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DESIGN OF ELEVATOR SMOKE CONTROL SYSTEMS FOR FIRE EVACUATION

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ABSTRACT

A joint U.S./Canadian project was undertaken to evaluate the feasibility of using elevators for the evacuation of the handicapped during a fire. This project consisted of conceptual studies, full-scale fire experiments, and theoretical analysis. This paper summarizes the findings that are relevant to the design of smoke control systems for elevators.

A method of dealing with elevator piston effect is discussed. Elevator piston effect is the transient pressures produced by elevator car motion, and this effect depends on air temperature, building leakage areas, elevator car velocity, and hoistway size. All other things being equal, piston effect is considerably greater for single-car hoistways than for multiple-car hoistways. Different approaches for dealing with the pressure fluctuations due to the opening and closing of building doors are presented. An approach for design analysis is presented with example analyses of two different elevator smoke control systems. Results indicate that many types of elevator smoke control systems can be designed to provide acceptable levels of pressurization even under severe conditions of doors opening and closing.

INTRODUCTION

Throughout most of the world, signs next to elevators indicate they should not be used in fire situations; stairwells should be used for fire evacuation. These elevators are not intended as means of fire egress, and they should not be used for fire evacuation (Sumka 1987). However, some people cannot use stairwells because of physical disabilities, and the use of elevators is a potential solution to this problem. The logistics of evacuation, reliability of electric power, elevator door jamming, water damage to electric controls, and need for fire and smoke protection are long-standing obstacles to the use of elevators for fire evacuation, but all these obstacles except smoke protection can be addressed by existing technology (Klote 1983).

A joint U.S./Canadian project was undertaken to evaluate the feasibility of using elevators for the evacuation of the handicapped during a fire. Full-scale fire experiments were conducted in a 10-story fire research tower near Ottawa (Tamura and Klote 1987a,b,c; 1988). These experiments verified that pressurization can provide smoke protection for the elevator system. Additionally, the project addressed the impact of pressure disturbances caused by elevator car motion on smoke control (Klote and Tamura 1986b, 1987; Klote 1988). Such piston effect is a concern, because it can pull smoke into a normally pressurized elevator lobby. This paper summarizes the findings of the joint project that are relevant to the design of smoke control systems for elevators.

PISTON EFFECT

Analysis of the airflows and pressures produced by elevator car motion in a pressurized hoistway (elevator shaft) was developed by Klote (1988) based on the continuity equation for the contracting control volume in a hoistway above an ascending car. From this analysis, an expression was developed for the critical pressure difference from the elevator lobby to the building at which piston effect cannot overcome lobby pressurization:

$$\Delta p_{crit} = \frac{\rho_s K_{cp}}{2}\left(\frac{A_e A_s V}{A_{rl} A_a C_c}\right)^2 \tag{1}$$

where

Δp_{crit}	=	critical pressure difference, in. H_2O (Pa)
ρ_s	=	air density in hoistway, lb/ft^3 (kg/m^3)
A_s	=	cross-sectional area of the hoistway, ft^2 (m^2)
A_{rl}	=	leakage area between the lobby and the building, ft^2 (m^2)
A_a	=	free area around the elevator car, ft^2 (m^2)
A_e	=	effective area between the hoistway and the outside, ft^2 (m^2)
V	=	elevator car velocity, ft/min (m/s)
C_c	=	flow coefficient for flow around car, dimensionless
K_{cp}	=	coefficient, 1.66×10^{-6} (1.00).

The flow coefficient, C_c, was determined experimentally (Klote and Tamura 1986b) at about 0.94 for a multiple-car hoistway and 0.83 for a single-car hoistway. An example calculation of piston effect is presented. The effective area between the hoistway and the outside is

$$A_e = \left(\frac{1}{A_{sr}^2} + \frac{1}{A_{rl}^2} + \frac{1}{A_{lo}^2}\right)^{-\frac{1}{2}} \tag{2}$$

where

A_{sr}	=	leakage area between the hoistway and the lobby, ft^2 (m^2)
A_{lo}	=	leakage area between the building and the outside, ft^2 (m^2).

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SYSTEM CONCEPT

Smoke control systems for elevator evacuation must provide smoke protection for elevator lobbies, hoistways, and machinery rooms. Protection of lobbies is essential so that people will have a safe place to wait for the elevator. Accordingly, the elevator smoke control concept discussed in this paper includes enclosed elevator lobbies with lobby doors that close automatically upon activation of the smoke control system. Protection of the machinery room is important to prevent damage to elevator machinery. Figure 1 illustrates a system that pressurizes the hoistway directly and pressurizes the elevator lobby and the machinery room indirectly. The hoistway vent is not shown, but this topic is addressed later in this paper.

Hoistway Pressurization and Lobby Pressurization

Considering the leakage from the elevator lobby to the outside to be negligible, the mass flow rate from the hoistway to the elevator lobby equals the flow from the lobby to the building space,

$$m = C_{sr} K_m A_{sr} \sqrt{2\, \rho_{sr}\, \Delta p_{sr}} = C_{ri} K_m A_{ri} \sqrt{2\, \rho_{ri}\, \Delta p_{ri}}\ , \tag{3}$$

where

- m = mass flow rate, lb/s (kg/s)
- C_{sr} = flow coefficient for path between hoistway and lobby, dimensionless
- C_{ri} = flow coefficient for path between lobby and building, dimensionless
- ρ_{sr} = air density in path between hoistway and lobby, lb/ft^3 (kg/m^3)
- ρ_{ri} = air density in path between lobby and building, lb/ft^3 (kg/m^3)
- Δp_{sr} = pressure difference from hoistway to lobby, in. H_2O (Pa)
- Δp_{ri} = pressure difference from lobby to building, in H_2O (Pa)
- K_m = coefficient, 12.9 (1.00).

Considering $\rho_{sr} = \rho_{ri}$ and $C_{sr} = C_{ri}$, Equation 3 leads to

$$\frac{\Delta p_{sr}}{\Delta p_{ri}} = \left(\frac{A_{ri}}{A_{sr}}\right)^2 \tag{4}$$

For elevator doors with wide gaps, which are common in most buildings, Tamura and Shaw (1976) showed that the leakage area of the gaps is generally in the range of 0.5 to 0.7 ft^2 (0.05 to 0.07 m^2). Based on general experience with building leakages (Klote and Fothergill 1983), A_{ri}/A_{sr} is about 0.4 for construction of average tightness and about 0.1 for tight construction. From Equation 4, $\Delta p_{sr} / \Delta p_{ri}$ is, therefore, 0.16 and 0.01 for average and tight construction. Thus, the pressure in the elevator lobby can be expected to be close to the pressure in the hoistway, provided that the construction is not unusually leaky. Pressurization air can be supplied to the elevator lobbies (Figure 2). However, from the above discussion it seems that this direct lobby pressurization does not result in any significant improvement in pressurization over supplying the air into the hoistway as illustrated in Figure 1.

Direct lobby pressurization has some advantage over direct hoistway pressurization in purging small amounts of smoke from the lobby. Part of the pressurization air in an elevator smoke control system goes from the hoistway to the outside, and the rest goes from the lobby through the building to the outside. With direct lobby pressurization, both these amounts flow through the lobby. Such an

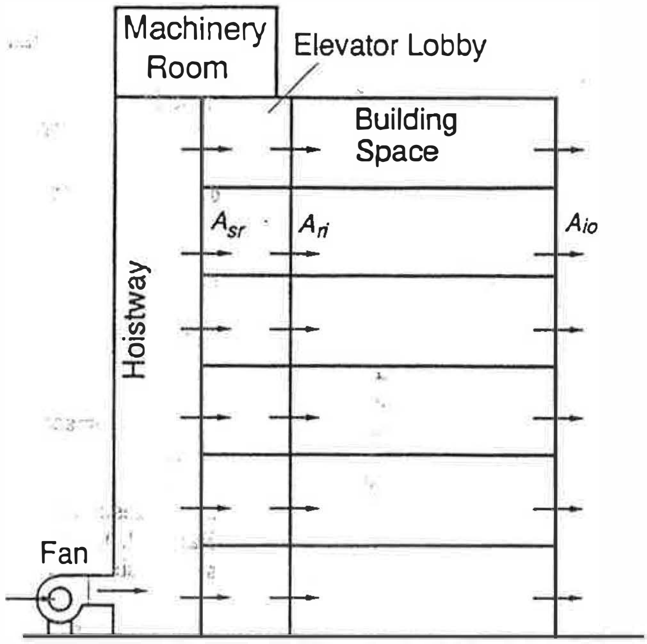

Figure 1 Elevator smoke control by shaft pressurization

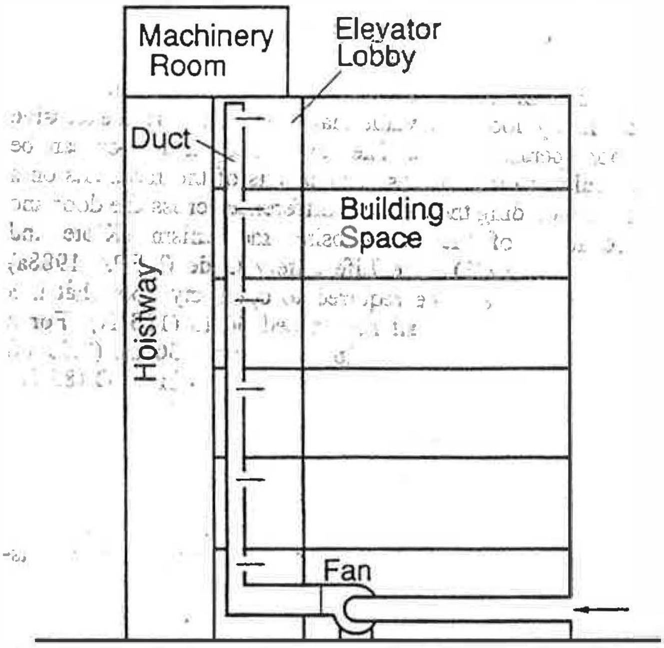

Figure 2 Elevator smoke control by lobby pressurization

increased flow rate tends to better purge any small amounts of smoke that would get into the lobby before smoke control activa ion or when a person is entering the lobby. The relative benefit of this improved purging compared to its cost has not been evaluated. The following discussions have been focused arbitrarily on the hoistway pressurization systems.

Pressure Fluctuations Due to Open Doors

Elevator systems must be designed to maintain design pressure differences under the likely conditions of opened and closed doors. Klote and Tamura (1986a) showed that opening a large flow path from the pressurized spaces to the outside can result in a significant loss in pressurization. For exa ple, opening the elevator doors, elevator lobby doors, and exterior doors resulted in a pressure drop from 0.13 in. H_2O (32 Pa) to 0.03 in. H_2O (7 Pa) for a sys em without features to resist pressure fluctuation.

During a fire, it is expected that several exterior doors will be propped open, and the elevator doors will open and close as elevators are used for evacuation. Further, stairwell doors are likely to be opened and closed as people use them for evacuation. It is envisioned that lobby doors will close automatically upon activation of the smoke control system. However, lobby doors can be inadvertently blocked and the closing mechanism can fail. It is anticipated that occupants will close any such opened lobby doors to prevent being exposed to smoke. Doors may not be closed on floors where there is no smoke danger or there are no people waiting in the elevator lobby. The smoke control system should be designed to maintain pressurization when some elevator lobby doors are open on floors away from the fire. The examples presented la er deal with pressure fluctuations due to doors opening and closing.

DESIGN PRESSURE DIFFERENCES

The maximum allowable pressure difference across the lobby doors is a value that does not result in excessive door-opening forces. The force to open a door can be calcula ed by a hydrostatic analysis of the moments on a door including the pressure difference across the door and the force of the door-closing mechanism (Klote and Fothergill 1983). The Life Safety Code (NFPA 1988a) states that the force required to open any door that is a means of egress shall not exceed 30 lb (133 N). For a door-closing force of 10 lb (45 N) on a 36-in. (0.91 m) wide door, a pressure difference of 0.34 in. H_2O (85 Pa) results in a door-opening force of 30 lb (133 N).

Besides the maximum value, a system should also operate above a minimum value sufficient to prevent smoke infiltration into the lobby. The design approach is for this minimum value o incorporate the fire effect of buoyancy and to account for other driving forces discussed later in the analysis. The pressure difference due to buoyancy of hot fire gases between a fire compartment and its surroundings is expressed as

$$\Delta p = K_s\, h \left(\frac{1}{T_o} - \frac{1}{T_f}\right) \tag{5}$$

where

Δp = pressure difference, in. H_2O (Pa)
h = height above neu ral plane, ft (m)
T_o = air temperature outside of fire compartment, °R (K)
T_f = temperature inside fire compartment, °R (K)
K_s = coefficient, 7.64 (3460).

For a fire compartment temperature of 1700°F (930°C), the pressure difference 6.0 ft (1.82 m) above the neutral plane is 0.065 in. H_2O (16 Pa). NFPA 92A (NFPA 1988b) sugges s a minimum value of 0.10 in. H_2O (25 Pa) for an unsprinklered building with a ceiling height of 9 ft (2.74 m). This considers the neutral plane at 6 ft (1.82 m) below the ceiling and allows a safety factor of 0.035 in. H_2O (9 Pa). NFPA 92A also suggests a minimum value of 0.05 in. H_2O (12 Pa) for sprinklered buildings.

The minimum pressure difference discussed above applies to the fire floor, because this is where the fire puts its major stress on the smoke control system. A smoke control system that requires no information about the location of the fire floor must maintain at least the minimum pressure difference across the lobby doors on all floors.

The above discussion of minimum pressure differences does not apply to variable-supply air systems that maintain a set pressure difference across the lobby doors on the fire floor. This set pressure difference is discussed later. The set pressure should be high enough so that the system is not adversely affected by transient pressures when adjusting to the opening or closing of doors.

SMOKE CONTROL SYSTEMS

Elevator smoke control systems can incorporate features to deal with pressure fluctuations due to opening and closing doors. These features include pressure-relief vents, vents with barometric dampers, variable-supply air fans, fire floor venting, and fire floor exhaust.

Pressure-Relief Vent System

This system has a "constant-supply" air rate fan and a pressure-relief vent to the outside, as illustrated in Figure 3. The area of this vent is fixed and is sized for operation in the smoke control system. The vent can be fitted with automatic dampers if it is desired for it to be normally closed. The supply rate varies to some extent with the pressure across the fan, but the term "constant-supply" is used to differentiate this fan from one that has a "variable-supply" rate. The vent must be large enough that the maximum allowable pressure difference is not exceeded when all doors are closed. When paths to the outside are opened, air flows through them and the hoistway pressure drops. This system must maintain at least the minimum allowable pressure difference when some design combination of paths is open.

Barometric Damper System

This system is similar to the one above, except that the vent has a barometric damper that closes when the

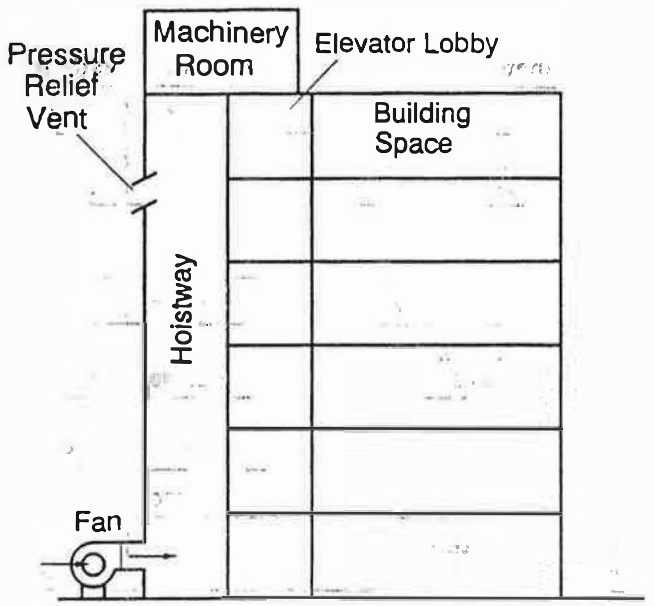

Figure 3 Elevator smoke control with a pressure relief vent

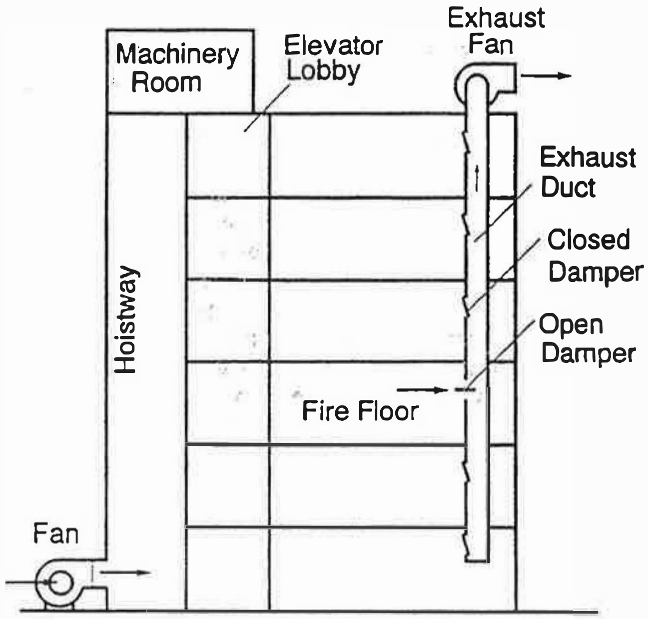

Figure 4 Elevator smoke control with fire floor exhaust

pressure drops below a specified value. The use of these ampers minimizes air losses when paths from the elevator shaft are opened, and the pressurization fan can be sized smaller than for the above system. A normally closed automatic damper in front of (or after) the barometric damper can prevent damper chatter caused by the wind.

Variable-Supply Air System

Variable-supply air can be achieved by using one of many fans commercially available for a variable flow rate. Alternatively, a fan bypass arrangement of ducts and ampers can be used to vary the flow rate of supply air to the hoistway. The variable-flow fans are controlled by one or more static pressure sensors that sense t e pressure difference between the lobby and the building. There are two approaches for use of the sensors. The airflow rate can be controlled by the average of signals from the sensors on all floors or it can be controlled by the signal from the fire floor.

Using the average of all the signals has the advantage that no information is required about where the fire is located. Using the fire floor sensor signal requires information about the fire location. This information can come from smoke detectors, heat detectors, or sprinkler water flow indicators. Using the fire floor signal has the advantage that the system maintains a set pressure difference at this most critical location.

System with Fire Floor Venting or Exhaust

Smoke venting and smoke exhaust of the fire floor can improve system performance. The venting or exhaust increases t e pressure difference from the lobby to the fire floor. The vents can be exterior wall vents or non-powered smoke shafts. Figure 4 shows a fan-duct system intended to exhaust the fire floor. Upon detection of fire or smoke, the damper opens on the fire floor and the exhaust fan is activated. The detection system must be configured to identify the fire floor.

ANALYSIS OF SMOKE CONTROL SYSTEMS

The design of an elevator smoke control system includes selection of a system for dealing with pressure fluctuations, determining appropriate values for leakage areas and other parameters, as well as calculating the performance of the smoke control system. The following section discusses a computer program that can be used for analysis of these systems. This program evaluates the effec ts of outside temperature, forced ventilation, and the wind.

Neither of the example analyses that are provided addresses t e effects of wind. A wind of 50 mph (22 m/s) results in a velocity pressure on the order of 1 in. H_2O (250 Pa). Occurrence of such high-velocity wind is infrequent. However, such high velocities should not pose a problem, provided that windows do not break. The likelihood of the fire resulting in broken windows is considered to be much lower for a sprinklered building than for an unsprinklered one. Further, local obstructions such as surrounding buildings can significantly reduce wind pressures on building surfaces. The variable-supply air system analyzed below has the advantage that it will work to maintain its set pressure difference even under conditions of broken windows with wind effects.

Network Computer Program

Elevator smoke control systems can be analyzed by the computer program for analysis of smoke control systems (ASCOS) presented by Klote and Fothergill (1983). In this program, a building is represented by a network of spaces or nodes, each at a specific pressure and temperature. Shafts such as hoistways and stairwells are modeled by a series of vertical spaces, one for each floor. Air flows through openings from regions of high pressure to regions of low pressure.

In this model, air from the outside can be introduced by a pressurization system into any level of a shaft or even into other b ilding spaces. This allows simulation of elevator smoke control systems. The flows and leakage paths are considered to be the mid-height of each level. The net air supplied by the HVAC system or by the pressurization system is considered constant and independent of pressure. The outside air tempera ure is considered constant. The program calculates the steady flows and pressures throughout the network, including the driving forces of wind, the pressurization system, and inside-to-outside temperature difference.

Example Analysis of Pressure-Relief Vent System

The 11-story building wi h a typical floor plan shown in Figure 5 was selected arbitrarily for this example. Because the building is symmetric, only half of each floor was analyzed. The minimum and maximum allowable pressure differences from the lobby to the building a e 0.05 and 0.34 in. H_2O (12 and 85 Pa). The other design paramete s are listed in Table 1. A value of 24 ft^2 (2.23 m^2) for the relief vent area is selected arbitrarily.

Pressurization air is supplied to the hoistway at the second floor. The objective of the design analysis is to determine a flow rate of pressurization air that will result in acceptable pressurization with a minimum and a maximum design number of large open paths from the hoistway to the outside. Following is one approach to the analysis for the pressure-relief vent system.

Step 1 Calculat the flow rate of pressurization air that results in the minimum allowable pressure difference when the maxim m design number of large paths is open from the hoistway to the outside. This flow rate is for either summer or winter design conditions, whichever flow ra e is largest.

Step 2 Calculate the pressure differences resulting from the flow rate of *Step 1* when the minimum design number of large paths is open.

Step 3 If the pressure differences from *Step 2* are less than or equal to the maximum allowable pressure difference, the system can maintain acceptable pressurization. If not, another system or another variation of this system should be considered.

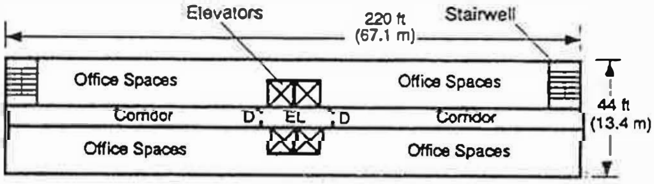

Figure 5 Typical floor plan (above first floor) of example building

TABLE 1
Parameters of Example Smoke Control Systems

Flow Areas	ft^2	m^2
First floor exterior wall (exterior doors closed)	0.940	0.0873
First floor exterior wall (exterior doors opened)	22.0	2.04
Exterior walls (except on 1st floor)	0.540	0.0502
Stairwell to building (stair door closed)	0.270	0.0251
Stairwell to building (stair door opened)	10.5	0.975
Building floor	0.270	0.0251
Building to elevator lobby (lobby doors closed)	0.42	0.0390
Building to elevator lobby (lobby doors opened)	22.0	2.04
Elevator lobby to hoistway (elevator door closed)	1.60	0.149
Elevator lobby to hoistway (elevator door opened)	8.00	0.743
Pressure-relief vent from hoistway to outside at 8th floor	24.0	2.23
Other Parameters		
Height between building floors	10.0 ft	0.929 m
Number of floors	11	11
Building air temperature	70°F	21°C
Winter outside temperature	5°F	-15°C
Summer outside temperature	90°F	32°C

Step 4 Apply a safety factor to the flow rate calculated above.

The maximum design number of large pa hs should consist of one on the first floor plus some others on upper floors. The first-floor path consists of open elevator doors, elevator lobby doors, and exterior doors. The paths on the other floors consist of an open elevator lobby door and an open stairwell door. This results in large paths to the outside, because the exterior stairwell door is open. For this analysis the design numbers of large open paths have been selec ed arbit arily as:

Minimum Number of Large Paths Open: Zero—all doors are closed.

Maximum Number of Large Paths Open: First-floor path plus paths on the top two floors.

Table 2 lists the arrangement of doors for the computer analysis. Runs 1 and 2 are the maximum number of paths open (*Step 1*), and runs 3 and 4 are the minimum paths open (*Step 2*). The pressure differences for these runs are listed in Tables 3 and 4. For winter conditions, the ASCOS program was executed a few times to determine that 33,400 cfm (15,800 L/s) of pressurization air is needed to maintain at least the minimum allowable pressure difference when the maximum design number of large paths are open (run 1). At this flow rate with the maximum design number of large paths open in summer (run 2), the pressure differences are all greater than the minimum allowable pressure difference. At this same rate of pressurization, the pressure differences with the minimum paths open (runs 3 and 4) are all below the maximum allowable pressure difference.

For the design analysis, 33,400 cfm (15,800 L/s) of pressurization air is sufficient to maintain acceptable pressurization under design conditions of large open paths from the hoistway to the outside. A safety factor is suggested to account for differences between the estimated leakage areas of this analysis and those of the actual building. If a safety factor of 25% were used, the supply fan would be sized for about 42,000 cfm (19,800 L/s). The system should be designed so that the flow rate can be adjusted in the field as appropriate.

TABLE 2
Arrangement of Doors for Computer Analysis of Example Smoke Control System with a Pressure-Relief Vent

Run	Season	1st Floor Exterior Door Open	Elevator Doors Open on Floors:	Elevator Lobby Doors Open on Floors:	Stairwell Doors Open on Floors[1]:
1	Winter	Yes	1	1, 10, 11	10, 11
2	Summer	Yes	1	1, 10, 11	10, 11
3	Winter	No	None	None	None
4	Summer	No	None	None	None

[1]Exterior stairwell door on the ground floor is closed when no other stair doors are opened, and it is open when any other stair door is opened.

Example Analysis of Variable-Supply Air System

The same building is used as in the above example. The flow rate of the variable-supply air fan is controlled by a sensor on the fire floor to maintain a setpoint of 0.05 in. H_2O (12 Pa). The system maintains the setpoint when the elevator lobby door is closed on the fire floor. However, when the elevator lobby door is open on the fire floor, the flow rate of pressurization air increases in an attempt to maintain the setpoint, and high pressure differences can result across elevator lobby doors on other floors. These high pressures should not exceed the maximum allowable pressure difference, which is again 0.34 in. H_2O (85 Pa). Again, pressurization air is supplied to the hoistway at the second floor.

As with the preceding example, the objective of the design analysis is to determine a flow rate of pressurization air that will result in acceptable pressurization

TABLE 3
Computer-Calculated Pressure Differences for Example Smoke Control System with a Pressure-Relief Vent (IP)

	Pressure Difference in inches H_2O from Elevator Lobby to Building on Floors										
Run	1	2	3	4	5	6	7	8	9	10	11
1	Open	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	Open	Open
2	Open	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.08	Open	Open
3	0.16	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.11	0.12	0.12
4	0.24	0.22	0.20	0.19	0.17	0.15	0.14	0.12	0.12	0.12	0.12

TABLE 4
Computer-Calculated Pressure Differences for Example Smoke Control System with a Pressure-Relief Vent (SI)

	Pressure Difference in pascals from Elevator Lobby to Building on Floors										
Run	1	2	3	4	5	6	7	8	9	10	11
1	Open	20	17	17	15	15	15	12	12	Open	Open
2	Open	37	32	30	27	25	22	20	20	Open	Open
3	40	40	37	35	32	30	27	27	27	30	30
4	60	55	50	47	42	37	35	30	30	30	30

with a minimum and a maximum design number of large open paths from the hoistway to the outside. Below is another approach to the analysis for the pressure-relief vent system:

Step 1 Calculate the flow rate of pressurization air that results in the maximum allowable pressure difference across any closed elevator lobby door when the lobby door is open on the fire floor. This calculation should be made for summer and winter design conditions with the fire floor being on the top or second floor. The smallest of these flow rates is the value that should not be exceeded.

Step 2 Calculate the flow rate of pressurization air that results in the minimum allowable pressure difference when the maximum design number of large paths is open from the hoistway to the outside. This flow rate is for either summer or winter design conditions, whichever flow rate is largest.

Step 3 If the flow rate from *Step 1* is greater than that from *Step 2*, the system can maintain acceptable pressurization. If not, another system or another variation of this system should be considered.

Step 4 Apply a safety factor to the flow rate calculated above.

The maximum design number of large paths open is the same as in the first example. Initially the minimum number of large paths open was also zero. However, *Step 3* of the analysis indicated that this system would not maintain acceptable pressurization. The system was modified such that the minimum number of large paths open is the one on the first floor. This means that the elevator lobby doors and the exterior doors must be opened automatically or remain opened upon system activation. The data presented in the rest of this analysis are for this second system with these doors opened on activation.

The conditions of open and closed doors are listed in Table 5 for six computer runs, and the resulting pressurization flows and pressure differences are listed in Tables 6 and 7. For each run, the ASCOS program was executed a few times to find the flow rate of pressurization air that produced the desired pressure difference. Computer runs 1, 2, 3, and 4 were made for *Step 1*. From these runs, the pressurization flow rate should not exceed 19,800 cfm (9,300 L/s). Runs 5 and 6 are for *Step 2*, and they indicate that the flow rate must be at least 8,500 cfm (4,000 L/s). Thus, the system can maintain acceptable pressurization (*Step 3*). Using the same safety factor as the first example, the fan should be sized to deliver 11,000 cfm (8,200 L/s). The system should be designed so that the flow rate can be adjusted in the field as appropriate.

TABLE 5
Arrangement of Doors for Computer Analysis of Example Smoke Control System with Variable-Supply Fan

Run	Season	1st Floor Exterior Door Open	Elevator Doors Open on Floors:	Elevator Lobby Doors Open on Floors:	Stairwell Doors Open on Floors:
1	Winter	Yes	1	1, 2	None
2	Winter	Yes	1	1, 11	None
3	Summer	Yes	1	1, 2	None
4	Summer	Yes	1	1, 11	None
5	Winter	Yes	1	1, 10, 11	10, 11
6	Summer	Yes	1	1, 10, 11	10, 11

Example Piston Effect Analysis

For the smoke-control systems of the above examples, the parameters for analysis of piston effect are listed in Table 8 for two cars in a hoistway. The elevator flow coefficient, C_c, was evaluated experimentally (Klote and Tamura 1986b). From Equation 2, the effective area, A_e, is 0.325 ft^2 (0.0302 m^2). From Equation 1, the critical pressure difference from the elevator lobby to the building

TABLE 6
Computer-Calculated Pressure Differences for Example Smoke Control System with Variable-Supply Fan (IP)

Run	Flow Rate[1] (cfm)	Pressure Difference in inches H_2O from Elevator Lobby to Building on Floors: 1	2	3	4	5	6	7	8	9	10	11
1	19,800	Open	Open	0.29	0.32	0.32	0.33	0.33	0.34	0.34	0.34	0.34
2	20,200	Open	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.33	Open
3	22,000	Open	Open	0.32	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
4	20,200	Open	0.34	0.32	0.32	0.31	0.31	0.31	0.31	0.30	0.28	Open
5	8,500	Open	0.05	0.05	0.06	0.06	0.07	0.08	0.08	0.08	Open	Open
6	8,500	Open	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	Open	Open

[1]Flow rate of pressurization air into the hoistway at the second floor

TABLE 7
Computer-Calculated Pressure Differences for Example Smoke Control System with Variable-Supply Fan (SI)

Run	Flow Rate[1] (L/s)	Pressure Difference in pascals from Elevator Lobby to Building on Floors 1	2	3	4	5	6	7	8	9	10	11
1	9,300	Open	Open	72	80	80	82	82	85	85	85	85
2	9,500	Open	85	85	85	85	85	85	85	85	82	Open
3	10,400	Open	Open	80	85	85	85	85	85	85	85	85
4	9,500	Open	85	80	80	77	77	77	77	75	70	Open
5	4,000	Open	12	12	15	15	17	20	20	20	Open	Open
6	4,000	Open	12	12	10	10	10	7	7	7	Open	Open

[1]Flow rate of pressurization air into the hoistway at the second floor

is 0.024 in. H_2O (6.0 Pa). For these example smoke control systems, the lowest pressure difference across this same path is 0.05 in. H_2O (12 Pa) in the winter. Thus, piston effect would not be a problem for these systems.

All other things being equal, the critical pressure difference from the lobby to the building is higher for a single-car hoistway than for a multiple-car one. For a single-car hoistway with A_s of 60.4 ft^2 (5.61 m^2), A_a of 19.4 ft^2 (1.80 m^2), C_c of 0.83, and the other parameters listed in Table 8, Equation 1 gives a critical pressure difference of 0.13 in. H_2O (33 Pa). This pressure would be a concern for the smoke control systems of the above examples. Possible solutions include a slower car speed, use of another elevator with multiple cars in the hoistway, and a higher level of hoistway pressurization.

CONCLUSIONS

1. Elevator smoke control systems can be designed to provide acceptable levels of pressurization under severe conditions of doors opening and closing.
2. While the example analyses were for a pressure-relief vent system and a variable-supply air system, other systems can be used to deal with the pressure fluctuations caused by doors opening and closing.
3. Transient pressures produced by the motion of a car in a hoistway are of concern because of their potential for pulling smoke into an elevator lobby. All other things being equal, this elevator piston effect is considerably greater for single-car hoistways than for multiple-car hoistways. Equation 1 can be used to design systems so that piston effect is not a problem.

TABLE 8
Parameters for Piston Effect Example

A_s	121 ft^2	11.2 m^2
A_{ir}	0.420 ft^2	0.0390 m^2
A_a	79.8 ft^2	7.41 m^2
A_{sr}	1.60 ft^2	0.149 m^2
A_{io}	0.54 ft^2	0.0502 m^2
ρ_o	0.075 lb/ft^3	1.20 kg/m^3
V	500 ft/min	2.54 m/s
C_c	0.94	0.94

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DISCUSSION

J. Brooks Semple, President, Smoke/Fire Risk Management, Warrenton, VA: How much more engineering effort is required to expand a handicapped evacuation system to a total population evacuation system? How much time is involved for the total evacuation?

J.H. Klote: In the paper we discussed smoke control for elevator evacuation. You have asked about the engineering effort involved in the evacuation system. Smoke control is only a small part of an elevator evacuation system. In fact, elevator evacuation systems may be possible without smoke control. I am currently engaged in a project funded by the U.S. General Services Administration to study the feasibility of elevator evacuation from office buildings. There are many possible variations of elevator evacuation systems, and we do not know enough to be able to discuss relative engineering effort for different types of systems.

Richard E. Masters, P.E., Partner, Jaros, Baum & Bolles, New York, NY: This was an excellent presentation with valuable information for design engineers.

Klote: Thank you.