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IRE SAFETY IN HIGH-RISE APARTMENT BUILDINGS

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ABSTRACT

Fire safety in high buildings has been a significant issue for architects for over 100 years. However, provision for occupant safety from such fires was only addressed in the 1970s. This article identifies the unique fire safety problems in high-rise apartment buildings, and their associated fire risk. It then addresses the means to provide fire safety in high buildings from both design and codes perspectives. It elaborates on the need to provide both building- and occupant-based protection to achieve the best results. It concludes with an overview of the special problems associated with high-rise residential buildings combined with atria or located over a subway system.



OBJECTIVES

After reading this article, an architect should:

1. Understand the fire risk associated with high-rise apartment buildings.
2. Identify the unique fire safety problems associated with high-rise buildings.
3. Identify strategies for providing fire safety in high-rise apartment buildings and how they relate to the building design and to the occupants.
4. Understand how fire safety strategies work independently, and together, to reduce the risk to occupants of high-rise apartment buildings.



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1.0 INTRODUCTION

Numerous questions have arisen as to the safety of occupants in high-rise buildings following the World Trade Center aircraft collision, fire and collapse. While occupant safety in buildings due to aircraft impact and collapse has emerged as a front page issue for the design profession, it is safety from fire that should represent the long-term focus in high-rise buildings. The focus of this article will be somewhat narrower – How safe from fire are occupants in Canadian high-rise apartment buildings?/What are the fire safety measures which provide this safety?

The first high-rise buildings in North America appeared around the end of the 19th century, and the first reported cases of fire, early in the 20th century. The invention of a safe passenger elevator and the development of better structural framing systems made such buildings possible. In this article, it will be assumed that a high-rise building is any building six storeys or more in height.

The first Canadian high-rise fire fatalities occurred in Montreal hotels where, in 1949 and 1956, there were fires resulting in single deaths. Table 1 gives a partial list of Canadian high-rise residential building fires⁽¹⁾. It can be seen that most of the fires involve a single death, often in the

unit of origin. This mirrors fire experience in low-rise buildings. Thus, fire history surprisingly does not demonstrate a major fire safety problem with Canadian residential high-rise buildings – based on statistics. Based on the potential fire risk, given the large numbers of units and occupants involved in each building, high-rise buildings, however, represent the potential for a major fire and loss of life.

TABLE 1
Representative Canadian Residential High-rise Fires

Year	Building Type	City	Height, Storeys	Deaths
1949	Hotel	Montreal, QC	21	1
1956	Hotel	Montreal, QC	9	1
1964	Hotel	Ottawa, ON	12	3
1972	Apartments	Verdun, QC	14	1
1977	Apartments for Aged	Hull, QC	8	6
1981	Hotel	North York, ON	23	8
1982	Apartments	Toronto, ON	38	1
1983	Apartments	Ottawa, ON	20	3
1984	Apartments	Toronto, ON	23	2
1984	Apartments	Montreal, QC	22	4
1992	Apartments	Toronto, ON	25	1
1995	Apartments	North York, ON	30	6
1995	Apartments	Montreal, QC	8	5
1997	Apartments	Ottawa, ON	25	2

1.2 Risk to Life from Fires in High-rise Apartment Buildings

A precise risk to life from fire in high-rise apartments is not easily discernible due to the numerous deficiencies in data. However, by examining the factors which make up fire risk, the higher potential risk in high-rise apartments can be identified.

Risk is defined as the probability that an event will happen, multiplied by the consequences of that event when it does happen. The equation is shown as:

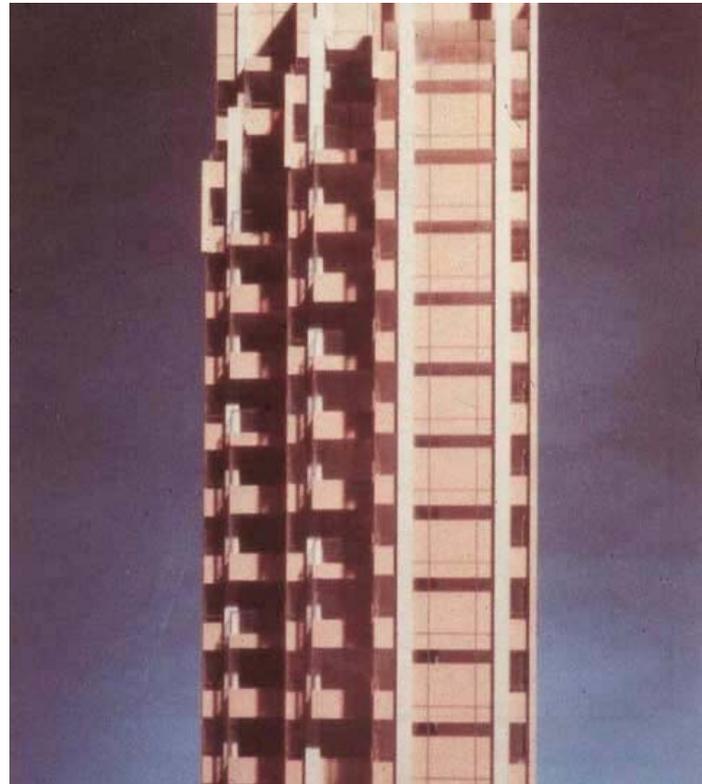
$$\text{Risk} = \text{Probability} \times \text{Consequences}$$

The risk to life from fire is calculated on the basis of all probable fires occurring at all probable locations in a building while examining the consequences of all of these fire scenarios⁽²⁾. For an in-depth review of this subject, architects are directed to the SFPE Handbook of Fire Protection Engineering⁽³⁾. It can quickly be seen then that the fire risk in a high-rise apartment building would be significantly higher than in a lower rise building given the potential for more fire locations, and greater consequences of the fire itself (e.g., stack effect) to a greater number of occupants. This means both the probability and the consequences would be much higher, and the resulting risk would be even higher. It is this higher risk, then, that results in demands for greater fire safety in high-rise apartment buildings.

2.0 REPRESENTATIVE CANADIAN RESIDENTIAL HIGH-RISE FIRES

The following are examples of the types of fires thus far encountered in Canadian residential high-rise buildings. While Canadian codes now require sprinkler systems in high-rise residential buildings, these unsprinklered examples show what can happen if a fire is not suppressed by sprinklers.

1967 Montreal Hotel⁽⁴⁾ – This fire represents a classic fire in the non-sprinklered, lower-level public/shopping area creating a smoke hazard for the adjoining 38-storey hotel tower. The fire was confined to a basement restaurant/bar area, but



this unsprinklered steel frame building and contents suffered damage throughout as smoke spread upward through exit stairways and elevator shafts. While not a factor in this fire, this building was connected to a major underground shopping complex and the subway system. There were no fatalities from this fire.

1981 Toronto Hotel⁽⁵⁾⁽⁶⁾ – This fire began on the second floor of a 23-storey hotel. Significant smoke spread to upper guest room floors and caused 6 fatalities. The building was not sprinklered. The fatalities occurred in one of the stairwells or on the upper floors of the hotel. The fire was, however, contained to the meeting room area of origin. Vertical smoke spread was through elevator, stair and vertical service shafts.

1992 Toronto Apartments⁽⁷⁾ – This 25-storey unsprinklered apartment building was of reinforced concrete construction. Each apartment had a balcony. In this case, the fire occurred on the 9th floor. The occupants of the apartment of origin escaped but left their door open. Within ten minutes of the original alarm, smoke spread to all floors above the ninth, and to the exit stairwells. The one fatality occurred in opening the elevator door at the fire floor. The fire itself was essentially contained to the apartment of origin.

1997 Ottawa Apartments⁽⁸⁾ – This fire occurred in a 25-storey, unsprinklered, condominium apartment building. It began in a 6th floor unit and smoke spread was mostly confined to that floor. The fire was put out within seven minutes of the arrival of the fire department. Many of the building occupants stayed in their apartments or on balconies and were not affected by the fire. The fatalities included an occupant of the apartment of origin and another senior citizen who died of a heart attack in the evacuation. This fire illustrated the necessity of providing apartment building occupants with clear instructions on evacuation.

1995 Toronto Apartments⁽⁹⁾⁽¹⁰⁾ – The fire in this 30-storey, reinforced concrete high-rise began in a 6th floor apartment. The occupant escaped, leaving the door open. Essentially contained to the unit of origin, the fire resulted in rapid smoke spread throughout the building. The scissors stairs arrangement resulted in confusion among firefighters and exiting occupants. Six fatalities occurred, as a result of smoke, near the top of the two stairwells.

These residential high-rise building fires illustrate a number of points that designers should take into consideration:

- Unsuppressed fires in high-rise buildings generate large quantities of smoke that can spread vertically or horizontally through the building, even if the fire is

contained to only one room or apartment. A contained, but not extinguished, fire can also generate significant smoke.

- Vertical smoke spread is exacerbated by wind and by “stack effect” which occurs when the building's inside temperature is greater than the outside. Thus in Canadian winters, lower floor fires tend to have the greatest extent of smoke spread to upper floors.
- Despite the type of structure (steel or reinforced concrete), most damage, deaths and injuries result from the spread of smoke.
- In multiple-death fires in residential high-rise buildings, many fatalities occur in the egress routes (stairways and corridors) due to smoke from a fire elsewhere in the building.
- In apartment fires with doors left open or burned-through, smoke will spread to the corridors, shafts and upper levels.
- Sometimes it may be safer for building occupants to remain in their apartments or rooms rather than to exit through smoke-filled corridors and stairshafts.
- Appropriate instructions to occupants during a fire are essential if it is expected that they should take specific actions.

While the examples shown above address buildings not built to current code requirements, architects must realize the consequences of failure of built-in protection or the absence of appropriate occupant-based programs on risk to life for occupants of high-rise apartment buildings. Architects must understand how building and occupant-based safety need to work together and how fire risk is reduced by the fire safety measures that are employed. Simply complying with a building code does not necessarily provide optimum fire safety.

3.0 FIRE RISK ISSUES IN HIGH-RISE APARTMENT BUILDINGS

3.1 Fire Statistics

While Canada-wide statistics on high-rise apartment building fires are limited, there is a wealth of data from the USA⁽¹⁾⁽¹¹⁾. Even though from USA high-rise fires, these statistics can be considered to be representative of high-rise apartment building fires in Canada.

- Civilian deaths and injuries in high-rise apartment buildings represent 7% of deaths and 10% of injuries in all apartment building fires whereas 9-10% of reported apartment fires occurred in high-rise buildings.
- In these buildings, 94% of fires were confined to the room of origin, 4.3% to the floor of origin and 1.7% spread beyond the floor of origin. About half of civilian deaths occurred in fires confined to the room of origin; 42% in fires confined to the floor of origin and 7.4% occurred when the fire spread beyond the floor of origin. In other words, while 6% of fires spread beyond the room of origin, these caused almost 50% of civilian fire deaths.
- Floor levels of fire origin show that 27.8% occurred on or above the 7th storey while 72.2% occurred below that level. Remember that in Canada, stack effect exacerbates the effects of smoke spread from lower levels.
- Two thirds of reported fires in high-rise apartments occurred in buildings without automatic sprinkler systems.
- Areas of origin of fires in high-rise apartment buildings compared to low-rise are shown in Table 2. It can be seen that the fire origin patterns in both types of buildings are essentially the same.

TABLE 2

Areas of Origin of Apartment Fires⁽¹⁾

Area	High-Rise	Not High-Rise
Kitchen	56.2%	46.1%
Bedroom	10.0%	15.1%
Means of Egress	6.4%	4.8%
Living Room, Family Room	5.2%	7.2%
Other Area	22.2%	26.8%

Notes: ⁽¹⁾ Taken from Reference 11

3.2 Fire Risk

While a precise risk to life from fire is not easily discernible, comparative risks for high and low rise buildings can provide an indication of relative risk based on statistics.

Ontario Position – Table 3 shows apartment fire statistics in Ontario between 1995 and 1999. As a measure of relative risk, these figures have been divided by the number of low-rise and high-rise apartments in Ontario to give a loss per 100,000 apartments. Based on these, the risk is lower in terms of number of fires, deaths and injuries in high-rise apartments. The 5 year average shows the risk in low-rise buildings, based on the number of fires, is 1.36 times higher; on fire deaths, 2.6 times higher; and on injuries, 2.3 times higher than in high-rise. Based on these fire statistics, the apparent risk from fire in Ontario high-rise apartment buildings is less than in low-rise.

TABLE 3

Losses in Ontario High & Low Rise Apartment Buildings⁽¹⁾

Year	HR Fires/ 100K Units ⁽²⁾	LR Fires/ 100K Units ⁽³⁾	HR Deaths/ 100K Units	LR Deaths/ 100K Units	HR Inj/ 100K Units	LR Inj/ 100K Units
1995	4.5	5.9	0.050	0.060	0.421	0.856
1996	3.9	5.5	0.031	0.068	0.361	0.922
1997	3.5	5.0	0.033	0.120	0.373	0.946
1998	3.4	4.2	0.030	0.076	0.262	0.484
1999	3.1	4.3	0.016	0.096	0.228	0.637
5-yr Avg ⁽⁴⁾	3.7	5.0	0.032	0.084	0.329	0.769

Notes:

- (1) Fire losses obtained from Ontario Fire Marshal's Office. Numbers of high and low rise units obtained from Canada Mortgage and Housing Corporation.
- (2) High-rise fires per 100,000 apartments.
- (3) Low rise fires per 100,000 apartments.
- (4) Arithmetic mean of 1995-1999.

As we will see, despite this statistical analysis, the real risk to life based on probable fires and probable consequences in high-rise apartments has been shown to be greater than in low rise – and this is also the perception of code writers and code-adopting authorities. Given that, more stringent fire safety is required for these buildings. Thus, it is important to identify their unique fire safety problems and the corresponding measures to address these problems.

4.0 WHAT IS UNIQUE ABOUT FIRE SAFETY FOR HIGH-RISE BUILDINGS

Why is the risk from fire perceived to be so much higher for high-rise apartment buildings? The following represent some of the most significant of their unique features⁽¹²⁾⁽¹³⁾:

1 Egress Systems – The potential for crowding and slow movement in exit stairs in high buildings exists because of the increased number of storeys and because exit stairs do not normally increase in width as they descend, Stair shafts also represent one of the primary means by which smoke moves vertically. Additionally, the time it takes an occupant to descend a stairway increases with the height of the building, thus increasing the potential for smoke exposure. The basic issue is that the building egress system must provide sufficient evacuation time before smoke reaches lethal levels, and thus harms those occupants still remaining in the building.

2 Fire Department Access – Even with modern aerial apparatus, the fire department can still reach only 6 or 7 floors in a building. Thus exterior rescue and firefighting is restricted to the lower floors. With a fire above the reach of ladders, firefighters must move vertically inside the building and launch an interior attack at the same time that occupants are descending the stairs. This can result in delays in reaching and attacking a fire and to increased contamination of stair shafts if doors to exit stairs must be left open to run hoses.

3 The Forces of Nature – Stack effect and winds have a major impact on smoke movement in high buildings. Stack effect increases with increasing height of building. Wind velocity and direction also affect the course of a fire. They are significantly less of a problem in lower buildings.

4 Increased Density of Occupant and Fuel Load – By adding floors to a building, the occupant and fuel densities increase within a given building footprint. Despite horizontal fire barriers, fire tends to move upward, thus potentially adding more fuel and affecting more occupants.

5 Complex Vertical Utility Services – A complex series of pipes, ducts, cables and conduit run vertically through high-rise buildings. As well, fire protection water supplies must also be provided from either the top or bottom of the building – both with associated problems. As a result of these vertical utilities, other fire problems can occur such as cables to fire systems being damaged by fire on one level and affecting many other floors.

6 Integrated Fire Problems – High-rise apartment buildings are no longer stand-alone structures. Typically, they are situated above shopping malls or other commercial

occupancies, above atrium buildings containing, for example, offices, or above subway systems. Each occupancy has its own unique fire safety problems and coupled with those in a high-rise apartment building, the problems require special engineered solutions to ensure occupant safety.

Each of these unique features presents a special problem to be resolved before a designer can achieve a fire-safe high-rise design. While the Codes provide generalized solutions to many of the problems, architects must be aware of the problems and the need for unique solutions based on sound fire safety engineering.

5.0 BASIC FIRE SAFETY STRATEGIES

Architects must understand basic fire safety strategies. One of the most frequently used means to define these strategies is found in NFPA 550 – *Guide to the Fire Safety Concepts Tree*⁽¹⁴⁾. NFPA 550 presents its strategies in the form of a tree with a number of branches representing the individual strategies. The upper four levels of that tree are shown in Figure 1.

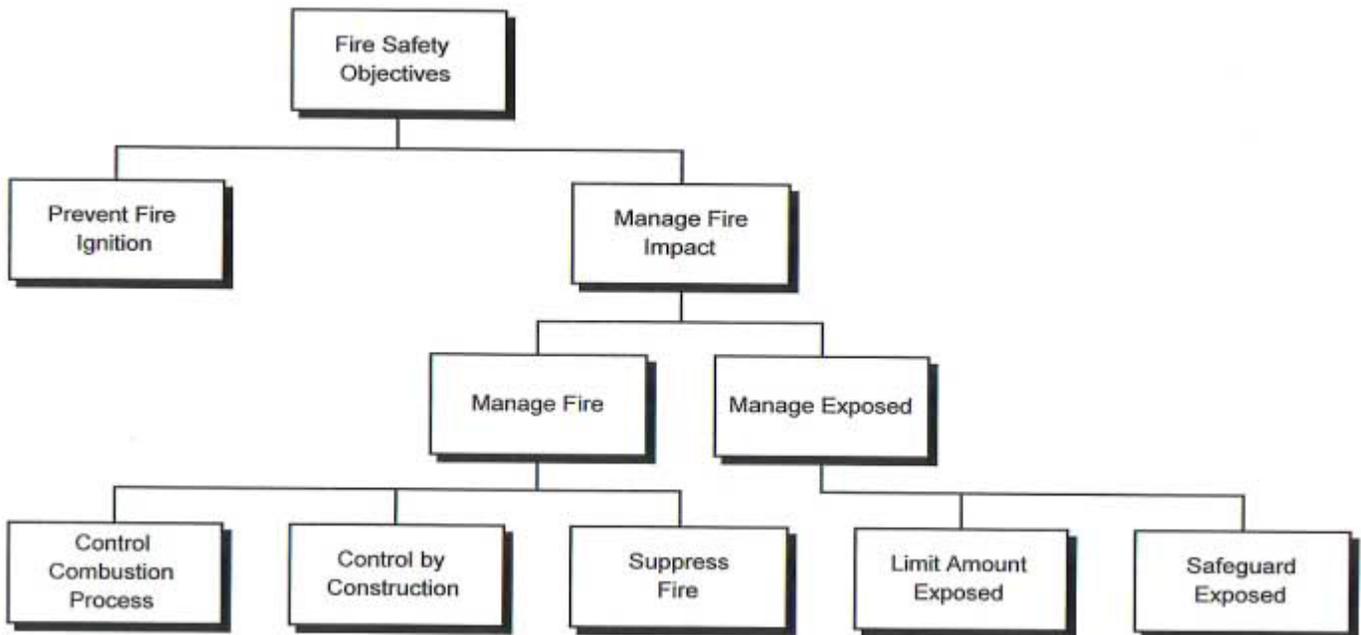


Figure 1 - Fire Safety Concepts Tree

Each box in the tree shows how the fire safety objectives of the box above can be met. For high-rise apartment buildings, the NBCC objectives are to minimize loss of life and injury to occupants as a result of a fire, especially to those occupants outside the apartment of fire origin. These, then, become the objectives which the architect must meet.

Prevent Fire Ignition Strategy – At the second level of the tree, it can be seen that two strategies can achieve that objective: *Prevent Fire Ignition* or *Manage Fire Impact*. The tree assumes that, if the strategy is 100% reliable and effective in itself, the objective of the box above is met. While means to reduce fire ignitions are incorporated in the design and operation of a high-rise apartment building, statistics show that fire ignitions will still occur (e.g., cooking, smoking) and thus the strategy employed to achieve the objective is to manage the impact of the fire.

Manage Fire Impact – To manage the impact of the fire, an architect automatically thinks of compliance with the NBCC – and that is often one means of achieving that objective. However, it is preferable to follow the logic of the tree to ascertain which fire safety strategies to employ and how code requirements fit into these strategies. The third level of the tree shows how to achieve the objective of managing the impact of the fire (to minimize deaths and injuries): either the fire itself must be managed (*Manage Fire*) or those exposed must be managed (*Manage Exposed*). The “exposed” in this case refers to the occupants, but could also mean valuable property, the building or an essential activity. Since no strategy is 100% reliable and effective, architects (and the codes) will usually employ multiple strategies to manage both the fire and the exposed.

Manage Fire – The 4th level of the tree in Figure 1 shows that the fire can be managed by any one of three alternatives:

- *Control the Combustion Process* – by controlling either the fuel (construction materials and contents) or the fire environment. Noncombustible construction and limitations on the quantity and flammability of combustible materials are employed. Interior wall and ceiling finishes, carpeting and insulations will burn, however, as will the furnishings which the occupants move into the building. Thus, while this strategy has some impact, by itself it cannot achieve the objective; in particular, because there is no means to control the occupants’ furnishings.
- *Control by Construction* – limits the growth of fire and the movement of smoke using construction elements such as walls and floors. Fire-rated floor assemblies, apartment enclosures, corridors, shafts, etc are provided to meet this objective.

Structural stability for a certain duration under fire attack is part of the strategy. Case studies show that doors may not be closed or firestops may be missing. Therefore, *Control by Construction* will not necessarily be 100% reliable and effective. It does, however, provide another basic building block for fire safety.

- *Suppress Fire* – Usually water is used to extinguish the fire, either automatically or manually. Standpipe systems provide the water supply for fire fighters, as well as for automatic sprinkler systems. Interior firefighting in high-rise apartment buildings is difficult and is not always effective during the time needed for occupant evacuation. Studies⁽¹⁵⁾ have shown that sprinkler systems are highly reliable and effective, but not 100%. Thus, this strategy can serve as another building block but cannot be relied upon by itself to meet the manage fire objective.

Manage Exposed – Given that, in real life, the *Manage Fire* strategy may not be 100% reliable and effective, strategies are required to manage the occupants exposed to the fire. The 4th level of the tree provides two means to achieve that objective:

- *Limit Amount Exposed* – The number of occupants that are exposed to the fire is limited. Since architects have little control over the numbers of occupants in a building's lifetime, this strategy is one that is seldom employed at the design stage and will not be addressed further.
- *Safeguard Exposed* – To protect them from the impact of the fire, the design must either defend the occupants in place or move them to a safe location. Smoke-filled exits may make it preferable for occupants in a high-rise apartment building to remain in their apartments (or especially on their balconies) to “wait out” the fire. This is a form of defend-in-place. A defend-in-place strategy must be undertaken only with the full knowledge and participation of the responding fire department. This strategy is often employed to protect occupants with mobility limitations when they are expected to wait for assistance in a protected exit stair or vestibule. Given the many difficulties with defend-in-place design and the currently-held belief that evacuation is essential, the alternative strategy of moving the exposed is usually employed. Moving the exposed occupants requires that the architect provide: a means to initiate movement (fire alarm/voice communication); a protected means to facilitate movement (smoke-free exit stairs of adequate size); and a safe destination, usually outside the building.

Figure 1, the Fire Safety Concepts Tree, provides the architect with the strategies to achieve fire safety in high-rise buildings. In fact, by looking at these strategies, the architect can see the many fire safety elements currently incorporated into building codes. Architects will typically use an amalgam of these strategies in seeking to achieve the fire safety objective.

6.0 STRATEGIES TO CONTROL THE COMBUSTION PROCESS

The combustion process can be controlled by selection of appropriate construction and finish materials, as well as contents, to reduce the fuel load or the burning rate of the fuel. Most of the fuel in an apartment building consists of the combustible furnishings about which there is little that the architect can do. Therefore, this strategy alone will not meet the objective of managing the fire.

Those fuel load aspects over which the architect has control in a high-rise apartment building include:

- Construction Materials – Tall buildings should be of noncombustible construction, although certain combustible construction elements are inevitable in any building. By having the major construction elements noncombustible, there is significantly less fuel to burn. Subsection 3.1.5 of the NBCC provides a list of those combustible elements permitted in noncombustible construction. Examples include roofing materials, glazing and skylights and some interior finishes and insulation. The incremental effect on fuel load and burning rates of these permitted materials is expected to be minimal, compared to the contribution from the occupants' combustible furnishings.
- Finish Materials – Given that finish materials, such as ceiling, wall and floor coverings, are often ignited early in a fire, an architect should select those materials which will be essentially noncombustible or which will burn at lower rates. Benchmarks for appropriate finish materials are their flame spread ratings. The same test method that determines a material's flame spread rating also evaluates the quantity of smoke, called a "smoke developed classification". Subsection 3.1.13 and other provisions of the NBCC place limits on flame spread ratings and smoke developed classifications for interior finish materials with more restrictive limits applied to more critical building spaces, such as exits. While the NBCC ratings are the maximums permitted, a good practice is to use materials

which have the lowest flame spread ratings and smoke developed classifications to minimize the contributions these materials will have on overall fire development. Some examples of required NBCC flame spread ratings for high-rise apartment buildings are shown in Table 4. Recall that all such new buildings must now be sprinklered according to the NBCC.

While the NBCC has imposed no limits on the flame spread ratings of most floor coverings, a prudent designer will select carpets and other floor coverings with the lowest flame spread ratings. Examples contained in Appendix D to the NBCC include wool, nylon and polypropylene carpets and some blends, depending on such factors as pile weight, underlay and attachment method.

Table D-3.1.1.B.

Flame-Spread Ratings and Smoke Developed Classifications for Combinations of Common Floor Finish Materials and Surface Coatings⁽¹⁾

Materials	Applicable Standard	FSR/SDC ⁽²⁾
Hardwood or softwood flooring either unfinished or finished with a spar or urethane varnish coating	None	300/300
Vinyl-asbestos flooring not more than 4.8 mm thick applied over plywood or lumber subfloor or direct to concrete	CSA A126.1-M	300/300
Wool carpet (woven), pile weight not less than 1120 g/m ² , applied with or without felt underlay	CAN/CGSB-4. 129-93	300/300
Nylon carpet, pile weight not less than 610 g/m ² and not more than 800 g/m ² , applied with or without felt underlay ⁽³⁾	CAN/CGSB-4. 129-93	300/500
Nylon carpet, pile weight not less than 610 g/m ² and not more than 1355 g/m ² , glued down to concrete	CAN/CGSB-4. 129-93	300/500
Wool/nylon blend carpet (woven) with not more than 20% nylon and pile weight not less than 1120 g/m ²	CAN/CGSB-4. 129-93	300/500
Nylon/wool blend carpet (woven) with not more than 50% wool, pile weight not less than 610 g/m ² and not more than 800 g/m ²	CAN/CGSB-4. 129-93	300/500
Polypropylene carpet, pile weight not less than 500 g/m ² and not more than 1200 g/m ² , glued down to concrete	CAN/CGSB-4. 129-93	300/500

Notes to Table D-3.1.1.B.:

- ⁽¹⁾ Tested on the floor of the tunnel in conformance with provisions of CAN/ULC-S102.2M, "Test for Surface Burning Characteristics of Flooring, Floor Covering, and Miscellaneous Materials and Assemblies".
- ⁽²⁾ Flame Spread Rating/Smoke Developed Classification.
- ⁽³⁾ Type 1 or 2 underlay as described in CGSB 4-GP-36M, "Carpet Underlay, Fibre Type".

TABLE 4

Flame Spread Ratings (FSR) for High-rise Apartment Buildings

Space	Maximum FSR Sprinklered Building	Maximum FSR Non-Sprinklered Building
Exit Walls/Ceilings	25	25
Vertical Service Space Walls/Ceilings	25	25
Bathroom Walls and Ceilings	200	200
Light Diffusers	250	250
Public Corridor Walls	150	175
Public Corridor Ceilings	150	25
Walls in Apartments and other Rooms	150	150
Ceilings in Apartments and other Rooms	25	25
Doors within Apartments	No Limit	No Limit
Doors to Corridors and Exits	200	200
Exit Floors	No Limit	25
Corridor Floors	No Limit	300
Apartment Floors	No Limit	No Limit

7.0 CONTROL BY CONSTRUCTION

The *Control by Construction* strategy contains the fire and ensures the stability of the structural elements against fire attack. The statistics, showing that 94% of fires in apartment buildings are contained to the room (apartment) of origin, clearly attest to the ability of fire resistant walls, ceilings and floors to contain a fire. As well, there are seldom reports of failures of structural elements from fires in apartment buildings. These same construction elements, however, may not be as effective at controlling the spread of smoke.

Structural Elements – The extent to which the major structural elements (beams, floors, columns) should resist fire attack is often a topic of considerable debate – and essentially depends on the time required for occupant evacuation and firefighting operations. While the time for able-bodied occupants to evacuate a high-rise building may be only a few minutes, additional time is required for those individuals who have mobility limitations. The evacuation time for these individuals may be measured in the tens of minutes or even longer. As well, for occupants who may not be able to evacuate without

considerable assistance, or not be able to evacuate at all, significant additional time is necessary. Thus, the prudent architect selects the fire resistance of the major construction elements in the range of approximately 2 h, which is among the highest normally used in standard construction. This extra fire resistance also provides additional time for firefighters to establish an attack on the fire. Article 3.2.2.42 of the NBCC requires that major structural elements in high-rise apartment buildings have a 2 h fire resistance rating.

In light of the fire and collapse at the World Trade Center (WTC) in New York, architects may ask whether the structural elements in a high-rise apartment building in Canada would have fared better. It is impossible to state in real terms what the difference in response would have been. However, an examination of the fire and fire resistant structural elements has merit. The WTC steel structure was comprised of a structural central service core and exterior structural steel tubes allowing virtually the entire floor areas to be column free. A typical high-rise apartment building will have a structural service core and columns on the perimeter and throughout the floor area. The structural members may be steel or concrete. More importantly, the apartment floor area will be divided into a number of fire-rated compartments (corridors and apartments). With an aircraft collision, the apartment building, due to the high level of compartmentation, would have a greater chance of containing the fire and thus keeping protection to some of the structural members. This does not imply that there may not be collapse in an apartment building; only that the collapse has a greater chance of being localized due to the compartmentation. The positive effect of a highly compartmented building was demonstrated in the aircraft collision with the Empire State Building in New York in 1945. While damage was by no means minimal, the compartmentation clearly contained the fire to a manageable area and the structure was not badly compromised.

Fire Containment – Typically, an architect should provide sufficient fire resistance to an apartment's walls to contain a flashover fire (a fire in which all of the combustibles in a space ignite and burn). Given the combustible furnishings in an apartment, a flashover fire is possible, should automatic sprinklers fail. Since the time for burnout of the contents of an apartment is extremely difficult to predict, the NBCC requires a 1 h enclosure for apartments. The statistical evidence of fires confined to the apartment of origin (typically with 1 h ratings), indicates that 1 hour is a reasonable limit.

A 1 h fire resistance rating does not necessarily mean that a construction element will withstand all fires for that duration. The 1 h is a rating in a standard furnace test using an

exposure that approximates a growing fire in cellulosic materials. The rating is just a means to rank assemblies exposed to the same fire for the same time.

Part 3 of the NBCC requires certain minimum fire resistance ratings for structural and non-structural assemblies, examples of which are shown in Table 5.

TABLE 5
NBCC Fire Resistance Ratings for High-rise Apartment Buildings

Element	Minimum Fire Resistance Rating
Loadbearing Floors, Columns, Walls	2 h
Apartment Enclosures	1 h
Public Corridors serving Apartments	1 h
Exit Stairs	2 h
Tenant Storage Rooms	1 h
Common Laundry Rooms	1 h

Control by construction does not apply only to the construction elements themselves but also to openings such as doors and windows, and penetrations for ducts, cables and piping. Often these details have a significant effect on fire spread and smoke spread so architects must exercise special care in their design.

Since *Control by Construction* may not be 100% effective in limiting smoke movement, other measures are needed to further ensure the safety of occupants during evacuation and for those remaining in their apartments.

8.0 FIRE SUPPRESSION

One of the most effective strategies to manage a fire is to provide fire suppression materials to extinguish the flames. While there are numerous gaseous and liquid materials available for fire suppression (e.g., carbon dioxide, foam), the only fire suppression agent reasonably affordable and effective for high-rise apartment fires is water. Water is applied either by hose streams (manual suppression) or automatic sprinklers (automatic suppression).

Manual Fire Suppression – Occupants of high-rise apartment buildings most often think of the arrival of firefighters and their use of hoses to extinguish fires. The mandatory sprinklers now required for Canadian high-rise apartment buildings may change that image.

There is still, however, an important and essential role for manual firefighting – either as a result of a failure of the automatic sprinklers or, more likely as the result of a fire in a concealed location inaccessible to the water from sprinklers, such as in an occupant’s wardrobe.

Fighting a fire in an apartment requires firefighters to travel along interior corridors with charged hoses, usually moving from the stairways⁽¹⁶⁾. These corridors are often smoke filled and can be very hot, thus making the firefighters’ task more difficult. On occasion, two hose lines will be used simultaneously during this type of interior attack.

Water for manual suppression must be available throughout the building height from a standpipe system, usually supplied from underground mains and booster pumps. A standpipe system might also be fed from interior tanks located at the top of a building (see Figure 2). Architects should also be aware of the need for a supplementary water supply for standpipe systems from fire department pumpers (see Figure 2). A fire department connection is normally provided to the standpipe – the location of which must be closely coordinated with the fire department access routes and external street hydrants.

Standpipe hose connections are normally placed in the exit stairs at each floor level. This allows firefighters a reasonably safe location from which to mount an attack. For buildings over 25 m in height, Article 3.2.5.10 of the NBCC requires that hose connections be available for 64 mm diameter hose; for lower

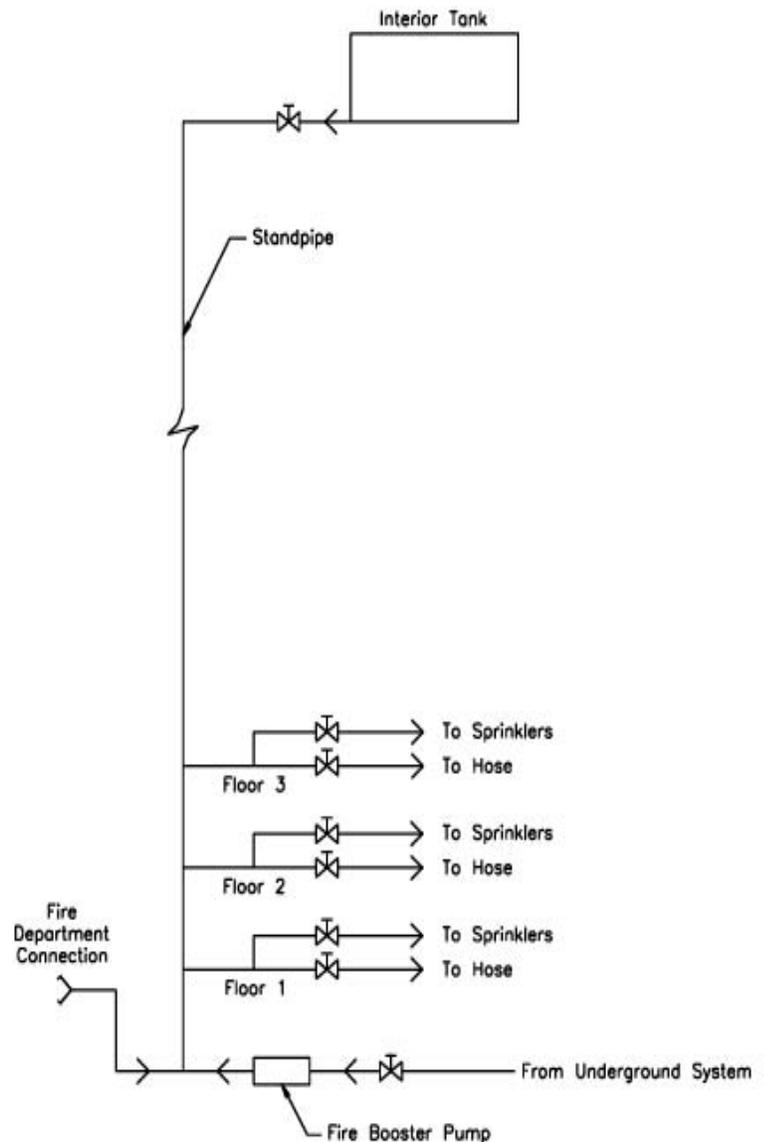


Figure 2 – Standpipe System

buildings, connections for 38 mm diameter hose must be provided.

One detail that is often missed in high-rise design is the need for firefighters to move hoses through stairway doors. This may permit smoke to enter the stairway – which may be while occupants are still evacuating. One solution sometimes proposed⁽⁷⁾ is the provision of a small port at the bottom of the door through which the hose can be fed while keeping the door closed. These solutions should be discussed with the door manufacturer and the local fire department before implementation.

The details for the design and installation of standpipe systems are provided in Article 3.2.5.10 of the NBCC and NFPA 14 – *Standard for the Installation of Standpipe, Private Hydrant and Hose Systems*⁽¹⁷⁾. In a building equipped with automatic sprinkler systems, both the sprinklers and the hose connections may be fed from the same standpipe riser as shown in Figure 2.

Automatic Fire Suppression – Automatic sprinklers have become the most commonly used strategy for managing fire in high-rise apartment buildings with the adoption of the NBCC 1995. As well as being required by code, designers should be aware that automatic sprinklers are still the most reliable and effective fire safety measure available today. With the advent of the residential sprinkler in the 1980s, the protection afforded by sprinkler systems expanded significantly from primarily property protection to include protection for occupants in the room of fire origin.

The details for the design and installation of automatic sprinkler systems are provided in Article 3.2.5.13 of the NBCC and NFPA 13 – *Standard for the Installation of Sprinkler Systems*⁽¹⁸⁾. Certified plastic pipe is permitted in certain applications in high-rise apartment buildings, provided the pipe is installed behind a protective barrier. Architects should consult both the certification documents for the pipe and the NBCC to determine limitations such as the fire resistance effectiveness of the barrier and the occupancies in which it is permitted.

While automatic sprinkler systems are both reliable and effective at suppressing fires, and thus reducing the quantity of smoke produced, there are a few instances where a fire may be concealed under a bed or a desk or in a cupboard and, while contained in area, it will continue to generate significant quantities of smoke⁽¹⁹⁾. To protect occupants from smoke in these instances, architects should be cognizant of the need for additional measures to limit smoke movement.

9.0 STRATEGIES TO SAFEGUARD OCCUPANTS EXPOSED TO A FIRE

Occupant fire safety requires more than just a fire alarm bell and exit stairs to the outside. To be reliable and effective, the system must include:

- means to alert occupants and make them promptly take appropriate action,
- means to communicate with them in a meaningful manner,
- means to protect occupants who cannot evacuate at the same speed or who may require assistance,
- exits that are sufficiently large and as smoke free as possible, and
- means to defend certain occupants in place should that strategy be used.

9.1 Strategies to Cause Occupant Movement

The first strategy is to ensure that occupants will begin to take evacuation action. Early fire detection and notification of the occupants and emergency responders are required.

Fire Detection – Fire detection occurs manually, when an occupant activates the fire alarm system, or automatically by smoke detectors or automatic sprinklers. Occupants should be instructed on actions to take in the event of discovery of fire as part of a building fire safety plan. Both bulletin boards, in frequently-used locations, and in-house meetings can be employed to demonstrate necessary techniques.

Smoke alarms in each apartment will detect a fire and alert the unit occupants. Smoke alarms are not connected to the building fire alarm system so occupants often need to take manual action to activate the building fire alarm system to alert other occupants and the emergency responders. Appropriate instructions to occupants are essential. Automatic sprinklers throughout the building provide another means of fire detection since the fire alarm system is automatically activated upon water flow in the sprinkler piping. Existing buildings without sprinkler systems will normally have heat detectors in each apartment connected to the building fire alarm system. Subsection 3.2.4 of the NBCC requires smoke detectors, connected to the building fire alarm system, in each public corridor and exit shaft to provide an early alarm should smoke originate in or migrate to these spaces.

Notification of Emergency Responders – Fire alarm signals must be transmitted to the fire department as early as possible. Signals from a sprinkler system waterflow detection device are required to be transmitted automatically to the fire department (or via

a central station). However, architects would be well advised to ensure a system design that notifies the fire department upon any alarm signal from the fire alarm system. Signals from smoke alarms would not be transmitted automatically since they are not connected to the fire alarm system.

Audibility of Fire Alarm Signals – With increased acoustic isolation of apartments, researchers have discovered significant problems with fire alarm audibility⁽²⁰⁾. To waken occupants, the NBCC specifies a minimum sound pressure level of 75 dBA in bedrooms. With a maximum sound pressure level of 100 dBA to prevent hearing damage, architects must carefully consider the location of the sounding devices. In many cases, they will be required in every apartment to avoid exceeding the 100 dBA limit in a corridor. Information is now available to assist architects to better locate sounding devices⁽²¹⁾.

The factors which determine the attenuation of sound include the “hardness” of the room and its furnishings, room size and rooms (and closed doors) separating the sounding device from the hearer.

In addition to audibility needs, occupants with hearing or sight limitations may need specialized vibrating devices or strobe lights (or both) to alert them to the alarm. As well, occupant communication among themselves during an emergency is essential to ensure a successful evacuation. Very loud fire alarm sounding devices will impede this communication⁽²²⁾.

Notification of occupants – The four objectives of the fire alarm signal are to⁽²²⁾:

- Warn occupants of a fire
- Indicate the need for prompt action
- Indicate the need to initiate evacuation
- Allow sufficient time for escape.

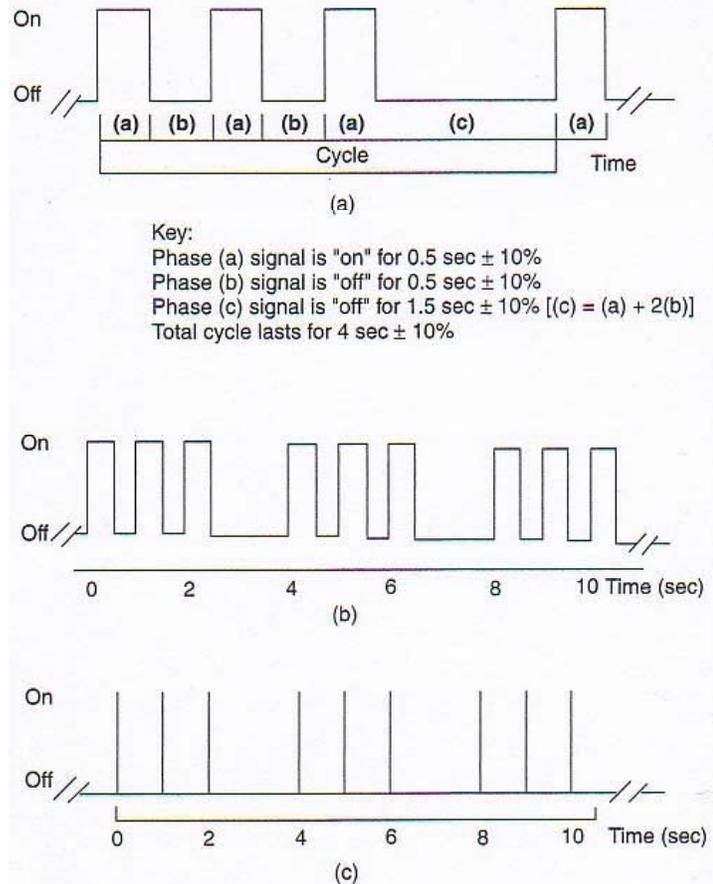


Figure 3 – Temporal 3 Pattern Alarm Signal

The fire alarm signal must be distinctive so that there is no ambiguity in the occupants' minds. Subsection 3.2.4 of the NBCC now requires the temporal pattern fire alarm signal, which has been adopted as the international signal for evacuation. Architects should be aware of this “temporal 3 pattern” and its intent to cause occupants to evacuate. Most occupants (94%) are not aware that the temporal 3 pattern alarm means to commence evacuation⁽²³⁾. (Figure 3.)

Occupants of apartment buildings tend to ignore fire alarms, regardless of the type of signal⁽²²⁾. The problem stems from frequent nuisance alarms. As the number of “false” alarms increases, occupants tend to respond less. There are many actions that an architect can take to minimize the major sources of nuisance alarms⁽²²⁾ shown in Table 6.

TABLE 6
Estimated Sources of Nuisance Alarms⁽¹⁾

System Malfunctions	45.0%
Unintentional Calls	27.0%
Malicious, Mischievous Calls	15.8%
Other False Alarms (bomb scares, etc.)	12.2%

Notes: ⁽¹⁾Extracted from Reference 22.

Firstly, ensure that the system is reliable and that potential system malfunctions are minimized. Select quality equipment and ensure it is installed to current standards. Provide for a long-term maintenance and testing program. Install fire detectors only after dust-producing finishing is complete. Use new methods to protect pull stations from malicious use. However, design cannot address the well-intended, non-fire calls or other potential emergencies. Only through effective training can some of these calls be eliminated or reduced.

Following a fire alarm signal, it is essential for occupants to initiate evacuation. The time to start evacuation varies from 2.5 min to 5.3 min⁽²⁴⁾. Gathering valuables, getting dressed, finding pets and children and gathering information on the event are the most common reasons for the delay. The need to decrease the evacuation start time cannot be overemphasized. Regular evacuation drills, as part of the implementation of the building's fire safety plan, is one means.

A voice communication system used after the initial fire alarm signal is another. Research⁽²⁵⁾ shows that voice messages directly from staff or through a communication system are taken most seriously by occupants, compared to bells and other alarms. It is important, therefore, to select equipment that enables voice messages throughout the apartment building, including the corridors and exit stairs. CAD-compatible software can assist in the design for voice intelligibility⁽²⁶⁾. Testing equipment for assessing intelligibility⁽²⁶⁾ is also becoming available. Pre-recorded messages are ineffective and even dangerous in some situations⁽²²⁾. Article 3.2.6.8 of the NBCC requires a voice communication system in all high-rise buildings where the floor of the top storey is more than 36 m above grade (approximately 12 storeys). However, architects are encouraged to install them in all high-rise apartment buildings.

Occupant behaviour is influenced by many factors during a fire emergency as shown in Figure 4. Architects may not be able to influence some of these factors, but they can ensure that their designs acknowledge the relationship of these occupant, building and fire characteristics.

By early fire detection, an unambiguous audible alarm, avoidance of nuisance alarms and appropriate voice messages, architects will have gone a long way to ensuring that occupants have sufficient exit time.

9.2 Strategies to Provide Means for Occupant Movement

Occupants evacuate an apartment building by moving from their units, through the common egress system (corridors and stairs) to reach a place of safety, usually outside the building. Architects must provide measures all along this path to ensure occupant safety as shown by the following:

Occupant Characteristics – Figure 4 shows occupant characteristics that may determine behaviour during a fire.

- Familiarity and experience within the building will greatly influence the evacuation route chosen⁽²⁵⁾. Thus, occupants will normally choose an exit stair that they use routinely (or try to use an elevator), unless training and drills have demonstrated the need to use other routes.
- Occupants are prepared to move through smoke while evacuating, despite knowledge that smoke can harm them⁽²⁵⁾. However, smoke often reduces the speed of evacuation.

- Able bodied, normal evacuation speed will be 60 to 74 metres per minute along corridors and walkways, and about 10 seconds per storey on stairs⁽³⁾.

Figure 4 – Occupant Characteristics

Occupant Characteristics	Building Characteristics	Fire Characteristics
Profile <ul style="list-style-type: none"> • Gender • Age • Ability • Limitation 	Occupancy <ul style="list-style-type: none"> • Residential (lowrise, midrise, highrise) • Office • Factory • Hospital • Hotel • Cinema • College and University • Shopping Centre 	Visual cues <ul style="list-style-type: none"> • Flame • Smoke (colour, thickness) • Deflection of wall, ceiling, floor
Knowledge and Experience <ul style="list-style-type: none"> • Familiarity with the building • Past fire experience • Fire Safety training • Other emergency training 	Architecture <ul style="list-style-type: none"> • Number of floors • Floor area • Location of exits • Location of stairwells • Complexity of space/Wayfinding • Building shape • Visual access 	Olfactory cues <ul style="list-style-type: none"> • Smell of burning • Acrid smell
Condition at the Time of Event <ul style="list-style-type: none"> • Alone vs. with others • Active vs. passive • Alert • Under Drug – Alcohol – Medication 	Activities in the Building <ul style="list-style-type: none"> • Working • Sleeping • Eating • Shopping • Watching a show, a play, a film, etc. 	Audible cues <ul style="list-style-type: none"> • Cracking • Broken glass • Object falling
Personality <ul style="list-style-type: none"> • Influenced by others • Leadership • Negative toward authority • Anxious 	Fire Safety Features <ul style="list-style-type: none"> • Fire alarm signal (type, audibility, location, number of nuisance alarms) • Voice communication system • Fire safety plan • Trained staff • Refuge area 	Other cues <ul style="list-style-type: none"> • Heat
Role <ul style="list-style-type: none"> • Visitor • Employee • Owner 		

Capacity of Exits – Section 3.4 of the NBCC states how to calculate the minimum width of exits. A typical high-rise apartment building would require a minimum of two exit stairs, each at least 1100 mm wide. Due to the low occupant loads on each floor, this would be sufficient to enable occupants to evacuate without appreciable congestion in the

stairways. Thus, evacuation speed is not significantly affected by the stairway width in this case. For very high buildings or buildings with large numbers of apartments per floor, there may be cases of congestion occurring at lower floor levels. The issue of providing adequate exit capacity does not require significant design effort for apartment buildings.

However, some conditions will have an effect on occupant evacuation speed. The factors shown in Figure 4 all play a role. Currently available calculation techniques⁽³⁾ can ascertain the minimum time needed for fire containment or control of smoke in relation to evacuation time. While these provide reasonable estimates of time to evacuate, most of them do not take into account the composition of the occupant load in the building (e.g., families vs singles, aged vs young), the abilities of the population (e.g., disabled, aged, very young) or the effect of fatigue (long distance down stairs), stress as a result of being in a fire situation, and the effects of moving through smoky conditions⁽²⁵⁾. As such, architects should consider the calculation methods as providing optimistic results and increase potential evacuation times to account for the above factors.

Route Completeness – Once occupants enter an exit stair, the Code requires that they be able to stay in that protected space until a place of safety is reached – usually outdoors. If exit stairs discharge into a lower-level corridor or through a lobby, the continued protection for the occupant

is required. Obvious and visible wayfinding cues are also needed throughout the evacuation route. Research has shown the benefit of appropriate wayfinding signage⁽²⁷⁾ in routine and emergency situations. Photoluminescent way guidance systems⁽²⁸⁾ are most effective tools as well. Figure 5 shows the benefits of a photoluminescent wayfinding system.



Figure 5 – Photoluminescent wayfinding

9.2.1 Protected Path

Protection of egress routes from smoke is also vital.

Smoke – Reduced visibility from particulates and incapacitation from toxic gases are the two dangers of smoke. Particulates are not usually the cause of fatalities in building fires. However, they do cause eye irritation and respiratory problems, and reduce the visibility needed for safe egress. The major toxic gases in smoke are carbon monoxide, carbon dioxide, hydrogen cyanide, hydrogen chloride and nitrogen dioxide. Concentrations of those that can be dangerous to occupants are shown in Table 7. Generally short-term exposures are measured in minutes and long term in hours. Perhaps the most important toxic gas from a fire perspective is carbon monoxide which is produced in large quantities in most fires. Given the great difficulty in predicting which gases will be produced in a fire, it is usually the visibility reduction (smoke density) factor that is used as a governing parameter in the design of systems to control smoke movement.

TABLE 7⁽¹⁾

Maximum Allowable Concentrations of Toxic Gases

Toxic Gas	Maximum Allowable Concentration, ppm	
	Prolonged Exposure	Short Period Exposure
Carbon Monoxide	100	4,000
Carbon Dioxide	5,000	100,000
Hydrogen Cyanide	10	300
Hydrogen Chloride	5	1,500
Nitrogen Dioxide	5	120

Notes: ⁽¹⁾ From Reference 29.

Design is based on limiting smoke concentrations so that the optical density does not exceed set limits. Exit signs and other wayfinding devices can then be seen by occupants. A commonly quoted design optical density/m is 0.043 which corresponds to a visibility through smoke of approximately 25 m⁽⁵⁾. This limit is the basis to determine the success of smoke control systems. Other criteria for limiting smoke movement (NBCC Article 3.2.6.2) are based on a percentage of contaminated air (smoke) in a given volume. This means of stating design criteria is essentially the same as the use of optical density/m.

Both result in criteria that limit the quantity of smoke in a given quantity of clean air in the protected space.

Smoke Movement – Differential pressures are primarily responsible for smoke movement through “leakage openings” in compartment boundaries. These openings include cracks around windows and doors. References 5 and 30 provide background and calculations needed to determine leakage openings and the means to prevent smoke movement through them. An example of the air leakage rate for cracks around typical stair and elevator doors is shown in Figure 6. A designer must provide sufficient mechanical pressurization capacity to ensure that pressure losses due to these openings do not result in a substantial pressure drop.

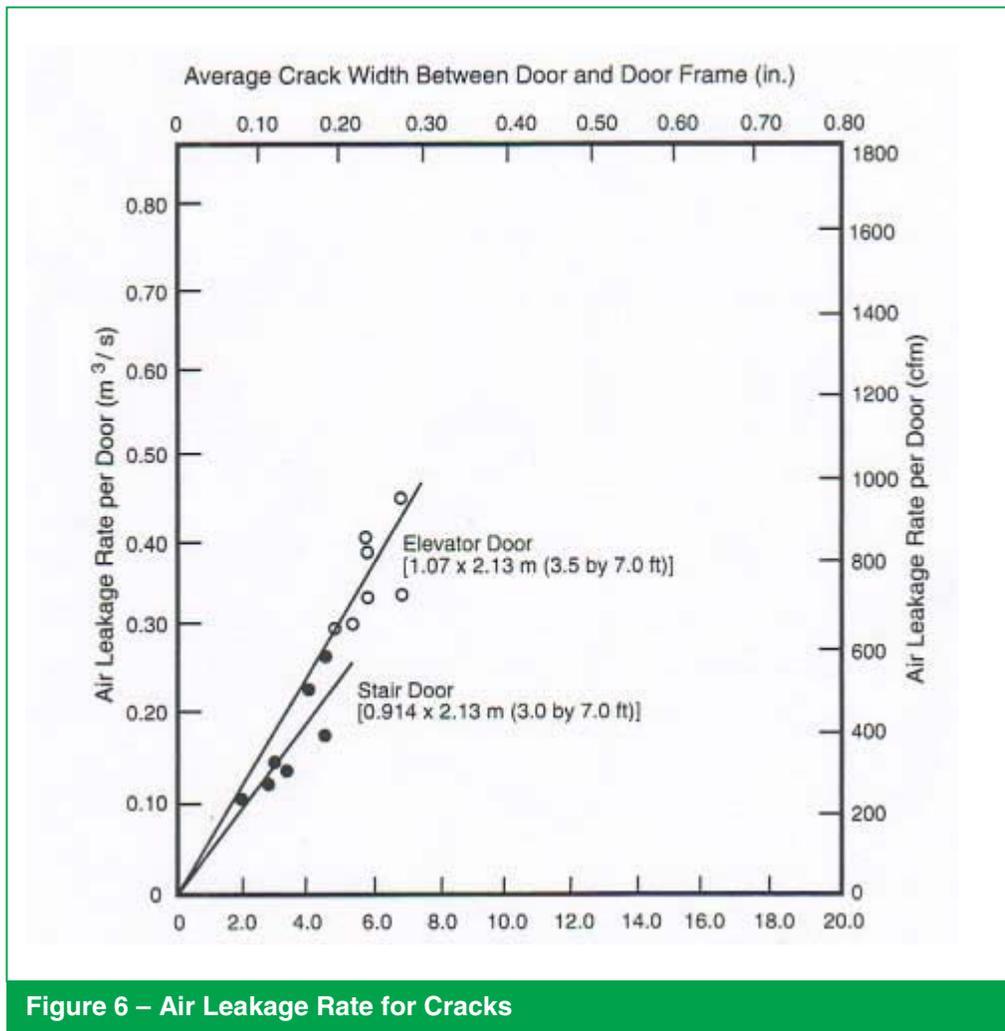


Figure 6 – Air Leakage Rate for Cracks

In high-rise apartments, the major forces which cause pressure differences are:

- Thermal expansion of gas. Heat generated by the fire increases gas volume. This in turn increases the pressure in the room of fire origin, driving smoke through the compartment boundaries.

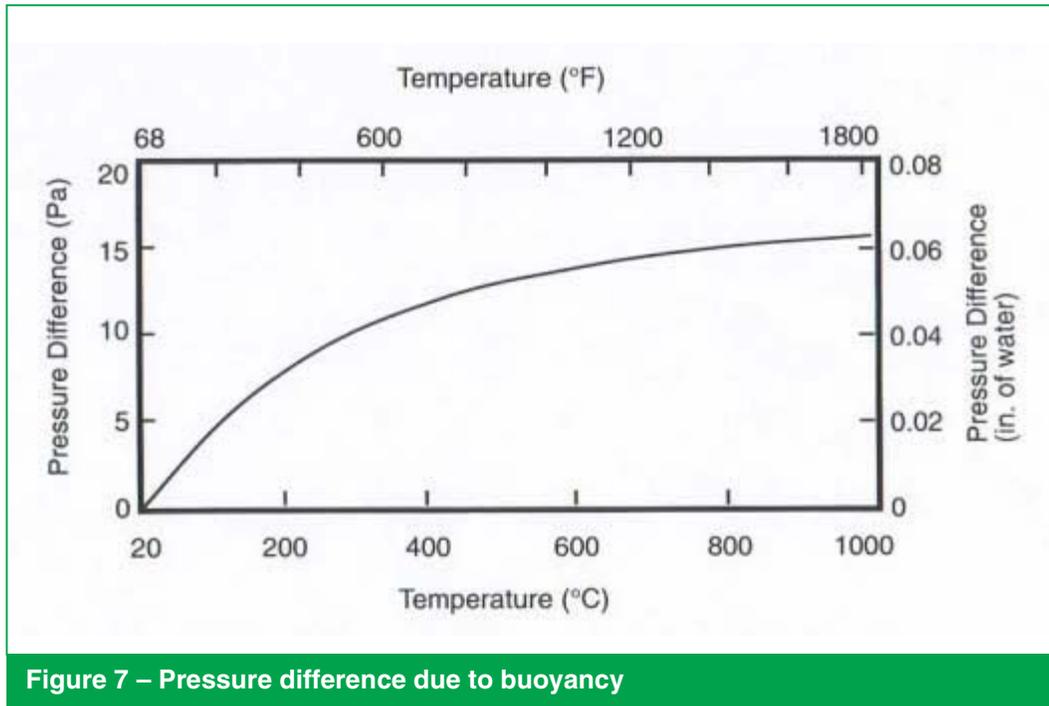


Figure 7 – Pressure difference due to buoyancy

- Buoyancy of heated smoke. High temperature smoke from a fire is buoyant and tends to rise, escaping through leakage openings at the higher levels of the boundaries. At the same time, cooler air enters from outside the fire compartment through leakage openings at the lower levels. For a fire temperature of 600-1000°C in a room with a ceiling height of only 3.5 m, the pressure difference caused by buoyancy is in the range of 15 Pascals (Pa) as shown in Figure 7⁽⁵⁾. This is why it is important to keep the fire small, or to cool it through suppression.
- Stack effect. Stack effect is the upward or downward movement of air or smoke as a result of temperature differences between the inside and outside of the building. In effect, this may look like a larger scale version of the buoyancy effect. Figure 8 shows normal stack effect in a high-rise building where the outside temperature is lower than the inside (in Canadian winters) and reverse stack effect where the inside temperature is lower than the outside (as in an air-

conditioned building in summer)⁽³⁰⁾. In winter, air enters the building below the neutral plane and exits above it. Thus, air and smoke move upward through the building. In the latter case, air exits the building below the neutral plane and air enters above it, thus causing a downward flow of air and smoke through the building.

Stack effect increases with increasing height and with temperature differences between inside and out. Thus, in a very high apartment in the cold of winter, the pressure differentials across boundaries and the upward movement of

smoke from a fire can be significant. For example, for a 100 m tall building (approximately 30 storeys) with an inside temperature of 21°C and an outside temperature of 0°C, the pressure differential at the top of the building would be about 100 Pa.

- Wind effects. Wind creates significant pressure differences, air leakage and more smoke movement. The calculation of wind effect depends on the terrain, the wind direction on the building surfaces, the height of the building with respect to surrounding buildings and other factors. The airflow inside a building from wind effects is mainly horizontal under normal conditions. In a fire where a window has broken, however, the increased pressure on the fire floor can drive smoke into adjacent floors and vertical shafts.
- Piston effect of elevator cars. Article 3.2.6.5 of the NBCC requires that an elevator be designed for use by firefighters, while discouraging the use of

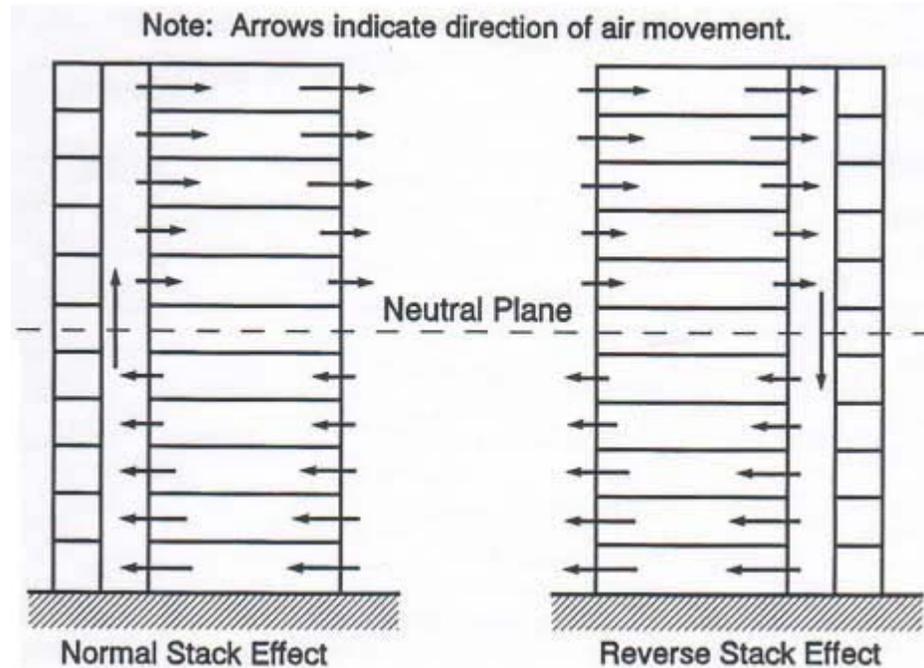


Figure 8 – Stack Effect

elevators for evacuating occupants. This elevator can cause a suction effect inside the shaft thus drawing smoke into this protected area and potentially causing it to move to other areas of the building. The mechanical system design must account for this.

- Air handling systems. Normal HVAC systems in a high-rise apartment building provide an extensive series of ducts through which smoke can flow. Without fans running, the ductwork provides an avenue for smoke spread due to the factors mentioned above. As well, normal recirculation of air by the air handling system can distribute smoke from one zone to other parts of the building. Designers should be cognizant of this potential and, through the installation of dampers and fan shutdown, or by adapting the system to provide favourable pressure difference patterns⁽⁵⁾, use the HVAC systems to provide a protected environment for evacuating occupants. For example, in apartment buildings, this can mean keeping the corridors at positive pressure with respect to the apartments since most fires will occur inside apartments.
- Combined forces. To achieve a relatively smoke-free environment in the exit system, the individual pressures acting on the building and the exit shafts must be calculated. This will also determine which combination of forces is likely to be present in the event of a fire. The result will be the design pressure differences across the exit shaft or space boundaries that a smoke control system must overcome to prevent smoke movement into those protected spaces. This is normally a part of the mechanical system design. References (5), (30) and (31) provide extensive information on the design of systems to minimize smoke spread.

9.2.2 Protection of Disabled during Evacuation

In the context of evacuation, any person who is incapable of using the stairs and other exits can be considered to be disabled. This could include blind or mobility-impaired occupants, as well as occupants who may be temporarily bedridden. The evacuation or protect-in-place strategies needed for bedridden occupants would mirror those of a hospital or nursing home and, as such, are beyond the scope of this article. There are, however, strategies that can be employed to provide protection for blind or mobility-impaired occupants (and occasionally for temporarily bedridden occupants).

It is most important for these occupants to be identified in the Fire Safety Plan for the building and appropriate provisions made with the Fire Department.

The evacuation of disabled occupants will take longer than the able-bodied population. As such, the time during which protection, especially against smoke movement, must be provided may need to be extended. Strategies to be considered to increase the time for evacuation include:

- Exterior balconies from apartments.
(These can serve as places of temporary refuge.)
- Cross-corridor separations to create at least two zones on a floor that can be protected against smoke movement. Each zone is served by its own exit stair. (see Figure 9)
- Protected vestibules adjacent to the protected firefighters' elevator.
- Protected vestibules adjacent to protected exit stairs as shown in Figure 10.
- Additional space on protected exit stairway landings to wait for assistance in evacuation.



Protection of Disabled Persons

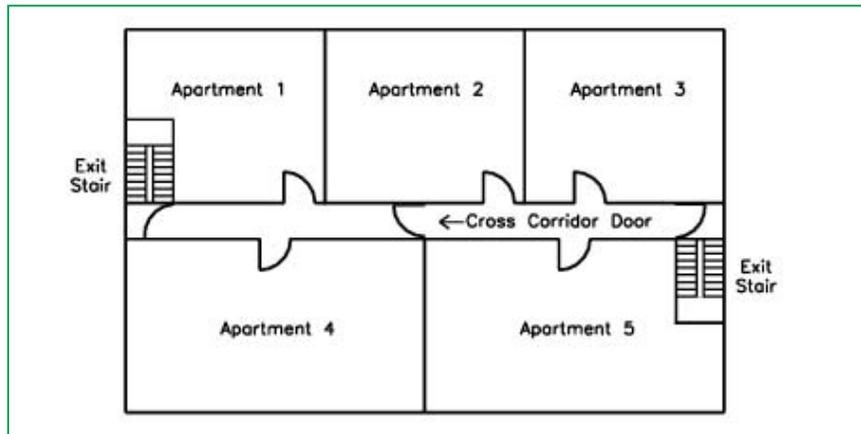


Figure 9 – Cross Corridor Separation

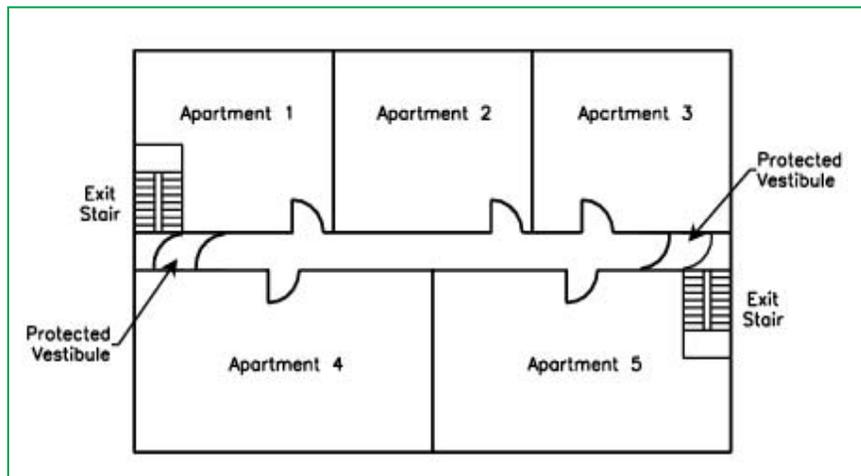


Figure 10 – Protected Vestibules

All of these strategies must be coordinated with the barrier-free provisions of the NBCC to ensure that access and use is appropriate for those requiring these facilities. That may mean having occupants with disabilities located on the first six floors of the building so that ladder evacuation can be employed as a last resort. A good source of information for designers in choosing evacuation strategies for persons with disabilities can be found in Reference 32. The most important strategy in ensuring safe evacuation for the disabled is in the planning with the occupants, building management and fire department which should be a part of the fire safety plan for the building.

9.2.3 Protect Occupants in Place

There may be situations in high-rise apartment buildings when occupants will not be able to evacuate either for medical or other reasons. To provide safety for these occupants, the architect may need to consider strategies to defend those occupants in place. A first element is to ensure that the necessary strategies are part of the fire safety plan. Recall that high-rise apartment buildings do not meet the same defend-in-place strategies required for hospitals and nursing homes. However, it is important to understand how safety in those buildings is provided.

This strategy provides fire and smoke separation for sufficient time to “wait out” the fire. One obvious first step is to permit defend-in-place strategies to be used only in sprinklered high-rise buildings, as currently required by the NBCC. Following that, employing the “control by construction” and “smoke control” strategies, discussed earlier, will help ensure that the space being defended remains as smoke and fire free as possible. Since the affected occupants probably cannot move or be moved easily to an open balcony, that strategy may not work without provision for access to the balcony and planning for the movement of the occupant by others.

10.1 SPECIAL PROBLEMS

10.1 Buildings Containing Atria

High-rise buildings are often constructed with atria or are located over buildings with atria. Architects must recognize the inherent fire safety issues associated with atria and provide appropriate protection for their occupants. Subsection 3.2.8 of the NBCC contains

an extensive set of fire safety provisions for buildings containing atria called “interconnected floor spaces”. These are needed to provide protection due to the breach of one of the basic code building blocks – floor-to-floor fire separations. As a result of this deficiency, a number of extra requirements include improved egress and smoke removal, in addition to the basic requirement for automatic sprinklers.

When a high-rise has an associated atrium, the major focus usually becomes smoke spread. Smoke needs to be limited and tenable conditions maintained in egress routes open to the atrium. Research on smoke movement and control in atria⁽³³⁾⁽³⁴⁾ provides principles to follow. The potential size and location of fires and how mechanical exhaust will be used to keep the atrium and protected spaces smoke free will determine the measures required. Design solutions are presented in References (5) and (30) as well as NFPA 92B – *Guide for Smoke Management Systems in Malls, Atria and Large Areas*⁽³⁵⁾. The safety measures for the atrium must be integrated with those for the high building to achieve a successful fire-safe design.

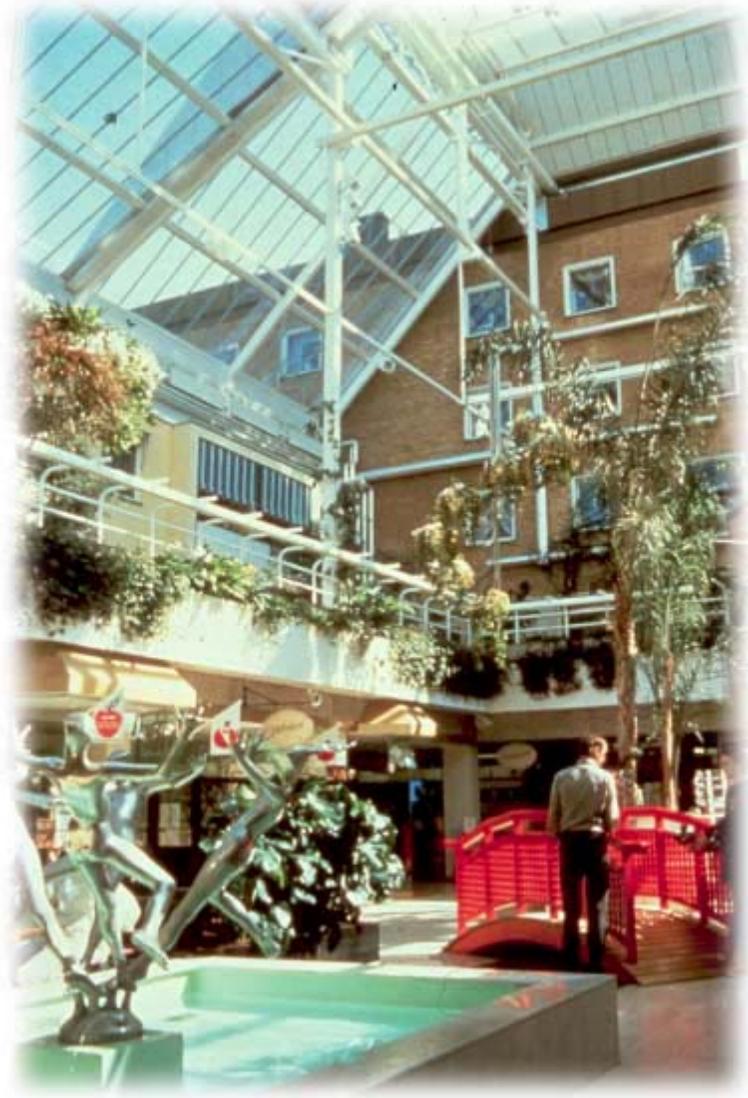


Figure 11 - Atrium

10.2 Buildings above Subway Systems

In crowded downtown areas, planners have used the space over subways as locations for large buildings. The rapid transit system and the connection to the building create fire hazards greater than if the subway connection were not there.

The architect needs to be sure that the subway station and its associated spaces will not create a significant fire and smoke problem for the high-rise building. The most commonly used method of achieving fire safety is employing NFPA 130 – *Standard for*

Fixed Guideway Transit and Passenger Rail Systems⁽³⁶⁾. By using this standard, the exposure to the high-rise building is minimized.

Next, the potential impact of a fire in the subway system on the high-rise building needs to be determined. Smoke spread from the subway to the building and the effect of the evacuation of large numbers of occupants from the subway system on the evacuation of the high-rise building are important issues.

To prevent smoke spread, a preferred method is the provision of a significant fire separation with a pressurized vestibule between the subway system and the building. As well, openings between the two occupancies should be minimized to prevent smoke movement across the barriers. Also, the piston effect of subway trains needs to be considered in a manner similar to that discussed previously for elevators.

An important measure is to totally separate the exit facilities for the subway system and the high-rise building, not only for minimizing smoke spread potential but also to prevent potential overcrowding of the exits by travellers from the subway. It is usually not desirable to integrate the fire alarm systems for the two structures, given the potential confusion for the high-rise residents.

11 POST CONSTRUCTION CONSIDERATIONS

Fire safety in high-rise apartment buildings can only be assured when appropriate precautions are also taken during occupancy. A Fire Safety Plan for the building will consolidate them. The original plan should be prepared by the architect and the building owner (manager) in conjunction with the fire department prior to occupancy. Copies of this plan should be given to all new tenants when they arrive. As well, copies should be prominently posted in the building. Translation should be done if some occupants do not speak the language of the original Plan. If any design arrangements have been made for the evacuation and safety of the disabled, those should be noted in the fire safety plan prior to building occupancy.

Every plan needs practice evacuation drills at least yearly. A clear, accurate set of instructions should explain what occupants are expected to do in the event of a fire. The Fire Safety Plan should also contain the maintenance and testing needs for the fire safety features. The architect must ensure that these needs are transferred into the Plan to maintain the safety built-in at the time of construction.

12.0 QUESTIONS

12.1 Questions

1. From a fire safety viewpoint, what are the unique features that differentiate a high-rise apartment building from a low rise?
2. From a statistical standpoint, how safe are occupants in high-rise apartment buildings compared to low-rise apartment buildings? How does the risk to life for the occupants compare?
3. What causes smoke to move in a high-rise apartment building during a fire? Can it actually move downward?
4. How do firefighters control and suppress a fire in a high-rise apartment building if they can't reach the level of the fire from their aerial ladders?
5. What actions can an architect typically expect occupants to take upon hearing a fire alarm in a high-rise apartment building?
6. What can a designer do to improve the manner in which occupants respond to a fire alarm in a high-rise apartment building?
7. What are the other construction measures that an architect can build into a high-rise apartment building to provide fire safety? From a firefighting perspective, what are important considerations in the design of windows and glass areas?
8. What is the role of automatic sprinkler systems in high-rise apartment fire safety?
9. How is fire safety provided for occupants with physical disabilities in a high-rise apartment building?
10. Are there extra precautions that an architect should take if an atrium is incorporated in a high-rise building? How do codes treat such arrangements? What are the fire precautions that an architect should consider when apartment buildings are located over subway stations?
11. Are there differences in the fire responses of high-rise buildings constructed with steel or concrete structures? Why did the World Trade Centre buildings collapse following the aircraft collision and fire? Would Canadian high-rise apartment buildings behave in the same manner?

For the answers to these questions, please refer to your professional association's Web page.

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- Figure 1 Basic Fire Safety Strategies
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- Figure 3 Temporal 3 Evacuation Signal
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- Figure 4 Factors Impacting on Human Behaviour in Fire
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- Figure 5 Stairwell with Normal Lighting and Photoluminescent Marking with No Other Lighting
Photo courtesy of Dr. Guylène Proulx, National Research Council of Canada.
- Figure 6 Air Leakage Rates for Cracks Around Stair and Elevator Doors and
& 7 Pressure Differences as a Result of Buoyancy of Fire Gases Press:
Reprinted with permission from Smoke Movement and Control in High-rise Buildings Copyright ©1994, National Fire Protection Association, Quincy, MA 02269.
- Figure 8 Air Movement Due to Normal and Reverse Stack Effect
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