Technical Analysis of the Need for Enclosed Elevator Lobbies

Prepared for the ICC CTC by the Elevator Lobby Study Group

EXECUTIVE SUMMARY

The ICC Executive Board directed the Code Technology Committee (CTC) to study the issue of elevator lobby separations in November 2010 due to the number of code change proposals submitted addressing this issue over a number of code change cycles. The Code Technology Committee formed a study group on the elevator lobby separation issue in December 2010. The code change proposals submitted are the result of the CTC's study of the issue.

This focus of the study group began with a review of technical documents and the history of the code provisions over the years. This led to extensive discussions on the intent and need for enclosed elevator lobbies and included calculations to determine the effect of stack effect in high rise buildings. This technical review resulted in a technical analysis that determined when enclosed elevator lobbies should be required.

Enclosed elevator lobbies should not be required for:

- Low-rise and mid-rise buildings not provided with sprinkler protection
- High rise buildings where the elevator hoistway is 420 feet or less in height.

Enclosed elevator lobbies should be required for:

- Elevator hoistways exceeding 420 feet in height
- Fire Service Access Elevators regardless of building height
- Occupant evacuation elevators regardless of building height

The basis for eliminating the requirement for enclosed elevator lobby separations in low-rise and mid-rise buildings (whether or not provided with sprinkler protection) is that these buildings can be evacuated in a relatively short period of time. Hence, any hazard of the spread of smoke via the elevator hoistways in these buildings is mitigated by evacuation of the building occupants.

The basis for eliminating the requirement for enclosed elevator lobby separations in high rise buildings (where the height of the elevator hoistway is 420 feet or less) is the many fire safety features required by the building code, including automatic sprinklers, that mitigate the hazard of the spread of smoke via elevator hoistways. The cooling of the smoke by automatic sprinkler discharge also reduces its buoyancy, the principal driving force which causes migration of smoke between floors. The "stack effect", the pressure differentials between floors due to differences in indoor and outdoor temperatures, is not significant enough to cause large quantities of smoke from the floor of origin to migrate to other floors in the building.

The decision to require enclosed elevator lobbies in buildings where the elevator hoistway height exceeds 420 feet in height relates to the greater concern with stack effect in such tall shafts and the potential consequences of fires in taller buildings with larger occupant loads further from the level of exit discharge.

One of the concerns that the CTC wrestled with in developing these proposals is the reliability and effectiveness of a building's many fire safety features but most specifically automatic sprinklers. To further address these concerns the technical analysis presents a brief analysis of the various protection features available in high rise buildings and how they work together. This analysis makes it clear that sprinklers are just one of many fire safety features that are part of a holistic protection strategy in high rise buildings.

TECHNICAL ANALYSIS

Background

One of the fundamental objectives of fire safety in buildings is to limit the spread of fire and its effects (heat, smoke, and toxic gasses). This is usually accomplished by limiting the ignitability and burning rate of materials, by physical barriers (compartmentation) and by suppression (automatic and/or manual). In specific areas where it is most critical to prevent direct exposure of building occupants that might injure or interfere with evacuation, physical barriers may be supplemented by active or passive smoke control.

The driving force that causes the migration of smoke through a building is differences in temperature (and resulting differences in density) resulting from the fire and from the fact that the environment in many buildings is heated or cooled for comfort. Air flows resulting from these temperature differences increase with increasing difference in temperature and in relation to the area of openings (including visible and hidden gaps and cracks) between spaces at different temperature. It is assumed that smoke flows in a similar manner as air flows inside a building.

One of the early lessons learned from fire disasters is the need to protect shafts that can act as "chimneys," carrying heat, smoke, and gasses to remote areas of a building. Smoke and fire spread up hoistways and stairways accessed through non-rated doors had been implicated as early as in 1911 in the 146 fatalities at the Triangle Shirtwaist Fire [Sunderland 2011]. Other significant fires that involved smoke and fire spread up stairways and hoistways include the Equitable Building Fire, New York, NY, January 9, 1912; and the MGM Grand Hotel, Las Vegas, NV, November 21, 1980.

It should be noted that these were all unsprinklered or partially sprinklered, and the fire started in an unsprinklered area.

Stack Effect

Stack effect is defined as air flow in shafts induced by indoor-to-outdoor temperature differences that lead to density differences and flow. By convention, stack effect flows are upwards when outdoor temperatures are colder than indoors, and reverse stack effect is a downward flow observed when outdoor temperatures are warmer than indoors. The upward flow results when air from lower floors is drawn into the shaft and flows out on upper floors. Thus, there exists a height in the building at which there is no flow into or out of the shaft, which is called the "neutral plane." Flow rates increase with height above and below the neutral plane. This is illustrated for normal (upward) stack effect in Figure 1.

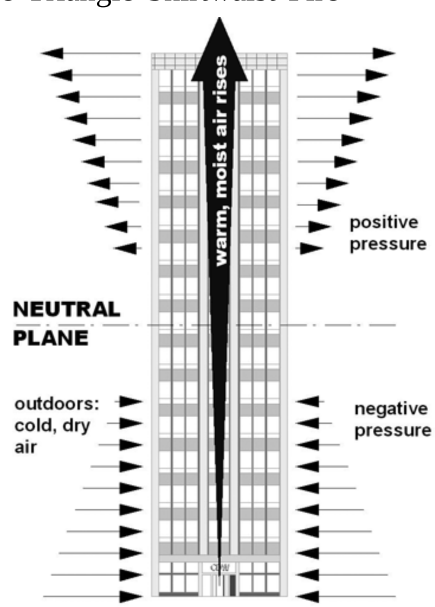

Figure 1 – Stack Effect Flows

Stack effect flows can be induced in any shaft in a building, including mechanical, plumbing, and electrical shafts. Stack effect creates the greatest problems in elevator hoistways because the hoistways cannot be closed at intervals as can plumbing and electrical shafts, and the landing doors at every floor at which the elevator stops are leaky because they open laterally, making them difficult to seal. Problems associated with stack effect range from annoying (strong flows blowing from openings) to safety hazards when stack effect moves smoke and gasses from fires or accidental chemical releases vertically within the building.

The pressure induced at each floor is a function of the leakage areas, the height of the shaft and the temperature difference. Stack effect pressures across elevator landing doors can range up to 3 in. water (800pa) in an 800 ft building, as shown in Figure 2. [Tamura, G., 1968] Worst case pressures are observed in winter conditions since the indoor to outdoor temperature differences are greatest.

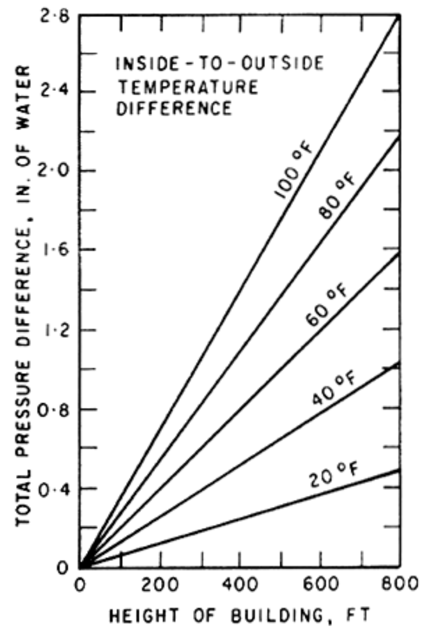

Figure 2 – Pressures Produced by Stack Effect Across Landing Doors

Because elevator landing doors open laterally, excessive pressure across the door can cause the door to bind and not open or close properly. If a landing door doesn't open, people cannot get on/off and if the door doesn't close fully, the elevator cannot leave the floor. Representatives from the elevator industry have indicated that in some buildings that experience significant stack effect, elevator mechanics must come to the building to adjust landing doors at least twice a year.

In fires, the fire itself can result in shaft flows driven by large temperature differences between fire gasses and ambient air. A paper by Bukowski [Bukowski 2005] based on an analysis by Klote showed that, in a fully sprinklered building (with operational sprinklers), fire temperatures are held low enough that significant shaft flows are never observed and the generation of smoke/toxic gasses that might present a hazard to occupants is limited because of the greatly reduced burning rates. Since stack effect is present whether there is a fire or not, shaft flows during fires still occur, but there is much less smoke/toxic gases if there are operating sprinklers.

Enclosed Elevator Lobbies

Enclosed elevator lobbies are intended to address one or more of the following issues:

1. **Protecting hoistways as vertical openings that could spread smoke/toxic gasses**

   For this to be an issue, one needs to have smoke present in sufficient quantities to be hazardous, and pressure differences to drive it to and up or down the hoistway. Smoke is only present in a fire. Pressure differences that drive flows can come from fire temperatures, stack effect, mechanical systems, or elevator piston effect. Sprinklers maintain fire temperatures at only a slightly elevated level, so there is no significant driving force. Fires in sprinklered buildings produce relatively small quantities of smoke/toxic gasses. [Klote 2004; Klote 1992; **NIST** 2010; **NISTIR 7120,** 2004; **NBSIR 80-2097,** 1980.]

Stack effect derives from building (shaft) height, leakage areas between the shaft and the inside/outside, and indoor/outdoor temperature differences. Elevator piston effect is not significant in other than single-car hoistways [Klote and Tamura 1986, Klote 1988].

Absent a fire, stack effect flows can be a nuisance but are rarely a health or safety hazard. In a fire, it is possible for stack effect forces to carry smoke up or down shafts where elevator hoistways would see the largest flows because landing doors have the largest leakage areas. However, the quantity of smoke and gas produced in a sprinkler-controlled fire is small and when distributed into the building volume the concentration, and thus the potential effect on occupants, is small. Further, in a sprinkler-controlled fire, temperatures are held only slightly above ambient, so the only force available to move smoke and gas up shafts is stack effect, and stack effect flows are low.

Using the accepted equation from the 2009 ASHRAE Fundamentals Handbook, estimates of volumetric flows due to stack effect in a 500 ft (152 m) tall hoistway range from just over 1000 CFM to just over 4000 CFM within a range of outdoor temperatures between -40 and +40 F (-40 to +4.4 C). Nuisance problems associated with stack effect are being addressed by designers of very tall buildings by interrupting the shaft height about every 40 stories, but this is not possible on elevators (especially shuttle and service cars) that need to serve every floor. A secondary effect of addressing the nuisance problems is that many shafts are no longer tall enough to yield significant stack effect.

From these facts it can be concluded that elevator lobbies are not generally necessary to prevent smoke migration via hoistways in fires for sprinklered buildings except possibly in very tall buildings with large occupant loads that would require significant time to evacuate from those very tall buildings.

2. Protecting occupants during a fire (safe place)

Since elevators are not to be used in fires except those designated explicitly for Fire Service [IBC Section 3007] and Occupant Egress [IBC Section 3008] and both these sections require lobbies, then lobbies for general use elevators should not be needed to protect occupants during a fire. Exit stairwells are provided explicitly to provide a protected means of egress in fires. One conclusion in the refuge area study for GSA [Klote 1992] was that, in a fully sprinklered building, the entire building is an area of refuge. With respect to protecting occupants in elevators, ASME A17.1 anticipates Firefighter Emergency Operation (FEO) will take the elevators out of service and return them to the level of exit discharge before smoke can enter the hoistway, regardless of whether an enclosed lobby is provided. In Sections 3007 and 3008, the required lobbies are provided to delay recall as long as possible to permit safe use, along with providing a protected space for occupants to wait or for fire fighters to stage below the fire and to operate a forward command post.

Hoistway Pressurization Instead Of Enclosed Elevator Lobbies

Enclosed elevator lobbies are permitted to be eliminated where additional doors [Section 3002.6] or pressurized hoistways [Section 708.14.2] are provided. Pressures are required by the IBC to be between 0.10 and 0.25 in. of water, with the lower limit representing the minimum necessary to prevent flow into the hoistway and the upper limit representing the value above which the landing doors might jam.

In the course of this study, the Study Group discovered that common practice for mechanical designers is to utilize unconditioned outside air to pressurize the hoistway and to pressurize stairways. Filling shafts with air near the outside temperature reduces stack effect since these flows are driven by differences in temperature between the shaft air and outside air.

However, a question has been raised as to the effect of outside air of extreme temperatures (extreme hot or extreme cold) on the safe operation of the elevators, particularly "machine-room-less" elevators, where elevator machinery is located within the hoistway. Typically, elevator manufacturers publish temperature limits in their operating instructions; 95 F (35 C) non-condensing is a common limit. More study may be required to determine how long the equipment can be exposed to extreme temperatures before performance is degraded below safe levels.

The IBC smoke control provisions state that such systems must perform for 20 minutes or 1.5 times the evacuation time, whichever is less. While 1.5 times the evacuation time is reasonable, the 20 minute maximum may not be appropriate for very tall buildings as the time to egress even with elevators may be much longer (depending on the number of floors evacuating or relocating). Occupant self-evacuation elevator systems utilizing all public-use cars (as required in Section 3008 of the IBC) are capable of evacuating 100% of the occupants of any building in 1 hour or less [Bukowski 2008]. Also, the 20 minute maximum would certainly not be appropriate for Fire Service Access Elevators which are intended to be operational for the duration of a fire, not just during building evacuation. Standby power is required to be available for both types of elevators for two hours which may indicate the intended duration of operation.

Smoke Control Systems Design

In any building, there exist complex flow paths that include construction cracks and hidden spaces not normally apparent. The larger the building, the more complex these flow paths can become. In addition, there can be strong interaction between stair and hoistway pressurization systems in buildings that have both [Miller 2008].

Section 909.4 of the IBC requires a *rational analysis* to be performed and submitted with the construction documents, accounting for a number of factors including stack effect, fire temperatures, wind, HVAC, climate and duration of operation. The scope of the required analysis for many buildings results in a complexity that can only adequately be addressed through the utilization of computer (network) models such as CONTAM, developed and distributed by NIST [NIST 2011, Black and Price 2009, Emmerich, 2001].

Due to the existence of multiple, complex flow paths, all of which interact in complex ways, and especially where some are mechanically pressurized, it is crucial that the required rational analysis utilize network models for high-rise buildings that have one or more of the following characteristics:

- Buildings in which there is more than a 40% difference in floor area between any two floors due to the potential impact of conflicting airflows in the building,
- Buildings that contain a parking garage, whether open or enclosed due to large openings to the outside and introducing large amount of outside air and wind,
- Buildings that contain pressurized stairways, pressurized hoistways, atria (in some cases stacked atria) with mechanical smoke control due to the impact of conflicting airflows and pressure differences in the building.
- Buildings containing shafts taller than 420 feet due to increased stack effect.

Stairway Pressurization

Stairway pressurization generally is outside the scope of this Study Group, but there are many elements of stairway pressurization systems that impact how the elevator hoistways will perform during a fire. One of the most important issues is how stair pressurization affects the performance of the hoistway when the option of pressurizing the hoistway is chosen.

Sprinklered Buildings

A key observation in each of the historical fires cited is that the buildings (or at least the areas where the fires occurred) were unsprinklered. The discharge of water from operating sprinklers not only suppresses or extinguishes the fire, limiting the quantities and dynamics of the smoke, but also cools the air temperatures to near ambient levels. Even in the cases of fires shielded from the sprinkler discharge, ceiling temperatures are relatively low even though smoke and fire gas release rates can be increased due to incomplete combustion. Thus, in sprinklered buildings, there is little driving force to generate and cause migration of dangerous quantities of smoke and gasses around the building by way of stairways or hoistways.

Effectiveness and Reliability of Fire Safety Systems

This section provides a more thorough review of how the features of the building, whether passive or active, interact to control the fire and protect building occupants. This is demonstrated through the use of the Fire Safety Concepts Tree (NFPA 550).

Code intent and strategy

The intent of Section 713.14.1 requirements for an elevator lobby enclosure is to protect the elevator shaft from smoke infiltration and possible smoke spread onto other (non-fire) floors. ICC's International Building Code 2012 edition requires various fire safety systems and features based upon a building’s use and occupancy, height and area, and construction type. These features are part of an overall strategy to protect the building occupants and emergency responders from fire. Primary fire safety systems and features are:

- Automatic fire sprinkler system
- Automatic and manual fire detection and alarm system
- Structural fire protection
- Floor construction
- Maximum travel distance to an exit
- Egress/exit shaft enclosure
- HVAC system controls
- Elevator hoistway enclosure
- Elevator hoistway venting

Fire Safety Concepts Tree Analysis

The effectiveness and interaction of these systems and features to achieve fire safety is described by NFPA 550 *Guide to the Fire Safety Concepts Tree* (the “Tree”) 2007 edition (Appendix A). Rather than considering each fire safety system and feature separately, the *Tree* provides a “systems approach” to fire safety, examines all fire safety systems holistically to determine how they influence the achievement of fire safety goals and objectives.

The *Tree* uses logic gates to show a hierarchical relationship of fire safety concepts. There are two types of logic gates in the *Tree*: “or” gates and “and” gates. An “or” gate, represented by a circle with a plus sign in it, indicates that any of the concepts below it will cause or have as an outcome based on the concept above it. An “and” gate is represented by a circle with a dot in the middle. This indicates that all of the concepts below the “and” gate are needed to achieve the concept above the gate. The *Tree* can be used to identify gaps and areas of redundancy in fire protection strategies.

As noted, elevator lobbies required by Section 713.14.1 are intended to limit smoke exposure to occupants on non-fire floors. Figure 3 illustrates the top tier gates of the *Tree* to accomplish that objective. The building code assumes the fire occurs, thus, the driving objective is to “manage fire impact” by “manage the fire” or “manage exposed.”

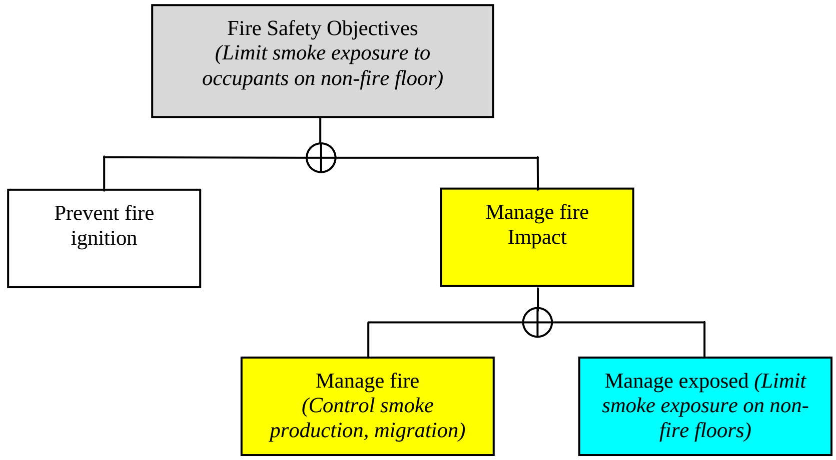

Figure 3: Top-gates of the Tree annotated with the intent of IBC §713.14.1

Figure 4 illustrates the two or three possible options to achieve "manage fire." Suppressing the fire by an automatic fire sprinkler system installed in accordance with IBC Chapter 9 **or** controlling fire (vertical migration) by construction features in accordance with IBC Sections 713 (shafts), 711 (horizontal assemblies), 716 (opening protectives) ***or*** venting fire/smoke that infiltrates into the elevator shaft in accordance with Section 3004 are each ways to limit the smoke exposure to occupants on non-fire floors. Controlling the combustion process, while identified as an option that can be used in general and used to a limited extent by the IBC's requirements for interior finish, is not practical or sufficient to solely achieve the objective in a building.

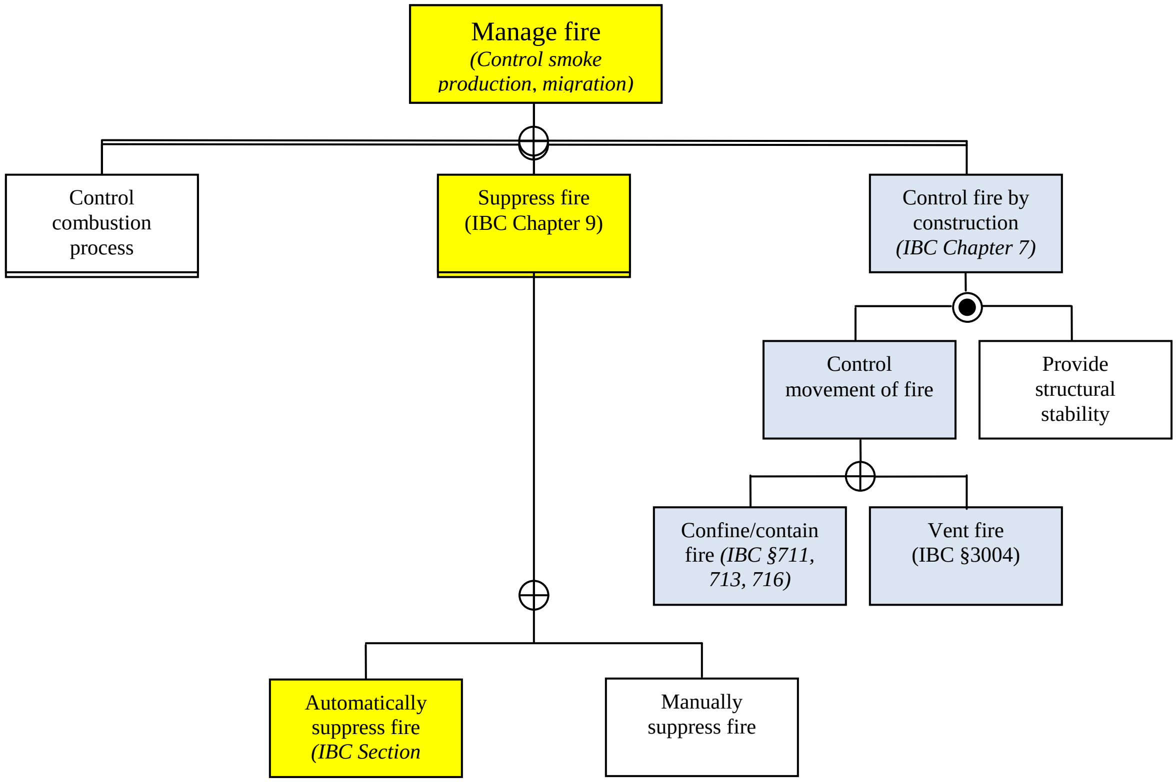

Figure 4: IBC 2012 required features and systems that contribute to limiting smoke production and migration to non-fire floors.

Figure 5 illustrates the options to achieve "manage exposed." "Safeguard exposed" is accomplished by "defend-in-place" and "move exposed." IBC Chapter 9 and Sections 403.3 and 403.4 require various fire safety systems to detect and alert the building occupants of a fire condition and to initiate evacuation. The provisions of IBC Chapter 10 and Section 403.5 both require various fire safety features and systems to protect the building occupants during egress or evacuation, thus limiting smoke exposure to occupants on non-fire floors. Section 403.2.3 requires egress stair and elevator hoistway enclosures in Risk Categories III and IV high rise buildings (Table 1604.5), and all buildings over 420 ft in height to exhibit impact resistance that resists the passage of fire and smoke into the shafts, minimizing the potential for inadvertent compromise of the enclosure.

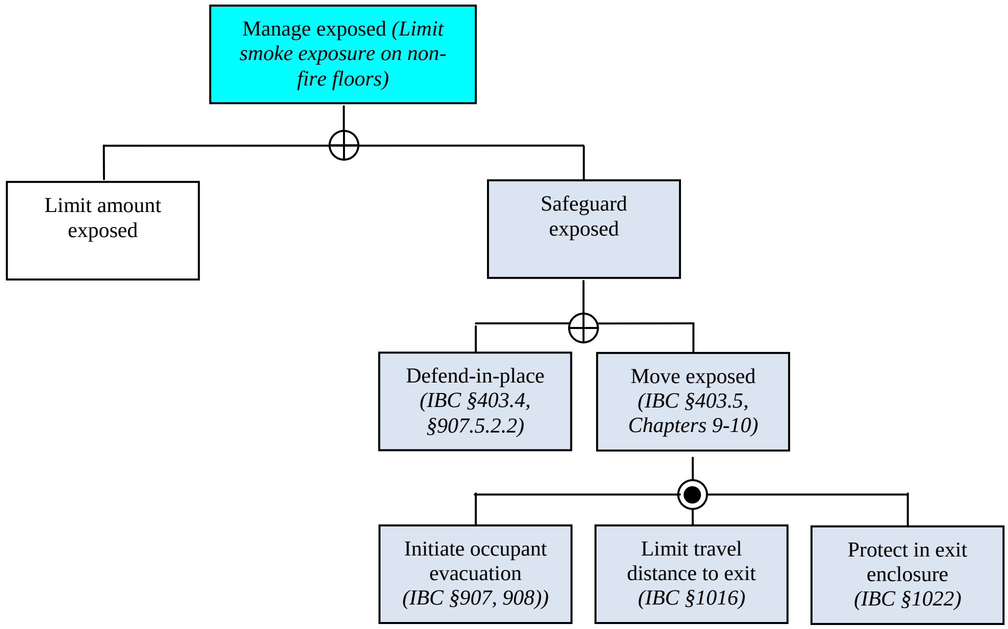

Figure 5: IBC 2012 required features and systems that limit smoke exposure to occupants on non-fire floors.

Fire Suppression Systems Availability

To address the automatic fire suppression (automatic sprinkler) system reliability, it is possible to use the Tree to show the primary system components, features and safeguards required by the IBC to ensure availability of suppression operation. The Tree can identify "single point failure" elements that could result in an unacceptable outcome in the event of a fire. This approach can be used in lieu of a quantitative risk analysis which requires system performance data, event tree and fault tree analysis, as well as occupant exposure analysis (an Available Safe Egress Time vs. Required Safe Egress Time comparative analysis). This could be a line diagram of an IBC-required sprinkler system in a high-rise building including the system components analysis as follows:

- A single sprinkler fails to operate:

  NFPA 13 requires that the design assume that multiple sprinklers will operate. In some cases this results in fire control vs. fire extinguishment which significantly reduces smoke production versus no sprinkler activation. This assumption provides a factor of safety and addresses the failure of a single sprinkler fails to operate.

- Sprinkler system floor control valve is closed/no water available:

  Statistically the most probable cause for sprinkler system failure is a closed water supply control valve. IBC Section 903.4 requires electronic supervision of water supply, monitored both on-site and off-site for increased reliability/availability.

Section 403.3.1 requires buildings over 420 feet in height to be provided with two risers located in remote exit enclosures with each riser supplying the sprinklers on alternate floors. The sprinkler systems must be arranged such that a single closed floor control valve could at most result in failure of the sprinklers on one floor with those on the floors above and below still functional.

- Sprinkler/standpipe riser is out-of-service:

  IBC Section 905.2 requires all sprinkler/standpipe risers be interconnected at the base and control valves to be provided at the base of each riser providing redundancy and greatly reducing the potential of a loss of a sprinkler/standpipe riser.

- Automatic fire pump fails to operate:

  Pump failure: jockey pump operates, sufficient water supply for one- to two-sprinklers and building fire alarm notification. For buildings less than 420 ft. in height above fire department connection, fire department pumper is capable of supporting flow demand for either the sprinkler or standpipe systems.

- Pump failure due to no utility power supply:

  IBC Section 403.4.8 requires emergency power system for redundancy.

- No water in city/municipal water main or valve closed at connection to city/municipal water supply

  IBC Section 403.3.2 requires a connection to a minimum of two city water mains, minimizing the potential for loss of municipal water supply.

Reliability of Other Systems

Sprinkler systems are not the only fire protection feature within a building. Buildings typically have combinations of other types of fire protection features which may include fire and/or smoke rated walls, floor/ceiling assemblies, egress systems, detection systems, alarm systems, smoke control systems, and other mechanisms for protecting people from fire and the products of combustion.

The discussion above regarding sprinkler system reliability is an example of how a risk analysis might be approached. Similar types of analyses with potential failure modes for each of these other systems in a building would need to be performed for the other fire protection features in order for a risk analysis to be complete. Such a risk analysis could be performed using the same methodology as that used for the sprinkler system reliability discussion.

Recommendations for IBC Regarding Elevator Lobbies

Based on the forgoing, the following recommendations are suggested for consideration by the CTC:

1. Unsprinklered low- and mid-rise buildings (buildings with an occupied floor less than 55 feet above the lowest level of fire department vehicle access or less than 75 feet above the lowest level of fire department access with an occupant load less than 30 on each floor)

    - **No enclosed elevator lobbies required for traditional elevators.**

        - *Rationale: While fire temperatures can be high, causing smoke and gas migration throughout the building, occupants traveling at the typical rate of about 150 ft/min over the maximum permitted travel distance of 200 ft can reach the safety of an egress stairway in approximately 1.3 minutes and can descend to the level of exit discharge in less than five minutes. This time frame is merely an approximation but provides an indication of the required time necessary for egress in low and mid-rise buildings.*

          Additionally, code officials participating in the study group stated that lobbies have traditionally not been required in these type buildings in their jurisdictions and their experience has been good.

          Sprinklers are required in any building containing Fire service access (3007) and occupant evacuation (3008) elevators so these would not be found in buildings in this category.

          Elevator lobbies serving as an area of refuge in accordance with Section 1007.6 for accessible means of egress are required to be enclosed by smoke barriers

2. Sprinklered buildings with occupied floors less than or equal to 75 feet to the lowest level of fire department vehicle access:

    - **No enclosed elevator lobbies required for traditional elevators**

        - *Rationale: In sprinklered buildings fire temperatures are kept relatively low so hot gas expansion and buoyancy are not driving forces Traditional elevators are not to be used by occupants in fires, so any small infiltration into the hoistway is not significant. Shafts shorter than 75 feet have limited stack effect flows.*

    - **Enclosed lobbies required for fire service access (3007) and occupant evacuation (3008) elevators**

- *Rationale: Fire service access and occupant egress elevators need to continue in operation during a fire. Lobbies provide a protected space to stage and to await the elevator and further provide a physical barrier to smoke that might activate a lobby smoke detector and trigger Phase I recall.*

3. Sprinklered buildings with an occupied floor more than 75 feet to the lowest level of fire department vehicle access and with elevator hoistway heights less than or equal to 420 feet.

- **No enclosed elevator lobbies required for traditional elevators.**

  - *Rationale: In sprinklered buildings fire temperatures at the ceiling are kept relatively low so hot gas expansion and buoyancy are not driving forces. Traditional elevators are not to be used by occupants in fires, so any small infiltration into the hoistway is not significant. Shafts shorter than 420 feet have limited stack effect flows.*

- **Enclosed elevator lobbies required for fire service access (3007) and occupant evacuation (3008) elevators**

  - *Rationale: Fire service access and occupant egress elevators need to continue in operation during a fire. Lobbies provide a protected space to stage and to await the elevator and further provide a physical barrier to smoke that might activate a lobby smoke detector and trigger Phase I recall.*

~~4.~~ Sprinklered buildings with hoistway heights more than 420 feet ~~in building height~~

- **Enclosed elevator lobbies or pressurization of the elevator hoistways required for traditional elevators.**

  - *Rationale: While traditional elevators are not permitted to be used in fires, the elevator hoistway height may result in smoke migration due to "stack effect" and spread to remote areas. Enclosed lobbies with smoke tight construction or pressurization of the hoistways will limit infiltration. The consequences of smoke spread in tall buildings with elevator hoistway heights over 420 feet was of greater concern to the Study Group.*

- **EXCEPTION:**

  1. **Hoistways for traditional elevators separated into vertical sections not exceeding 420 feet in height with no communication of the hoistway environment between sections shall not require enclosed lobbies or pressurization as long as the following condition is met.**

2. **Where connection of elevator banks is by a transfer corridor, it shall be necessary to pass through at least 2 swinging doors or a revolving door that maintains a separation of the environments to pass from one section to another.**

    - *Rationale: By separating the hoistways into shorter sections and limiting communication of different shaft environments, both "stack effect" and smoke migration will be limited.*

- **Enclosed elevator lobbies required for fire service access (3007) and occupant evacuation (3008) elevators**

    - *Rationale: Fire service access and occupant egress elevators need to continue in operation during a fire. Lobbies provide a protected space to stage and to await the elevator and further provide a physical barrier to smoke that might activate a lobby smoke detector and trigger Phase I recall.*

5. Elevator hoistway pressurization design

- **The design of pressurization systems for elevator hoistways shall be based on a *rational analysis* in accordance with Section 909.4 that utilizes a network model approved by the AHJ and which includes an analysis of possible interactions between building shafts pressurized by different systems, and between pressurized and unpressurized shafts that exceed 420 feet in height.**

  Add guidance to commentary for 909.4 that the rational analysis should show that the pressurization design will maintain the estimated Fractional Effective Dose (FED) below 0.5 and the estimated visibility distance above 25 feet within the stairway for 1.5 times the estimated evacuation time for each of the design fires selected.

    - *Rationale: Taller buildings with more complex flow paths require analysis utilizing a network model that can account for these interacting flow paths. The criteria suggested for commentary represents the standard of practice for a fire hazard analysis performed as the required rational analysis.*

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