Is There A Need to ENCLOSE ELEVATOR LOBBIES IN TALL BUILDINGS?

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Several proposals have been submitted in recent years to model building code organizations to require enclosure of elevator lobbies in order to restrict the movement of smoke to other parts of buildings via hoistways. A significant development in this area occurred recently when the National Institute of Standards and Technology (NIST)—which was already involved with a consortium of industry representatives, codes and standards developers, and other interested parties in a study of the protection of elevators for occupant evacuation and fire service access[1]—was asked by the U.S. General Services Administration (GSA) to research the conditions under which enclosed elevator lobbies were called for. This article will provide an overview of the progress made to date on this line of research.

Background

Vertical shafts in tall buildings are subject to something called "stack effect," which describes an induction of airflow resulting from differences in temperature between the inside and outside of the shaft. When the outside temperature is colder, the induced flow is upward (normal stack effect); when the outside temperature is warmer, the flow is downward (reverse stack effect). 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 it 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 in which smoke spread in shafts has been implicated in deaths on upper floors, with perhaps the most infamous being the November 21, 1980, conflagration at the MGM Grand in Las Vegas. Although the flames were confined to the casino area on the first floor of the structure, 61 of the 85 casualties occurred on upper (above the 20th) floors due to smoke spread up elevator hoistways and seismic joints between the building core and wings.[3]

It is not surprising that such tragedies are frequently cited as substantiation for proposals to enclose elevator lobbies. However, the potential for smoke flow in hoistways is a function not only of leakage of the elevator doors but also of the strength of the stack flow, fire temperature (buoyancy flows) and the height of the shaft. Each of these factors was taken into account in NIST's analysis of the potential flows under varying conditions in order to identify those situations where significant shaft flows might be expected.

Shaft Flow Analysis

NIST contracted with John H. Klote, Inc.—which is a well known for its expertise in the fields of both smoke management and elevators—for the analysis. Klote's report contains the details of the scenarios examined and the results obtained for each[4] and was summarized in a paper presented at the 2004 ASME Workshop on Use of Elevators in Fires and Other Emergencies.[5]

Scenarios Studied

A number of primary variables were identified for study, including building size and configuration (five types), extent of fire (three types), lobby enclosure (two conditions), weather (winter or summer), and two alternate methods of preventing smoke flow in the shaft. This resulted in the 27 scenarios shown in Table 1, which were then evaluated using a combination of numerical models and NIST's Consolidated Model of Fire Growth and Smoke Transport (CFAST)[6] and CONTAM multizone airflow and contamination transport analysis software programs.[7]

Table 1. 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, 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 for 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 meters (13.1 feet) except for the ground floors, which were assumed to have heights of 6.0 meters (19.7 feet). Total building heights ranged from 6 to 58 floors. The number of elevators and their arrangements were typical for the building's sizes and configurations—see Table 2. The buildings were based on several actual GSA office buildings previously studied.[8]

Table 2. 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 displayed 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]

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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 p 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 floor, respectively.
6. This elevator door is 1.07 m (3.5 ft) wide. It is used for all passenger elevators in this study except for that in Building E.
7. This elevator door is 1.22 m (4.0 ft) wide. It is used for the passenger elevators in 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).

Weather

Because stack effect is driven by the difference between inside and outside temperatures, typical environmental conditions needed to be taken into account. The following representative conditions were used in the calculations.

- winter outdoor temperature: -16°C (3°F)
- summer outdoor temperature: 35°C (95°F)
- wind speed: 11 meters per second (25 miles per hour)

Interior Temperature

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

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 other 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 cars. Gaps, the provision of safety mechanisms to prevent the doors from closing on passengers, and the tendency of sliding doors to jam when subjected to pressure differences all tend to exacerbate the leakage problem. As a result, solutions to reduce smoke leakage into hoistways 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. Both of these approaches were evaluated.

Suggestions have been made that hoistways themselves could be blocked during a fire by an extendable or inflatable barrier, mounted either within them or on the bottoms of the cars, 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 a car 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 elevator controllers appropriately. Therefore, the study also evaluated the "judicious" positioning of elevator cars near the neutral plane to limit shaft flow.

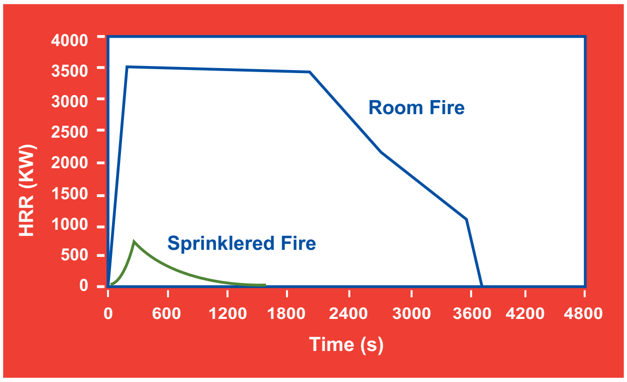
Another new technology is a type of elevator door seal that is intended to be tight enough to restrict smoke leakage into hoistways. These type of seals are currently being tested in Japan (where they originate) and the U.S. In the past, however, similar seals were found to be problematic because they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

Methodology

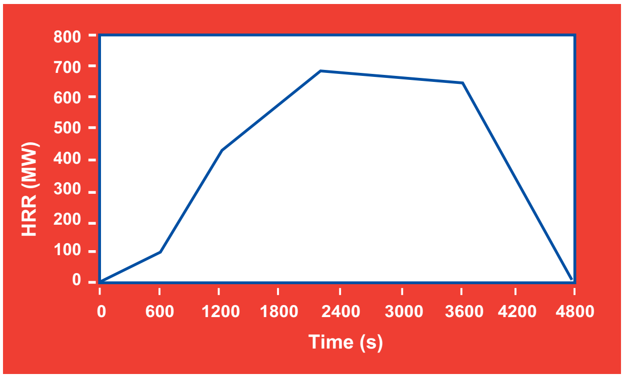
Fires on a lower floor during winter and on an upper floor in summer were examined to determine the quantity of smoke that might spread to the upper or lower floors, respectively, by means of the hoistways (heat is not a significant hazard long distances from a fire source because temperatures rapidly diminish to near ambient level through entrainment and heat losses to the surroundings). It was assumed that all exterior and interior stairway doors were closed. Windows to the exterior were also assumed to be closed except for in the case of a fully developed floor fire, the intense heat of which can break the glass.

The hazards of smoke obscuration and toxic potency were assessed using engineering criteria frequently employed in building performance analysis.[11] A fire (heat release rate) curve representative of the scenario being considered was first chosen—see Figure 1 for the heat release rates selected. Then the CFAST fire model 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 was also computed.

The energy and mass produced moves through the building by buoyancy and building flows, including stack effect. These were calculated by the model CONTAM, resulting in estimates of temperature, smoke density and gas concentrations over time in spaces remote from the fire. The exposure of evacuating occupants would change as they moved from space to space, but the analysis used the more conservative approach of evaluating the exposure of stationary occupants in order to take into account those with disabilities or otherwise unable to escape.



(a) HRR for sprinklered fire and room fire.



(b) HRR for floor fire.

Figure 1. Heat release rates.

Results

As expected, sprinklered fires were not shown to represent a significant hazard to occupants because the sprinklers activated and extinguished the fires before they could release significant energy or mass. Little or no smoke or gasses entered the hoistways, and none reached remote locations in any building regardless of height or other conditions examined.

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Fully developed room fires (flashovers) released significant energy and mass, and strong fire-induced flows drove those products to the hoistways. Enclosed lobbies prevented any substantial portion of that mass or energy from entering the hoistways, but the absence of a lobby resulted in untenable conditions in terms of reduced visibility and toxicity on the upper floors of the tallest building, which had the greatest stack effect.

Where the fire spread to the entire floor, enclosed lobbies continued to provide 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. In addition, times at which visibility limits were exceeded occurred significantly later when lobbies were present. The increases in time to untenable visibility increased by 50 percent to 200 percent for lobbies enclosed by normal construction and by 0 percent to 20 percent with the use of 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 "judicious" positioning of elevator cars had no effect on smoke flow in the hoistways because the leakage area around cars is quite large.

Discussion

It may therefore be concluded from the study results that enclosed elevator lobbies are not necessary in buildings with operational fire sprinkler systems. From a risk management perspective, this means that the need for enclosed elevator lobbies depends on the probability that a sprinkler system will not work (operational reliability) and the consequences (expected losses) of such a failure.

Sprinkler System Reliability

Data on in-service failures of wet pipe sprinkler systems in U.S. Department of Energy (DOE) facilities show operational reliabilities of 99.2 percent,[12] but these systems are subject to testing and maintenance programs more rigorous than those typically performed on commercial systems. Studies of commercial sprinkler systems installed per industry standards indicate an operational reliability of about 95 percent,[13] so the decision whether or not to incorporate enclosed lobbies might be based on a 5-percent probability of sprinkler system failure unless a maintenance program comparable to the DOE's is in place.

Statistics indicate that most sprinkler system failures are due to impaired water supplies such as closed valves, blocked pipes, impaired sources, etc., which tend to affect sections of or the entire system. As such, system reliability can be increased by active monitoring of water supplies and controls. The general consensus is that problems with individual sprinkler heads are rare. However, it may well be asserted that current data do not accurately reflect the upsurge in the use of quick-response heads, and the fact that several models of these have been involved in recent recalls underscores the need to update field reliability data for light hazard systems commonly used in business and residential occupancies.

Consequences of Failure

Minimal stack effect was produced in shafts—including hoistways—in low-rise buildings (less than 7 stories or 75-feet high), so the spread of smoke and fire gasses to upper floors may be considered to be of no great concern even when there are no operational sprinklers. While smoke from fully developed floor fires exceeded tenability limits in low-rise buildings without elevator lobbies, this occurred long after such buildings would be expected to be fully evacuated. A risk manager might therefore conclude that enclosed lobbies are not needed in low-rise buildings, particularly when sprinklered.

In taller buildings, which experience greater stack effect and require more time for occupant egress, untenable conditions are reached much sooner if lobbies are not provided and if sprinkler system failure allows a fire to grow to room flashover or full floor involvement. A risk manager may therefore decide to provide enclosed elevator lobbies in high-rise buildings even when sprinklered unless the sprinklers can be shown to have operational reliabilities similar to that achieved by DOE systems. Elevator lobbies should be of 2-hour fire-resistance rated construction (1-hour rated in fully sprinklered buildings) and have direct access to an egress stair. ◆

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