, J., Hoffman, L, Laroche C., 1995, IR#706, Housing Evacuation of Mixed Abilities Occupants in High rise Buildings, NRC-CNRC, National Research Council of Canada.

Proulx, G., McQueen, C., 1994, IR#660, Evacuation Timing in Apartment Buildings, NRC-CNRC, National Research Council of Canada.

Quintiere, J. G., 1974, "Some Observations on Building Corridor Fires", 15th Symposium on Combustion, pg 163-174.

Runyan, C. W., Bangdiwala, S. I., Linzer, M. A., Sacks, J. J. and Butts, J., 1992, "Risk Factors for Fatal Residential Fires" New England Journal of Medicine, 327 (12), pg 859-863.

Saunders, W. L., 1997, "Occupant Decision Making in Office Building Fire Emergencies: Experimental Results", Fire Safety Science – Proceedings of the 5th International Symposium, pg 771-782.

Sekizawa, A. I., 1991, "Statistical Analyses on Fatalities Characteristics of Residential Fires", Fire Safety Science – Proceedings of the 3rd International Symposium, pg 475-484.

Sekizawa, A., Ebihara, M., Notake, H., Kubota, K., Nakano, M., Ohmiya, T. and Kaneko, H., 1999, "Occupants' Behaviour in Response to the High-rise Apartments Fire in Hiroshima City", Fire and Materials, vol. 23, pg 297-303.

Semple, J. B., "Vertical Exiting: Are Elevators Another Way Out", NFPA Journal, May/June 1993 pg 49-52.

Sherry, J., (March, 1983) "Real-World Problems with Zoned Evacuation" Fire Journal, National Fire Protection Association, pg 32-33, 55.

Seigel-McKelvey, S., 1999, "Know When to Go", NFPA Journal, May/June 1999, pg 86.

Sime, J. D., 1996, "Assessing Occupant Response Time: A Key Issue For Fire Engineering", in Barham, R., Fire Engineering and Emergency Planning: Research and Applications, London, E&FN Spon, ch. 48, pg 442-449

Sime, J. D., 1996, "Assessing The Occupant Response Safety Factor in Evacuation Time Calculations" Interflam 1996, Proceedings of the 7th International Fire Science and Engineering Conference. pg 763-775.

Sultan, M. A. and Halliwell, R. E., 1990, "Optimum Location for Fire Alarms in Apartment Buildings", Fire Technology, November 1990, pg 242-356.

Taylor, R. E., 1975, "The Carlyle Apartment Fire: Study of a Pressurised Corridor", ASHRAE Journal, Vol. 17, pg 52-55.

Teh, K. J., 1994, "Concepts in the Design for Fire Safety in Tall Buildings", Fire Engineers Journal, March, Pg 18-23.

Teh, Ken-jin, 1994, "Concepts in the Design For Fire Safety in Tall Buildings" Fire Engineers Journal, Pacific Rim ed. Vol 54, no. 172, pg 18-23.

Timoney, T., 1984, "Howard Johnson's Hotel Fire – Orlando, Florida", Fire Journal, Sept 1984, pg 37-45.

Tremblay, K.J. and Fahy, R. F., 1998, "Catastrophic Fires – 1997", NFPA Journal, Sept/Oct 1998, pg 42-57.

Tremblay, K.J., 1993, "Catastrophic Fires and Deaths Drop in 1992", NFPA Journal, Sept/Oct 1993, pg 56-67.

Tremblay, K.J., 1994, "Catastrophic Fire Deaths: The Numbers Are Back Up", NFPA Journal, Sept/Oct 1994, pg 88-106.

Tremblay, K.J., 1995, "Catastrophic Fires of 1994", NFPA Journal, Sept/Oct 1995, pg 48-62.

Tremblay, K.J., 1996, "Catastrophic Fires of 1995", NFPA Journal, Sept/Oct 1996, pg 86-99.

Tremblay, K.J., 1997, "1996 Catastrophic Fires", NFPA Journal, Sept/Oct 1997, pg 46-56.

Tremblay, K.J., 1999, "Catastrophic Fires of 1998", NFPA Journal, Sept/Oct 1999, pg 46-57.

Watrous, L. (January 1972), "Fatal Hotel Fire New Orleans", Fire Journal, National Fire Protection Association, pg 21-24.

Willey, A., (May 1973), "Fire Baptist Towers Housing For the Elderly", Fire Journal, pg 28-36 National Fire Protection Association.

Wolf, A., 1999, "What Went Wrong", NFPA Journal, May/June 1999, pg 84-88.

Wolf, 2000, Chapel Hill Fraternity Fire Strikes Down Five, NFPA, Online available http://www.nfpa.org/Research/Fire_Investigation_Chapel_Hill_Fire/chapel_hill_fire.html, 21 August 2000.

17 APPENDIX A – FIRE CASE SUMMARIES

Table 22 – Fatal residential fire cases

Case	Fatalities/injuries. Significant factors
Dormitory Fire, Cornell University, 1967. (Gaudet, 1967). 3 storey building (including basement), 48 rooms. Fire started in basement.	9 fatalities, 60 injuries. Doors from basement were wedged open. No alarm system was present. Students had to alert others by knocking on doors. 7 victims were found attempting to escape. 2 victims returned to their rooms after leaving their door open and were overcome by smoke.
Hotel, New Orleans, 1971. (Watrous, 1971). 17 storey hotel Fire started in 12th floor room.	6 fatalities. All victims were found on the 12th floor. 5 victims were using the lift for egress and the lift opened on the 12th floor exposing them to heat and smoke. One victim was a staff member investigating the fire. Staff investigating the fire forced open the room door and left it open.
Baptist Towers, 1972. (Willey, 1973) 11 storey apartment building. Fire started in 7th floor apartment.	10 fatalities 9 victims were found on the floor of origin, one victim was found on the 10th floor. Elderly housing building, with occupants having disabilities. Two victims died from burns, the others from CO. One victim was found in the lift. Fire burnt through apartment door and spread to corridor. One occupant stayed in their rooms and used towels to prevent smoke egress.
Cambridge Ohio, Holiday Inn, 1979. (Demers, 1980). 2 storey, 107 guest rooms, 200 guests. The fire started in the first floor corridor that connected the lobby and guest rooms.	10 fatalities, 82 injuries Combustible interior finishes, unprotected vertical openings and inadequate notification of occupants contributed to the fatalities. 5 fatalities were found in the 2nd floor corridor, 2 were found in 2nd floor rooms with their doors open, two were found in the stairs and one died in hospital.

MGM Grand Hotel Las Vegas, 1980. (NFPA, 1982). 21 storey hotel, 3,400 guests. Fire began on ground floor and extensive smoke spread occurred throughout the hotel.	85 fatalities, 600 injuries. 61 victims were found in the tower, 18 were found on the casino level (ground floor), 3 were found on the roof and 3 died in hospital. Of the documented victims in the tower (61), 25 were found in rooms, 22 were found in corridors, 9 in stairways, 5 in lifts.
Inn on The Park Hotel Fire, 1981, (NFPA, 1981). 23 storey hotel. Fire started in electrical room on the 2nd floor.	6 fatalities, 67 injuries. All of the victims were found in one of hotel's 2 exit ways. Hotel telephone operator gave out conflicting information, asking some occupants to evacuate and others to remain in their rooms. Smoke spread through unprotected vertical openings. 20 occupants attempting to evacuate to the roof had to force a locked door.
Las Vegas Hilton, 1981 (NFPA, 1982). 30 storey hotel, 2783 rooms. The fire began on the 8th floor and spread externally to the 28th floor.	8 fatalities, 350 injuries. 3 fatalities in the central tower lobby. 1 occupant fell/jumped. 4 fatalities in guestrooms, evidence that their doors had been opened. No fatalities where occupants kept their door closed.
Orrington Hotel, 1981. (Juillerat, 1981). 8 storey hotel, 60 guests. Fire started in third floor lift lobby.	No fatalities The training and actions of staff contributed to the lack of fatalities. Upgrades to fire safety also increased building safety.
Dorothy Mae Apartment Hotel, 1982. (Bell, 1983a). 4 storey, 43 unit apartment. Fire started on 2nd floor.	24 fatalities, 32 injuries Arson fire started in 2nd floor exit corridor. 19 of the fatalities were located on the 2nd and 3rd floor stairway landings. Doors to stairways were open during the fire.
Rockefeller Park Towers, 1982. (Bell, 1983b) 6 storey apartment, 133 units, 180 residents. Fire started on 3rd floor.	5 fatalities, 17 injuries Apartment consisted mainly of elderly occupants that had various disabilities. There were delays in fire brigade notification. Failure to close doors allowed smoke into the corridors. All victims were occupants of the 3rd floor and were found near the room of origin. Many occupants waited in their apartments for rescue.

Ramada Inn, 1983. (Cote et al, 1984) 2 storey hotel, 80 rooms, 90 guests. Fire started in first floor corridor igniting rolls of carpet and padding.	5 fatalities, 33 injuries. Exit ways became untenable early, 2nd floor occupants had to jump from windows. No Alarm system and detection system was inadequate. All fatalities were found in guest rooms and they were out of bed. Four were on the 2nd floor one was on the 1st floor. Rooms with doors closed sustained little fire damage.
Howard Johnston's Hotel, 1984. (Timoney, 1984) 14 storey hotel, 300 guests. Fire started in 7th floor corridor.	35 injuries. Rapid detection, prompt response by hotel staff, protection provided by guest room doors and prevention/education program and fire protection features prevent any loss of life. 3 guests found in the corridor sustained serious injuries.
Dupont Plaza Hotel, 1986. (Klem, 1987). 20 storey hotel. Fire started in 1st floor ballroom.	97 fatalities, 140 injuries 85 victims were found in casino who were trapped when it flashed over. 5 of the remaining victims were found in the lobby, 3 were found in an lift, two were found near a pool side bar, one was found in a 4th floor room and one person died in hospital.
East 50th St Apartments, 1988. (DeVita and Dunn, 1988). 10 storey apartment Fire started in ground floor lobby	4 fatalities. All victims were found outside their rooms attempting to escape. Lobby stair doors contributed to smoke spread and smoke logged stairs. Occupants who remained in their apartments were safe. Occupants had to be removed by portable ladders.
Phi Kappa Sigma Fraternity House Fire, 1990. (NFPA 2000b). Multi-storey fraternity house. Fire started in assembly room.	3 fatalities, 2 injuries. Open stairs, combustible interior finishes, lack of compartmentation and lack of fire safety training contributed to the fatalities.

The Polo Club Condominium, Denver, Colorado, 1991. (Harvey, 1992-1993). 20 storey apartment, 150 apartments. Fire began on 7th floor, from and electric blanket.	1 civilian injury and 5 fire fighters were injured. All fire fighting equipment had to carried to 7th floor, resulting in fatigue. The fire was confined to unit of origin and occupants who were not evacuated were told to remain in their apartments.
Paxton Hotel, Chicago, 1993. (NFPA, 2000c)	20 fatalities, 28 injuries. Hotel occupants were mainly the elderly and low-income people. The fire spread to several rooms and corridors. Occupants were required to be rescued externally.
Ontario Apartment Fire, 1995. (Proulx, 1996). 30 storey, 13 apartments on each floor. Fire started in 5th floor apartment.	6 fatalities, 11 injuries. the 6 fatalities were found between the 27th and 30th floor in the staircase. All occupants who stayed in their apartments were safe. Late evacuation contributed to fatalities. Occupants were prepared to move through smoke.
Dormitory Fire, Franklin, MA, 1995. (NFPA, 1995) 3 storey dormitory, 28 occupants. Fire began on the 2nd floor.	No fatalities or loss of life. Building was a total loss. The closure of the door of fire origin allowed time for occupants to escape. Opening of door by security personnel contributed to the fire spread. The age and agility of residents, familiarity of the building's means of egress and quarterly fire drills contributed to the lack of fatalities.
Phi Gamma Delta Fraternity, Chapel Hill, 1996. (Wolf, 2000). 4 storey fraternity house, 20 occupants. Fire started in the basement.	5 fatalities. 4 victims were found in bedrooms, one victim was found partially in the hallway. Two victims were found in locked bedrooms. All victims were on the second floor. Wood panelling in the basement contributed to the fire spread.

Ontario Apartment Fire, 1997. (Proulx, 1999). 25 storey, 295 condominiums. Fire started on 6^{th} floor and burned through door and spread into the corridor.	2 fatalities, 4 injuries. The 2 fatalities suffered heart attacks. All respondents above the fire floor that attempted to evacuate encountered smoke. Tubular-core wood apartment doors contributed to fire and smoke spread.
Bremerton, WA Apartment Building Fire, 1997. (NFPA, 1999). 4 storey apartment, 142 units Fire occurred in an apartment on the 3^{rd} level.	4 fatalities, 12 injuries. Manager investigated smoke detector and failed to close apartment door. Wood panelling in corridor contributed to fire spread. Fire spread externally via window. Combustible wall linings, open apartment door inadequately protected means of escape and inadequate fire alarm system, contributed to the fatalities.
Ottawa high-rise apartment (Proulx, 1999). 25 storey apartment. 296 condominiums. The fire began on the 6^{th} floor and burned through the door. The fire brigade arrived and extinguished the fire within 10 minutes.	2 fatalities. 4 people suffered inhalation, two people suffered heart attacks. Fire dept ordered occupants to evacuate. 83% attempted to evacuate 54% were successful. Remaining returned to apartment or sought refuge in another apartment.
NFPA Catastrophic Fires	
Florida, Residential Hotel, 1990 (Fahy and Tremblay, 1991) 3 storey, 101 rooms Fire began in the crawl space between the first and second floors.	9 fatalities Fire spread through the loft area. Most of the victims were elderly.
New York, Apartment, 1990 (Fahy and Tremblay, 1991) 3 storey Fire deliberately lit in first floor stair well.	5 fatalities All victims found on third floor. Second floor occupants escaped via rear window.

New York, Apartment, 1990 (Fahy and Tremblay, 1991) 4 storey, 23 units An occupant on first floor ignited curtains in the bedroom.	5 fatalities All victims were elderly
Minnesota, Hotel, 1991 (Miller and Tremblay, 1992) 3 storeys Fire began in first floor dining room.	7 fatalities Hotel was in a rural area without fire department coverage. It is undetermined if the occupants attempted to escape or awoke.
New York, Apartment, 1991 (Miller and Tremblay, 1992) 3 storey, 3 units Occupant ignited mattress in hallway.	6 fatalities Escaping occupants and fire fighters were hindered by furniture in the hallways.
Michigan, Apartment, 1991 (Miller and Tremblay, 1992) 5 storey, 46 units Incident unreported pending litigation.	6 fatalities
New Jersey, Apartment, 1991 (Miller and Tremblay, 1992) 3 storey, 3 units Heater ignited combustibles in a first floor bedroom.	5 fatalities Escaping occupants aided fire spread by leaving doors open. Three children were trapped on the third floor by the advancing fire.
Illinois, Apartment, 1991 (Miller and Tremblay, 1992) 3 storey, 6 units Fire began in second floor apartments from an electrical fault.	5 fatalities Two were under the influence of alcohol.

California, Apartment, 1991 (Miller and Tremblay, 1992) 2 storey, 6 units Flammable liquid was poured through the front door mail slot.	5 fatalities 15 sleeping occupants were trapped.
Illinois, Apartment, 1992 (Tremblay, 1993) 3 storey, 36 units Fire started on the second floor and spread to the third floor trapping occupants.	5 fatalities Interior fire doors were propped open allowing the fire to spread. Occupants were forced to jump out of windows.
Illinois, Hotel, 1993 (Tremblay, 1994) 4 storey, 140 rooms Fire started on the first floor between two rooms. Fire spread via the un-enclosed stairs and concealed spaces.	20 fatalities Fire doors protecting the stairwells on the top three floors had been removed, security bars trapped occupants. More occupants required rescue than the fire department could handle.
California, Apartment, 1993 (Tremblay, 1994) 3 storey, 69 units Fire started on the second floor and spread to the third via open fire doors.	12 fatalities Fire doors protecting stairwells on the top three floors were blocked open. Occupants on the third floor were trapped.
Michigan, Apartment, 1993 (Tremblay, 1994) 2 storey, 5 units Fire started on the second floor corridor and spread via combustible finishes.	9 fatalities All victims died of smoke inhalation and were found in second floor apartments. Occupants on the first floor escaped.

Rhode Island, Apartment, 1993 (Tremblay, 1994) 3 storey, 3 unit Fire started in the stairwell on the first floor.	6 fatalities The door to a third floor apartment had been left open allowing the fire to spread. All six victims were found in this apartment.
California, Apartment, 1993 (Tremblay, 1994) 2 storey, 17 unit apartment Gas fuelled wall heater ignited timber structure on the first floor.	6 fatalities Victims were found on the second floor and died of smoke inhalation.
Texas, Apartment, 1993 (Tremblay, 1994) 2 storey, 8 units Fire began in the living room on the first floor. Fire did not leave unit of origin.	5 fatalities All fatalities were found in second floor bedrooms.
North Carolina, Apartment, 1993 (Tremblay, 1994) 2 storey, 8 units Fire began in the living room of a first floor apartment. Fire spread to the second floor externally.	5 fatalities Four victims on the second floor had their primary exit blocked by fire. One tenant in unit of origin died of smoke inhalation.
Ohio, Apartment, 1993 (Tremblay, 1994) 2 storey, 4 units Fire started on a chair in first floor living room. Occupant tried to remove chair and blocked the front door and stairs. Fire spread up stairs.	5 fatalities Fire breached fire-wall dividing the building in half.

Illinois, Apartment, 1994 (Tremblay, 1995) 4 storey, 47 units Flammable liquid was spread in the stair on the third floor. Fire spread throughout the third and fourth floor.	9 fatalities Six victims were found at the rear of the fourth floor, 1 victim jumped from the fourth floor, remaining victims were rescued and died later. Numerous occupants were rescued by ladders and aerial towers.
Louisiana, Apartment, 1994 (Tremblay, 1995) 2 storey 4 units Fire began in second floor apartment and spread to other second floor apartment.	5 fatalities All victims were in bedrooms. One was rescued, but later died.
Pennsylvania, Fraternity house, 1994 (Tremblay, 1995) 2 storey Fire on couch in partially enclosed porch travelled up un-enclosed stairway.	5 fatalities All victims made some attempt to evacuate. All had alcohol in blood, three had marijuana and one had cocaine.
Minnesota, Apartment, 1995 (Tremblay, 1996) 2 storey, 4 units Cigarette ignited couch in first floor apartment.	7 fatalities All victims were in the apartment of origin. Victims died from CO poisoning, they all had a carboxyhemoglobin $> 55\%$.
California, Apartment, 1995 (Tremblay, 1996) 2 storey, 4 units Bedroom carpeting on the first floor was ignited.	5 fatalities All victims were in the apartment of origin. 5 children were rescued but later died. Security bars on windows and entrance doors.

Rhode Island, Apartment, 1995 (Tremblay, 1996) 2 storey, 6 units Fire began in a second floor living room.	5 fatalities All victims were in the apartment of origin. The fire spread to the sleeping areas and trapped all the victims.
Oregon, Apartment, 1996 (Tremblay, 1997) 3 storey, 24 units Fire deliberately lit in stair well blocking occupant egress.	8 fatalities. Two people died in one apartment and 6 died in another. Both were on the 3rd floor and had doors open. Survivors escaped via windows or patio doors.
California, Apartment, 1996 (Tremblay, 1997) 3 storey, >20 units Fire started in bedroom and spread to the apartment's, hallway and dining room/kitchen.	7 fatalities All 7 were in the room of fire origin, 5 died from smoke inhalation, 2 died from thermal burns.
North Carolina, Fraternity house, 1996 (Tremblay, 1997) 3 storey Fire started in basement bar.	5 fatalities 4 people found on the 2nd floor had a blood alcohol level of >0.14. The 5th victim had no alcohol in her blood and was found in her bedroom door.
Pennsylvania, Apartment, 1997 (Tremblay and Fahy, 1998) 3 storey, 7 units Fire ignited a bed in first floor apartment.	6 fatalities Advancing fire blocked the only interior escape route. Occupants had to escape from windows.
New Jersey, Apartment, 1997 (Tremblay and Fahy, 1998) 3 storey, 6 units Fire spread from first floor apartment bedroom through structural voids and open stairwell	6 fatalities Six children in third floor apartment died of smoke inhalation. They were gathered around a window blocked by an air-conditioner.

Kentucky Apartment, 1997 (Tremblay and Fahy, 1998) 2 storey, 3 units Fire began in second floor apartment kitchen.	6 fatalities Two victims died attempting to escape from a second storey window. One victim was in the bedroom of the apartment of origin. The remaining victims were in a bedroom in the apartment across the hall.
Illinois, Apartment, 1997 (Tremblay and Fahy, 1998) 2 storey, 3 units Combustibles on a first floor porch were ignited and the fire spread vertically trapping second floor occupants.	6 fatalities All victims were on the second floor, four victims were found near the interior stairway, one was in a bedroom and remaining victim was rescued and died later.
Illinois, Apartment, 1997 (Tremblay and Fahy, 1998) 3 storey, 6 units Electrical fault started fire in first floor living room.	6 fatalities Location of victims was not reported
California, Apartment, 1997 (Tremblay and Fahy, 1998) 3 storey, 8 units Fire started in third floor living room.	6 fatalities All victims in the apartment of origin.
Massachusetts, Apartment, 1997 (Tremblay and Fahy, 1998) 3 storey, 12 units Fire started in the basement and spread through the concealed spaces and structural voids.	6 fatalities All victims were attempting to escape. Five members of one family were separated as they attempted to evacuate and were overcome by smoke.

Colorado, Hotel, 1997 (Tremblay and Fahy, 1998) 2 storey, 110 rooms Fire started in a first floor storeroom. Flames spread rapidly engulfing a breezeway.	5 fatalities The fire trapped 4 victims in their rooms. One victim was caught in the flashover. All victims' rooms opened into the breezeway.
Oklahoma, Apartment, 1997 (Tremblay and Fahy, 1998) 3 storey, 5 units Occupant on second floor accidentally ignited sofa from cigarette. He tried to move the sofa outside, and stopped in front of an open door. The fire spread to the wooden exterior stairway that was the exit for the attic apartment.	5 fatalities All victims were in the attic apartment. Their only other exit was nailed shut.
Virginia, Apartment, 1998 (Tremblay, 1999) 3 storey, 13 units Fire started on second floor stairwell.	6 fatalities Stairwell was compromised by fire. All victims were on the 3rd floor.
Tennessee, Apartment, 1998 (Tremblay, 1999) 2 storey Fire ignited combustibles in a first floor living/dining room area.	5 deaths All victims were found on the second floor. The fire travelled through the concealed spaces and the second floor collapsed.

The NFPA defines a Catastrophic Fire, as a fire with five or more fatalities in residential buildings (single family dwellings, apartments, hotels and motels) or three or more fatalities in a non-residential buildings. Non-residential buildings include health care facilities.

Some of the problems encountered in health-care fires are applicable to apartment fires. Health care facilities consist of occupants with mixed abilities and characteristics similar to apartment buildings. For example, the limited abilities of patients and slower egress times can also be characteristics of apartment building occupants. NFPA catastrophic health-care facility fires, greater than one-storey, have been summarised below.

Table 23 – Health-care facilities greater than one storey (non-residential)

Case	**Fatalities/injuries. Significant factors**
Detroit, Board and Care Facility, 1992. (NFPA, 2000). 3 storey, 16 occupants. Fire started in 1st floor kitchen	10 fatalities Elderly occupants were disabled. Lack of fire safety training, sprinkler protection, combustible finishes, second exit (on 2nd floor) and open stairways contributed to the fatalities.
St. Genevieve, Quebec Board and Care Fire, Fire Investigations, 1996. (NFPA, 2000a) 3 storey, 41 residents. Fire began in room on 2nd floor.	7 fatalities. Board and Care facility contained elderly residents. Fire spread externally to 3rd floor via window. Corridor and stair well doors were propped open. Combustible contents in the corridor, fire spread through concealed spaces, open doors, fire brigade notification delays and lack of sprinklers contributed to the fatalities.
Harvey Lakes PA, 1997. (NFPA, 1997). 2 storeys plus basement, 21 residents. Fire started in enclosed porch area. By cigarette.	10 Fatalities Occupants were elderly with disabilities. Self-closing device was deactivated. Inadequate means of escape, ineffective actions by staff, open fire doors, lack of self-closers and inadequate fire rated doors contributed to the fatalities.
Board and Care, Arlington Washington, 1998. (NFPA, 1998). 2 storey, 32 occupants and 2 staff. Fire started in first floor room.	8 fatalities. 3 victims located in room of origin. Lack of smoke detectors, open door from room of origin, open fire doors, open room doors allowed the fire to spread and contributed to the fatalities.
NFPA Catastrophic Fires	
Texas, Board and care facility, 1990 (Miller and Tremblay, 1991) 2 storey Resident on first floor ignited fabric in living room.	4 fatalities All victims were trapped on the second floor.

Michigan, Board and care facility, 1992 (Tremblay, 1993) 3 storey Smoking material was carelessly discarded in the kitchen.	10 fatalities Lack of second floor exit hindered escape. Open stairwell and unprotected openings allowed vertical fire spread. Victims were found in escaping positions.
New York, Hospital, 1993 (Tremblay, 1994) 8 storey, 705 beds Fire started on the 7th floor in patient's room from medical equipment. Components containing oxygen were damaged resulting in an unlimited supply of oxygen at 50psi.	3 fatalities Two patients in room of origin died and a third victim in a near by room died of smoke inhalation. Their doors were left open. Staff closed most bedroom doors, automatic doors in corridors limited fire spread and smoke. Sprinklers were present in corridors and helped prevent fire spread.
Alabama, Board and care facility, 1994 (Tremblay, 1995) 2 storey Fire began in first floor storage utility room.	6 fatalities All victims were mentally handicapped, 5 victims were found in second floor bedrooms, the 6th attempted to escape by using a stair that had burned away.
Tennessee, Board and care facility, 1996 (Tremblay, 1997) 2 storey Improperly disposed of smoking material ignited fire in wastebasket in bedroom.	4 fatalities Door to room of origin left open. 1 victim in room of origin died from burns. Two residents in opposite room died from smoke due to bedroom door being blocked open. 1 victim was rescued and died in hospital
Connecticut, Board and care facility, 1996 (Tremblay, 1997) 3 storey Third floor occupant fell asleep and cigarette ignited love seat.	3 fatalities One victim was rescued from his room, but died in hospital, 1 victim was overcome by smoke in her bathroom. (Location of 3rd victim is unknown). The rooms did not have self-closers, so when the occupant left, smoke made the corridor untenable. Several occupants stayed in their units until fire fighters rescued them.

Pennsylvania, Board and care facility, 1997 (Tremblay and Fahy, 1998) 2 storey, 21 residents Improperly discarded cigarette ignited exterior wood siding. The fire spread externally. Heat and smoke spread internally through the enclosed stair.	10 fatalities The duty staff member thought the fire was a false alarm and switched off the alarm. The fire rated door to the stair well was open and the self-closer was deactivated. Occupants were between the age of 58 to 99 and some had mental disabilities.
Washington, Board and care facility, 1998 (Tremblay, 1999) 2 storey Resident on first floor ignited bedding.	8 fatalities The fire spread from room of origin through open door into the corridor. 3 victims in room of origin died. 2 victims found in bathroom on 2^{nd} floor adjacent stair well. 3 victims found in bedroom on 2^{nd} floor opposite stair well.

18 APPENDIX B – BCA EGRESS REQUIREMENTS

Clauses for the number of exits, exit travel distances, distance between alternative exits and dimensions of exits and paths of travel, extracted from the BCA (ABCB, 1996).

D1.2 Number of exits

(a) All buildings – Every building must have at least one exit from each storey.

(b) Class 2 to 8 buildings – In addition to any horizontal exit, not less than 2 exits must be provided from the following:

(i) Each storey if the building has an effective height of more than 25m.

(ii) A Class 2 or 3 building subject to C1.5

(c) Basements - In addition to any horizontal exit, not less than 2 exits must be provided from any storey if egress from that storey involves a vertical rise within the building of more than 1.5m, unless-

(i) the floor area of the storey is not more than 50 m^2; and

(ii) the distance of travel from any point on the floor to a single exit is not more than 20m.

(g) Access to exits – without passing through another sole-occupancy unit, every occupant of a storey or part of a storey must have access to-

(i) An exit; or

(ii) At least 2 exits, if 2 or more exits are required.

D1.4 Exit travel distances

(a) Class 2 and 3 buildings

(i) The entrance doorway of any sole-occupancy unit must be not more than-

(A) 6m from an exit, or from a point from which travel in different directions to 2 exits is available; or

(B) 20m from a single exit serving the storey, at the level of egress to a road or open space: and

(iv) no point on the floor of a room which is not a sole-occupancy unit must be more than 20m from an exit or from a point at which travel in different directions to 2 exits is available.

D1.5 Distance between alternative exits

Exits that are required as alternative means of egress must be-

(a) distributed as uniformly as practicable within or around the storey served and in positions where unobstructed access to at least 2 exits is readily available from all points on the floor including the lift lobby areas; and

(b) not less than 9m apart; and

(c) not more than-

(i) in a Class 2 or 3 building – 45m apart

(d) located so that alternative paths of travel do not converge such that they become less than 6m apart.

D1.6 Dimensions of exits and paths of travel to exits

In a required exit or path of travel to an exit-

(a) the unobstructed height throughout must be not less than 2m; except the unobstructed height of any doorway may be reduced to not less than 1980mm; and

(b) the unobstructed width of each exit or path of travel to an exit, except for doorways, must be not less than-

(i) 1m; or

(ii) 1.8m in a passageway. Corridor or ramp normally used for the transportation or patients in beds within a treatment area or ward area; and

(c) if the storey or mezzanine accommodates more than 100 persons but not more than 200 persons (or part) in excess of 100; or except for doorways, must be not less than-

(i) 1m plus 250mm for each 25 persons (or part) in excess of 100; or

(ii) 1.8m in a passageway, corridor or ramp normally used for the transportation of patients in beds within a treatment area or ward area; and

(d) if the storey or mezzanine accommodates more than 200 persons, the aggregate unobstructed width, except for doorways, must be increased to-

(i) 2m plus 500mm for every 60 persons (or part) in excess of 200 persons if egress involves a change in floor level by a stairway or ramp with a gradient steeper than 1 in 12; or

(ii) in any other case, 2m plus 500mm for every 75 persons (or part) in excess of 200; and

(e) in an open spectator stand which accommodates more than 2000 persons, the aggregate unobstructed width, except for doorways, must be increased to 17m plus a width (in metres) equal to the number in excess of 2000 divided by 600; and

(f) the unobstructed width of a doorway must be not less than-

(i) in patient care areas through which patients would normally be transported in beds, if the door opens into a corridor of width-

(A) greater than 1.8m and less than 2.2m - 1200mm; or

(B) not less than 2.2m – 1070mm; or

(ii) in patient care areas in horizontal exit – 1250mm; or

(iii) the unobstructed width of each exit provided to comply with (b), (c), (d) or (e) minus 250mm; or

(iv) in any other case except where it opens to a sanitary compartment or bathroom – 750mm wide; and

(g) the unobstructed width of a required exit must not diminish in the direction of travel to a road or open space, except where the width is increased in accordance with (b)(ii) or (f)(i).

19 APPENDIX C – EXTERNAL FIRE SPREAD BUILDING CODE REQUIREMENTS

The Building Code of Australia (ABCB, 1996) prescriptive requirements for vertical separation of openings in external walls:

C2.6 Vertical separation of openings in external walls

If in a building (other than an open-deck carpark or an open spectator stand) which is required to be of Type A construction and does not have a sprinkler system complying with Specification E1.5 and part of a window or other opening in an external wall, (except openings within the same stairway)-

(a) is above another opening in the storey next below; and

(b) its vertical projection falls no further than 450mm outside the lower opening (measure horizontally),

the opening must be separated by-

(c) a spandrel which-

(i) is less than 900mm height; and

(ii) extends not less than 600mm above the upper surface of the intervening floor; and

(iii) is of non-combustible material having an FRL of not less than 60/60/60; or

(d) part of a curtain wall or panel wall that complies with (c); or

(e) construction that complies with (c) behind a curtain wall or panel and has any gaps packed with a non-combustible material that will withstand thermal expansion and structural movement of the wall without loss of seal against fire and smoke; or

(f) a slab or other horizontal construction that-

(i) projects outwards from the external face of the wall not less than 1100mm; and

(ii) extends along the wall not less than 450mm beyond the openings concerned; and

(iii) is non-combustible and has an FRL of not less than 60/60/60

The Acceptable Solutions to the NZBC (BIA, 1991), external fire spread prescriptive requirements:

4.4.5 External fire spread between different levels of the same building

Except where firecells are sprinklered, one of the measures described in Paragraphs 4.4.6 to 4.4.7 shall be provided where either of the following conditions occur:

a) *Firecells containing purpose groups SC, SD, SA, SR or IE are one or more levels above the final exit, or*

b) *Firecells containing purpose group CM are two or more levels above the final exit.*

4.4.6 Where the conditions of Paragraph 4.4.5 occur, unprotected areas in the external walls of firecells shall be separated by no less than:

a) *2.5m where any part of the unprotected areas are vertically aligned above one another, or*

b) *900mm where the unprotected areas on one level are horizontally offset from those on other level.*

4.4.7 Where the separation requirement of Paragraph 4.4.6 is not satisfied, an apron shall be provided between the lower unprotected areas and those in the upper firecell. The apron shall:

a) *project horizontally no less than 600mm from the face of the building,*

b) *continue no less than 600mm beyond the outer corners of the unprotected area, and*

c) *have a FRR of no less than that of the floor between the upper and lower firecells*

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