In a highrise building fire, smoke causes the maximum damage

An Overview of Pressurization Smoke Control

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Introduction

Smoke is recognized as the major killer in building fires, and smoke control systems can provide significant protection from smoke. The physical mechanisms that can be used to control smoke in a building fire are compartmentation, pressurization, dilution, airflow, and buoyancy. A smoke control system is an engineered system that includes any or all of these mechanisms to modify smoke movement.

The primary purpose of smoke control systems is to maintain tenable environment in means of egress. Smoke control systems can also reduce smoke movement beyond the fire area, provide conditions to help fire service, reduce property damage, and aid in post-fire smoke removal.

This article provides general information about stair pressurization, elevator pressurization, and zoned smoke control. More complete information is provided in a new smoke control handbook published by ASHRAE[1].

Pressure Differences

Figure 1 shows a pressure profile of a pressurized stairwell in an air conditioned building in summer, and it can be seen that there is a tendency for larger pressure differences on lower floors and smaller ones on higher floors. There is an opposite tendency in winter. Smoke control systems operate over a range of pressure differences, and some common pressure difference criteria are

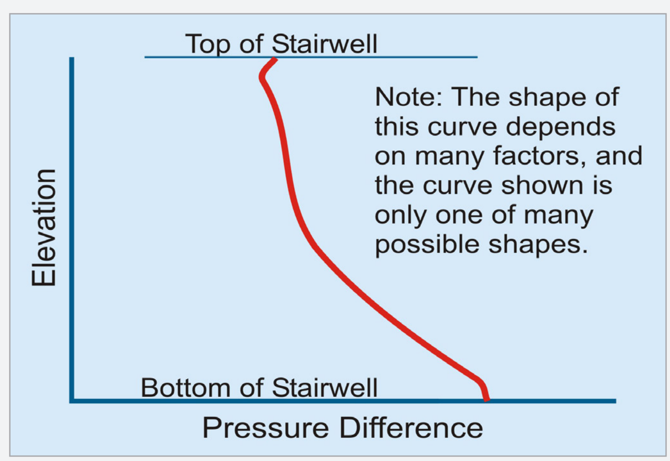

Figure 1: Pressure profile for a pressurized stairwell in summer

About the Author

Dr. John Klote is well known as an expert in smoke control due to his many books on the topic and his 19 years of fire research conducted at the U. S. National Institute of Standards and Technology (NIST) in Maryland, USA. After leaving NIST in 1996, John has worked as a consultant on smoke control systems. John teaches about smoke control for ASHRAE and the Society of Fire Protection Engineers. He is one of the authors of the Handbook of Smoke Control Engineering and six other books on the subject. John has authored over 80 papers. He is a member and past chair of *ASHRAE TC 5.6 Fire and Smoke Control Committee*, and is a member of *NFPA Smoke Management Committee*.

*Table 1: Some common pressure differences criteria for pressurized elevators and stairwells**

System	Minimum (Pa)	Maximum (Pa)
Pressurized elevators	25	62
Pressurized stairwells	25	87

**These criteria are consistent with requirements of the IBC, and some localities may have different criteria.*

listed in *Table 1*. The minimum pressure difference criteria are intended to prevent smoke flow into protected spaces. The maximum pressure difference criteria for stairwells are intended to prevent excessive door opening forces. The maximum pressure difference criterion for elevators is intended to prevent the elevator doors from jamming closed.

Network Modeling

The network model, CONTAM[2], is often used for design analysis of pressurization smoke control systems. CONTAM simulates the flows and pressures throughout a building taking into account wind, any pressurization systems, and the inside and outside temperatures. Because CONTAM has a sophisticated graphic interface and superior numerical routines, it has become the *de facto* standard for analysis of pressurization smoke control systems. CONTAM was developed by the US National Institute of Standards and Technology (NIST), and can be downloaded at no cost from *www.bfrl.nist.gov/IAQanalysis/CONTAM*.

The primary purpose of a CONTAM analysis is to determine if a particular smoke control system is capable of being balanced such that it will perform as intended. A secondary purpose is to size pressurization and exhaust fans. For some systems in simple buildings, a designer may know from experience that a system is capable of being balanced as intended, and a CONTAM analysis is not necessary. Designers can size fans using algebraic equations. Alternatively, a designer can size fans using a rule of thumb based on experience with a similar system in a similar building.

Stairwell Pressurization

Stairwells are often pressurized with the intent of keeping smoke out of the stairs during a building fire. A single injection system has pressurization air supplied at one location. *Figure 2a* shows a single injection pressurized stairwell with a top mounted centrifugal fan. The fan can be located elsewhere, and other kinds of fans can be used. Wall mounted propeller fans are not recommended because the wind can adversely impact fan performance. The exception is when an engineering analysis shows that the performance of a pressurized stairwell with wall mounted fans is not adversely impacted by the wind.

For a single injection system with the fan located at the bottom, some of the supply air can short circuit the system by flowing directly out the opened exterior doorway reducing system effectiveness. Generally, it is suggested that the air can be introduced into the stairwell at least one floor above or below the exterior doors to minimize this problem.

For tall stairwells single injection systems can fail when a few doors near the air injection point are open. Much of the pressurization air can be lost through these open doors, and the system can then fail to maintain acceptable pressurization. To reduce the potential for such failure, multiple injection systems are used. Multiple injection systems can consist of one fan supplying air through a duct located in a shaft *(Figure 2b)*, and multiple injection systems can eliminate the shaft and much of the duct by using more than one fan *(Figure 2c)*. There has been no research on this subject, but the consensus is that single injection systems for stairwell heights more than 30.5m need a design analysis using CONTAM.

Stairwells with Open Doors

When any stair door is opened in a simple stairwell pressurization system, the pressure difference drops significantly. A compensated stairwell pressurization system is one that adjusts for opening and closing of doors with the intent of minimizing such pressure drops. Considering that any smoke that leaks into a pressurized stairwell will be diluted by the pressurization air, some professionals believe that the benefits of these compensated systems are not worth the added system complexity and expense. These compensated systems are not required by the *International Building Code* (IBC)[3], but they are included in the NFPA *Standard for Smoke Control Systems*[4].

The most commonly used compensated systems are the Canadian system and variable air volume (VAV) system. As the name implies, the Canadian system originated in Canada. With this system, the exterior stairwell door is automatically opened before the pressurization fan is activated. By eliminating opening and closing of the exterior stairwell door, the Canadian system eliminates the major cause of pressure fluctuations. This system is simple and relatively inexpensive, but there are many locations where opening exterior doors automatically raises issues of building security.

With the VAV system, the flow rate of supply air to the stairwell is adjusted by a VAV fan to account for opening and closing of doors. With the VAV system, the flow of supply air to the stairwell is controlled by one or more static pressure sensors that

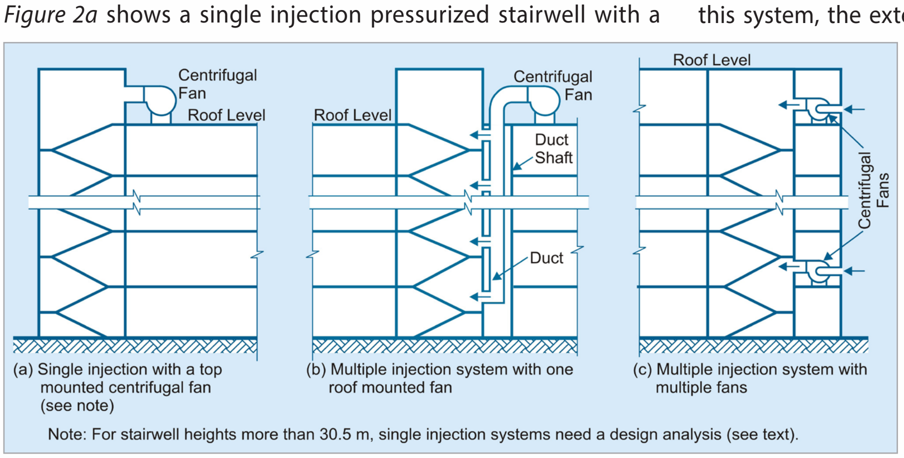

Figure 2: Single and multiple injection stairwell pressurization systems

sense the pressure difference from the stairwell to the building.

Experiments on these VAV systems were conducted at the National Research Council of Canada[5]. After a door was opened, it took from 3 to 7 minutes for the pressure to recover to the initial value. When only one door was open, closing it caused a pressure spike of 181Pa. This spike lasted only about 30 or 40 seconds, but the peak was much more than any reasonable maximum design pressure difference. This peak is a concern. A person encountering such a spike, would probably not be able to open the stair door, but they could open it a minute or so later provided they knew enough to try. *It is possible that a person encountering such a spike would think the stair door was locked, and he or she might not try to open it again.*

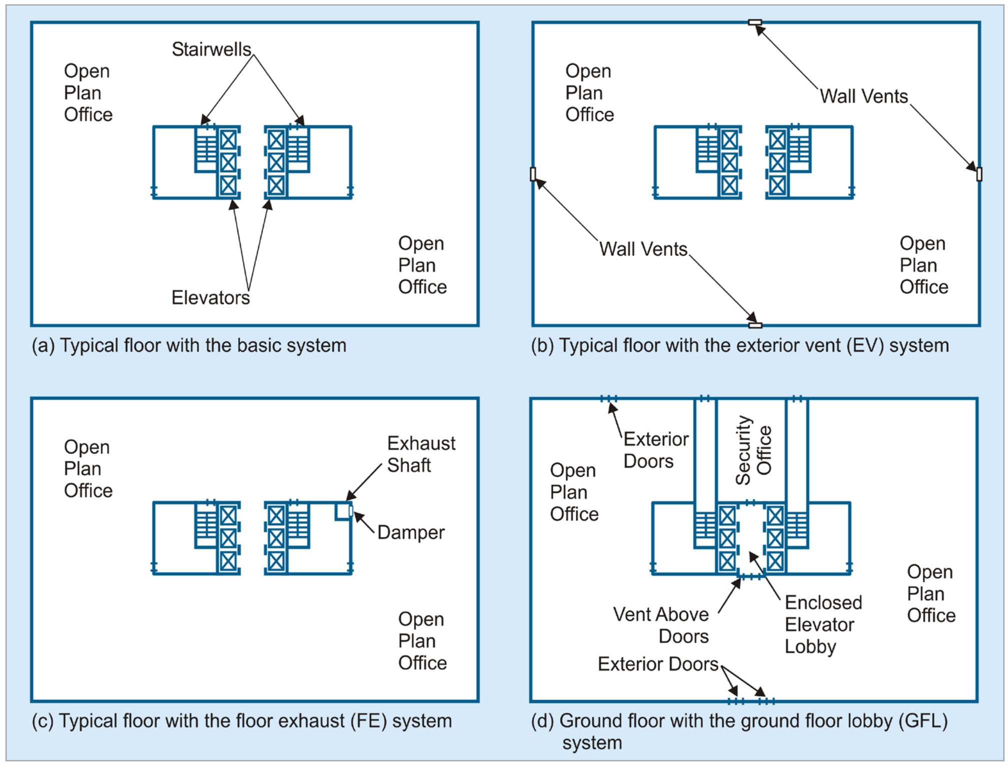

Figure 3: Elevator pressurization systems in the example building

With the exterior stairwell door open in some building designs, wind can cause a VAV system to produce pressure differences that may exceed the maximum criterion by as much as 100%. For this reason, it is recommended that design analysis of a VAV compensated stairwell pressurization systems include CONTAM simulations under wind conditions.

Pressurized Elevators

The elevator pressurization systems discussed here are intended to prevent smoke from flowing through an elevator shaft and threatening life on floors remote from the fire. Smoke control for emergency elevator evacuation is not discussed here, but it is discussed in Chapter 12 of the new smoke control handbook[1].

The elevator pressurization systems discussed here are: (1) the basic system, (2) the exterior vent (EV) system, (3) the floor exhaust (FE) system, and (4) the ground floor lobby (GFL) system. For a 14 storey example office building with an open floor plan, these systems are illustrated in *Figure 3*. The brief discussion that follows is based on CONTAM simulations of these systems in the example building. For more complete information, see Chapter 11 of the new smoke control handbook[1].

Elevator pressurization systems need much more supply air than is needed for pressurized stairwells, and this means that the leakage of the building is especially important with elevator pressurization. The classification of exterior wall leakage is tight, average, loose and extra loose, and the new smoke control handbook[1] has information about the leakage of these walls and other building components.

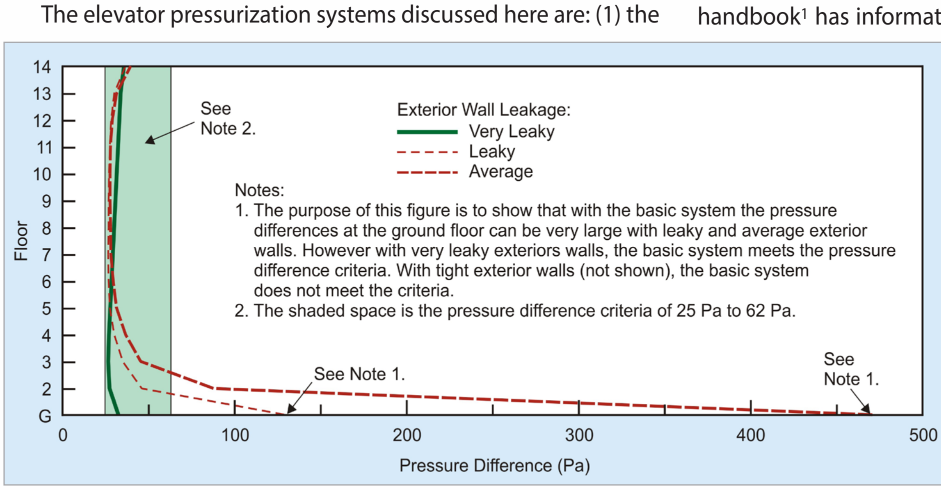

Figure 4: Elevator pressure differences for basic system in the example building

Basic System

In the basic system *(Figure 3a)*, each stairwell and elevator shaft has one or more dedicated fans that supply pressurization air. For most buildings, the building envelope is not capable of effectively handling the large airflow from both the elevators and stairwells, and the basic system does not result in successful pressurization for most buildings. By successful pressurization it is meant that the pressure differences across the elevator shaft (or stairwell) are

continued on page 82

continued from page 80

within the design minimum and maximum values of *Table 1*.

For the basic system in the example building with average and leaky exterior walls, it can be seen from *Figure 4* that the pressure differences across the elevator shaft at the ground floor greatly exceed the maximum criterion. However, it also can be seen that with very leaky exteriors walls, the basic system is successfully pressurized. The air needed for successful pressurization is 13.1 m^3/s for each elevator shaft and 3.09 m^3/s for each stairwell.

It is expected that for some relatively leaky buildings, there may be enough wall leakage to accommodate the large amount of pressurization air needed for elevators, and successful pressurization may be possible with the basic system. This should be evaluated with a CONTAM analysis.

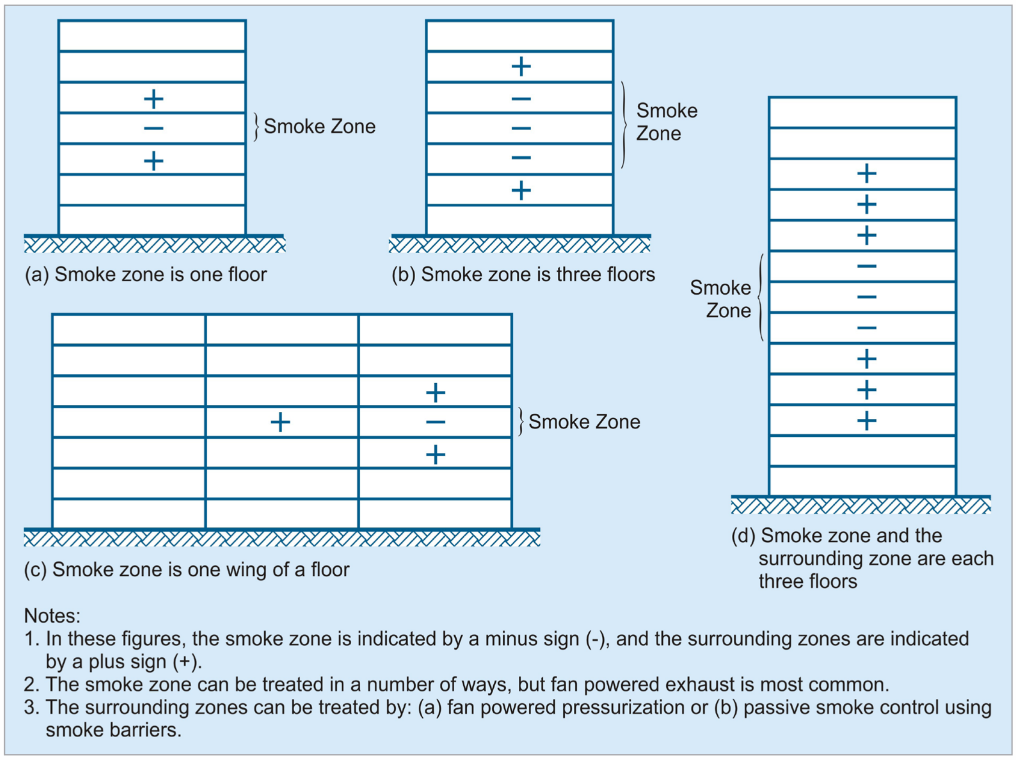

Figure 5: Smoke arrangements of smoke control zones

Exterior Vent (EV) System

The idea of this system is to increase the leakage of the building such that successful pressurization can be achieved. Because the example building is an open plan office building, this can be done by the use of vents in the exterior walls as shown in *Figure 3b*. For the example building with the EV system, the vents were sized so that successful pressurization was achieved with the same amount of pressurization air as was needed with the basic system.

For a building that is not open plan, the flow resistance of corridor walls and other walls can have a negative impact on system performance. This negative impact can be overcome by the use of ducts that act as paths for airflow from the elevator to the outdoors. These ducts can be located under the ceiling or above a suspended ceiling. The ducted EV system can be used for other occupancies such as hotels and condominiums. Duct penetrations of a fire rated wall may have fire resistance requirements depending on code requirements.

The vents should be located in a manner to minimize adverse wind effects, and the supply intakes need to be located away from the vents to minimize the potential for smoke feedback into the supply air. These vents may need fire dampers depending on code requirements.

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 stairwells, 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. Because the FE system only maintains pressurization at some floors, it needs to be approved by the code authorities.

For the example building, the FE system is shown in *Figure 3c*. Each elevator shaft needed 7.14 m^3/s, and each stairwell needed 1.79 m^3/s. The floor exhaust ranged from 2.28 to 2.55 m^3/s depending on the particular floor being exhausted. For a building with interior partitions, the exhaust should be from a space that is open to both the elevator lobby and the stairwell doors.

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. As can be seen from *Figure 4*, elevator pressurization systems have a tendency to produce very high pressure differences across the elevator doors at the ground floor, and an enclosed elevator lobby can reduce this pressure difference. The GFL system often has a vent between the enclosed 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 criteria of *Table 1* apply to the GFL system with some modifications because of the lobby doors on the ground floor. *Figure 3d* shows the ground floor of the example building with the GFL system. For the example building, the air supplied to the shafts was nearly the same as that needed for the basic system and the EV system. For the example building, the floor-to-floor leakage had an impact on the performance of a GFL system.

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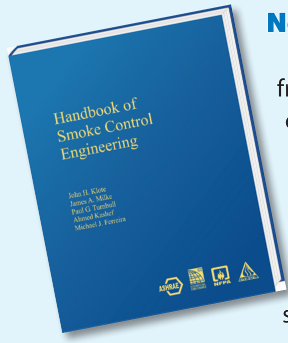

New ASHRAE Book Has Comprehensive Treatment of Smoke Control

A new handbook providing comprehensive treatment of smoke control technology is now available from ASHRAE. The Handbook of Smoke Control Engineering addresses fundamental concepts, smoke control systems and methods of analysis. The systems included are pressurized stairwells, pressurized elevator and zoned smoke control. The handbook is the first smoke control book to include chapters on fire and smoke control in transport tunnels as well as climatic data. This book is co-published by the Society of Fire Protection Engineers (SFPE), the International Code Council (ICC) and the National Fire Protection Association (NFPA). The book is in both SI units and traditional units, and includes many example calculations. Because the book addresses the principles of how smoke control systems function, it will be useful to engineers throughout the world.

Zoned Smoke Control

Smoke arrangements of smoke control zones are shown in *Figure 5*. The smoke zone is the zone where the fire is located, and the smoke zone can be treated in a number of ways, but fan powered exhaust is the most common. The methods that can be used for the zones surrounding the smoke zone are: (1) fan powered pressurization, or (2) passive smoke control using smoke barriers. Fan powered pressurization of the surrounding zones has a negative impact on stairwell pressurization that needs to be taken into account during design.

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