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What's New in Atrium Smoke Management?

Innovative design and technology solutions to atrium smoke management and potential changes to future NFPA guidelines

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All atrium smoke management approaches depend on the buoyancy of hot smoke. During a fire, a plume of hot smoke rises above a fire. As this smoke rises, surrounding air is entrained into the plume so that the plume temperature drops as the smoke rises. Additionally, the plume mass flow increases with height above the fire. This smoke continues to rise until it forms a smoke layer under the ceiling. The idea of atrium smoke exhaust is to exhaust smoke from this layer so that people do not come into contact with the smoke.

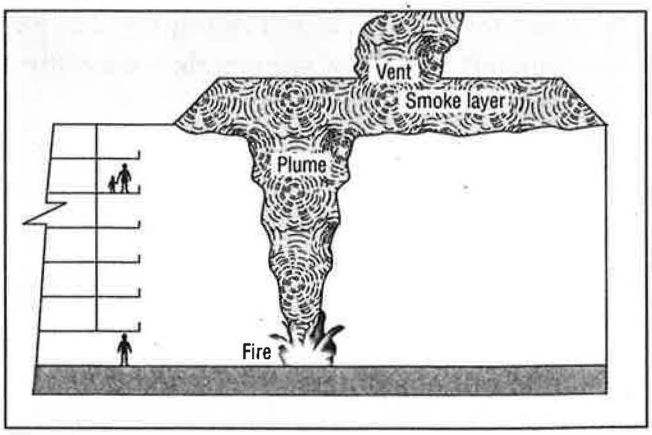
Because the temperature of smoke decreases as it rises, smoke may not be hot enough to activate sprinklers mounted under the ceiling of an atrium. Even if such sprinklers activate, the delay in activation can allow fire growth beyond the suppression capability of the sprinklers. In this article, the term *ceiling height* is used to mean the floor-to-ceiling height unless specifically noted otherwise.

The ceiling height at which a sprinkler can be defeated depends on the specific materials burning, the geometry of those materials, and the sprinkler system. This happens when the flame height is only a fraction of the ceiling height as would be anticipated for many atrium fires. However, there is no clearly defined ceiling height above which sprinkler suppression would be expected not to work and below which it would be expected to work. For atrium applications, it has been stated that the ability of sprinklers to suppress fire is limited for ceilings higher than 35 to 50 ft. This issue is addressed in NFPA 92B, and Section 1-5.4.3 of that document states:

"Activation of sprinklers near a fire will cause cooling of the smoke, resulting in a loss of buoyancy. The likelihood of sprinkler activation is dependent on the heat-release rate of the fire and the ceiling height. Thus, for modest fire sizes, sprinkler operation is most likely to occur in a reasonable time in spaces with lower ceiling heights, such as 8 to 25 ft (2.4 to 7.6 m)."

For these reasons, atrium smoke protection probably should be used in atrium spaces with ceiling heights greater than 25 ft.

Many engineering systems can be adjusted in the field under real operating conditions to assure that they will work, but this isn't appropriate for smoke management. The operating conditions for smoke management are fire conditions. Therefore, the designer needs to be sure that smoke management systems are designed and built so that they will work as intended when a fire occurs, which may be years or even decades after construction. Current design methods go a long way to assure this, and a few of the key points about atria design are discussed below. For further design information, see NFPA 92B *Guide for Smoke Management Systems in Malls, Atria, and Large Areas;* the ASHRAE/SFPE book, *Design of Smoke Management Systems,* by John Klote and James Milke; and *Method of Predicting Smoke Movement in Atria with Application to*



1 Natural venting is commonly used in the United Kingdom and Australia. Because of reliability and economic advantages, natural venting may find a place in the U. S.

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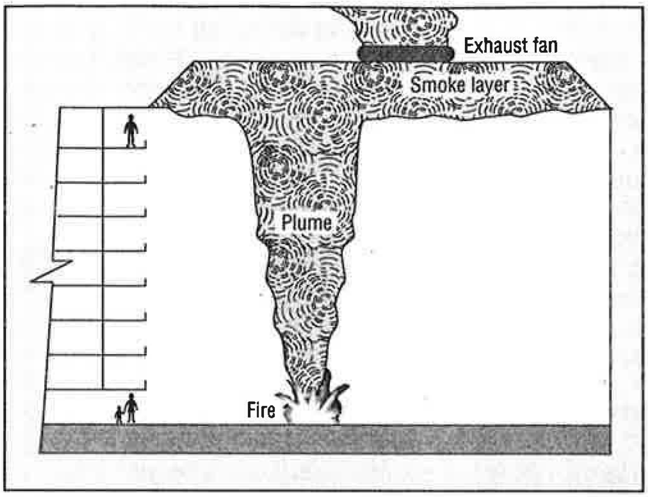
Smoke Management, NISTIR 5516, published by the National Institute of Standards and Technology (NIST).

To prevent confusion, readers of the above publications are cautioned about the meaning of the terms *smoke control* and *smoke management.* They reserve the term smoke control for systems that provide smoke protection by use of pressurization, such as a pressurized stairwell. Systems that use any technique, including compartmentation, pressurization, air flow, and buoyancy of hot smoke, are referred to as *smoke management systems*. Using this terminology, atrium exhaust systems are smoke management systems because they rely upon the buoyancy of hot smoke. This also holds true for the other types of atrium smoke protection discussed below.



2 A smoke plume rises above a fire to form a smoke layer under the ceiling. Exhausting the smoke from this layer using fans prevents smoke from descending and reaching occupants during evacuation.

Smoke filling

While smoke exhaust is probably the most common form of atrium smoke management in the United States, some atria are of such size that no smoke exhaust is needed to keep the occupants from contacting smoke throughout a fire evacuation. However, a form of smoke management called *smoke filling* requires no exhaust capabilities.

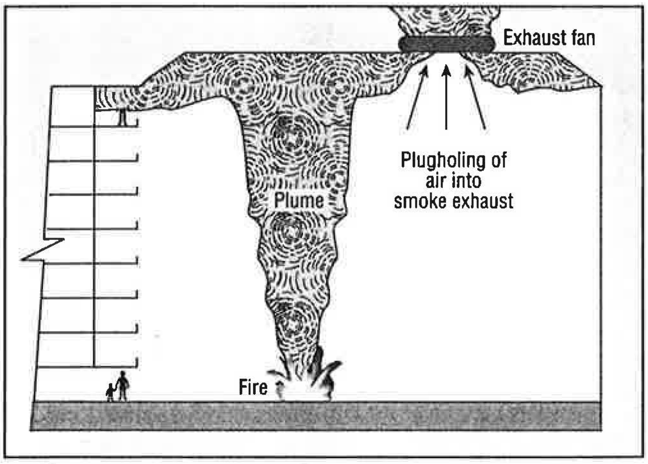
Without smoke exhaust, the smoke layer that forms under the ceiling grows thicker, and the bottom of that smoke layer drops downward. Equations can be used to calculate the time that it takes for the smoke to drop to a level that is above the heads of all of the people in the atrium during a fire evacuation. If this smoke filling time is greater than the evacuation time, smoke filling is a viable form of smoke protection.

People-movement calculations are used to determine the evacuation time. As we all know, when a fire alarm sounds, most people have a tendency to wait to see if there really is a fire or to see if conditions are threatening. This decision time needs to be allowed for in any calculation of evacuation time. Readers interested in people-movement calculations should read SFPE's *Handbook of Fire Protection Engineering.*

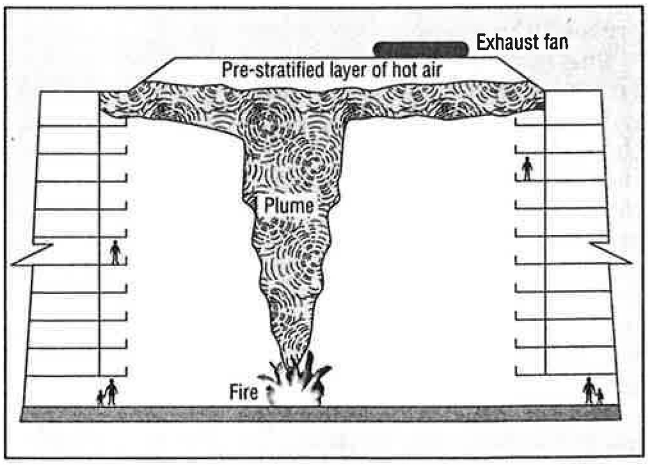
Natural smoke venting

In the United Kingdom and Australia, *natural venting* is often used (Fig. 1) where we in the U.S. would use fan-powered smoke exhaust (Fig. 2). This natural method consists of opening vents on an atrium ceiling or high on atrium walls to let the smoke flow out without the aid of fans.

The flow rate through a natural vent can be calculated, and it depends on the size of the vent, depth of the smoke layer, and temperature of the smoke. When smoke is detected, all the vents need to open at the same time. Thermally activated vents, such as those often used for industrial heat and smoke venting, are inappropriate for natural venting of atria because of the time delay in



3 Plugholing of air into the smoke exhaust can cause occupants to be exposed to smoke, but methods of preventing plugholing have been developed.



4 A pre-stratified layer of hot air can prevent smoke from reaching ceiling-mounted smoke detectors. Beam smoke detectors can be used to resolve this problem.

opening the vents.

The applicability of natural venting depends primarily on the size of the atrium, outside design temperatures, and wind conditions. Natural venting is simpler and less costly than fan-powered exhausting. Because loss of power is common during fire situations, there is a significant advantage in using a smoke management system that requires no power for fans.

Some people are uncomfortable with natural venting—probably because of the lack of positive assurance of obtaining the desired flow. However, the reliability and economic benefits of natural venting are such that I expect that natural venting will find a place in U.S. buildings in the future.

Smoke layer depth

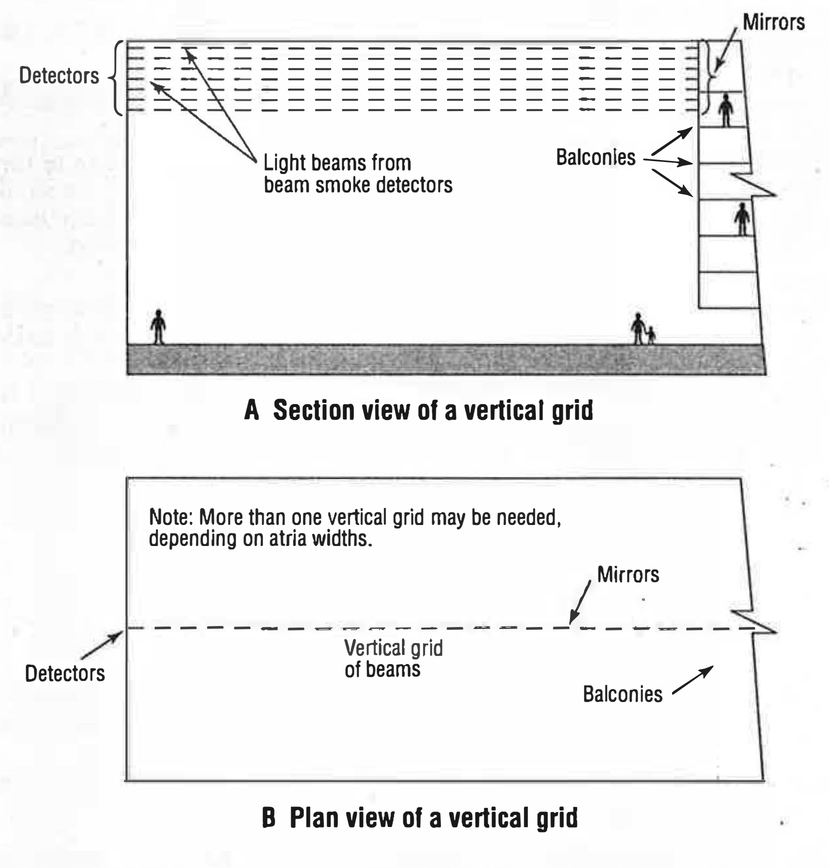
Many designers and researchers in North America, the United Kingdom, and Australia have been concerned about the possibility of air being pulled into the smoke exhaust along with the smoke. This *plugholing* of outside air into the exhaust can increase the smoke layer depth and possibly expose occupants to smoke (Fig. 3). The results of ASHRAE-sponsored atrium smoke exhaust experiments at the National Research Council of Canada[1] were consistent with a design approach used in the United Kingdom to prevent plugholing.

The maximum flow, Q_{max}, of smoke that can be exhausted without plugholing depends on the depth of the smoke layer and the temperature of the smoke. If the total smoke exhaust needed is greater than Q_{max}, a number of exhaust inlets are needed. These inlets need to be placed far enough from each other so that the flow near them is unaffected by other inlets.

The new ASHRAE handbook, expected publication by the end of this year, will address this topic, and it will probably be incorporated in the next issue of NFPA 92B.

Stratification and detection

Often a hot layer of air forms under the ceiling of an atrium—the result of solar radiation on the atrium roof. While studies have not been made of this *pre-stratified* layer, many professionals believe that such layers are often in excess of 120 F. When the temperature of the smoke plume is less than that of the pre-stratified layer, the smoke cannot reach the ceiling. In this situation, the smoke cannot activate ceiling-



Placement of Beam Smoke Detectors

Probably the most common approach for locating beam detectors is to place a number of them at different levels under the ceiling to form a *vertical grid,* as shown in the accompanying diagrams. The purpose of this approach is to detect the development of a smoke layer quickly at whatever temperature condition exists. The locations of the beams depend on the geometry and air flow patterns of the space, but the bottom of the vertical grid should be below the lowest level where smoke is expected to stratify.

An alternate approach consists of a *horizontal grid* intended to detect the rising plume rather than the smoke layer. For this approach, the beams must be installed at a level below the lowest level where smoke is expected to stratify and installed close enough to each other to assure intersection with the plume. Both the vertical grid and horizontal grid approaches require an understanding of the physics of atrium smoke transport.

mounted smoke detectors (Fig. 4).

One solution to this detection problem consists of using beam smoke detectors at intervals below the ceiling to detect the stratified smoke regardless of the depth of the pre-stratified layer (see accompanying sidebar).

Beam smoke detectors consist of a source that produces a light beam (a transmitter) and a light sensor (a receiver) that detects the beam. Typically, both the source and the sensor are located together with the beam traveling across the atrium and being reflected back to the sensor by a mirror installed for this purpose.

The use of beam smoke detectors to overcome the atrium stratification problem is so new that no formalized methods are in the codes and standards. However, the NFPA Smoke Management Committee will be considering two approaches for inclusion in the next revision of NFPA 92B.

When equations don't apply

The equations used to design atrium smoke management systems are based on the zone fire model concept. In the zone model, a smoke plume rises above a fire without obstructions and forms a smoke layer under the ceiling. This smoke layer is called the upper zone, and the air below is called the lower layer. The idealized zone model considers both the layers to be of uniform temperature.

The design equations do not apply if obstructions break up the usual form of the plume. They also do not apply if the smoke plume cools so much that smoke does not reach the ceiling. In fact, the equations do not apply for any case where the smoke movement does not follow the idealized zone model approach.

Techniques that can be used when the equations do not apply are scale modeling and computational fluid dynamics (CFD). Probably the most common kind of scale modeling is Froude modeling, which preserves the Froude number. This number can be thought of as the ratio of the inertia forces to gravity forces, and this number is important to smoke modeling because the buoyancy of hot smoke is a gravity force. Froude modeling consists of building a scale model and burning a scaled-down fire in that model in air at atmospheric pressure.

CFD modeling consists of dividing a space into a large number of spaces and obtaining approximate solutions to the fundamental equations of fluid dynamics for each space. Many computer CFD programs have been developed that are capable of simulation of fire-induced flows. Friedman (1992) discusses 10 such codes.[2]

Several of these are general-purpose codes that are commercially available. Readers should be aware that a thorough knowledge of CFD requires extensive understanding of graduate level fluid dynamics. NISTIR 5516 provides introductory information about both Froude modeling and CFD modeling.

Summary

- The designer needs to be sure that smoke management systems are designed and built so that they will work as intended when a fire happens.
- For some atria, a smoke filling system can be built that eliminates the need for atrium exhaust.
- In the United Kingdom and Australia, natural venting is often used where we in the U.S. would use fan-powered smoke exhaust. This approach has several advantages, and it could gain a level of acceptance in the U.S.
- The plugholing of outside air into the smoke exhaust has the potential of exposing occupants to smoke. A method of preventing plugholing has been developed, and it will be incorporated in design publications in the near future.
- A pre-stratified hot air layer under an atrium ceiling can prevent activation of ceiling-mounted smoke detectors. One solution for this problem uses beam smoke detectors.
- Scale modeling and CFD can be used when the usual design equations for atrium smoke management are not appropriate.

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3) Klote, J. K., and Milke, J. A. 1992. *Design of Smoke Management Systems,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Ga.

4) NFPA 1995. *Guide for Smoke Management Systems in Malls, Atria, and Large Areas,* NFPA 92B, National Fire Protection Association, Quincy, Mass.

5) SFPE. 1995 *Fire Protection Engineering Handbook,* National Fire Protection Association, Quincy, Mass.

Dr. Klote's company, John H. Klote, Inc., uses the results of research to provide consulting to fire protection engineers, mechanical engineers, and code officials concerning practical solutions to various fire protection problems.

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