Change

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Elevator shafts are a ready path for heat and smoke spread in building fires, and **current code mandates** requiring top venting must be reconsidered

The elevator may have fostered the development of high-rise buildings, but it has also created problems. First and foremost, from a life-safety perspective, is that elevator shafts are a ready path for heat and smoke in multi-story buildings. The hazards of vertical fire movement, in fact, became apparent as early as 1911, with New York's landmark Triangle Shirtwaist fire.

Even so, containing and controlling smoke buildup in elevator hoistways didn't gain much attention in U.S. codes until the 1970s. Fortunately, concerned parties continue today to evaluate traditional smoke protection and consider new strategies and methods.

For example, one accepted practice that the industry needs to reconsider is placing vents at the top of elevator shafts—for performance rather than historical reasons.

Venting hazards

Incorporated into elevator design in the 19th century, and well established in the codes and standards for many decades, vents have been placed at the top of hoistways to prevent excessive pressure during car ascent, control odors and vent smoke during a building fire.

The International Building Code (IBC) currently requires hoistway vents. These must be located at the top of the hoistway and either open directly to the outside or be routed to the outside in noncombustible ducts that are fire-rated the same as the hoistway.

Originally, these vents were passive openings. But with the rise of energy conservation, vents now are often equipped with mechanical dampers that open upon smoke-detector activation. IBC Section 3004 requires hoistways of more than three stories to have vents of 3 sq. ft., or 3.5% of the area of the hoistway. The IBC allows reductions in vent area where mechanical ventilation is provided. There are also some occupancy exceptions for buildings equipped with automatic sprinklers.

Such measures have merit, but when one considers some of the major historic U.S. fires that involved multiple fatalities, almost all these conflagrations started on the first floor, where vertical elevator and stairwell shafts became smoke-logged and spread heat and fire to upper floors. Much of this was due to the *stack effect* caused in part by the venting. In fact, the majority of deaths occurred on upper floors (see "Trails of Smoke," p.50).

And it isn't just fires on the first floor that are a problem. Buoyant fire gases—no matter what floor the fire is on—can enter around elevator doors and exit on upper floors. The many variables of a building fire make it difficult to predict which floors above a fire will become filled with smoke.

Top-down venting

One major step toward remedying the smoke-migration problem is realizing that the reasons given for placing vents at the top of hoistways have lost their validity.

In the aftermath of the Hester Hall Dormitory Fire, Murray, Tenn., in Sept. 1998, which took the life of one student and severely injured another, one can see how the elevator played a role in the spread of smoke and fire (above) from the staining on the upper left edge of the lobby door and smoke stain on the upper edge of the elevator threshold. **(Photo: Gregory Cahanin)**

Take, for example, the argument that an ascending car produces pressures that require venting for proper car operation. In fact, the pressures developed by elevator car movement in a shaft—called *piston effect*—are small. A downward-moving elevator car will force air below the car into the shaft above the car. Additionally, air leakage around elevator doors on each floor is significant.

Moreover, piston effect varies with the number of cars in the hoistway and the hoistway area. For example, for a single elevator car traveling at a velocity of 400 ft. per minute (fpm), there is a pressure differential of 0.08 in. H_2O. For a double-car shaft, it is only 0.02 in. H_2O for a car traveling at 400 fpm. In a double-car shaft with a car traveling at 700 fpm, the pressure differential is only 0.05 in. H_2O.

Also, the buoyant forces in a building are significantly larger than the piston effect. For high-rise buildings, when it is cold outside, air within the building has a buoyant force because it is warmer and less dense. The air will therefore rise within the building via shafts.

For high-rise buildings in warm climates with air-conditioned environments, a downward flow of air, called a *reverse stack effect,* can occur. The stack-effect pressure differentials published by ASHRAE range from 0.07 in. H_2O at 30 ft. to 0.7 in. H_2O at 300 ft. Additionally, a 15 mph wind perpendicular to a building can result in a wind-effect pressure differential from the windward to leeward side of 0.12 in. H_2O. When smoke enters a hoistway, the elevated temperature of the smoke increases stack effect. Reverse stack effect—where the building is cooler inside than outside—is decreased when smoke enters a shaft.

The argument that top vents are necessary to control odors comes from the use of elevator shafts as trash chutes during the 19th and

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early 20th centuries. But this is obviously not the case today.

Finally, the justification for top vents to exhaust fire smoke does not always hold up. The ability of a passive top vent to keep a hoistway clear of smoke depends on several variables: outside temperatures, stack effect, buoyancy, wind load, floor smoke-control systems and many others.

The variables considered

Let's break down the variables. Consider a room with a 10-ft. ceiling and a fully developed fire producing a ceiling temperature of 1,600ºF. A driving force of 0.11 in. H_2O is produced. The forces in a fully involved room fire will be greater than a vented hoistway resulting in a flow into the shaft around elevator doors when no lobby or other barrier is in place. ASHRAE tables that list flow areas around elevator doors indicate that the elevator doors contain gap leakage areas from 0.34 to 0.72 sq. ft. for a single door.

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A four-car hoistway would have a leakage area of 2.9 sq. ft. on each floor. Gap areas around elevator doors on the fire floor will encourage smoke entry into hoistways. Vents at the top of a shaft will exhaust smoke and encapsulated shaft air, the quantity dependent upon the vertical location of the fire in relation to the top of the shaft, the neutral pressure plane and stack effect within the shaft. The gap area around elevator doors on all floors will encourage smoke flow from stack effect in the shaft, further limiting top-vent effectiveness.

So what can be done? Isolation is the most reliable method of keeping fire and smoke products out of the hoistway. Passive protection, in the form of elevator-lobby protection or temporary barriers directly in front of elevator doors, can extend the amount of time before occupants are at risk from fire and allow for extended use of elevators for rescue and fire-department staging.

In a National Institute of Standards and Technology study of smoke migration through elevator hoistways, two methods were found to have a positive impact on reducing the hazard: enclosed elevator lobbies and temporary roll-down barriers directly in front of elevator doors.

An earlier study had already shown that the leakage area of the elevator doors is the primary factor in smoke movement to higher floors. Software modeling was used to analyze air movement and indoor-air quality in multi-zone buildings for a 10-story building. The conclusion was that if the leakage area of the elevator doors is reduced, then a three-fold increase in visibility can be attained on the upper floors, regardless of whether the building was sprinklered or not.

The NIST study did not include side-swinging smoke-rated doors at elevator openings. In the western U.S., under the legacy Uniform Building Code from the Int'l. Conference of Building Officials, it was common to find side-swinging doors with magnetic holders in front of elevator hoistways instead of lobbies. These were often used for three-to-four-story hotels. Barriers at the hoistway opening can be used effectively when the air-leakage rating under UL 1784 is 3 cu. ft./min./sq. ft. of opening or less at 0.10 in. H_2O. The current IBC Section 707.14.1, Exception 3, which allows for an additional door at the elevator opening, in lieu of a lobby, is a direct acknowledgement of this as an alternative.

Next up is compartmentation, which is important in multi-story buildings, for limiting not only the size of a fire, but also the movement of heat and smoke. The IBC legacy codes rely heavily upon automatic sprinklers and compartmentation. In the IBC, fire barrier

Trails of Smoke

Well-known cases where venting exacerbated fires include the 1963 Roosevelt Hotel Fire in Jacksonville, Fla.; the MGM Grand Hotel Fire in Las Vegas in 1980; and the Retirement Center Fire in Johnson City, Tenn. in 1989. At the time of each of these fires, the building codes in effect had hoistway-shaft vent requirements identical to the current IBC code. These cases clearly demonstrate the inability of hoistway vents to prevent smoke spread to upper floors of a multi-story building.

For example, the MGM Grand Hotel fire began in the first-floor casino area. Heat and smoke rapidly extended through seismic joints, elevator shafts and stairways to the 21 sleeping floors of the 26-story building. The result was a majority of fatalities on the 20th through 25th floors.

The MGM Grand fire is also significant in being the first high-rise fire in the United States in which helicopters evacuated people—nearly 300—from the roof of the building. They had been driven upward by the heat and smoke from the fire as it rose through the hotel.

Some References

- **International Building Code, Section 3004.1-2, 2003**
- **ASHRAE/SFPE Principles of Smoke Management, J.H. Klote and J.A. Milke, 2002**
- **NFPA Quarterly 57(4) 309-319, 1964, E.E. Juillerant**
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- **Analysis of the Life Safety Consequences of Smoke Migration Through Elevator Shafts, ASME 2003, J.H. Klote**
- **Analysis of Smoke Movement in a Building via Elevator Shafts, Smoke Safety Council 2000, J.J. Beitel, A.J. Wakelin, C.L. Beyler**
- **ADAAG Section 4.3.11.1(7)**
- **Elevator Piston Effect and the Smoke Problem, Fire Safety Journal 11(3): 227-233, J.H. Klote and G.T. Tamura, 1986**

requirements have been relaxed where automatic sprinklers are employed, because statistics demonstrate that properly installed and maintained sprinklers effectively contain fire growth. As for elevators, floor-to-floor separations in multi-story buildings are fire-rated with the largest opening being the hoistway shaft.

Pressurization of hoistways is similar to stairwells, but with added **vertical leakage**.

The IBC now includes requirements for elevator lobbies—with exceptions for some occupancies—additional doors and the installation of automatic sprinklers. A recently approved change to Section 707.14 requires a lobby or listed alternative where the elevator shaft connects three or more stories in unsprinklered buildings and in all high-rise buildings. And for the first time, a new exception will allow for pressurized elevator shafts in lieu of lobbies.

Hoistway active protection

So much for passive protection. Active smoke control can strive for one of two goals. First, a pressurized system can prevent smoke flow through the elevator shafts. Second, elevator smoke control can provide the extended tenability of using elevators for fire evacuation.

The Americans with Disabilities Act guidelines define "areas of rescue assistance" in new buildings and recognizes an elevator lobby as such when the lobby and adjacent shaft are pressurized. Traditional leakage around elevator doors is such that the lobby and shaft will readily equalize. Pressure difference within the elevator shaft must be adequate to overcome the fire growth pressures on a fire floor, in addition to leakage occurring through lobby doors.

It has been found that opening airflow paths from the hoistway shaft to outside the building in ground-floor lobbies can result in significant pressure fluctuations that mechanical systems must compensate for. Pressure drops of as much as 0.10 in. H_2O in simple systems that are not reactive to pressure changes readily occurred. Pressurization systems can use fans to introduce air into the elevator shaft or the connected lobby space on each floor, in addition to employing pressure-relief vents, barometric dampers and multiple-point supply fans. Additionally, fire-floor smoke control by exhausting smoke to the outside can reduce the pressure fluctuations that could introduce smoke into pressurized elevator hoistways.

Elevator pressurization of hoistways is similar to stairwell-pressurization systems, but with additional vertical leakage at elevator doors. A basic assumption that the fire department will be staging on the first floor and the exterior doors will be open will result in higher cfm for the hoistway system. Overpressure vent-relief systems using open vents or barometric dampers can be employed in shaft pressurization designs to compensate for pressure fluctuations, but must be sized large enough so that the maximum allowable pressure difference when all doors are closed is not exceeded. The additional buffer that a lobby provides between the elevator shaft and the building floor where the fire is burning is often embraced in pressurization designs as well.

Where to now?

To sum up, smoke control in hoistways involves both active and passive solutions. The IBC currently requires compartmentation of building spaces to limit fire growth to a single floor and includes automatic sprinklers as a companion requirement.

As for vents at the top of shafts, they can only be expected to vent smoke contained within the shaft. Top vents also have the potential of attracting smoke into the shaft when elevator lobbies or door barriers are not in place, while lacking the capability of exhausting all of the smoke in either the shaft or a fire floor.

Accepted building code requirements to exclude smoke movement into hoistways were first based upon the use of lobbies on each floor and then alternative methods, including barriers at the elevator shaft door or pressurization of the hoistway shaft. Rolling smoke barriers are operated by the smoke detector outside of each floor's elevator doors and only deployed on floors where detectors go into alarm. The rolling smoke barrier, tested under UL 1784 to 400ºF, will fail if the heat of a fire approaches the elevator opening.

Finally, hoistway pressurization has the potential advantage of freeing up floor space that would otherwise be used for lobbies. This engineered solution has been in the codes for some time and is now allowed in the 2004 Supplement to the IBC. |cse|