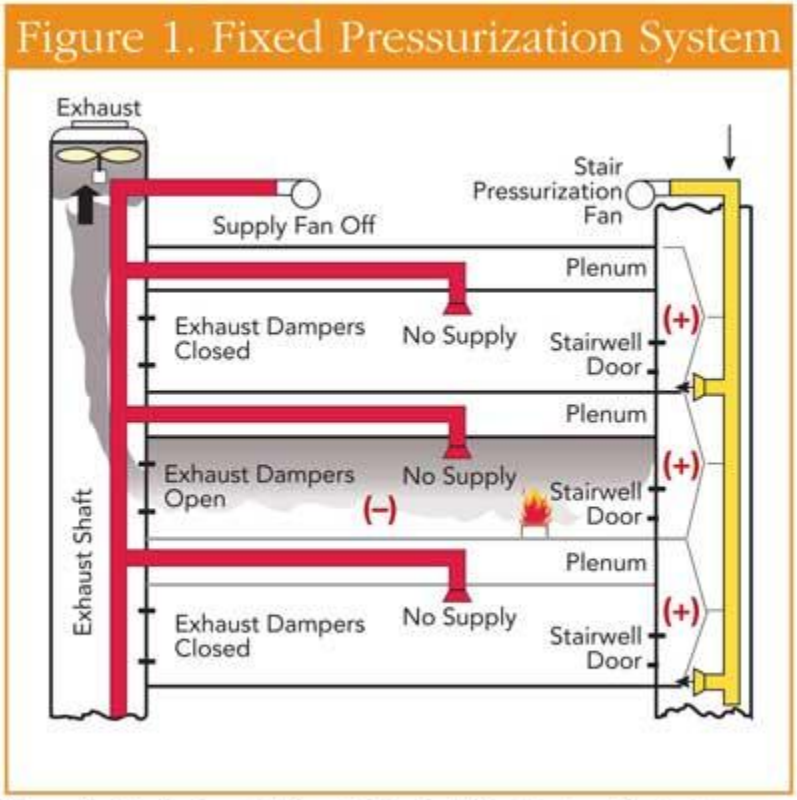
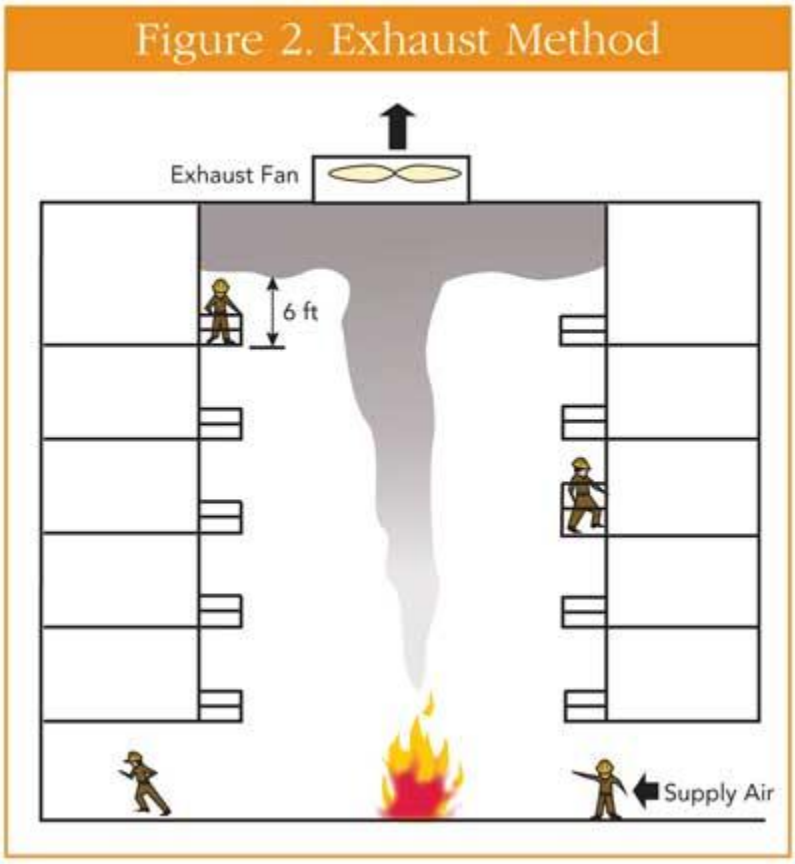
# Smoke Management in High-Rise Structures

Most modern building codes define a high-rise structure as a building greater than 75 feet in height from the lowest level of fire department vehicle access to the highest occupiable floor. When fires occur in high-rise structures, the responding firefighters are faced with many challenges. Because of the unique aspects of high-rise buildings, routine fire tactics, including ventilation, can become very difficult. Responding fire personnel must be familiar with fixed smoke management systems as well as options for positive-pressure ventilation (PPV) to ensure the safety and effectiveness of fireground operations.




Source for illustrations: National Institute of Standards and Technology.




The spread of smoke and toxic gas is recognized as a major hazard in all structure fires. In high-rise buildings, smoke can travel to locations remote from the fire through stairwells, elevator shafts, and other vertical openings. As smoke spreads to upper floors and through stairwells, visibility and toxicity become major concerns. Firefighting operations and evacuation can be complicated by smoke-filled stairways. Using both built-in or "fixed" smoke management systems and PPV can increase the survivability of occupants and effectiveness of firefighting operations.

# FIXED SMOKE MANAGEMENT SYSTEMS

Some modern high-rise structures are provided with fixed smoke management systems. These systems are designed to provide a tenable environment for safe egress for building occupants. As stated in the 2009 *International Building Code* (IBC) Section 909.1, these systems are not intended for assistance in fire suppression and overhaul activities. Although not designed for use in fire suppression and overhaul, fixed smoke control systems can be used in conjunction with other fireground tactics to effectively manage smoke, heat, and other products of combustion.

On the upper floors of a typical high-rise, most smoke management systems use the pressurization method of smoke control. In most cases, the system is designed to provide a negative pressure on the fire floor. This negative pressure is obtained by exhausting the corridor

(or major path of egress) on the fire floor. Activation of the smoke-control equipment is provided through a zoned sprinkler system, engineered smoke detection systems, or manual activation at the system's control panel.

The fixed smoke management systems also include positive pressurization of all stairwells that serve the high-rise portion of the structure. This positive pressure is obtained through mechanical fans that inject outside air into the stairwell. The purpose of maintaining the positive pressure differential in the stairwell is to keep the stairwell clear of smoke and toxic fumes that may migrate into the stairwell during a fire. Smoke can flow only from a higher pressure to a lower pressure. The fire creates its own pressure, and fans create a slightly higher pressure to control or stop the flow of smoke. Most fire alarm devices in the structure, including sprinkler waterflow alarms, smoke detectors, and heat detectors, will activate the stairwell pressurization fans, as well as manual activation at the system's control panel.

Another type of fixed smoke management system uses what is referred to as the "exhaust method" to manage smoke. This type of system is commonly used in covered malls, atria, or other large spaces. These systems are designed with the intent of maintaining the smoke layer a minimum of six feet above the highest walking surface. This is achieved by using large mechanical fans near the ceiling to exhaust smoke from the space. These systems also use mechanical fans to provide supply or "makeup" air.

# POSITIVE-PRESSURE VENTILATION

For the fire service to provide the same level of protection that a fixed stairwell pressurization system does, it requires thinking beyond the current PPV use of ventilating and examining the fan's ability to pressurize. When a structure is pressurized and a vent is provided, the PPV fan creates a residual pressure inside the structure that is higher, forcing the flow to the lower pressure outside. The increased pressure provided by the fan works with the increased pressure created by the fire and combines the natural and mechanical ventilation forces to speed up the ventilation process.

This same principle can be used to ventilate a stairwell or a hallway, but it leaves the section of the stairwell or hallway between the fire and the top of the stairwell or remainder of the hallway full of smoke and hot gases continually until no more smoke and hot gases are being supplied by the fire. The residual pressure provided by the PPV fan slows the amount of smoke coming into the area to be protected because there is less of a pressure gradient leading into this area, but smoke and hot gases are still entering this space. Fresh air forced in by the fan mixes with the smoke and hot gases as it travels past the fire and out of the vent. This dilutes the toxicity of the smoke and cools the hot gases but does not eliminate the problem of a contaminated stairwell or hallway.

PPV fans used without a vent are able to create an elevated static pressure. The static pressure can be used against the increased pressure created by the fire. The fire wants to naturally ventilate out of the fire floor or room and into the stairwell or hallway, which has a lower pressure. If the static pressure created by the fan is greater than the pressure created by the fire, then no smoke will flow into the stairwell or hallway.

# NIST RESEARCH

The Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST) conducted a wide range of experiments with PPV. These experiments included both laboratory and full-scale fire experiments in vacant high-rise buildings. NIST evaluated the ability of PPV fans to pressurize a high-rise stairwell to prevent the infiltration of smoke.

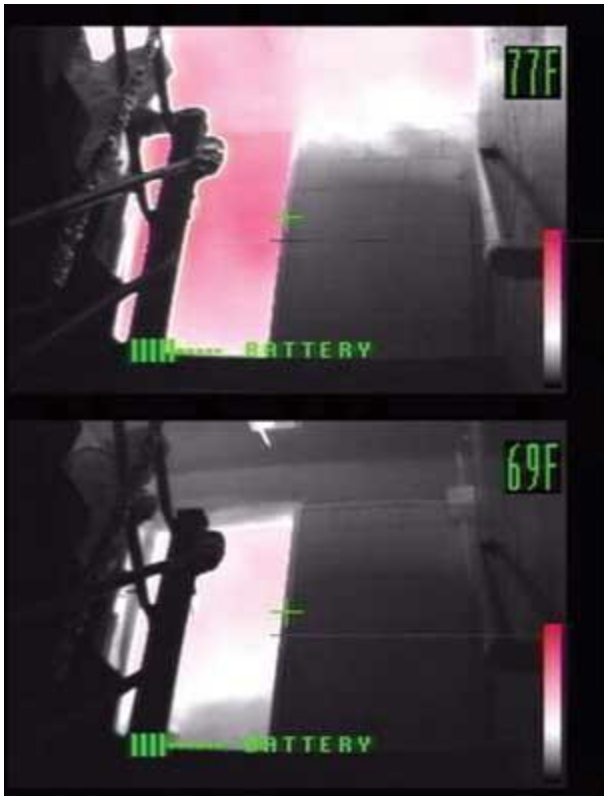
NIST evaluated many variables such as fan size, fan angle, setback distance, number of fans, orientation of fans, number of doors open, and location of vents open to determine the impact of each. Fans were oriented both in series and in parallel. Doors throughout the building were opened and closed to evaluate effects. NIST determined that PPV fans used correctly can help keep smoke out of the stairwell and provide a safe egress path for occupants and a safer environment for crews operating inside the structure.

The full-scale experiments demonstrated that to maximize the capability of PPV fans, the following guidelines should be followed:

- PPV fans should be placed four to six feet set back from doorways and angled at least 5° backward.
- Placing fans side by side in a V-shape is more effective than placing them in a series (photo 1).
- Opening interior stairwell doors reduces the desired impact of PPV. A significant increase in pressure could be achieved by closing the doorway to the width of a hoseline.
- When dealing with high-rise building fans, at least 24 inches are recommended because of the large volumes being pressurized.
- Carbon monoxide (CO) generation by the fans is minimal compared to the CO created by the fire.
- The taller the building, the more fans that may be needed. One fan at the base of a stairwell can create enough pressure to stop smoke spread from a well-developed fire in a 10-story building. Taller buildings require fans placed in the building. Placing the fan two floors below the fire floor in larger structures is a good rule of thumb.
- Fans should be set back and angled just as if they were positioned at an outside doorway.
- Placing a large trailer-mounted type fan at the base of the stairwell is another means of generating sufficient positive pressure into the stairwell.


(1) Fans placed in a series (top) and fans placed side by side (bottom). (Photo courtesy of NISTIR 7412.)

Temperatures in the stairwell were monitored using infrared (IR) cameras during the full-scale fire experiments conducted by NIST in a Chicago high-rise building. Photo 2 depicts thermal images from an IR camera that shows hot gases entering the stairwell through the open doorway. The image below shows conditions in the stairwell after the PPV fan was started. As shown through the IR camera, hot gases are no longer entering the stairwell.



(2) Thermal images from an IR camera.
(Photo courtesy of NISTIR 7468.)

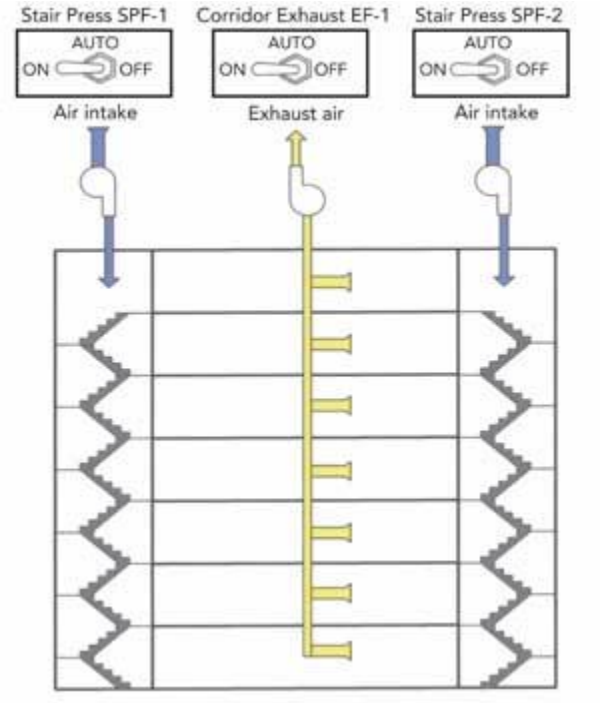
Using PPV fans to increase the pressure inside a stairwell requires a systematic and coordinated effort by the fire suppression crews. This method of PPV as well as fixed smoke management systems can provide a safe and tenable environment for interior crews to operate within the stairwell as well as create an atmosphere in which occupants can evacuate while firefighting operations are taking place. It is important to remember that PPV used to increase pressure in a stairway is a different tactic when compared to positive-pressure attack (PPA), which uses a fan at the back of the initial attack crew after ensuring an exhaust point has been established.

# PREPLANNING HIGH-RISE STRUCTURES FOR VENTILATION

Fire suppression personnel must be familiar with all the buildings in the areas to which they may be called to respond. Gathering preincident intelligence greatly improves firefighters' tactical capabilities. Familiarization with stairwell locations (including location of exit discharge to exterior), interior doorways, and fixed pressurization systems is imperative prior to using PPV. Some building features to identify during preplanning are the following:

- What is the method of smoke control—pressurization or exhaust?
- Are the stairs provided with automatic stairwell pressurization?
- What type of controls is available at the systems control panel for stairwell pressurization (Figure 3)?
- Do the stairs serving the high-rise portion of the building exit directly to the exterior?
- Can one fan or multiple fans be positioned at the ground-level entrance outside the structure?
- Where are the stairwell supply vents located? Do they have single or multiple-point injection?
- Where are the smoke exhaust vents located?

**Figure 3.** Smoke Control Panel with Automatic and Manual Fan Control



All stairwell pressurization systems are not the same. In southern Nevada, a local code amendment requires a controlled relief vent to discharge a minimum of 2,500 cubic feet per minute in the upper portion of the pressurized stairway. The purpose of this vent is to relieve excess pressures in the stair when doors are opened and closed. When a door is opened, the pressure in the stair is reduced and the relief vent will close, diverting the excess air to the open door. When the door closes, the vent serves as a relief for excess pressures in the stair to reduce door-opening forces. These types of features must be identified prior to using PPV to manually increase the stairwell pressure. If this relief vent were to remain functional during the use of PPV, the desired effect of the additional fans would not be achieved.

When fixed stair-pressurization systems are designed, a minimum pressure differential is required between the stairwell and the floor. The maximum airflow allowed into the stairwell is limited by the force required to open the door from the floor to the stairwell (usually 30 pounds of force to allow children and elderly occupants to exit). When fire suppression crews arrive and the building has been evacuated, the limiting force required to open the door is no longer a concern. At this point, if necessary, crews can supplement airflow into the stairwell using PPV to ensure a tenable environment for stairwell operations.

Although not considered a method of smoke management, some buildings are required to be provided with "mop-up" capabilities for fire department use after the fire has been extinguished, to clear any residual smoke. These systems use the existing HVAC equipment to purge smoke from the area under consideration. These types of systems, their use, and capabilities should also be identified during preplanning.

Fixed smoke management systems as well as PPV can increase the effectiveness of firefighting operations by reducing the amount of smoke and superheated gases within the stairwell. Firefighters must be familiar with the high-rise buildings in which they might be called to respond. Familiarization with the stairwell and fixed smoke management system is imperative prior to using PPV.