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Understanding smoke management and control

Modern smoke management systems are designed to help occupants escape from a building and not for smoke removal

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With the recognition that smoke is a lethal element in a building fire, building owners, designers and code authorities have increased their interest in smoke management (control) systems.

The purpose of a smoke management system is to maintain "a tenable environment in the means of egress during the time required for evacuation." A tenable environment is an "environment in which the quantity and location of smoke is limited or otherwise restricted to allow for ready evacuation through the space."[1]

The building code approach

Building codes generally require high-rise buildings (typically, those more than 75 ft; 23 m; high) to have smoke control systems.[2] Codes usually also contain smoke control requirements for other special facilities such as covered malls and atria.

In its section on smoke control systems, the BOCA 1987 *National Building Code* calls for "natural or mechanical ventilation for the removal of products of combustion" by one of three means:[2]

- Remotely operable panels or windows with 20 ft^2 (2 m^2) of opening for every 50 linear ft (15 m) of exterior wall may be installed to vent the fire floor. In sprinklered buildings, remote operation is not required if the openings can be operated manually from inside the fire floor. Fixed panels of approved tempered glass may be used instead of operable panels.

- In sprinklered buildings, mechanical ventilation may be used to exhaust air from the fire floor directly outdoors. The exhaust system must provide air flow of at least six air changes per hour.

- In unsprinklered buildings, the smoke control system may consist of any other design that is tested and approved by the code official.

The use of operable or breakable windows for smoke management probably predates the use of mechanical systems for smoke management. The likely theory behind the concept is to relieve increased pressure because of temperature rise or vent the fire.

The products of combustion from a typical building fire are commonly in the range of 1,700°F (927°C). Air heated from normal room temperature to 1,700°F (927°C) approximately quadruples in volume, so pressure on the fire floor would build up quickly without some provision to relieve the expansion.

While venting the fire will not produce the desirable negative pressure contemplated by today's mechanical smoke management systems, it does help reduce positive pressure on the fire floor, thereby reducing the migration of smoke to other parts of the building.

Newer model codes (including the BOCA 1990 *National Building Code* and the SBCCI 1991 *Standard Building Code*) take a more up-to-date approach. These codes recognize that "the purpose of smoke control is to restrict movement of smoke to the general area of fire origin and to maintain means of egress in a usable condition."[3] The *ICBO Uniform Building Code* also recognizes that smoke containment is the primary function of a smoke control system, and it includes helpful design information on how to achieve satisfactory containment.[4]

These newer codes have shifted the emphasis toward containing smoke to facilitate safe egress as opposed to the old idea of removing smoke in the 1987 and earlier editions of the BOCA code. "Containment of smoke shall be considered as confining smoke to the fire area involved without migration to other fire areas."[5] Limiting smoke migration enhances life safety by making egress safer, and it enhances property protection by reducing smoke damage in areas not directly involved in the fire (see *Figure 1*).

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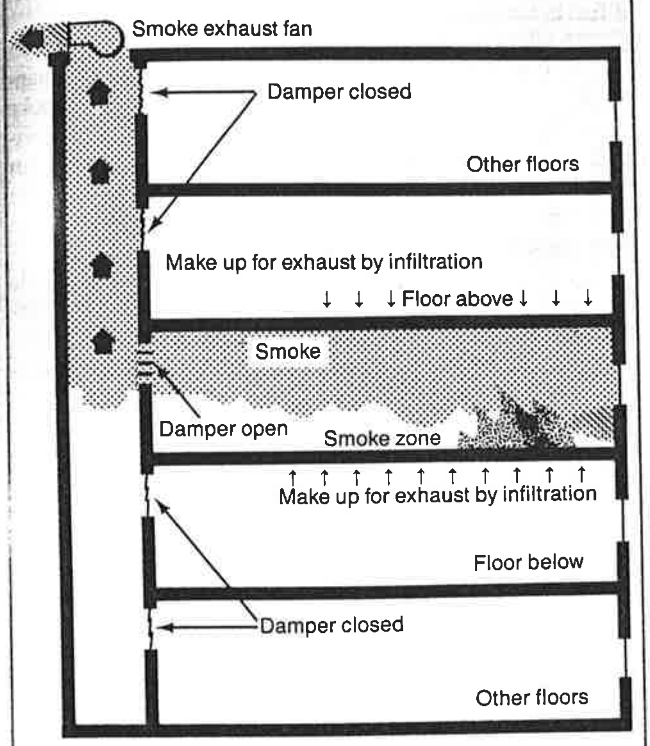

Figure 1. Smoke exhaust system inhibits smoke migration to other floors.

System performance criteria

The only performance criterion in the BOCA building code for a smoke management system that utilizes mechanical exhaust is a requirement for six air changes per hour (ACH), which is one air change in 10 minutes. Some readers have mistakenly interpreted that requirement to mean that all smoke should clear within 10 minutes. However, even with perfect mixing, 37% of the original smoke will remain in the space after 10 minutes of operation at six ACH.[1]

In real buildings, mixing is far from perfect, so the amount of smoke remaining after 10 minutes will likely exceed 37% of the initial concentration. Furthermore, in a real fire, smoke continues to be generated even after the smoke management system has been activated. The smoke concentration decreases to 37% of its initial amount after 10 minutes only if no new smoke is added after the six ACH smoke management system starts. Therefore, any expectation of the amount of smoke removed or the increase in visibility after some set time period is not realistic.

The consensus of experts today is that the approach accepted by model codes for covered malls and other large spaces should be applied to all smoke management systems. "The fundamental objective of a smoke control system is the immediate and automatic set up of smoke barriers at the first indication of a fire in a building."[6] The function of these smoke barriers is to inhibit smoke migration from the fire floor to other parts of the building so occupants can evacuate safely or take refuge while awaiting rescue.

It is important to remember that the design criteria for smoke management systems generally contemplate a fully sprinklered building. The sprinkler system increases the effectiveness of the smoke management system by limiting fire growth and reducing the temperature in the fire room. At lower temperatures, the products of combustion expand less, thereby reducing their tendency to raise the pressure in the fire room.

Smoke-free spaces are possible with pressurization (see *Figure 2*), which prevents smoke movement across smoke barriers into the higher pressure space.[7] The smoke barriers are the envelope around the fire floor, including the floor, ceiling (deck above) and walls.

With a pressure difference between the surroundings and the fire floor, air will tend to flow in through openings and construction joints. If the incoming air velocity is sufficient, smoke will not flow against the air flow (see *Figure 3*). Therefore, the pressure difference and resulting air velocity are the important parameters, not the air quantity itself.

The amount of exhaust from the fire floor required to maintain the desired pressure difference is a function of how tight the envelope is around the space. This can be described by the following formula:[8]

$$Q = KA(dP)^n$$

where,

- Q = the flow required (cfm)
- K = the coefficient (2,610) to correct units
- A = the area of openings (ft^2)
- dP = the pressure differential (in. wg)
- n = the flow exponent (usually between 0.5 and 1.0, and dimensionless). For large openings like doors (turbulent flow), n will be close to 0.5. For tiny openings like cracks around closed doors (laminar flow), n will be close to 1.0.

The pressure difference is the critical parameter for smoke management system performance. The amount of air flow required to produce that pressure difference depends on the geometry of the space and will be different for every building. Therefore, the exhaust rate of six ACH mandated by building codes may or may not be appropriate.

In tight, nearly square spaces with few doors, six ACH may be more than necessary. However, in loose, oblong spaces with several doors, six ACH may be insufficient to maintain the desired pressure difference.

Smoke management systems exhaust from the fire floor and rely on infiltration for make-up air. Delivering make-up air directly to the fire floor would reduce the negative pressure on the fire floor, thereby reducing the effectiveness of the smoke management system.

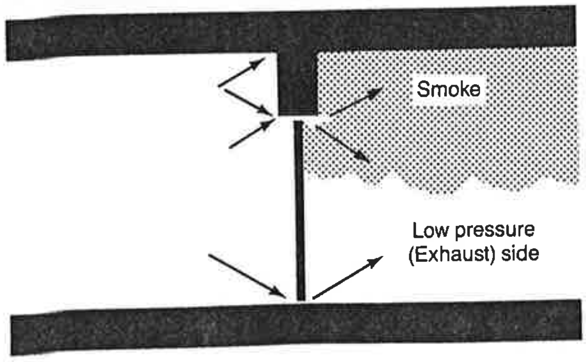

Figure 2. Pressure difference across a barrier helps confine smoke.

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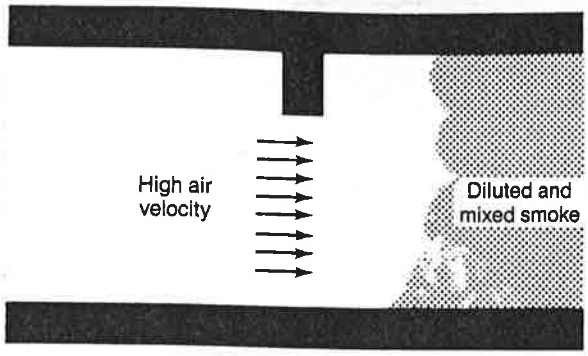

Figure 3. Relatively high air velocity (and large air volume) are required to confine smoke across large openings.

Smoke control systems should more correctly be named smoke containment or smoke confinement systems. There is no intent in any of the ASHRAE, NFPA or other technical literature to use these systems for smoke removal.

Smoke purging

Smoke management systems (which rely on air flow and pressure differences to help contain smoke) are distinct from smoke exhaust or smoke evacuation systems. Smoke exhaust or smoke evacuation systems are intended to clear smoke from the fire zone after the fire is out. They often use a combination of exhaust and supply air to the fire zone.

A smoke management system is a "pressurization back-up to the compartmentation barriers that is intended to aid in sealing off smoke migration through existing openings. Smoke exhaust (or smoke evac) systems are not smoke management or even control. Smoke exhausting or venting is mostly a firefighters tool to obtain control."[7]

"Smoke management with air changes is not effective during the smoke development/fire period. Alternatively pressurization is not a smoke clearing mode, it is a smoke containment aid. Smoke evac or smoke purging is now known to be of questionable success in either prevention or rapid clearing of smoke."[7]

During smoke bomb tests of smoke management systems, make-up air delivered to the fire floor has been credited with improving visibility and aiding smoke removal. That experience is not relevant to a real fire because the smoke bomb eventually stops creating smoke. Therefore, the use of make-up air in a smoke bomb test is more akin to conditions after the fire is out than during the fire.

Visual observations during a series of smoke bomb tests revealed that make-up air probably contributes more to diluting the smoke at the point of origin and mixing it throughout the fire floor than it does to aiding the exhaust by pushing or flushing smoke out of the space.

In a real fire, make-up air can actually make the fire worse. Air delivered from an HVAC system is known to promote mixing in the space. Contact between this turbulent air flow and the flames of the fire will increase the surface area of the flame and potentially enhance ignition of surrounding combustible material.

Moreover, in most building fires, fire size is limited as the fire consumes oxygen from the space. Introducing make-up air quickly provides enough oxygen, so the only limit on fire size is the amount of fuel in the space.

The dilution of smoke in the fire area of a compartmented building is not a means of achieving smoke control. A smoke management system is not an air change arrangement, and smoke control cannot be achieved by simply supplying air to and exhausting air from the compartment.[1] "Testing such as Operation San Francisco and the Naval Air Development Center Aircraft Fire Testing (even with three air changes per minute) demonstrated the smoke clearing incapability."[7]

Purging cannot ensure breathable air in the fire space while the fire is burning and producing smoke. However, it can remove smoke from the fire space after fire extinction.[8] Once the fire is out, the capabilities of the entire HVAC system are available to remove smoke from the area. In addition, many fire departments have portable fans that are suitable for clearing smoke.

Other HVAC equipment

The HVAC system is designed to distribute and mix air throughout the building and, therefore, it is a potential conveyance for smoke from the fire to the rest of the building. For that reason, HVAC equipment that is not part of the smoke management system should shut down when the building is in the smoke control mode.

If left in operation during the smoke mode, toilet exhaust fans can contribute to the negative pressure on the fire floor. However, they also remove air from the adjacent floors where a positive pressure is sought.

On the other hand, shutting off the toilet exhaust system would provide an unprotected vertical path for smoke to migrate from floor to floor. While the toilet exhaust system might have fire dampers, smoke alone is often too cold to melt the fusible link in a fire damper, and a considerable amount of smoke could migrate before the damper closed.

The toilet exhaust quantity in an office building is relatively small. Therefore, on balance, the benefits of allowing it to continue to operate during the smoke mode probably outweigh the benefits of shutting it down.

Some buildings utilize fan powered terminal units as part of the HVAC distribution system. These units circulate air between the ceiling plenum and the occupied space. Allowing them to continue to operate during the smoke mode will contribute to air mixing in the fire space but will not ordinarily spread smoke from the fire zone to other parts of the building.

Nevertheless, NFPA 92A recommends shutting off the terminal unit fans that serve the smoke zone. NFPA 92A suggests that terminal unit fans serving smoke control zones adjacent to the smoke zone may continue to operate normally.[1]

Atriums and large spaces

Atriums and other large spaces are exceptions to the general rule that the function of the smoke management system is only to maintain pressure differences.[4] In atriums and large spaces, the smoke management system has the additional objective of exhausting smoke from the space at approximately the same rate it is produced.

Tenable conditions for egress are maintained by allowing buoyant smoke to rise to the top of the space and collect there (see *Figure 4*). By removing smoke at approximately the same rate as it is produced, the exhaust system maintains an interface between the smoke layer and the breathing zone that is sufficiently high above floor level for people to leave the space.

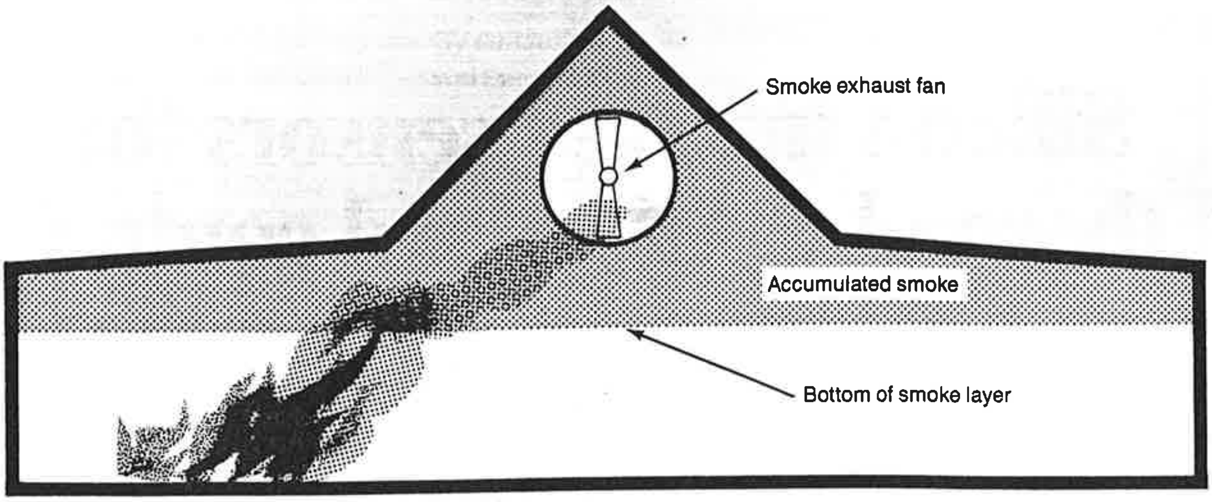

Figure 4. The smoke exhaust system in atriums or large spaces allows smoke to accumulate up high, keeping occupied level clear for egress.

In very high spaces, the smoke layer can even be allowed to grow down toward floor level as long as the smoke will not reach the occupied level in less time than people need to leave the space. Smoke management for these special spaces is discussed in *Guide for Smoke Management in Malls, Atria and Large Areas (NFPA 92B)*.[9]

Conclusion

Smoke management works by using pressure differences and air velocities through cracks and small openings to help confine smoke to the fire floor. In doing so, the system maintains tenable conditions in egress paths so people can leave the building safely.

Maintaining a sufficient pressure difference to control smoke movement requires a relatively tight envelope around the space. The more openings in the space, the more air flow will be required to maintain the desired pressure difference.

Make-up air introduced directly to the fire floor is not necessary and can inhibit the performance of the smoke management system. The make-up air constitutes openings that reduce the desired pressure differential. It also provides additional oxygen that can feed the fire.

Smoke bomb tests that show improved smoke dilution with make-up air and increased air changes after the smoke bomb has stopped fuming are not representative of fire conditions. According to Klote:

> Dilution of smoke in a zone in which a fire occurs is not a means of smoke control. This process is sometimes referred to as smoke purging, smoke removal, or smoke exhaust. Many people have unrealistic expectations about what this approach can accomplish. There is no theoretical or experimental evidence that using a building's HVAC system for smoke dilution will result in any significant improvement in tenable conditions within the fire space. It is well known that HVAC systems promote a considerable degree of air mixing within the spaces they serve. Because of this and the fact that very large quantities of smoke can be produced by building fires, it is generally believed that dilution of smoke by an HVAC system in the zone in which there is a fire will not result in any practical improvement in the tenable conditions in that zone.[10]

Exhaust systems are not highly directional, although there is a general flow toward the inlets. For that reason, it may be possible to reduce the tendency of exit access pathways on the fire floor to fill with smoke by locating smoke exhaust system inlets away from egress doors. However, the objectives of removing smoke generated during a fire from the fire floor as an aid to egress or to aid firefighters in locating and fighting the fire is beyond the design intent and capability of today's smoke management systems. ■

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