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Fire Protection Challenges of the Americans Disabilities Act: Elevator Evacuation and Refuge Areas

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Abstract

There is a rising concern for the safety of persons from fire who cannot travel building emergency exit routes in the same manner or as quickly as expected of able persons. One proposed solution for providing safety for persons with mobility limitations is the use of elevators for fire evacuation. Another proposed solution is the concept of areas of refuge where they can "safely wait" until they can be assisted in leaving the building. The system concepts and interrelationships of these two alternatives are discussed. An overview of an area of refuge study conducted at NIST is presented. Other topics addressed are elevator people movement, elevator water problem, and smoke control concepts.

1. Introduction

There is a rising concern for the safety of persons from fire who cannot travel building emergency exit routes in the same manner or as quickly as expected of able persons. Historically, persons with disabilities found barriers that hindered their efforts to work in or otherwise do business in all types of buildings. Progressively, improvements in barrier free access have opened building access to move people. These improvements are expected to continue. With increased building access comes the need to provide for safety in the event of fire. Two approaches to providing fire safety for people with mobility limitations are elevator evacuation and areas of refuge (AOR). Several regulatory documents such as the Life Safety Code (NFPA 1991) and the guidelines for implementation of the Americans with Disabilities Act (Department of Justice 1991) address these approaches.

Today's elevators are not intended as means of fire egress, and they should not be used for fire evacuation (Sumka 1988). However, the idea of using elevators to speed up fire evacuation and to evacuate persons with disabilities has gained considerable attention (Bazjanac 1974, Bazjanac 1977, Pauls 1977). On February 19 and 20 of 1991, the American Society of Mechanical Engineers (ASME) held a symposium in Baltimore entitled *Fire and Elevators*. Several of the papers at this symposium dealt with fire evacuation by elevators (Degenkolb 1991; Fox 1991; Gatfield 1991; Klote and Tamura 1991; Pauls, Gatfield and Juillet 1991).

The AORs are intended as spaces in which people with disabilities can "safely wait" until they can be assisted in safely leaving the building. To facilitate rescue, these areas generally are adjacent to elevators or stairs. AORs have also been called areas of rescue assistance and staging areas.

This paper discusses elevator evacuation and AORs including the interrelation of these approaches, system requirements and future efforts. This paper does not address all the possible considerations of these systems. Readers are referred to Klote, Alvord, Nelson and Groner (1992) and Klote, Deal, Levin, Groner and Donoghue (1993) for additional information about elevator evacuation and to Klote, Nelson, Deal and Levin (1992) for additional information about AORs.

2. System Concepts and Interrelationships

The total system associated with elevator evacuation includes the elevator equipment and controls, the hoistway (elevator shaft), the elevator machinery room, and the elevator lobbies. The elevator lobbies are included, because people need a safe place to wait for the elevators. To assure operation of the elevators throughout evacuation, systems need to be protected from fire, heat, smoke, loss of electric power, and water damage to elevator equipment in the hoistway. Human considerations are also a significant factor in elevator evacuation.

Similarly, AOR systems need to be protected from fire, heat and smoke; but the need to provide communications capability with rescue teams is also important. AORs that use pressurization smoke control also need to be protected from loss of electric power. Fire information and training is an important factor. AORs are often located adjacent to elevators so that the elevator system can be used for rescue. Protected elevator lobbies needed for elevator evacuation thus become AORs.

Fire resistive construction, reliability of electrical power, and communications are not addressed further in this paper because there is extensive experience in the building community on these subjects. The following sections address elevator people movement, elevator water problem, smoke control, and the AOR concept. While human considerations are important, they are not addressed in detail in this paper. For information specifically about human considerations for elevator evacuation, see Groner and Levin (1992) and for AORs, see Levin and Groner (1992).

3. Elevator Evacuation

3.1 Elevator People Movement

Analysis of the movement of people during a fire is complex because some elevators and stairs are used by the fire service, some evacuation routes cannot be used because of smoke or fire, and some occupants go against the normal flow of people to rescue others. People movement is more complicated during a fire than during fire drills. A computer program, ELVAC, was developed by Klote, Alvord, Levin, and Groner (1992) to calculate the evacuation time by elevators during a fire drill. This idealized evacuation time is useful in comparing the relative evacuation time for different buildings.

The approach used in ELVAC is based on quitting time (outgoing) traffic calculations of Strakosch (1983). In ELVAC, the evacuation time, t_e, is

$$t_e = t_a + t_o + \frac{(1 + \eta)}{J} \sum_{j=1}^{m} t_{r,j} \qquad (1)$$

where $t_{r,j}$ is the time for an elevator to make a round trip j, m is the number of round trips, J is the number of elevators, η is the trip inefficiency, t_a is elevator evacuation start up time, and t_o is the travel time from the elevator lobby to the outside or to another safe location.

The round trip time depends on the travel time of the elevator and on the number of people traveling in the elevator as discussed later.

The travel time from the elevator lobby to a safe location can be evaluated by conventional methods of people movement [i.e. Nelson and MacLennan (1988) or Pauls (1988)].

The trip inefficiency accounts for trips to empty floors and trips for only a few stragglers.

The elevator evacuation start up time is the time from activation to the start of the round trips that evacuate people. For automatic elevator operation, the evacuation starts after all the elevators have been moved to the discharge floor. For manual operation, the start up time includes the time for elevator operators to be alerted and then get to the elevators.

The round trip time consists of the standing time plus twice the travel time. The standing time is the sum of the time to open and close the elevator doors twice, the time for people to enter the elevator, and the time for people to leave the elevator. Typically, elevator travel consists of constant acceleration motion, transitional acceleration motion, constant velocity motion, transitional deceleration motion, constant deceleration motion, and leveling motion as shown in figure 4. The time for most of these motions are obtained from equations that can be found in most elementary physics texts. The transitional times are generally very short and were estimated by a simple equation. The leveling time is taken to be a constant.

3.2 Elevator Fire Protection

The safe installation of new elevators in the U. S. is guided by ASME/ANSI A17.1 (1990a) Safety Code for Elevators and Escalators and existing elevator installations must conform to ASME/ANSI A17.3 (1990b) Safety Code for Existing Elevators and Escalators. The elevator industry specifies shaft dimensions but fire protection of the shaft and machinery room are governed by the building codes, which are tailored to the occupancy of the building. The NFPA Life Safety Code Section 6.2.4.4 in general requires the barriers of shafts that connect four or more stories have two hour resistance rating, based on the NFPA 251 (1990), Standard Methods of Fire Tests of Building Construction and Materials. Exceptions are allowed for hotels and apartments that are fully sprinklered and have a supervised alarm system. Less than four stories must have a one hour barrier, and existing buildings must have a one half hour barrier. Doors to these shafts must be fire and smoke rated. The machinery room is considered a special hazard area and as such generally requires a one hour fire barrier.

It would appear that for new construction the elevator system is generally protected from fire for one hour enabling their use for building evacuation if that evacuation can be completed in that time. The protection provided in existing buildings is quite limited and puts a shorter time limit on elevator use for evacuation. As a rule of thumb, the evacuation time for large buildings using stairs takes one minute per floor. Therefore, taller buildings would probably need additional protection. Obviously sensors in the shaft and machinery room should be used to monitor the integrity of these areas during a fire.

3.3 Elevator Smoke Protection

Elevator systems can be protected from smoke infiltration either by compartmentation or smoke control. To be consistant with NFPA 92A (1988) and the ASHRAE smoke control design book (Klote and Milke 1992), the term *smoke control* is used here to mean the use of fans to produce pressures at barriers to limit and direct smoke movement. Since this smoke protection is only a part of total building fire protection, the selection of the technique used depends on the other fire protection features used.

Smoke control systems for elevator evacuation, (and for AORs connected to elevators or stairs) can use either direct or indirect pressurization as shown in figure 1. Pressurization air can be supplied directly into each lobby or it can be supplied indirectly through an elevator shaft connected to the lobby. The direct system has the added expense of an air distribution duct and possibly a duct shaft including a corresponding loss of usable floor area.

Pressure fluctuations due to the wind, and doors opening and closing can have a significant effect on system performance. The following techniques that have been used to mitigate pressure fluctuations in stairwells may be applied to elevators.

Pressure-Relief Venting This approach uses a vent to the outside and a "constant-supply[1]" fan. The area of the vent is sized for operation of the smoke control system. The vent may be fitted with automatic dampers if it is desired for it to be normally closed. The vent must be large enough that the maximum pressure difference is not exceeded when all the doors are closed. When paths to the outside are open (doors and broken window), air flows through them and the pressure in the lobby drops. This system must maintain the minimum allowable pressure difference when a design number of doors and windows are open under design wind conditions.

Barometric Damper Venting This approach is similar to the one above, except that the vent has a barometric damper which closes when the pressure falls below a specified value. This minimizes air losses under the low pressure conditions.

Variable-Supply Air Variable-supply air can be achieved by using one of many fans commercially available for variable flow rate. Alternatively, a fan bypass arrangement of ducts and dampers can be used to vary the flow rate supplied to the shaft or to the lobby. The flow rate is controlled by static pressure sensors located between the lobby and the building.

Fire Floor Exhaust Exhausting smoke from the fire floor can improve the pressure difference across the lobby doors on the fire floor. Upon detection of fire, the fire floor is exhausted. The detection system must be configured to identify the fire floor.

Smoke control systems can be analyzed by the computer program for analysis of smoke control systems (ASCOS) presented by Klote and Milke (1992). 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 ASCOS, air from the outside can be introduced by a pressurization system into any level of a shaft or even into other building spaces. This allows simulation of elevator smoke control systems. The flows and leakage paths are considered to be at the mid-height of each level. The net air supplied by the

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[1]The supply rate is not actually constant, but varies to some extent with the pressure across the fan. For centrifugal fans this variation can be small. The term constant-supply is used here to differentiate this approach with that of using variable-supply air flow.

HVAC system or by the pressurization system is considered constant and independent of pressure. The outside air temperature 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.

Further information about design and analysis of smoke control for elevators is available from Klote and Milke (1992) and for AORs is available from Klote (1993).

3.4 Elevator Water Protection

Of all the engineering considerations about elevator evacuation, the most significant is the potential for water damage to elevator system components inside the hoistway. During a building fire, water from sprinklers and fire hoses can damage electronic, electrical, and mechanical components of the elevator system. Two potential solutions to the elevator shaft water problem are:

1. use elevator system components that can function in a wet environment, and
2. prevent water from entering the shaft.

Currently many elevators operate outdoors on exterior walls of buildings with many of the system components exposed to rain, wind and extremes of temperature. Thus, it is technically feasible to build elevators with water protected components which will operate during a fire. However, maintenance of such water resistive components on elevators not exposed to the elements is a concern because systems inadvertently repaired with non-water resistive components can operate properly under normal conditions without indication of the improper parts.

Elevators can be constructed to prevent water entering the shaft by use of floors sloping away from the elevator door. Floor drains can be part of such an approach. This approach has the advantage of requiring almost no maintenance. Further research is needed to determine which approach to water protection for the elevator shaft is the most practical and cost effective.

The New York City Fire Department and the ASME A17.1 Emergency Operations Committee are developing a test program to study the effects of water entering elevator hoistways to assess the reliability of elevators for firefighter's service under conditions encountered during a fire. It is generally assumed that the presence of water in the hoistway indicates that water has probably been applied to the fire suppressing or extinguishing it, consequently reducing threat to life. Further research concerning the extent of the water problem and potential solutions is needed.

3.5 Elevator Piston Effect

The transient pressures produced when an elevator car moves in a shaft are a concern for elevator smoke control. Such piston effect can pull smoke into a normally pressurized elevator lobby or hoistway. Analysis of the air flows and pressures produced by elevator car motion in a pressurized hoistway was developed by Klote (1988), based on the continuity equation for the contracting control volume in hoistway above a moving elevator car.

Piston effect experiments (Klote and Tamura 1987) were conducted on an elevator of a hotel in Mississauga, Ontario, Canada. This elevator served each floor of the 15 story building, and the hoistway was pressurized by a vane axial fan. Figure 3 is a comparison of measured and calculated pressure differences due to an elevator car ascending from the ground floor to the top floor. The general trends of the calculations are in agreement with the measurements. On the ground floor, piston effect causes a rapid drop in pressure followed by a gradual pressure increase as the car moves away from the ground floor. Intuitively, a reduction in pressure is expected below an ascending car. This pressure reduction decreases as the car moves away due to the effect of increasing leakage area of the shaft below the car. On the top floor, piston effect due to the ascending car causes a gradual pressure increase with distance traveled until the car gets close to that floor. On a middle floor (the 8th) the pressure increases as the car approaches, drops suddenly as the car passes and increases after it travels away. For the ground and 8th floors, the extremes of the calculated curves deviate from those of the measured curves by only about 1 Pa (0.004 in H_2O), and for the 15th floor the extremes deviate by about 8 Pa (0.03 in H_2O).

From the analysis by Klote, an expression was developed for the critical pressure difference at which piston effect cannot overcome the elevator pressurization system. The critical pressure difference is from the shaft elevator lobby and the building:

$$\Delta P_{crit} = \frac{K_{pe}\rho}{2}\left(\frac{A_s A_e V}{A_a A_{ir} C_c}\right)^2 \tag{2}$$

where
ΔP_{crit} = critical pressure difference, Pa (in H_2O);
ρ = air density in hoistway, kg/m^3 (lb/ft^3);
A_s = cross sectional area of the hoistway, m^2 (ft^2);
A_{ir} = leakage area between the building and the lobby, m^2 (ft^2);
A_a = free area around the elevator car, m^2 (ft^2);
A_e = effective area between the hoistway and the outside, m^2 (ft^2);
V = elevator car velocity, m/s (ft/min);
C_c = dimensionless flow coefficient for flow around car; and
K_{pe} = coefficient, 1.00, (1.66x10^{-6}).

The flow coefficient, C_c, was determined experimentally (Klote and Tamura, 1986a) at about 0.94 for a multiple car hoistway and 0.83 for a single car hoistway. The effective area between the hoistway and the outside is

$$A_e = \left(\frac{1}{A_{sr}^2} + \frac{1}{A_{ir}^2} + \frac{1}{A_{io}^2}\right)^{-1/2} \tag{3}$$

where
A_{sr} = leakage area between the lobby and the shaft, m^2 (ft^2); and
A_{io} = leakage area between the outside and the building, m^2 (ft^2).

If an elevator smoke control system produces a pressure difference greater than that of equation (2), smoke will not be pulled into the elevator lobby due to piston effect. Thus it is recommended that equation (2) be used in the design of elevator smoke control systems to assure that piston effect is not a problem.

4. Areas of Refuge Study

The National Institute of Standards and Technology (NIST) worked with the General Services Administration (GSA) to evaluate the concept of AORs. The methods and considerations of the AOR study also are relevant to elevator lobbies.

The AOR project consisted of field tests, fire threat analysis, and human behavior studies. A brief overview of the project is presented here. If more detailed information is desired, the reader is referred to Klote, Nelson, Deal and Levin (1992) and Levin and Groner (1992).

GSA modified six buildings for fire protection of persons with mobility disabilities, using two different approaches, AORs and horizontal separation. Horizontal separation consists of one or more barriers which divide a floor into separate areas with the intent of restricting smoke and fire. These barriers include automatic closing doors.

Spaces that were turned into AORs included passenger elevator lobbies, service elevator lobbies, sections of corridor, and rooms. Table 1 lists the protection approach used for each of these buildings along with some other general information, and figure 2 shows typical floor plans of the buildings. Not all of the AORs had direct access to stairwells or elevators. When the AORs did not open directly onto stairs or elevators, these areas were located near a stairwell or elevator. All AORs in the six GSA buildings were pressurized with outside air. Many of the AORs had power operated, folding doors that had a level of fire endurance.

Field tests of the six GSA buildings were conducted to determine the smoke protection expressed in terms of leakage area between the AORs and other building spaces. These leakage areas were obtained by pressurization tests using the AORs own pressurization smoke control systems. Also the leakage areas of gaps around doors in barriers used for horizontal separations were measured.

An essential step in evaluating the capability of the AORs and related systems to fulfill the fire safety needs of persons with disabilities is the evaluation of the potential fire threat that may be faced. The procedures used include: models and other evaluation features contained in the fire hazard analysis programs of FPETOOL (Nelson 1990); procedures outlined by Steckler (1989) for estimating the conditions developed by smoke flow through corridors; the smoke flow model ASCOS (Klote and Milke 1992); and the N-GAS Toxicity Model (Bukowski et al. 1989). Fires were selected so that, for each location, there would be: (1) a fire that would (if not suppressed) produce flashover in the given room or space being analyzed, (2) a fire that in the same space would approach but would not reach flashover, and (3) a smoldering fire. Analysis of estimated movement time to AORs were made for able and disabled persons. Many of the buildings were sprinklered (table 1), and the heat release rates of the sprinklered fires were modeled by a sprinkler fire suppression algorithm[2] developed by Madrzykowski and Vettori (1992).

The following conclusions from the study apply specifically to the installations investigated in six of the GSA buildings. Since these buildings represent a wide range of sizes, shapes, geographical locations and approaches to safety, it is believed that methods of analysis used in this paper are applicable to many other buildings. However, individual buildings will require individual engineering analysis.

1. AORs can be either a haven or a hazard. The difference is highly dependent on details of design, the type of fire exposure, outside wind and temperature conditions, and the capability and reliability of the smoke control pressurization system. Without pressurization, all AORs are subject to lethal failure.

2. In many cases, the persons most needing the AOR protection may be unable to reach that area before their pathways (corridor or aisle ways) become lethal.

3. The organizational and human behavior problems involved in the use of AORs are significantly more complex than those associated with the traditional total exit approach. There is a distinct need for more research in this area as there is no guidance on how to use AORs and on what to expect when they are used.

4. The operation of a properly designed and maintained sprinkler system eliminates the life threat to all occupants regardless of their individual abilities and can provide superior protection for people with disabilities as compared to AORs.

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[2]This algorithm is based on data from sprinklered fire tests of furniture and other materials commonly found in offices and grouped in arrangements common to offices. These fire tests included shielded fires in fuel arrangements often observed in offices. The algorithm does not represent long burning shielded fires like crib fires developed by Mawhinney and Tamura (1993) which were constructed of 545 kg (1200 lb) of lumber in pieces 0.09 x 0.09 x 1.78 m (3.5 x 3.5 x 70 in). These sprinklered fires are significant because they produced high levels of CO (up to 2.5%). No commonly occurring fuel arrangements have been identified in office buildings that would be expected to have burning characteristics like the fires of Mawhinney and Tamura. Further study is planned by Mawhinney concerning the extent of applicability of this kind of fire to various occupancies.

5. Future Direction

The application of elevator evacuation for the disabled population only is much simpler than for the general population and is the next logical step. Such an application could consist of modifying an existing building or incorporating elevator evacuation into a new design. Such a project would need the sincere cooperation of owners, designers, contractors, code officials, and the fire service. Additional information about water protection is needed, and research about water protection could be part of the project. The design of the project should include the input of human behavior experts, and human behavior tests of the system during fire drills is needed to ensure that people can use the system. Acceptance tests are needed to determine that the system physically performs as envisioned. Based on what is learned in this step, an application for the general population could follow.

6. Summary

Elevator evacuation systems need to be protected from fire, heat, smoke, water damage, and loss of electric power.

The computer program, ELVAC, was developed to calculate the evacuation time by elevators during a fire drill. This program can provide information about the relative benefits of different elevator evacuation systems, but the flow in ELVAC is much less complicated than that which occurs during fires. Research is needed concerning analysis of the complex people movement using elevators during fire.

Of all the engineering considerations about elevator evacuation, the most significant is the potential for water damage to elevator system components inside the hoistway. While it is possible to build elevators that operate with water in the hoistway, maintenance of these systems is a concern. Floor drains and sloped floors can be used to prevent water from reaching the hoistway, but these approaches have architectural limitations. Further research is needed concerning the water problem.

Smoke control systems for elevator evacuation systems and for AORs connected to elevators or stairs can be either direct or indirect pressurization as shown in figure 1. The direct system has the added expense of an air distribution duct and possibly a duct shaft including a corresponding loss of usable floor area. The computer program, ASCOS, can be used to design many different types of smoke control systems to overcome the pressure fluctuations due to the wind and doors opening and closing.

The transient pressures produced when an elevator car moves in a shaft are a concern for elevator smoke control. Such piston effect can pull smoke into a normally pressurized elevator lobby or hoistway. Equation (2) can be used to determine a level of pressurization above which piston effect will not be a problem. The application of elevator evacuation for the disabled population only is much simpler than for the general population and is the next logical step.

For the six buildings of the GSA study, AORs can be either a haven or a hazard, and in many cases the persons most needing the AOR protection may be unable to reach that area before their pathways (corridor or aisle ways) become lethal. Further, for these buildings, the operation of a properly designed sprinkler system eliminates the life threat to all occupants regardless of their individual abilities and can provide superior protection for people with disabilities as compared to AORs. The methods of this study have application to AORs and elevator lobbies in other buildings.

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Table 1. Description of protection approach in GSA buildings

Building	Sprinklers[1]	Stories[2]	Base-ments[3]	Comments
VA	QR	14	3	Two rooms were made into AORs on each basement level, and horizontal separation is used on floors 2-11
Pension	AS[4]	5	1	Rooms near stairs were made into AORs.
Whipple	AS	8	1	Service elevator lobbies were made into AORs.
Toledo	NS	8	1	Passenger elevator lobbies were made into AORs.
Bemidji	NS	5	1	Section of corridor were made into AORs.
Cohen	NS	6	1	A room was made into an AOR in the basement, and horizontal separation is used on floors 2-5.

[1]QR indicates the building is sprinklered with quick response sprinklers, AS indicates the building is sprinklered with standard sprinklers, and NS indicates the building is not sprinklered.
[2]This is the total number of stories including basements.
[3]This is the number of basement levels.
[4]As in offices and walkways but not in atrium

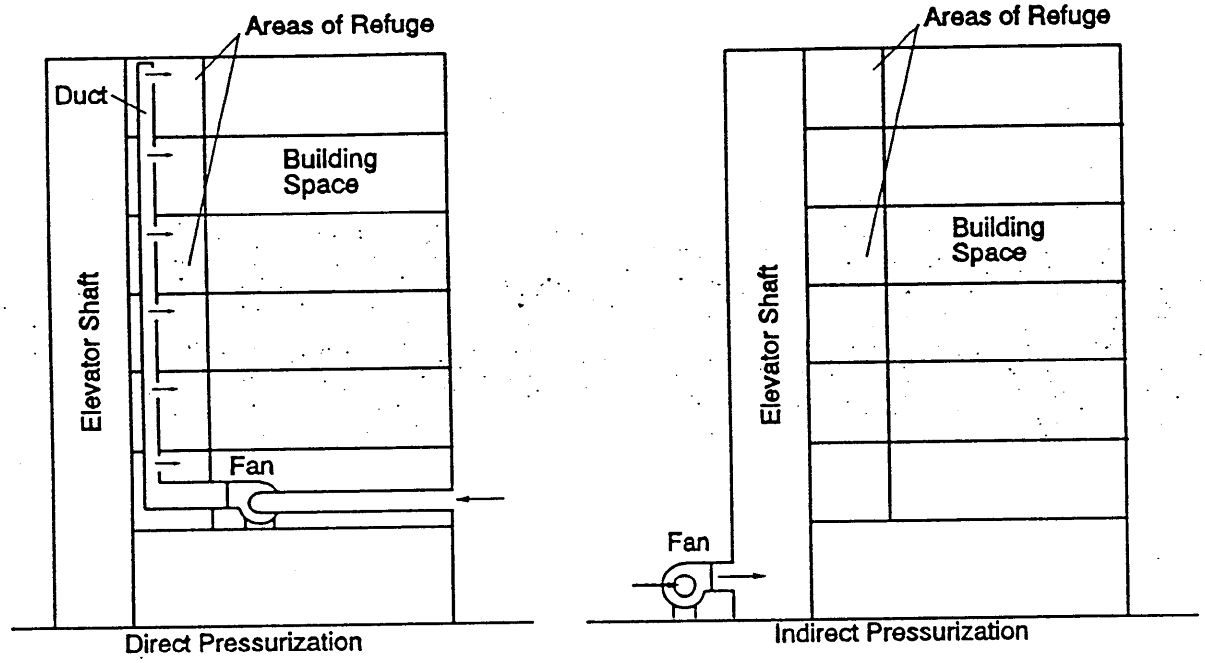

Figure 1. Direct and indirect smoke control systems for AORs and elevator evacuation.

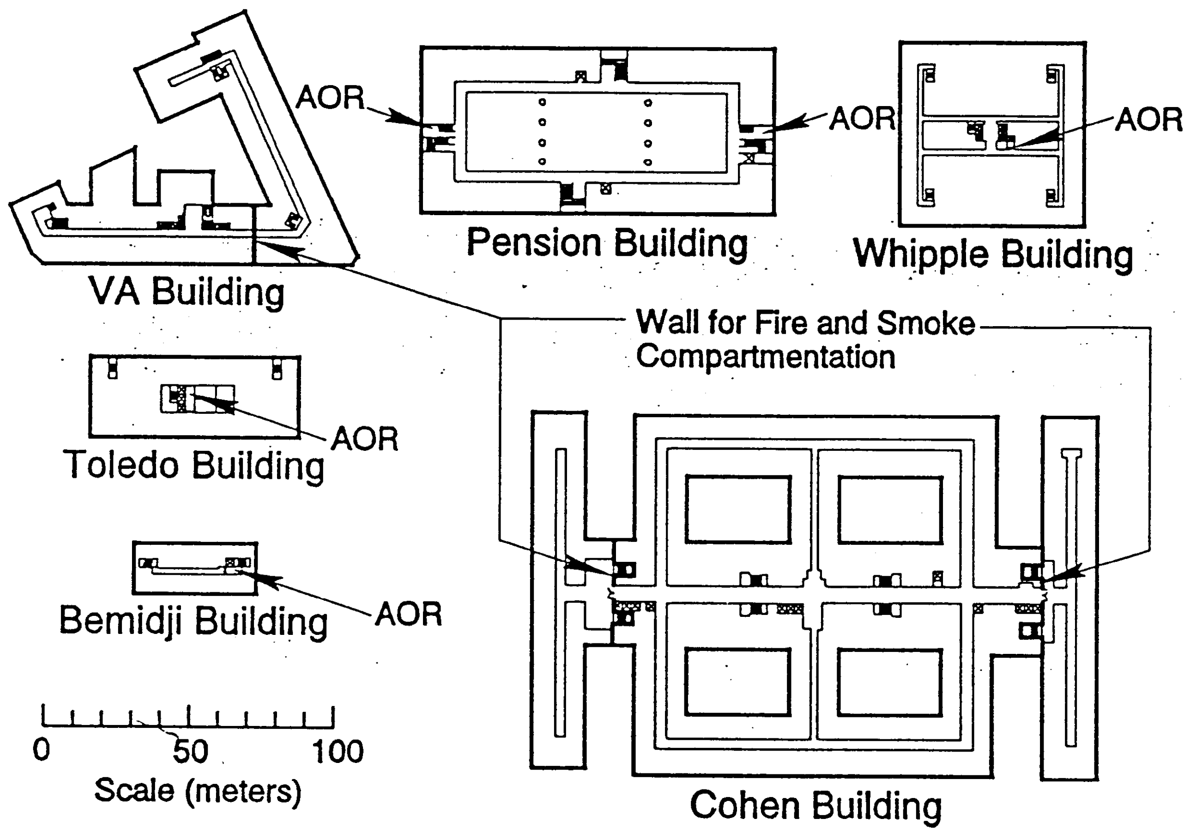

Figure 2. Typical floor plans of the buildings retrofitted with horizontal separation and AORs.

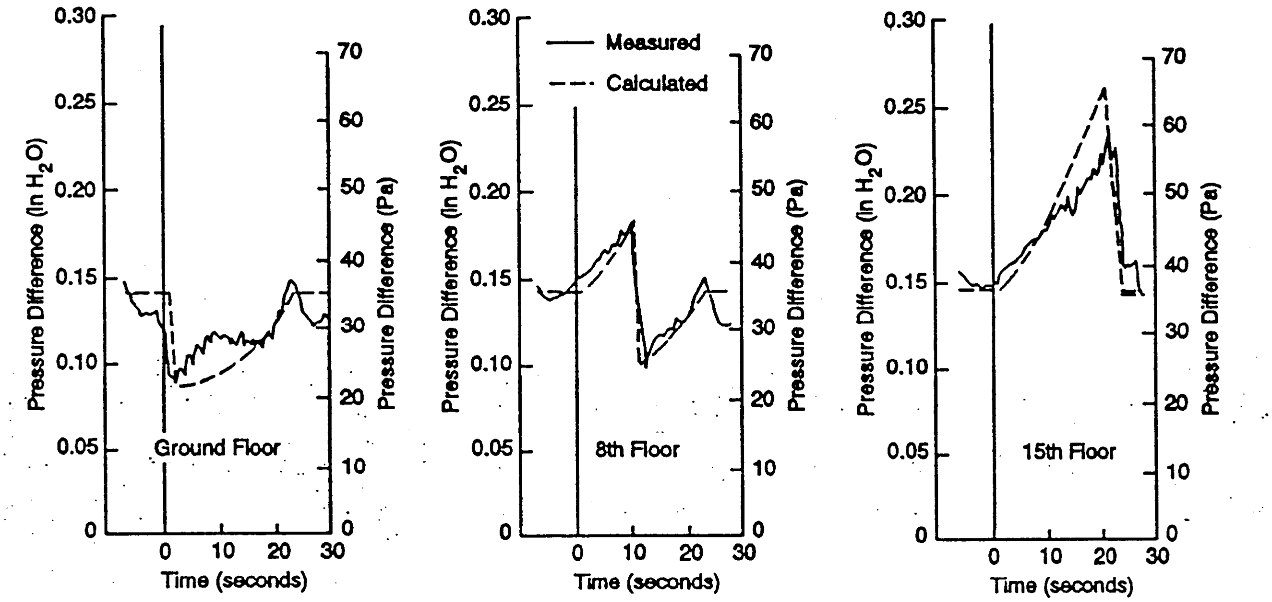

Figure 3. Comparison of measured and calculated pressure differences due to the piston effect of an ascending car.

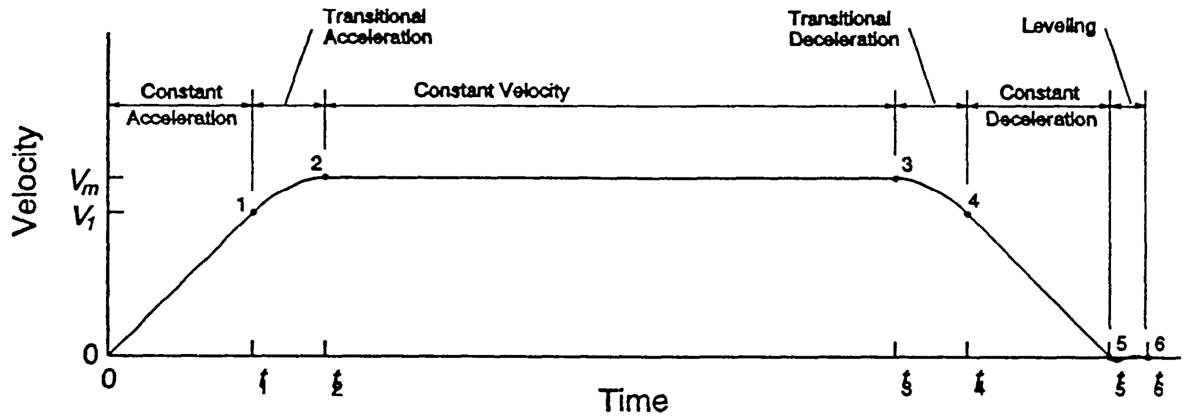

Figure 4. Motion of elevator car reaching constant velocity.