Is There a Need to Enclose Elevator Lobbies in Tall Buildings?

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Introduction

In recent years there have been several proposals submitted to model building code organizations to require enclosure of elevator lobbies that restrict the movement of fire smoke via hoistways to other parts of the building. NIST is involved with a consortium of industry (elevator and fire alarm), codes and standards developers (NFPA, ICC, ASME, …) and other interested parties (US Access Board) to develop and implement protected elevators for fire service access and occupant evacuation (including assistance to people with disabilities) that includes elevator lobbies as an integral component[1]. Thus NIST was asked by GSA to determine the conditions under which enclosed elevator lobbies were needed and where they were not.

Background

Vertical shafts in tall buildings are subject to something called stack effect, which is an induced airflow resulting from differences in temperature between the inside and outside. When the outside temperature is colder the induced flow is upward (called normal stack effect) and when the outside temperature is warmer the flow is downward (called reverse stack effect). This is the same phenomenon that causes chimneys to draw smoke up and out of a fireplace. While firestopping is effective in limiting the upward spread of flames through vertical openings and shafts, smoke is far harder to stop because even small leakages can allow smoke to pass. This has led to the use of smoke management systems which employ pressure differences to block smoke flow even through small cracks[2].

There are several examples of fires where smoke spread in shafts was implicated in deaths on upper floors. One is the November 21, 1980 MGM Grand fire in Las Vegas that killed 85 and injured more than 600[3]. The fire was confined to the casino area on the first floor, but 61 of the victims died on upper (above the 20th) floors due to smoke spread up elevator hoistways and seismic joints between the building core and wings. While the guest floors were sprinklered, the casino and adjacent spaces were not sprinklered because they were open and occupied 24/7 (except that at the time of the fire the restaurant where the fire originated had begun closing after midnight due to low business). This lack of sprinkler protection is cited as allowing the fire to spread rapidly on the first floor.

Fire experience like MGM Grand is often cited as substantiation for the proposals to enclose elevator lobbies. However the potential for smoke flow in hoistways is a function not only of the leakage of the elevator doors but also of the strength of the stack flow (driven by outside to inside temperature differences), fire temperatures (buoyancy flows), and the height of the shaft. Thus NIST undertook an analysis to evaluate the potential flows under varying conditions to identify those situations where significant shaft flows might be expected.

Shaft Flow Analysis

NIST contracted for the analysis with John Klote, Inc. well known both in smoke management and in elevator issues. Klote's report[4] contains the details of the scenarios examined and the results obtained for each. The work was summarized in a paper presented at an ASME Symposium on Emergency use of Elevators, which is also available[5].

Scenarios studied

A number of primary variables were identified for study including building size and configuration (5 types), extent of fire (3 types), lobby enclosure (2 conditions), weather (winter or summer), and two, alternate methods of preventing smoke flow in the shaft. This resulted in 27 scenarios (Table 1) that were evaluated using a combination of numerical models CFAST[6] and CONTAM[7].

Table 1 – List of Scenarios Examined

Scenario	Building[1]	Fire Type[2]	Fire Floor[3]	Enclosed Elev. Lobby	Weather[4]	Alternative Methods[5]
1	A	SP	2	Y	W-NW	None
2	A	FDR	2	Y	W-NW	None
3	A	FDF	2	Y	W-NW	None
4	A	FDF	2	N	W-NW	None
5	B	FDF	2	Y	W-NW	None
6	B	FDF	2	N	W-NW	None
7	B	FDF	2	N	W-NW	TB
8	B	FDF	2	N	W-NW	JPC
9	C	FDF	2	Y	W-NW	None
10	C	FDF	2	N	W-NW	None
11	C	FDF	2	N	W-W	None
12	C	FDF	2	N	W-NW	TB
13	C	FDF	2	N	W-NW	JPC
14	D	FDF	2	Y	W-NW	None
15	D	FDF	2	N	W-NW	None
16	D	FDF	2	N	W-NW	TB
17	D	FDF	2	N	W-NW	JPC
18	D	FDR	2	Y	W-NW	None
19	D	FDR	2	N	W-NW	None
20	D	FDR	2	N	W-NW	TB
21	D	FDR	2	N	W-NW	JPC
22	D	FDF	36	Y	S-NW	None
23	D	FDF	36	N	S-NW	None
24	E	FDF	2	Y	W-NW	None
25	E	FDF	2	N	W-NW	None
26	E	FDF	2	N	W-NW	TB
27	E	FDF	2	N	W-NW	JPC

[1] See Table 2.

[2] SP is a sprinklered fire. FDR is a fully developed room fire. FDF for fully developed floor fire.

[3] FDR fires are located in a conference room on the floor indicated, and FDF fires are located in the open floor plan space on that floor.

[4] W-NW for winter with no wind. S-NW for summer with no wind. W-W winter with wind.

[5] TB for temporary barriers over elevator car doors. JPC for judicious positioning of cars within hoistways.

Building characteristics

The buildings considered were all office use and were assumed to have typical floor heights of 4.0 m (13.1 ft) except for the ground floor, which is 6.0 m (19.7 ft). Total building heights varied from 6 to 58 floors. The number of elevators and their arrangements were typical for the building size and configuration (see Table 2). The buildings were based on several, actual GSA office buildings studied previously[8].

Table 2 – List of Building Characteristics

Building	Number of Stories*	Passenger Elevators	Service Elevator
A	6	1 Bank of 3 Elevators	None
B	13	1 Bank of 6 Elevators	None
C	16	1 Bank of 6 Elevators	None
D	35	3 Banks of 6 Elevators: Low, Medium & High Rise	2
E	58	3 Banks of 8 Elevators: Low, Medium & High Rise	2

*Does not include mechanical penthouse.

Flow Paths

Buildings are surprisingly leaky and these leaks are characterized in the smoke management literature[9]. Leakages occur through construction cracks and around doors, especially elevator doors. Values typical of reasonably tight construction were assumed for this study and are found in Table 3. Hoistway vents required by the building codes and increased leakage due to warpage of some doors by the heat of the fire are included[10].

Weather

Stack effect is driven by inside to outside temperature differences, so typical winter and summer conditions in addition to wind were needed. The values used in the calculations were selected to be representative:

Winter Outdoor Temperature	–16°C (3°F)
Summer Outdoor Temperature	35°C (95°F)
Wind Speed	11 m/s (25 mph)

Interior temperature

Interior temperatures in buildings are normally maintained in a narrow range around 23°C (73°F), so this value was used in the calculations.

Table 3 – Flow Coefficients and Equivalent Leakage Areas for Building Flow Paths

Component	Path Type[1]	Path Identifier[2]	Flow Coefficient[3]	Area[4] m^2/m^2 (ft^2/ft^2)	
Exterior Wall	O	W-EXT	0.65	0.00017	
Exterior Wall Below Grade[5]	O	W-UG	0.65	0.000085	
Interior Wall	O	W-INT	0.65	0.00011	
Elevator Wall	O	W-EL	0.65	0.00084	
Floor	O	FLOOR	0.65	0.000052	
Roof[5]	O	ROOF	0.65	0.000026	
Closed Doors:				m^2	ft^2
Single Door	T	DR-SI	0.65	0.016	0.17
Double Door	T	DR-DO	0.65	0.027	0.29
Elevator Doors[6]	T	DR-EL42	0.65	0.047	0.50
Large Elevator Doors[7]	T	DR-EL48	0.65	0.049	0.53
Warped Single Door	T	DR-SI-W	0.65	0.043	0.46
Warped Double Door	T	DR-DO-W	0.65	0.070	0.75
Open Doors:					
Single Door	T	DR-SI-O	0.35	1.95	21
Double Door	T	DR-DO-O	0.35	3.90	42
Shaft Equivalent Area[8]:					
Stairwell	O	STAIR	0.60	2.3	25
3 Car Passenger Elevator	O	EL-P3	0.60	230	2500
4 Car Passenger Elevator	O	EL-P4	0.06	360	3900
2 Car Service Elevator	O	EL-S2	0.60	160	1700
Open Elevator Vent[9]:					
3 Car Passenger Elevator	O	EL-P3V	0.32	0.70	7.5
4 Car Passenger Elevator	O	EL-P4V	0.32	1.05	11.3
2 Car Service Elevator	O	EL-S2V	0.32	0.52	5.6
Roll Down Barriers	T	ROLL	0.65	0.011	0.12
Shafts with Cars in Place:					
3 Car Passenger Elevator	O	EL-P3C	0.65	6.5	70
4 Car Passenger Elevator	O	EL-P4C	0.65	9.1	98

[1] O indicates an orifice path for which flow is in one direction. T indicates a two-directional flow path. The two-directional flow is used for doors, and the leakage is uniformly distributed over the height of the door.

[2] The path identifiers are used with CONTAMW for data input.

[3] The flow coefficient is defined as $m A^{-1} (2 \rho \Delta p)^{-1/2}$ where m is the mass flow through the path, ρ is the density of gas flowing in the path, and Δp is the pressure difference across the path.

[4] Areas for walls and floors are listed as area of flow path per unit of area of wall or of floor as appropriate.

[5] Due to lack of experimental data, the flow areas of the exterior wall below grade and the roof were estimated at half that of the exterior wall and the floor respectively.

[6] This elevator door is 1.07 m (3.5 ft) wide. It is used for all passenger elevators of this study except for Building E.

[7] This elevator door is 1.22 m (4.0 ft) wide. It is used for the passenger elevators of Building E and the service elevators.

[8] Shaft equivalent areas are used to calculate the pressure losses due to friction in shafts. For more information, see chapter 6 of Klote and Milke(2002).

[9] Vent area was calculated at 3.5% of the shaft area but not less than 0.28 m^2 (3 ft^2).

Limiting the Spread of Smoke in Shafts

The spread of smoke in shafts can be limited by sealing leakages and/or by producing pressure differences that result in airflows in the desired direction. The recognition that many leakages are hidden or difficult to seal leads to the use of active smoke management techniques, particularly for egress stairways. But there are some techniques that might be effective in reducing leakages into elevator hoistways to low levels. Landing doors for both passenger and freight elevators are known to be particularly leaky because they open laterally by a mechanism carried on the elevator car. Gaps, the provision of safety mechanisms to prevent the door from closing on people, and the tendency of sliding doors to jam when subjected to pressure differences, all tend to exacerbate the leakage problem. Thus solutions to reduce smoke leakage into the hoistway generally involve the provision of an enclosed lobby (creating an air lock with an entry door capable of far better sealing against infiltration) or by a roll down barrier that covers the normal elevator door (see Figure 1). Both of these approaches were evaluated.

Figure 1 - Roll down barrier deploying over an elevator door (courtesy Smoke Guard)

Suggestions have been made that the hoistway itself could be blocked during a fire by an extendable or inflatable barrier mounted in the hoistway or on the bottom of the car that would be deployed when needed. This approach has many limitations (e.g., interference by the elevator cables unless the car is above the barrier) but it was decided to examine the potential for positioning the car itself near the neutral plane to partially block the hoistway and reduce the flow in the shaft. If found to be effective this could be done for no additional cost beyond programming the elevator controller to do so. Thus the study also evaluated the “judicious” positioning of elevator cars near the neutral plane to limit shaft flow.

Another new technology is a new type of elevator door seal that is intended to be tight enough to restrict smoke leakage into hoistways. These are currently being tested in Japan (where they originate) and in the U.S. In the past, similar door seals were shown to be problematic as the additional friction of the seal required adjustments to door closing forces that increased the hazard to passengers from being struck by the door. It remains to be seen if these new seals will perform better.

Doors and windows to the exterior

It was assumed in the study that all exterior and interior stairway doors were closed. Windows to the exterior were also assumed closed except for the fully developed floor fire, which is capable of breaking the glass.

Methodology for the Analysis

Fires on a lower floor of the buildings in winter or on an upper floor in summer were examined to determine the quantity of smoke (both visual obscuration and toxic potency) that might spread to the upper (or lower) floors by means of the hoistways. Temperature at long distances from the fire source is not a hazard because fire temperatures rapidly diminish to near ambient through entrainment and heat losses to the surroundings.

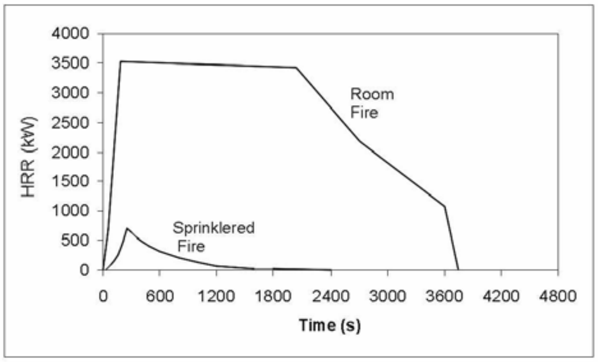
The hazards of smoke obscuration and toxic potency were assessed using engineering criteria normally used in building performance analysis[11]. A fire (heat release rate) curve representative of the scenario being considered was first chosen (see Figure 2 for the heat release rates selected). Then the fire model (CFAST) was used to determine the burning rate as affected by the geometry and ventilation, resulting in the production over time of energy, smoke particulates and combustion gasses. Consumption of oxygen and its effect on burning rate and combustion chemistry is also computed.

The energy and mass produced moves through the building by buoyancy and building flows, including stack effect. These are calculated by the model CONTAMW, resulting in estimates of temperature, smoke density, and gas concentrations over time in spaces remote from the fire. Ordinarily occupants would be evacuating and their exposure would change as they moved from space to space. A more conservative approach is to evaluate the exposure of stationary occupants as would occur for people with disabilities or otherwise unable to escape. This is the approach used in this analysis.

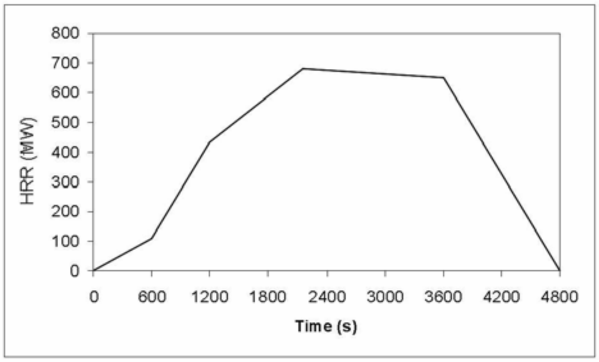
Results

As expected the sprinklered fire did not represent any hazard to occupants. The sprinklers activate and extinguish the fire before it can release significant energy or mass. Little or no smoke or gasses enter the hoistways and none reaches remote locations in any building regardless of height or other conditions examined.

For the fully developed room fire (flashover) significant energy and mass are released and strong fire induced flows drive those products to the hoistway. The enclosed lobby prevented any significant portion of that mass or energy from entering the hoistway, but without a lobby there were untenable conditions (visibility and toxic potency) predicted on upper floors of the tallest building, which had the greatest stack effect.



(a) HRR for sprinklered fire and room fire



(b) HRR for floor fire

Where the fire spread to the entire floor enclosed lobbies provided some protection, allowing sufficient smoke to exceed visibility limits at remote locations in all of the buildings, but limiting toxicity to less than the limiting value for the time studied. Times at which visibility limits were exceeded occurred significantly later with lobbies. The increases in time to untenable visibility increased by 50% to 200% for lobbies enclosed by normal construction and by 0% to 20% for roll down barriers, due to their greater leakage characteristics. Temporary barriers with better leakage characteristics would be expected to perform better. Without lobbies tenability conditions for both visibility and toxicity were exceeded at locations remote from the fire in all buildings regardless of height.

The so-called judicious positioning of elevator cars had no effect on the smoke flow in the hoistway. This is because the leakage area around the car is quite large, allowing significant flow around the stopped car.

Discussion of Results

It is widely accepted that operating fire sprinklers will prevent room flashover and full floor fires, and will limit the size of room fires consistent with the levels assumed in this study[12]. Thus it appears from this work that enclosed elevator lobbies are not necessary in buildings with an ***operational*** fire sprinkler system.

From a risk management perspective this means that the need for enclosed elevator lobbies depends on the probability that the sprinkler system will not work (operational reliability) and the consequences (expected losses) of such a failure.

Sprinkler System Reliability

Studies of typical commercial (NFPA 13) sprinkler systems indicate an operational reliability of about 95%[13]. Data on in-service failures of (wet pipe) sprinkler systems in US Department of Energy (DOE) facilities show operational reliabilities of 99.2%[14], but these are subject to testing and maintenance programs that exceed the levels normally found with commercial sprinkler systems. Thus the risk management decision to incorporate enclosed lobbies might be based on a probability of sprinkler system failure of 5% unless maintenance systems were in place that rose to the level required by DOE.

Statistics indicate that most of the observed sprinkler system failures are due to impaired water supplies such as closed valves, blocked pipes, impaired sources, etc., but which tend to affect sections of or the entire system. System reliability can be increased by active monitoring of water supplies and controls. Problems affecting one head are rare, but current statistics do not reflect the modern upsurge in use of quick response heads that tend to be more complicated. Recent sprinkler recalls have all involved such heads. There is a real need to update field reliability data for modern, light hazard systems that are extensively used in business and residential occupancies.

Consequences of Sprinkler System Failure

Low-rise buildings (<7 stories or 75 feet) produce little stack effect in shafts (including hoistways) to drive smoke and fire gasses to upper floors even where there are no operational sprinklers. While without lobbies fully developed floor fires exceeded tenability limits, this occurred long after such buildings would be expected to be fully evacuated. Thus a risk manager might conclude that enclosed lobbies are not needed in low-rise buildings, particularly where sprinklered.

In taller buildings which experience greater stack effect and require more time for occupant egress, times to untenable conditions occur much sooner (in up to half the time) without lobbies and if sprinkler system failure allows the fires to grow to room flashover or full floor involvement. Thus the risk manager may decide to provide enclosed elevator lobbies in high-rise (>6 stories or 75 feet in height) buildings even where sprinklered, unless those sprinklers can be shown to have operational reliabilities as high as have been achieved in DOE systems. Elevator lobbies should be of 2-hr fire resistive construction (1-hr in a fully sprinklered building) and have direct access to an egress stair.

Other Research

Current research by NIST and others is examining the incorporation of protected elevators that can be used for firefighter access and for occupant evacuation (including to assist people with disabilities) during fires[1]. These systems all utilize enclosed elevator lobbies to protect the hoistway and elevator system from direct exposure to fire conditions and to serve as a protected area to await the elevator. Details of construction, active protection, and communication with the building fire command center are all a part of the proposals being developed for the building codes and referenced standards (including the National Fire Alarm Code and the Safety Code for Elevators and Escalators) currently under development by a coalition of NIST, the building codes, and affected industry.

The provision of elevator lobbies in high-rise buildings even where sprinklered would be consistent with the direction of this technology development effort. The use of roll down barriers on elevators not protected for use during a fire can provide a small benefit, particularly in unsprinklered high-rise buildings but may not provide sufficient benefit (unless leakage characteristics were substantially improved) in sprinklered buildings given typical operational reliability of sprinkler systems. These decisions would need to be made by building owners or by regulators as public policy positions based on the risk and cost.

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