International Journal of High-Rise Buildings
December 2013, Vol 2, No 4, 341-344

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

Elevator Pressurization in Tall Buildings

John H. Klote†

Smoke and Fire Consulting, 19355 Cypress Ridge Terrace, Leesburg, VA 20176, USA

Abstract

During a building fire, smoke can flow through elevator shafts threatening life on floors remote from the fire. Many buildings have pressurized elevators intended to prevent such smoke flow. The computer program, CONTAM, can be used to analyze the performance of pressurization smoke control systems. The design of pressurized elevators can be challenging for the following reasons: (1) often the building envelope is not capable of effectively handling the large airflow resulting from elevator pressurization, (2) open elevator doors on the ground floor tend to increase the flow from the elevator shaft at the ground floor, and (3) open exterior doors on the ground floor can cause excessive pressure differences across the elevator shaft at the ground floor. To meet these challenges, the following systems have been developed: (1) exterior vent (EV) system, (2) floor exhaust (FE) system, and ground floor lobby (GFL) system.

Keywords: Elevator pressurization, Network modeling, Smoke control, Stairwell pressurization, Tall buildings

During a building fire, smoke can flow through elevator shafts threatening life on floors remote from the fire. To prevent such smoke flow, many buildings have pressurized elevators or enclosed elevator lobbies, but enclosed elevator lobbies are not discussed in this article.

The focus of this article is design of pressurized elevators for tall buildings. The design of pressurized elevators can be a challenge and it can be more challenging in buildings that also have pressurized stairwells. This article gives the reasons for this and describes kinds of elevator pressurization systems that can overcome these challenges. For extensive information about smoke control, see the Handbook Smoke Control Engineering (Klote et al. 2012). Chapter 11 of this handbook is about elevator pressurization, but this chapter does not address tall buildings.

Design Analysis

Network analysis models are often used for design analysis of pressurization smoke control systems. CONTAM (Walton and Dols 2005) is a network model that was developed primarily for indoor air quality, but it has been so extensively used for analysis of pressurization smoke control systems that it has become the de facto standard. This article discusses CONTAM, but it should be recognized that analysis with another network model is possible. In CONTAM, a building is represented as a network of spaces connected by flow paths such as gaps around closed doors, open doors, and cracks and holes in construction. CONTAM is capable of simulating the pressures and flows throughout very large and complex buildings. Because CONTAM is a product of the US National Institute of Standards and Technology, it can be downloaded at no cost (www.bfrl.nist.gov/IAQanalysis/CONTAM/download.htm). For specific information about using CONTAM for smoke control applications see Chapter 14 of the Handbook Smoke Control Engineering.

The primary purpose of CONTAM simulations is to determine if a particular smoke control system in a particular building is capable of being balanced such that it will perform as intended. A secondary purpose is to provide information to help size the system components such as supply fans, exhaust fans, and vents. Design analysis of elevator pressurization needs to include any other pressurization systems operating together as they would during a building fire.

The flows in CONTAM are calculated as $m = CA(2\rho \Delta p)^{1/2}$ where m is the mass flow through the path (kg/s), C is the flow coefficient (dimensionless), A is the flow area (m^2), Δp is the pressure difference across path (Pa), and ρ is the gas density in path (kg/m^3). The user inputs values of C and A for flow paths, and the CONTAM calculates the pressure differences and the flows. Table 1 lists values of C and A for doors. The flow areas are relatively leaky so that calculated supply air would be conservatively large, but other values may be appropriate for some projects.

Table 2 lists some values of C and A for some other flow paths with various leakage classifications. An engineer cannot exactly know the flow areas in a particular building, but an educated guess can be made that allows CONTAM simulations to determine if a specific smoke

†Corresponding author: John H. Klote
Tel: +571-258-0355; Fax: +
E-mail: jklote1111@aol.com

Table 1. Flow coefficients and flow areas of doors

Flow Path	Flow Coefficient	Flow Area[1] (m^2)
Single door (closed)	0.65	0.023
Single door (opened)	0.35	2.0
Double door (closed)	0.65	0.045
Double door (opened)	0.35	3.9
Elevator door (closed)	0.65	0.06
Elevator door (opened)	0.65	0.56

[1]Relatively leaky flow areas for closed doors were chosen so that calculated supply air would be conservatively large.

Table 2. Flow areas and flow coefficients of leakage paths

Flow Path	Leakage Classification	Flow Coefficient	Flow Area (m^2 per m^2)*
Walls	Tight	0.65	0.50×10^{-4}
	Average		0.17×10^{-3}
	Loose		0.35×10^{-3}
	Very Loose		0.12×10^{-2}
Floor (or roof)	Tight	0.65	0.66×10^{-5}
	Average		0.52×10^{-4}
	Loose		0.17×10^{-3}
			(m^2 per m)**
Curtain wall gap	Tight	0.65	0.00061
	Loose		0.0061

*This is m^2 of leakage per m^2 of wall, floor, or roof.
**This is m^2 of leakage per m length of curtain wall gap.

Table 3. IBC Pressure difference criteria

System	Minimum Δp (Pa)	Maximum Δp (Pa)
Pressurized Elevators	25	62
Pressurized Stairwells	25	87

control system in the building is capable of being balanced such that it will maintain acceptable pressurization. For more information about flow areas and flow coefficients, see Chapter 3 of the Handbook of Smoke Control Engineering.

Acceptable pressurization of elevator and stairwell pressurization systems happens when the pressure differences from the elevator shaft to the lobby are between minimum and maximum pressure differences, and the IBC requirements for these pressure differences are listed in Table 3.

Outdoor temperature and wind data are needed for the design and analysis of smoke control systems, and Chapter 2 of the Handbook Smoke Control Engineering provides such data and barometric pressures for 1663 locations throughout the world. Temperature and pressure decrease with altitude above sea level as described in the U.S. Standard Atmosphere (NASA 1976) (Fig. 1). For analysis of smoke control systems for tall buildings, a feature in CONTAM can be used to account for density to decrease

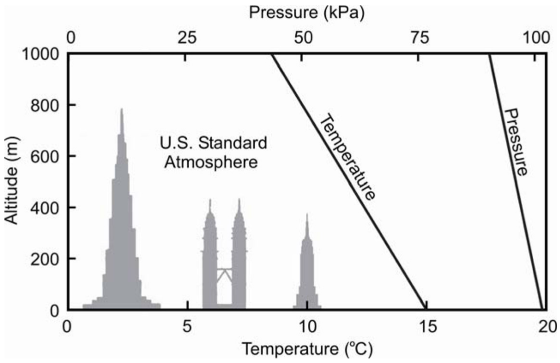

Figure 1. The US Standard Atmosphere shows temperature and pressure decreasing with altitude.

with (see "Simulation - Airflow Numerics Properties of the help or user manual).

Shaft Temperature

Elevator equipment has a typical range of operating temperature. Often there is no effort to maintain this temperature for passenger elevators during building fires, because the elevators are taken out of service. In some locations the elevator equipment may need to be maintained to give the fire service the option of using elevators during building fires.

Often supply air to elevator shafts is untreated such that the temperature in pressurized shafts is close to the outside temperature. The use of untreated air has the benefit on minimizing the adverse impact of stack effect. The shaft temperature can be expressed as $T_S = T_O + \eta(T_B - T_O)$ where T_S is the temperature in the shaft, T_O is the temperature outdoors, T_B is the temperature in the building, and η is a dimensionless heat transfer factor. As with pressurized stairwells, there has been little research conducted on the heat transfer factor for elevator shafts. For supply air that is conditioned to the building temperature, the heat transfer factor is one. For untreated supply air, a heat transfer factor of 0.15 is suggested as being conservative regarding the impact of stack effect.

The following discussions are specifically for systems that use untreated supply air, and it is recommended that systems that use treated supply air be analyzed with CONTAM.

Elevator Piston Effect

The motion of an elevator car causes transient pressures that are called elevator piston effect, and elevator pressurization systems should be designed so that this piston effect does not adversely impact the system performance.

An analysis of piston effect was developed and verified with experimental data by Klote (1988). Fig. 2 shows the pressure differences due to piston effect of an ascending elevator car in a 15 story building. From this figure it can

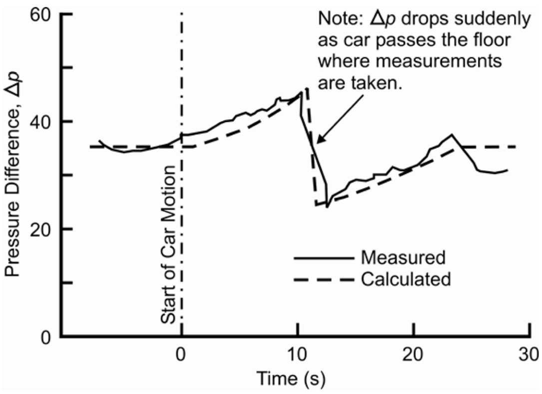

Figure 2. Pressure differences due to piston effect of an ascending elevator car.

be seen that the pressure difference dropped suddenly as the car passes the eighth floor where measurements were taken. For elevators in multiple car shafts with car velocities less than 5 m/s, piston effect should not adversely impact the performance of elevator pressurization. For elevators in single car shafts with car velocities less than 2.5 m/s, piston effect should not adversely impact the performance of elevator pressurization.

System Concepts

The simplest elevator pressurization systems consist of only providing pressurization air supplied to the elevator shaft at one or more locations. This kind of system is referred to as the basic system. Other elevator pressurization systems discussed below are: exterior vent (EV) system, floor exhaust (FE) system, and ground floor lobby (GFL) system. Regardless of the system used, any vent to the outdoors at the top of the elevator shaft needs to be closed during elevator pressurization, or the impact of such an open vent must be accounted for in the calculation of supply air to the elevator.

The design of pressurized elevators can be challenging, and it can be more so for buildings that also have pressurized stairwells. Typically pressurized elevators require three or four times as much supply air pressurized stairwells. The reasons for these challenges are: (1) often the building envelope is not capable of effectively handling the large airflow resulting from elevator pressurization, (2) open elevator doors on the ground floor tend to increase the flow from the elevator shaft at the ground floor, and (3) open exterior doors on the ground floor can cause excessive pressure differences across the elevator shaft at the ground floor.

In most large cities, the fire service props open exterior doors when they get to a fire to speed up mobilization, and the International Building Code (IBC) (ICC 2012) considers that elevator pressurization is with open exterior doors. Occupants also open some exterior doors during evacuation. In this article, it is considered that elevator pressurization needs to operate with a number of exterior doors open. If the system cannot also operate as intended with all exterior doors closed, some of these doors may need to open automatically before the elevators are pressurized. At locations where the fire service does not prop open exterior doors, a different approach to open exterior doors may be appropriate.

Basic System

For the basic system, the building envelope often is not capable of effectively handling the large airflow resulting from both elevator and stairwell pressurization. This can result in unacceptable pressure difference at lower floors as shown in Fig. 3. In this figure, acceptable pressurization was only achieved with very leaky exterior walls. However for some buildings it may be possible to achieve acceptable pressurization with other exterior walls, but this should be evaluated with a CONTAM analysis.

Exterior Vent (EV) System

The idea of the EV system is to increase the leakage of the building such that successful pressurization can be achieved. For an open plan office building, this can be done by the use of vents in the exterior walls. These vents open automatically on activation of the elevator pressurization system so that the pressure differences become similar to those of the building with very leaky exterior walls (Fig. 3). These vents need to be large enough so that successful pressurization will be achieved. The vents need to be larger on transfer floors than on other floors.

For a building that is not open plan, the EV system needs unobstructed flow paths to the outdoors. These flow paths can consist of ducts above a suspended ceiling from the elevator lobby to vents located in exterior walls. Duct penetrations of a fire rated wall may have fire resistance requirements depending on code requirements.

To minimize the impact of the wind, the vents in exterior walls should be located on four sides of the building. The supply intakes need to be located away from the vents to minimize the potential for smoke feedback into

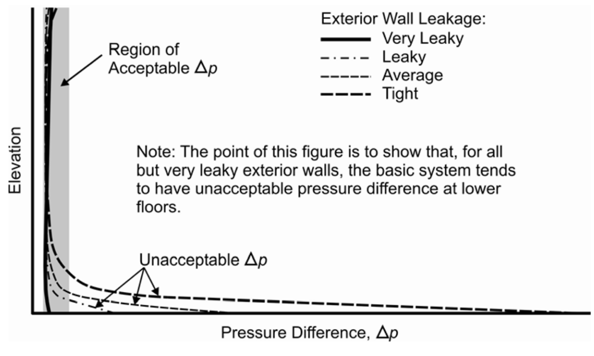

Figure 3. Typical pressure differences across elevator shaft for a basic pressurization system.

the supply air. These vents may need fire dampers depending on code requirements.

The pressurization air per floor needed for a shaft in a building with the EV system can be estimated as

$$V = (1+\eta)CA_{EL}\sqrt{\frac{2\Delta p_{EL}}{\rho}} \qquad (1)$$

V = pressurization airflow to elevator shaft per floor (m^3/s),

C = flow coefficient, dimensionless,

η = factor for other elevator shaft leakage (dimensionless),

A_{EL} = flow area of all elevator doors on the floor (m^2),

Δp_{EL} = pressure difference from elevator shaft to lobby (Pa),

ρ = gas density in path (kg/m^3)

For the EV system, the pressure difference from elevator shaft to lobby, Δp_{EL}, is larger than the minimum pressure difference but less than the maximum pressure difference. The factor for other elevator shaft leakage, η, depends on the specific shaft design, construction materials, and quality of workmanship. A value of $\eta = 0.15$ seems to be a reasonable allowance.

For example, consider a 27 story building with four elevator shafts that serve all floors. Each shaft has four elevator cars. The flow area of an open elevator door is 0.56 m^2, and that of a closed elevator door is 0.06 m^2. The elevators are open on the ground floor, and $A_{EL} = 4(0.56) = 2.24\ m^2$. On floors 2 to 27, the elevator doors are closed, and $A_{EL} = 4(0.06) = 0.24\ m^2$. The other parameters are $C = 0.65$, $\eta = 0.12$, $\Delta p_{EL} = 35$ Pa, $\rho = 1.2\ kg/m^3$. For the ground floor, $V = 12.5\ m^3/s$ of supply air. For the other floors, $V = 1.33\ m^3/s$. The estimated supply air to each of the four elevator shafts is $12.5 + 26(1.33) = 47\ m^3/s$.

Floor Exhaust (FE) System

The FE system deals with the building envelope issue by reducing the amount of supply air used. In the FE system, a relatively small amount of air is supplied to the elevator shafts, and the fire floor is exhausted such that acceptable pressurization is maintained on the fire floor where it is needed. It is common to also exhaust one or two floors above and below the fire floor. Fig. 4 shows pressure differences across an elevator shaft for a floor exhaust (FE) pressurization system. Because the FE system only maintains pressurization at some floors, it may need to be approved by the authority having jurisdiction.

The exhaust can be through a shaft with a fan located in a mechanical floor or on the roof, and dampers between the shaft and the floors are closed on all floors when the system is not operating. On system activation, the dampers open on the floors to be exhausted. The exhaust inlet needs to be in the elevator lobby or a space open to the elevator lobby. The outlet of the exhaust fan needs to be located away from the inlets of the supply fans to minimize the potential for smoke feedback into supply air.

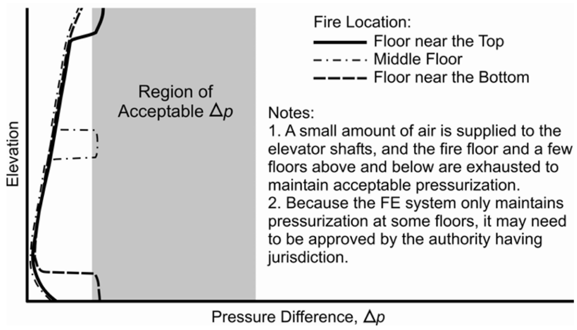

Figure 4. Typical pressure differences across elevator shaft for a floor exhaust (FE) pressurization system.

Ground Floor Lobby (GFL) System

This system has an enclosed elevator lobby on the ground floor, but the other floors do not have any enclosed elevator lobbies. This system is the complete opposite of the normal practice of having enclosed elevator lobbies on all floors except the ground floor, but it has the potential for successful elevator pressurization.

An enclosed elevator lobby can reduce the pressure differences across the lower floors of the elevator shaft. The GFL system often has a vent between the enclosed ground floor lobby and the building with the intent of preventing excessive pressure differences across the lobby doors. The lobby doors are the doors between the enclosed lobby and the building.

The pressure difference across the lobby door and the elevator door depend on the area of the vent, and this vent needs to be adjustable to allow for balancing during commissioning. The flow area between floors (floor leakage and curtain wall gap) is especially important for the performance of the GFL system.

References

ICC. (2012). International Building Code, International Code Council, Country Club Hills, IL.

Klote, J. H., et al. (2012). Handbook of Smoke Control Engineering. ASHRAE, Atlanta, GA.

Klote, J. H. (1988). An analysis of the influence of piston effect on elevator smoke control. NBSIR-88-3751. National Bureau of Standards, Gaithersburg, MD.

NASA. (1976). U.S. Standard Atmosphere, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and the United States Air Force. Avaliable from the National Geophysical Data Center, Bolder CO.

Walton, G. N. and Dols, W. S. (2005). CONTAM 2.4 User Guide and Program Documentation, NISTIR 7251, Revised December 14, 2010. National Institute of Standards and Technology, Gaithersburg, MD.