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UNIQUE SMOKE MANAGEMENT DESIGNS

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contents

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SMOKE CONTROL

To the uninitiated, the idea of somehow directing the smoke generated in a fire seems like a wonderful solution to the problem: by somehow keeping smoke away from the means of egress, the exiting occupants are protected; by exhausting and controlling smoke from fire, occupants who stay in a building during a fire are not exposed to the toxic products of combustion. According to Klote and Fothergill in the document entitled "Design of Smoke Control Systems for Buildings" (1983 from American Society of Heating, Refrigerating and Air-Conditioning Engineers), some form of airflow management has been done for more than 40 years.

The simplest method for controlling smoke is found in stair pressurization systems. Simply put, such systems work by forcing air into the stair enclosure, thereby creating a positive pressure inside the enclosure. When the doors to the enclosure are opened by exiting occupants, the smoke is kept out as the air from the stairs "pushes out" and keeps smoke from entering the stair. Injecting air via fans into a stairway or elevator shaft can be done from the top, from the bottom, or from multiple sources depending on the height of the building. The assumption is that, by doing so, the corridors leading to the stair and the remainder of the building will have a negative pressure in relation to the stair, so instead of going into the stair, the smoke is "pushed away" by a rush of air escaping the pressurized stair enclosure. Of course, for all of this to work as desired, the systems must have been designed to compensate for one or more doors being propped open or kept open by the occupants streaming into the stairway, have been tested and inspected on a regular basis, and not be dependent on an unprotected power source.

Smoke control for the building proper can involve a combination of different methods depending on what is actually desired. The simplest approach is to "sandwich" the fire floor by creating positive pressure on the floors above and below the fire floor. Most often this is done by using the existing heating, ventilating, and air conditioning system components (HVAC). Fans are activated, dampers are opened and closed, and essentially more air is forced into the floors above and below while air is exhausted from the fire floor. In some buildings, a dedicated smoke management system may be required. Such systems are there exclusively for managing smoke from fire. Automatic activation of the smoke management system components is not the most common method; it is more common for the responding firefighters to take control of the systems and activate them manually as they see fit.

Smoke control for malls, atria, and large areas requires the use of a combination of different smoke control methods. Atria are multistory, large, open spaces which communicate with multiple floors of the buildings they are found in. Malls are large, open spaces created when individual shops on multiple levels are under one common roof. Where malls tend to spread out horizontally, atria tend to be more vertical in orientation. Large-volume areas under a single roof which have not been divided up into separate spaces present a similar challenge to smoke control. Examples of such spaces are open manufacturing spaces, large warehouses, arenas, and the like.

For such spaces, a combination of smoke exhaust and a method for limiting the spread of smoke depending on the type of occupancy is common. The effect desired is selected based on the use of the building. In malls, arenas, convention halls, ballrooms, exhibition halls, concert halls, etc., and atria in hotels and office buildings, the desire is to protect the occupants and afford a safe means of egress for them. Where occupants are limited in number, the objective might be to prevent smoke damage to sensitive manufacturing equipment.

Nowadays, the design of smoke control systems for most structures frequently involves the use of computer modeling of different scenarios in order to come up with the most desirable method or combination of methods. Computer models can fairly realistically simulate different types of fires in different parts of a structure. Using these programs, the design engineer can simulate the effects of various methods of smoke control, singly and in combination, to come up with the best method to manage smoke in the space.

Ultimately, the success or failure of the installed systems depends on the building owners and how they test and maintain these systems. The components of smoke control systems are simple: fans, ducts, vents, dampers, etc. Keeping those devices in top working order is something else. Once installed, such systems are often not tested regularly. Changes to the structure will also create changes in how smoke moves within them. Minor changes don't usually trigger a review of the smoke control system and whether there is a need to make changes to it as well. Over time, the building interior may change substantially, while the fixed components of the smoke control system are either compromised or rendered useless. Perhaps if building maintenance people and building owners were more knowledgeable of how these systems are meant to work, they would be more conscientious about testing, maintaining, and including them in plans when changes are made to buildings.

Personally, I am skeptical about the effectiveness of the more complicated systems over the life of a building.

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DO THEY WORK?

By William A. Webb, P.E.

BACKGROUND

The development of modern smoke management systems began in the 1960s. After a series of high-rise fires, there was an increased interest in smoke management systems, which led to research on the time to evacuate high-rise buildings and smoke spread caused by stack effect. A few notable fires that occurred in buildings containing atria caused a reexamination of the provisions provided for smoke management in atria and in covered malls. All of the model codes have had changes to the requirement for smoke control or smoke management in each edition since at least 1970. *The International Building Code* (IBC)[1] has continued the trend.

A significant body of research influenced the code changes. The combined effect of the code changes and the research has been that smoke control requirements have been continually changing.

With all of the effort in code writing and research, it is fair to ask, "Has the effort been worth the cost; and do these systems work?"

This article will present information concerning how well these systems perform after they have been in service and to encourage discussion and research to determine their effectiveness and to improve their maintenance.

BRIEF HISTORY

In 1968, the National Research Council of Canada (NRCC) conducted a survey of exit facilities in 20- to 40-story office buildings.[2, 3, 4] The results revealed dangerously excessive exit

times. A little earlier, NRCC discovered a serious smoke control problem in tall buildings, partly due to stack effect and partly due to deficiencies in HVAC systems and other elements of construction.

On January 24, 1969, Chicago newspapers reported "Four Die in Chicago Apartment Fire." On Thursday, August 6, 1970, the headlines read, "Skyscraper Fire Kills Two" with a subheading that read, "31 Injured in Blaze on Wall Street." On December 4, 1970, a front-page story told of a fire on the fifth floor of a 47-story building in New York City that killed three workmen. The most disturbing part of these fires is that they all happened in modern fire-resistive, high-rise office buildings; all involved loss of life, poor elevator operation, substantial smoke spread through the building, and problems with exiting.

The fire protection industry reacted to these events with a series of conferences. Two notable ones were sponsored by the Fire Protection Engineering Department of the Illinois Institute of Technology in 1970 and by the U.S. General Services Administration in 1971.[5]

While code changes were being developed using the conclusions from the conferences, there were three high-rise fires of national prominence in November 1972. The first was a fire on the 95th floor of Chicago's John Hancock Center. The photographs were as spectacular as the fire loss, though there were no fatalities. The second and third came back to back in a New Orleans high-rise with a restaurant on the 19th floor and in an Atlanta retirement home where the fire started on the 12th floor.

The fires causing concern in Chicago were in apartment buildings; those in New York were in office buildings. Although the structures in the two cities had much in common, they differed to a major extent in compartmentation. This drove different solutions in the requirement initially adopted in each city for high-rise fire safety. New York's requirements, known as Local Law 5,[6] applied to office buildings. Either compartmentation and stair pressurization or automatic sprinkler protection was required, among other features such as voice evacuation, firefighters' communication, and elevator recall.

Chicago's requirements, adopted in 1975, applied to all high-rise buildings. They required either compartmentation and smoke control or sprinkler protection. The smoke control system was to be designed to pressurize nonfire compartments on the fire floor and exhaust the fire compartment. A smokeproof tower was required for nonsprinklered buildings. The voice evacuation and firefighters' communication requirements were similar to those in Local Law 5.

Fire safety requirements for high-rise buildings were subsequently adopted in the model codes and those of the major cities in North America. Among features intended to prevent smoke spread between floors or groups of floors included stair pressurization, HVAC system shutdown, fire-floor venting or exhausting, and automatic sprinkler protection. The specific features, required or allowed, varied among the codes. As the popularity of atrium hotels and covered malls increased, so did the concern for smoke spread in these occupancies. This caused additional smoke management considerations to be adopted in the codes.

Each year, the model codes have revised smoke management requirements. As a result, more and more sophisticated methods of smoke control and smoke management have been needed to comply with the code. The terms I use in this article for "smoke control system" and "smoke management system" are those defined on page 24.

EXPERIENCE

Although there have been relatively few high-rise fires, those that have occurred are often spectacular. The same is true of atrium fires. Even in those cases where protection was inadequate, a common thread separates the "failures" from the "successes." That common thread is inspection, testing, maintenance, and enforcement.

Let us consider a few examples.

The January 1982, NFPA *Fire Journal* reported on a fire at the MGM Grand. This incident clearly was an instance of inadequate protection and numerous deficiencies. Matters such as steel straps bolted across dampers, HVAC mixing rooms used for storage or as offices, fusible links replaced by steel wire, inadequate enclosure of exit passageways, and blocking of smokeproof tower smoke vents could have been discovered by inspection and prevented by proper maintenance. While this tragedy may not have been averted had the deficiencies been corrected, the deficiencies may have been contributing factors.

In another incident in a high-rise building in the Southwest, a fire occurred in the service elevator lobby on the 22nd floor of a hotel. The smoke detector in the lobby detected the fire and released the lobby doors. Recently installed carpeting, however, kept the doors from closing. In addition, stair doors had been blocked open. As a result, smoke infiltrated stairs and the elevator shaft, and five floors of the hotel had to be evacuated.

In this instance, the active portion of the smoke control system, i.e., the detection and fans, worked properly. The passive portion, namely the doors, failed because they were blocked open. This is another instance in which inspection and maintenance would have disclosed the deficiencies.

In another instance in the same city, the HVAC system in a portion of the building continued to operate, circulating smoke from a fire. The duct detectors had been disabled during maintenance. Inspection by those charged with fire safety could have discovered the deactivation of the smoke detectors so that alternative protection could have been provided during the shutdown period.

A *Fire Journal*[10] article reported on an atrium fire which occurred on November 19, 1973, at the Hyatt Regency O'Hare. The article states " . . . it was found that the atrium smoke exhaust system had failed to operate. On checking, it was found that the switch connecting the smoke detection system to the exhaust system had been turned off. The fans were then turned on, and the atrium was cleared of smoke."

An arson fire in the Blue Max Nightclub of the hotel spread fire and flames into the hotel atrium. The nightclub was on the second floor of the 10-story high atrium. The atrium was 145 feet (44 m) square, topped by a revolving restaurant. The article states,

"Although 1,000 guests were exposed to the fire conditions, only one required hospital treatment, because of a heart condition. One firefighter was treated for smoke inhalation." It should also be noted that the nightclub and guestrooms were not protected by sprinklers. Firefighters' prompt response and action prevented a tragedy. It is clear that inspection and maintenance would have disclosed the deficiency so that it could have been corrected.

The January 1979 edition of *Fire Journal* reported that a fire which started in a small office on the 10th floor of a 13-story office building broke a window which opened to the atrium and allowed smoke to enter the atrium.[11] Upon firefighter arrival, " . . . thick black smoke was pouring from the fire floor and banked down from the roof to below the 10th floor. Although the smoke detector operated, only two of the six smoke vents opened. The other four released; however, maintenance personnel reported that the springs had apparently lost sufficient strength to open them fully." The article goes on to state that maintenance personnel did open the vents, but smoke continued to bank down. The failure of all of the vents to operate does, however, clearly demonstrate the need for inspection and proper maintenance. In this case, maintenance would have replaced the springs or the vents.

CODES

The changes that have occurred to the model building codes since the 1970s included an exception to allow stair pressurization without a vestibule in buildings protected by automatic sprinklers in lieu of smokeproof towers having vestibules with natural or mechanical ventilation. For malls and atria, the requirements have migrated from four or six air changes per hour (ACH) of the interconnected volume to fire plume calculations based on *NFPA 92B*. In each of the revisions, most of the information has concerned installation for new buildings and for acceptance testing. Until recently, few, if any, requirements or guidance for routine inspections and maintenance have been adopted in building or fire codes. It is, therefore, no wonder that

regulatory authorities frequently state that the systems function properly when new, but may perform poorly after a few months or years in service.

Each of the current editions of the model building codes and the recently adopted *International Building Code* state that systems required by the code are to be maintained in accordance with the code. There are no specific maintenance requirements for smoke control systems. This can be expected because, generally, maintenance requirements are contained in fire codes.

The three model fire codes require smoke control and smoke management systems to be inspected and operated or tested. The frequency is quarterly for the *Uniform Fire Code*[12] and semiannually by the *BOCA National Fire Prevention Code*[13] and the *Standard Fire Code*[14]. The *International Fire Code*[15] has the most comprehensive requirements for maintaining smoke control and smoke management systems. It states that required systems shall be maintained in accordance with the manufacturers' instructions and the code. It requires a written schedule for routine maintenance and operational testing be established. Dedicated systems are to be operated semiannually and nondedicated systems operated annually.

In addition to the model codes, a logical place to look for the frequency of testing and maintenance of smoke control systems would be NFPA documents. Turning first to *NFPA 1*,[16] there are no specific requirements for testing and maintenance of smoke control systems. There is a general requirement that required fire safety systems are to be maintained. In this respect, *NFPA 1* is similar to the model fire codes.

NFPA 92A suggests that dedicated systems should be operated semiannually and nondedicated systems should be operated annually. It states, "Dedicated smoke-control systems are intended for the purpose of smoke control only. They are separate systems of air-moving and distribution equipment that do not function under normal building operating conditions. Upon activation, these systems operate specifically to perform the smoke-control function. Nondedicated systems are those that share components with some other system(s) such as the building HVAC system. Activation causes the system to change its mode of operation to achieve the smoke-control objectives." In each case, the systems should be operated under standby power. These tests are to be documented and a log made available for inspection. The purpose of the test is to determine that the correct output is attained for each input.

NFPA 92B suggests semiannual tests with the results documented in a log available for inspection. As with *92A*, the tests are to determine whether correct outputs occur for each input. The purpose is to demonstrate that the installed systems will continue to operate in accordance with the approved design. It is recommended that the tests include both measurements of airflow quantities and pressure differentials.

NFPA 90A[17] recommends that dampers be examined every two years. It also recommends that fans and motors should be inspected at least quarterly and that fan controls be examined and activated at least annually.

NFPA 101[18] contains a similar requirement to those of the model codes to maintain required systems. It also requires that mechanical stair ventilation systems have their operating parts tested semiannually and the results logged. The recently adopted performance option chapter of *NFPA 101* requires

that systems necessary to achieve the design performance be maintained for the life of the building. No specific smoke control or smoke management requirements are mentioned.

ASHRAE Guideline 5[19] provides methods for verifying and documenting that the performance of smoke management systems conforms to the design intent. It is critical that the designer and owner use a system such as *Guideline 5* if they expect the smoke control or smoke management system to perform as intended over the life of the building. The *Guideline* states, " . . . throughout the useful life of the building, there will be a need to recommission these systems periodically." A key component to recommissioning is the post-acceptance phase. It requires "as-built" or record documents be reviewed so that they reflect modifications made to the system during construction and throughout the life of the building. The *Guideline* specifies how documents are to be maintained so that they reflect current system performance. The commissioning documents contain records of all the original tests. These are useful in maintenance tests to see how the system performance has changed and to determine what maintenance or replacement is needed to restore the system to its original state.

It is unnecessary for codes to specify the details of how inspection, testing, and maintenance are to be performed; however, they should specify what and when these tasks are to be performed.

CONCLUSION

Returning to the question posed at the beginning of this article, there is insufficient information on fire experience and cost impact to judge whether these systems are worth the cost. It is clear that the systems generally do work when initially installed. There is anecdotal evidence to question their in-service performance.

As we embark on performance-based design in the *Life Safety Code* and the ICC Codes, emphasis continues to be placed on evaluating the initial design. The *International Fire Code* has, however, taken steps to determine that the design continues to meet the objective over the life of the building. Perhaps it is to be expected that it has taken so long to address maintenance, given the lack of attention that testing and maintenance have been given in the current codes. If the performance of smoke control and smoke management systems is questionable for those installed under prescriptive codes, what can we expect when they are an integral part of a fire protection solution using a performance code? Perhaps the reason we have not recorded more incidents of catastrophic failures of these systems is that the fire suppression systems and fire detection and alarm systems on which the smoke management systems depend are inspected and maintained more thoroughly. It seems obvious that a performance solution must include a detailed maintenance and testing protocol that regulatory officials must be prepared to enforce and owners and operators prepared to implement. If they are unwilling to expend the effort to inspect, test, and maintain the systems and to enforce the testing and inspection protocol, why should the systems be required at all? The cost might better be used to enhance the reliability of the systems, which they are prepared to inspect, test, and maintain.

This article is intended to be a call to collect information on how well existing smoke management systems already installed are being inspected, tested, and maintained. It is encouraging that the *International Fire Code* has included requirements for inspection and testing of in-service systems. The maintenance requirements should be interpreted to be similar to those contained in *ASHRAE Guideline 5* which states that a maintenance program should include developing and maintaining a standard method of recording maintenance tests and their results. It makes little difference to fire safety to develop good requirements based on sound engineering if the systems are not tested and the requirements are not enforced. Now that we have good smoke management requirements in the codes for installation, let us be sure that the systems are inspected and maintained properly.

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UNIQUE SMOKE MANAGEMENT DESIGNS

By Douglas Evans, P.E.

INTRODUCTION

Several of the most unique buildings in the world are located in Las Vegas, Nevada. Because of the unusual architectural designs incorporated into these buildings, the mechanical smoke management systems must also be just as unusual. This article provides an overview of two unique smoke management designs and demonstrates that structures need not be completely unique to warrant different ways of thinking about limiting smoke movement.

THE LUXOR PYRAMID

The 30-story Luxor Hotel and Casino is certainly one of the most unique structures in the world. Its principal feature is its pyramidal shape. The interior contains an atrium exceeding 595,000 m^3 (21,000,000 ft^3) in volume. Interior dimensions are approximately 150 m by 150 m (500 ft. by 500 ft.) at the base and 37 m by 37 m (120 ft. by 120 ft.) at the uppermost level, which is 61 m (200 ft.) up.

The casino level is actually the ground floor and is located directly below the lowest level of the atrium (Attractions Level). The Attractions Level contains several interior structures, including restaurants and three theaters, that are occupiable. Several additional structures are strictly facades and essentially unoccupiable.

Balconies, which are open to the atrium on 27 floors, provide access to more than 2,500 guest rooms. A room at the apex of the pyramid contains mechanical equipment.

SMOKE MANAGEMENT APPROACH

At the time the facility was being designed, the 1988 Uniform Building Code required a minimum mechanical exhaust capacity of four air changes per hour (ACH). In

Attractions Level. Notice slots in “obelisk” for beam detectors.

atria, the code also required one-half of the air being exhausted to be mechanically injected upward at the base of the atrium. This translated to an exhaust capacity of approximately 635 m^3/s (1,350,000 cfm) and 320 m^3/s (675,000 cfm) of supply.

These prescriptive requirements created several problem areas. The mechanical room at the top of the pyramid would have to be designed to accommodate this number and weight of fans. A significant wall area of exterior grills would be necessary. Since the atrium narrows as it approaches the top, the upper several levels of exit balconies could have excessive air velocity upon activation of the smoke management system. Stratification of smoke could limit the ability to exhaust smoke and cause intermediate levels to become untenable.

One of the main concerns was smoke obscuring exit balconies while it was being drawn upward. Smoke is expected to rise until it contacts one of the exit balconies. That balcony and balconies above can be expected to become untenable.

It appeared that strict code compliance might not solve these concerns and could actually increase the hazard to occupants on upper levels. It was agreed that a performance-based approach may be better able to achieve the desired goals than the prescriptive requirements. The basic fire protection goals agreed to were:

- Maintain a tenable environment for occupants not intimate with the fire.
- Limit temperature and smoke generated by a fire to maintain exit balconies tenable for evacuation purposes.
- Reduce the impact of stratification of smoke at an intermediate level.

The engineer working with the design team proposed a radical departure from the prescriptive code. He suggested a series of fans and ducts supplying air to the lowest level open to the atrium, oriented such that the entire volume of air would rotate (as viewed from above). This rotation was to work in conjunction with exhaust fans located in the mechanical room at the top of the pyramid. He theorized that this counterclockwise rotation would cause smoke to be drawn into the atrium void, away from exit balconies, while it was being exhausted out the apex of the atrium.

The Clark County review team (consisting of Clark County Building and Fire Departments and third-party peer reviewers) was skeptical that this proposal would achieve the desired goals but agreed that the concept would be considered if adequate documentation could be submitted to substantiate the proposed design.

The architectural design of the Attractions Level also needed to be taken into consideration. Due to the height of the space, the Attractions Level is essentially unprotected by automatic sprinklers. Agreements were reached that significantly restricted the combustible load in nonsprinklered portions of the Attractions Level. It was agreed that the fire size expected within the atrium would not exceed 2110 kW (2000 BTU/s) maximum heat release rate.

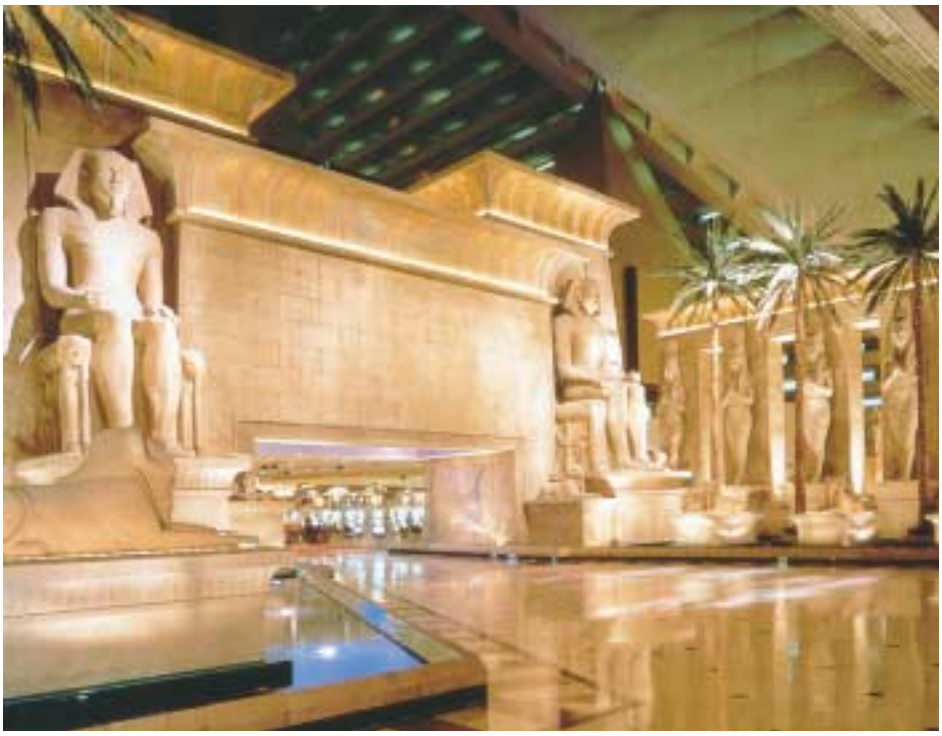
For estimating smoke quantity, carbon monoxide levels, direction of air movement, and temperature, the design team used several recognized references.[1, 2, 3, 4, 5, 6]

The FloVENT computer model[1] indicated that this counterclockwise rotation in conjunction with the mechanical exhaust, would draw the air mass toward the center of the atrium and up. Alternate calculations were performed to provide a comfort level that smoke would be diluted to tenable concentrations, as well as reduce heat buildup on exit balconies. Calculations indicated that temperature and carbon monoxide levels would be within tenable limits 23 m (75 ft.) above the nozzle of the vortex supply fans.

The Clark County review team thoroughly analyzed the proposed design. Several meetings and iterations of the design were necessary to achieve concurrence, which allowed this unique smoke control design to be conditionally approved. Final acceptance was based on the system's performance during commissioning.

Eight supply fans were installed outside the building at the base of the pyramid. Their associated ductwork was routed to the interior perimeter

Attractions Level. East interior view taken shortly after Luxor's grand opening in the mid-'90s.



First Floor. Main entrance into the casino complex.

portions at the base of the atrium. Each of these fans is capable of providing up to 14 m^3/s (30,000 cfm) at 16.0 m/s (3,150 ft. per minute). The discharge was oriented approximately 22 degrees from the horizontal and 11 degrees from guestroom balconies. A total atrium exhaust rate of 188 m^3/s (400,000 cfm) was provided at the apex of the atrium. This combination of exhaust and injection ports creates a high-velocity air stream parallel to guest room balconies, which causes a low-pressure area that draws smoke into the atrium to be exhausted out through the apex. This design actually provides less than one air change per hour.

The atrium smoke management system activates whenever any of the following events occur: automatic sprinkler water flow anywhere in the atrium (including any exit balcony); operation of any two of the more than 2,000 area smoke detectors installed on the exit balconies; or activation of any one of 24 beam smoke detectors located in a structure in the center of the Attractions Level. Manual overrides are also provided in a protected room specifically designated for fire department emergency response (FCC).

ACCEPTANCE TESTING/ COMMISSIONING

After the contractors and designers have confirmed fire protection systems function as intended and prior to granting occupancy for any major facility, Clark County Building and Fire Departments witness "all systems" tests. These series of tests are intended to simulate reasonable fire scenarios. A significant portion of the facility is methodically stepped through to confirm proper functioning, as well as coordination of all fire protection systems.

During testing of the atrium smoke-control system, a 2,110 kW (2,000 BTU/s), 3 m (10 ft.) diameter, propane burner was moved onto the Attractions Level. Theatrical smoke was injected into the heat plume generated by the propane burner to visually verify air movement. Through visual verification, as well as review of the computer output from carbon dioxide monitors and thermocouples placed at twelve locations on the exit balconies, it was determined that the atrium system functioned as indicated by the models. Proper configuring of all dampers, fans, and other operating equipment was also confirmed. Status and manual overrides were confirmed from the FCC.

To simulate a guestroom fire with the door blocked open, the engineer of record injected theatrical smoke onto one intermediate-level balcony. While the air mass was rotating, the "floor of origin" was relatively clear. The theatrical smoke did not adversely impact alternate floors. Smoke was drawn into the atrium and exhausted out through the apex. Without the air mass rotating, the theatrical smoke not only impacted the floor of origin, but also the balconies above and below.

During an alternate test, theatrical smoke was injected onto one of the corners of an exit balcony where the exit stairs and elevator lobbies create a partial enclosure. Initially, the smoke was so thick that visibility was reduced to approximately 1 m (3 ft.). Within a couple of minutes, the rotational air mass drew smoke from the enclosed portion of the balcony into the atrium and toward the exhaust fans to the extent that visibility was increased significantly.

THE MGM MANSION

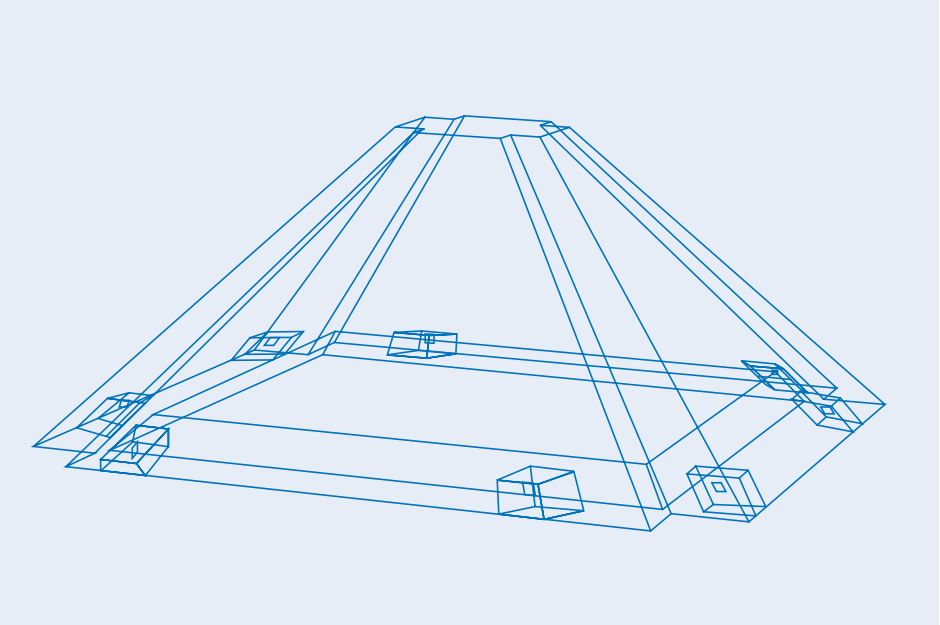
The MGM Hotel and Casino boasts more guestrooms than any other hotel in the world (more than 5,000). A few years after opening, the owners decided to add a four-story atrium with a domed skylight above a garden-like central court. This portion of the facility was to contain 25 guest suites for the world's elite, each ranging in size from 740 m^2 (8,000 ft^3) to 1100 m^2 (12,000 ft^3). Each suite was to be a single level with windows and private balconies opening onto the central court.

To make these "villas" as comfortable as possible, the designers decided on operable windows and doors from the suites into the atrium on all four levels. Furthermore, these doors and windows were proposed to be neither fire-rated nor self- or automatic-closing. The prescriptive codes adopted at that time were the 1994 Uniform Codes, which specifically required the interface between guestrooms and the atrium to act as a smoke barrier and, therefore, did not allow this proposed arrangement.

SMOKE MANAGEMENT APPROACH

To justify this arrangement, the fire protection engineer of record proposed mitigating measures to provide the level of protection intended by the prescriptive requirements. Since all exits above the atrium floor were independent of the atrium, it was proposed to use the atrium void as a smoke reservoir. Approximately one-half of the mechanically supplied air would be injected into the guest suites with the remainder injected at low velocity near the atrium floor. All exhaust fans were located at the top of the atrium.

This design concept was dependent on the area of fire origin. The smoke management scenario would be different if the fire were in the atrium or in a guest suite. To compensate for this, the automatic sprinklers protecting the suites were zoned independently from those protecting the atrium space. Beam-type smoke detectors were installed at two levels within the atrium to help compensate for stratification. In addition, area-type smoke detectors were installed in the suites at openings into the atrium, as well as within each sleeping room. Using these initiating devices, the supply air could be deactivated within the suites on the floor of origin if it were determined that the fire originated within one of the suites.



Three-dimensional view of Luxor interior, showing approximate locations of vortex injection fans.

Automatic sprinklers protecting the atrium were installed just below the atrium skylight, approximately 34 m (110 ft.) high. At this height, the automatic sprinklers are not expected to adequately control a fire on the floor. Therefore, a thorough analysis was conducted of reasonable fire scenarios on the atrium floor. Due to the limited combustible load, it was determined that the maximum expected fire size would not exceed the minimum fire size required by the Uniform Building Code of 5,275 kW (5,000 BTU/s). Doubling this fire size for a factor of safety, the smoke plume dynamics were estimated, and the exhaust fans were sized to provide at least 141 m^3/s (300,000 cfm). This design is expected

Luxor exterior, southeast exposure.

Luxor facility model showing new twin towers along with existing pyramid and sphinx. Viewed from northeast side.

to contain smoke from the maximum design fire at a reasonable level above the atrium floor, but it is not sufficient to maintain smoke below the upper guestroom levels.

The quantity of supply air into the suites was proposed to be limited to a maximum, based on all the doors and windows open. To restrict smoke migration from the atrium into the suites, the minimum velocity of supply air needed from the suites through these openings was estimated to be 0.66 m/s (130 ft./min), which was also less than the 1 m/s (200 ft./min) limit believed to impact plume dynamics. If all the doors and windows were closed, the pressure in the atrium would be negative relative to the guest suites, which would also restrict smoke migration into an uninvolved suite.

This arrangement is expected to protect occupants whether on the atrium floor or in an uninvolved suite by maintaining smoke above the atrium floor and restricting smoke migration into an uninvolved suite. This approach allows occupants to remain in uninvolved suites or safely evacuate the building.

ACCEPTANCE TESTING/ COMMISSIONING

Airflow and pressure differences were measured at various locations throughout the addition. Initial testing uncovered aspects of the system that were not performing as expected. Upon examination, the problem areas were determined, and correcting measures were implemented. In this case, it was not only necessary to modify the system, but it was actually necessary to revise the design concept in order to determine if the system actually was able to provide the level of protection intended by code.

The system as described above is the final design that was accepted for this facility; but this example not only illustrates a unique approach for managing smoke, it is also a reminder that we must not lose sight of our initial goal. In this case, our principal goal was to reduce the potential for smoke migration into an uninvolved suite and maintain the atrium floor safe for evacuation. If it appears that our first attempt to meet our goal has failed, maybe we only need to change the way we think about achieving that goal in order to realize the simplicity of the solution.

Douglas Evans is with the Clark County, Nevada, Department of Building.

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USING MODELS TO SUPPORT Smoke Management System Design

By James A. Milke, Ph.D., P.E.

An engineering analysis is needed to assess the ability of a smoke management system to satisfy stipulated performance criteria. This analysis can be conducted to verify acceptability, numerically test, or troubleshoot problems associated with the system.

The pressure difference between spaces is the focus of analyzing stair pressurization and zoned smoke control systems. For smoke management systems in atria, the analysis consists of assessing the residual hazard posed by smoke in terms of the extent of smoke spread, smoke layer depth, or smoke layer properties. In many cases, a simplified analysis involving the application of algebraic equations[1, 2] is suitable to assess the performance of smoke management systems.

However, in some cases, the assumptions associated with the algebraic equations are unacceptable. For stairwell pressurization systems, the algebraic equations neglect vertical leakage and wind, and require symmetry if more than one pressurized stair is provided. Limitations of algebraic equation methods for atrium smoke management are:

- steady or t^2 fires only;
- uniform horizontal cross-sectional area for all levels of the atrium;
- uniform conditions throughout the upper layer/zone, even in spaces with large horizontal areas; and
- analysis of the pre-venting, smoke-filling period or steady, equilibrium conditions during venting.

Algebraic equation methods cannot address the interaction between multiple smoke management systems, such as stair pressurization and atrium smoke exhaust, in the same building.

Several types of models are available to assist design professionals either in lieu of or as a supplement to the algebraic equations. These models include small-scale physical models, computer-based zone models, network flow models, and CFD models. While this article provides an overview of all of these models, the emphasis is on small-scale models and network models, given the extensive treatment of zone and CFD models elsewhere.

SMALL-SCALE MODELS

Small-scale models provide physical representations of a space, though in a reduced scale. Scale models are especially useful in examining atria with numerous projections or irregular shapes. Milke and Klote review the application of scale models as a design aid for smoke management systems[3]. Quintiere and Dillon developed a scale model to assess the performance of a smoke management system in a fire incident in a covered mall.[4]

A small-scale model may be designed following the principles of Froude modeling. Quintiere[5] provided a review of scaling relationships to preserve the Froude number. The scaling relationships seek to preserve the following ratios:

- fire energy/flow energy;
- fan flow/buoyant flow; and
- convection heat transfer/wall heat transfer.

The scaling relationships are:

Temperature: $T_m = T_F$ (1)

Position: $x_m = x_F\left(\frac{l_m}{l_F}\right)$ (2)

Pressure: $\Delta p_m = \Delta p_F\left(\frac{l_m}{l_F}\right)$ (3)

Velocity: $v_m = v_F\left(\frac{l_m}{l_F}\right)^{1/2}$ (4)

Time: $t_m = t_F\left(\frac{l_m}{l_F}\right)^{1/2}$ (5)

Convective Heat Release:

$$Q_{c,m} = Q_{c,F}\left(\frac{l_m}{l_F}\right)^{5/2} \quad (6)$$

Volumetric Flow Rate:

$$\dot{V}_{fan,m} = \dot{V}_{fan,F}\left(\frac{l_m}{l_F}\right)^{5/2} \quad (7)$$

The subscripts *m* and *F* correspond to model and full-scale, respectively.

Many of the parameters in equations (1) to (7) are functions of time. Thus the scaled parameters should also be functions of time. Froude modeling has the advantage of conducting experiments in air at atmospheric pressure. While Froude modeling does not preserve the Reynolds number, achieving fully developed flow by making the critical dimensions of the model at least 0.3 m minimizes this shortcoming. Fully developed flow only needs to be achieved in those areas where the smoke behavior is of interest. The critical dimension for a model of a shopping center and atria could be the distance from the floor to the underside of a balcony.

In addition, Froude modeling does not preserve the dimensionless heat transfer parameters. Often, this limitation has little effect because the temperature is the same for the scale model and the full-scale facility. While Froude modeling is inapplicable in high-temperature locations, e.g., near the flame, Froude modeling still provides useful information about smoke transport away from the fire.

Some surface effects can be preserved by scaling the thermal properties of the construction materials for the model. The thermal properties can be scaled by:

Thermal properties:

$$\left(k\rho c_p\right)_{w,m} = \left(k\rho c_p\right)_{w,F}\left(\frac{l_m}{l_F}\right)^{0.9} \qquad (8)$$

However, selection of enclosure materials may be acceptably based on flow visualization needs, rather than scaling of thermal properties, given the secondary effect of the thermal properties on fluid flow.

EXAMPLE 1

A scale model is proposed to determine the equilibrium smoke layer position for the atrium depicted in Figure 1. Because the horizontal cross-sectional area varies with height, algebraic equation and computer-based zone models are of limited value. The atrium height is 30.5 m, and the design fire is a 5 MW steady fire. The proposed exhaust fan capacity is 142 m^3/s. By applying the scaling relationships, the basic parameters for the scale model are:

- Height: 3.8 m tall model (1/8 scale)
- Fire size: 28 kW
- Fan capacity: 0.78 m^3/s

Given the 1/8 scale, the width of the scaled spill plume would need to be 1/8 of that at full scale.

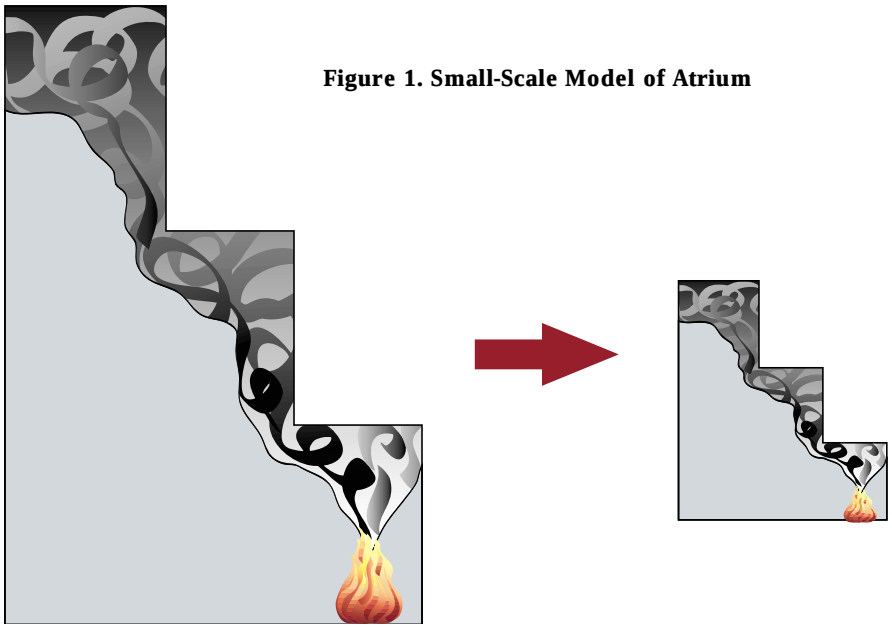

Figure 1. Small-Scale Model of Atrium

COMPUTER-BASED ZONE MODELS

Overviews of numerous zone models are available.[6, 7] Quintiere summarizes the assumptions of zone models[8]. The principal advantage of computer-based zone models is their ability to address transient effects involving smoke spread, delays in fan startup, effects of environmental conditions, and a variety of fire-growth profiles. Some computer-based zone models are applicable to spaces where the ceiling is sloped or the horizontal cross-sectional area varies with height. In addition, some of the computer-based zone models simulate conditions in multiple rooms or levels, where the algebraic equations are limited to a single compartment.

Limitations of these models result from their assumptions. For example:

- the smoke layer forms immediately, neglecting transport lag;
- the plume is unaffected by wind or mechanical ventilation;
- the upper layer/zone is uniform, independent of the area involved; and
- as smoke enters a tall room from a short room, entrainment is determined based on a new axisymmetric plume rather than from a balcony spill or line plume.

FIELD MODELS

Computational fluid dynamics (CFD) models simulate fluid flow at a level of detail impossible with other methods of computer modeling.[9, 10, 11] CFD models divide the fluid flow field into numerous small cells and numerically solve the conservation equations of mass, momentum, and energy for each cell. Boundary conditions are established at the room boundaries, openings to the outside, and exhaust inlets by specifying velocities.

While generalizations concerning the number and size of cells are difficult to make, given the wide range of features and capabilities of CFD models, generally the smallest cells are near the fire and at the ceiling. The governing equations cannot account for tur-

bulence on a scale smaller than the cells. Further, it is important that the cell size and time step be coordinated so that cells are not "skipped" from one time step to the next by the moving fluid.

NETWORK FLOW MODELS

Network flow models such as CONTAM96[12] can be applied to evaluate pressure differences between compartments, direction of mass flows, and movement of contaminants. CONTAM96 is often described as the successor to ASCOS, an early, widely used network flow model[13]. Network models simulate a building as a network of airflow paths comprised of doorways, windows, vents, and leaks in building assemblies.

The principle advantage of network flow models is their ability to consider:

- mechanical and natural ventilation;
- environmental conditions (including wind);
- interacting smoke management systems;
- buildings with complex geometries; and
- leakage paths between building spaces.

Limitations of network flow models such as CONTAM96 are:

- uniform conditions (temperature and concentration of contaminants) are assumed throughout each "zone", where a "zone" is at least one room.
- transient fire conditions (e.g., temperature or mass flow in the smoke plume or temperature in the fire zone) resulting from a growing fire are not considered.

However, fire conditions can be incorporated into the model by analogy. The volumetric flow in a smoke plume can be simulated as a shaft, with a fan supplying air at each level of the shaft. The air entrained at each level can be estimated using Heskestad's plume entrainment equation.[14]

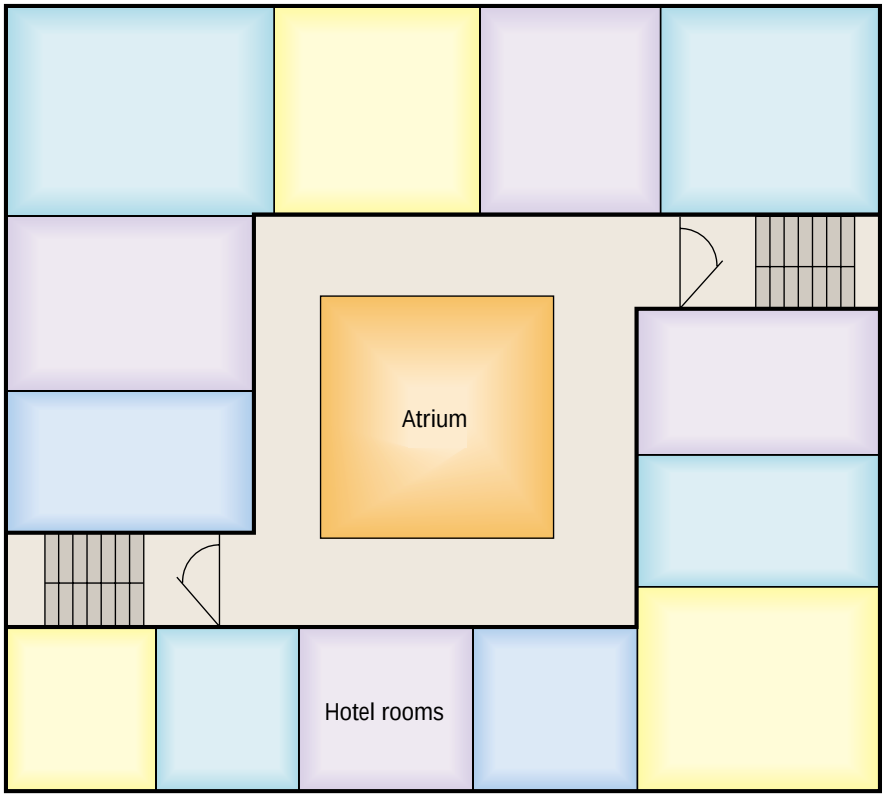

Figure 2. Typical floor of five-story building.

$$\rho \dot{V} = .071 \dot{Q}_c^{1/3} z^{5/3} + 0.0013 \dot{Q}_c \qquad (9)$$

where:

$\dot{V}$ = volumetric entrainment rate (m^3/s)
ρ = density of smoke (kg/m^3)
$\dot{Q}$ = convective portion of heat release rate (kW)
z = clear height (m)

The entrainment for a particular level needs to be determined based on the amount of air entrained only within that increment of height. As such, the amount of air entrained for a particular level of the building is the difference in the amount of air entrained up to the top of the level with that entrained up to the bottom of that level. Buoyancy effects can be included by setting the temperature at each level of the "shaft" using Heskestad's plume centerline correlation.[14]

$$\Delta T_c = 25 \dot{Q}_c^{2/3} z^{-5/3} \qquad (10)$$

where:

T_c = plume centerline temperature (°C)
$\dot{Q}$ = convective portion of heat release rate of fire (kW)
z = height above top of fuel (m)

While the centerline temperature of the plume overestimates the buoyancy of the overall plume, generally this approach is adequate for design purposes.

The mass release rate of contaminant can be estimated as:

$$\dot{m}_c = f_c \frac{\dot{Q}}{\Delta H_c} \qquad (11)$$

where:

$\dot{m}_c$ = generation rate of contaminant (kg/s)
f_c = yield fraction (kg contaminant/kg fuel) [the yield fraction depends on the fuel, burning mode (flaming, smoldering) and the available oxygen concentration]
$\dot{Q}$ = heat release rate of fire (kW)
ΔH_c = heat of combustion (kJ/kg)

CONTAM96 can conduct a steady or unsteady analysis of the flow of contaminants (smoke). Input for CONTAM96 includes:

- Area and height of spaces
- Shaft characteristics
- HVAC system

Table 1.
Pressure Difference at Stairwell (Pa) from CONTAM96 Analysis

Floor	No Atrium Exhaust	160 m^3/s exhaust 76 m^3/s supply	160 m^3/s exhaust 94 m^3/s supply
1	54.8	65.2	61.0
2	55.0	65.7	61.5
3	55.3	66.2	62.0
4	55.8	67.0	62.7
5	56.8	68.0	64.0
6	58.0	69.5	65.2

- Fans: constant volume, mass, or curve
- Environmental conditions: wind, temperature
- Connection of spaces via leakage paths
- Release rate of contaminant (kg/s): unsteady or steady

Output from CONTAM96 includes:
- Pressure difference between zones
- Airflow between zones
- Contaminant concentration in zone

An example application of CONTAM96 is provided for a five-story building (see Figure 2). Using CONTAM96, the interaction between the atrium smoke management and stairwell pressurization systems is investigated. The capacity of the stairwell pressurization fans is 2.83 m^3/s. The exhaust fan capacity in the atrium is 160 m^3/s, with two simulations conducted with the capacity of the make-up air fans being either 76 or 94 m^3/s. The resulting pressure differences are provided in Table 1. The pressure differences for the stairwell pressurization systems acting alone or together with the atrium smoke management system are appreciably different.

Computer-based and physical models are applicable as aids for smoke management design. Because each of the models provides simplifications of actual behavior, models can be used as an aid in establishing or testing the design of a smoke management system. The appropriateness of assumptions should be confirmed, either by comparing predictions to data or conducting a sensitivity analysis.

James Milke is with the University of Maryland.

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An Overview of

Atrium Smoke Management

By John H. Klote, Ph.D., P.E.

A few years ago, most codes in the United States mandated the air change method that based the smoke exhaust flow rate of an atrium on the volume of the atrium. While this method is simple to apply, it almost always provides the wrong answer. Today, most codes prescribe atrium smoke protection that is based on the zone fire model concept that is discussed later in this paper.

This paper is an overview of smoke control technology, including new information that has been proposed for addition to *NFPA 92B*. More detailed design information on this subject can be found in the following publications: *NFPA 92B*,[1] the ASHRAE/SFPE smoke control book by Klote and Milke[2], and *NISTIR 5516* by Klote.[3]

TERMINOLOGY

Readers of the above publications are cautioned about the meaning of the terms *smoke control* and *smoke management*. The term smoke control is reserved for systems that provide smoke protection by use of pressurization, such as a pressurized stairwell. Systems that use any technique including compartmentation, pressurization, airflow, 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 for the other types of atrium smoke protection discussed below.

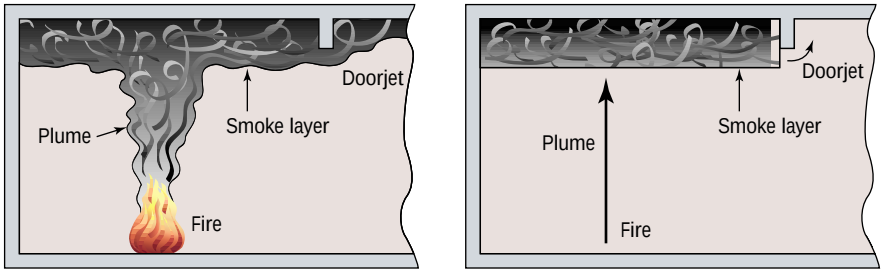
For smoke management purposes, *smoke* is considered to consist of the airborne products of combustion plus the air that is mixed with them. The airborne products are combustion gases, solid particulates, and liquid particulates. Inclusion of air in the definition of smoke allows us to consider smoke protection systems where the smoke being generated, exhausted, or vented is actually air mixed with relatively small quantities of particulates and combustion gases. Because the concentrations of these other quantities are relatively small, engineering design analysis for these smoke management systems considers the specific heat, gas constant, and other properties of smoke to be the same as those of air.

An atrium can be considered a large space of two or more stories. Other large open spaces include enclosed shopping malls, arcades, sports arenas, exhibition halls, and airplane hangars. The methods of this paper also apply to these spaces. For simplicity, the term atrium is used in this paper in a generic sense to mean any of these large spaces.

ZONE FIRE MODEL CONCEPT

All conventional approaches to atrium smoke management are based on the zone fire model concept. This concept is also the basis of several computer models.[4, 5, 6, 7, 8] This section is a brief synopsis of zone fire modeling, but for more information about this subject, readers are referred to other sources.[9, 10, 11, 12]

Because zone fire models were originally developed for room fires, this discussion will start with a room fire. In a room fire, hot gases rise above the fire, and these gases form a plume. Since the plume entrains air, the diameter and mass flow rate of the plume increase with elevation. Accordingly, the plume temperature decreases with



(a) Sketch of an atrium fire (b) Zone model idealization of atrium fire

Figure 1. Room fire (a) sketch and (b) zone model idealization

elevation. The fire gases of the plume flow upward and form a hot stratified layer under the ceiling. Hot gases in this smoke layer can flow through openings in walls to other spaces, and such flow is referred to as a doorjet. The doorjet is similar to a plume in that air is entrained with similar effects on mass flow and temperature. Figure 1(a) is a sketch of a room fire.

The concept of zone modeling is an idealization of the room fire conditions as illustrated in Figure 1(b). For this idealization, the temperature of the hot upper layer of the room is uniform, and the temperature of the lower layer is also uniform. The height of the discontinuity between the two layers is the same everywhere in the room. The dynamic effect on pressure is considered negligible, so that pressure is treated as hydrostatic. Other properties are considered uniform for each layer. Algebraic equations are used to calculate the mass flows due to plumes and doorjets.

Some computer zone fire models allow exhaust from the upper layer, and this capability is essential for simulation of atrium smoke exhaust systems. Many zone fire models estimate heat transfer by methods ranging from a simple allowance as a fraction of the heat release of the fire to more complicated simulations of conduction, convection, and radiation. Zone model application to atrium smoke exhaust is illustrated in Figures 2(a) and (b).

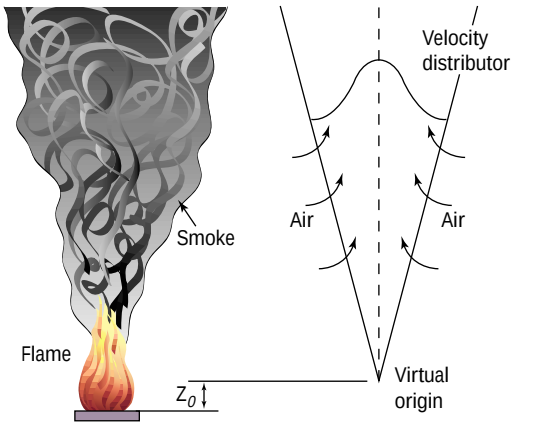
AXISYMMETRIC PLUME MODELS

Morton, Taylor, and Turner[13] developed the classic analysis of the time-averaged flow of plumes. For a height above the plume source, they considered the air entrained at the plume edge to be proportional to some characteristic velocity of the plume at that height. They considered the plume to be coming from a *point source* that may be either above or below the surface of the fuel. Figure 3 is an illustration of a plume next to the idealized model of an axisymmetric plume.

Researchers have extended the work of Morton, Taylor, and Turner to develop models of turbulent plumes due to fires in building spaces.[14, 15, 16] No exhaustive study has been conducted to evaluate these plume models for various applications. Based on the limited information available, it seems that the Heskestad model may be the most appropriate for atrium applications.

The axisymmetric plume equations of the design publications mentioned above are those of Heskestad except that the virtual origin correction has been neglected. The justification for this simplification is that the virtual origin correction, z_o, is small compared to the plume heights of interest in atrium applications. Further, for a general design fire of unknown fuel, the virtual origin correction, z_o, can be either positive or negative. Additional information about the virtual origin correction is provided by Klote.[3]

The mass flow of a plume depends on the height, z, and heat release rate, $\dot{Q}$. Because of an improved understanding of plume physics, the proposed *NFPA 92B* has changed z to mean the height above the base of the fuel rather than the height above the top of the fuel. This results in somewhat larger values of z and correspondingly higher smoke exhaust flow rates.



(a) Sketch of plume (b) Idealization of plume model

Figure 3. Axisymmetric, point source plume (a) sketch and (b) idealized model

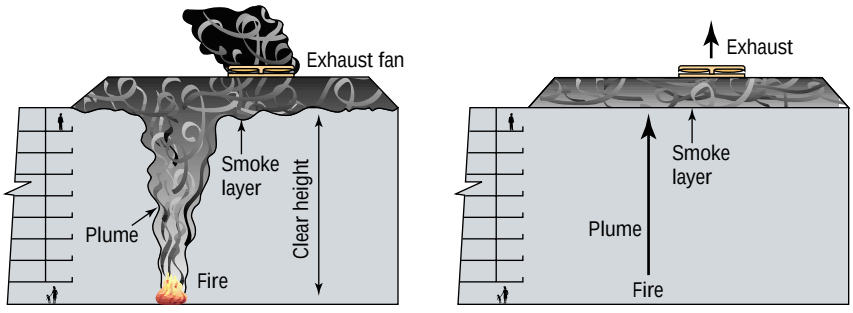
The temperature drop due to elevation is dramatic as can be seen from Figure 4, and the concern with sprinkler performance for high ceiling spaces becomes apparent.

Heskestad developed his equations for strongly buoyant plumes, and it follows that these equations are not applicable for small plume temperature rises above ambient. While little research has been conducted on these temperature limits, this author suggests that the axisymmetric plume equations of *NFPA 92B* not be used for temperature rises less than 2 °C (4 °F).

It should be noted that computer zone fire models do not use the plume equations of *NFPA 92B*. This is because of numerical difficulties associated with a discontinuity in these equations at the mean flame height. Readers should expect some differences between calculations made with the equations of *NFPA 92B* and computer zone fire models.

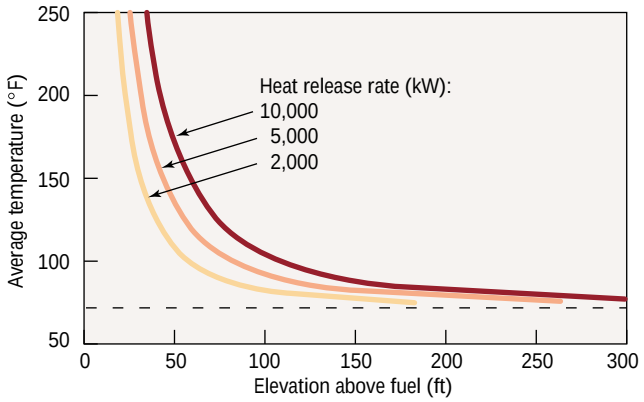
BALCONY SPILL PLUMES

NFPA 92B refers to balcony spill plumes and window plumes. These two types of plume are very different and should not be confused. A balcony spill plume can be from any size fire such that smoke flows under a balcony ceiling and into an atrium, and a window plume is from a post-flashover fire such that the smoke flows from the fire room through an opening to an atrium.



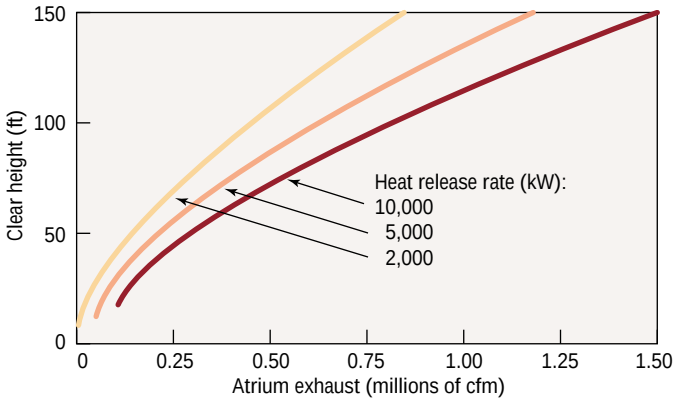
(a) Sketch of an atrium fire (b) Zone model idealization of atrium fire

Figure 2. Atrium fire (a) sketch and (b) zone model idealization



Note: Average temperature calculated from equations of *NFPA 92B* (1995).

Figure 4. Average temperature of axisymmetric plume



Note: Atrium exhaust calculated from equations of *NFPA 92B*.

Figure 6. Atrium exhaust needed to maintain a constant clear height with a fire in the atrium

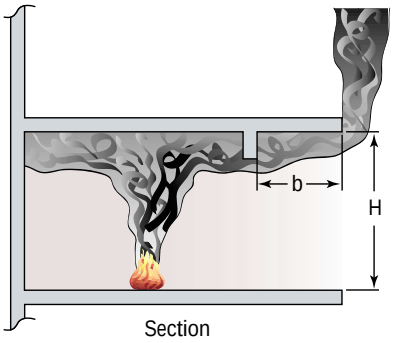
°C = (°F-32)/1.8 1 m = 3.3 ft. 1 m³/s = 2100 cfm

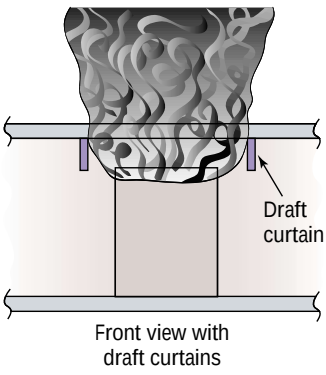
The balcony spill plume equations in *NFPA 92B* are for a fire in a room that opens to a balcony (see Figure 5). It should be noted that the balcony spill plume figure in the 1995 edition of *NFPA 92B* incorrectly shows the fire on the balcony, but this will be corrected.

The balcony spill plume equations of *NFPA 92B* only apply when there is a doorway lintel between the fire room and the balcony. This lintel must be enough below the ceiling so that the momentum of the ceiling jet in the fire room does not directly contribute to the flow out the opening. A ceiling jet consisting of smoke flowing radially under the ceiling forms where a fire plume impacts the ceiling. The depth of the ceiling jet is about 10 percent to 20 percent of the height from the base of the fire to the ceiling.

The balcony spill plume equations of *NFPA 92B* also are used in the United Kingdom.[17] Morgan et al.[18] present a number of approaches that go beyond the constraints of the *NFPA 92B* equations. In general, these approaches are based on the perimeter of the fire rather than the heat release rate, and they require somewhat more cumbersome calculations. When faced with situations that are different from the spill plume of *NFPA 92B*, designers may want to consider the approaches of Morgan, et al.

For narrow balconies, smoke can curl inward toward the structure and move into portions of any balconies above. Morgan et al. indicate that experiments have shown that such inward curling smoke can occur for balconies less than 2 m (6.6 feet) wide.





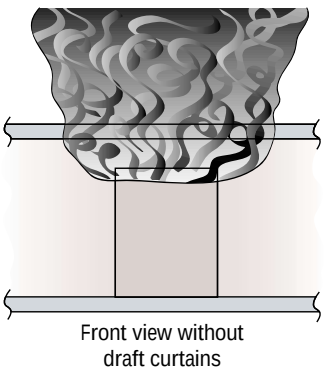


Figure 5. Balcony spill plume

WINDOW PLUMES

A window plume can occur from a post-flashover fire. A post-flashover fire is one in which every object in the fire room that can burn is burning. The heat release rate of a post-flashover fire depends on the amount air available for combustion, and the airflow into the room depends on the size and shape of the opening. Because of the common use of sprinklers, consideration of window plumes generally is reserved for unusual designs.

SMOKE MANAGEMENT SYSTEMS

The following are three types of smoke management systems: (1) fan-powered smoke exhaust, (2) smoke filling, and (3) gravity venting. These systems can be designed for a steady fire or an unsteady fire. For information about design fires, readers are referred to *NFPA 92B* and the ASHRAE/SFPE smoke control book.

The three system types are based on the objective of preventing smoke from contacting occupants. An alternative objective is a system designed to provide tenable conditions even with smoke coming into contact with people. Such tenability systems are recognized by *NFPA 92B*, the ASHRAE/SFPE smoke control book, and CIBSE[17]. Information about tenability design is provided by Klote[19].

SMOKE EXHAUST

Smoke can be exhausted near the top of an atrium to prevent smoke

contact with occupants during evacuation. There are two approaches to design of *smoke exhaust* systems: (1) size the smoke exhaust to maintain a constant clear height and (2) size the smoke exhaust so that a descending smoke layer does not contact occupants during evacuation.

The first approach has the advantage that the calculations are relatively simple, and Figure 6 shows the exhaust needed to maintain a constant clear height with a fire in the atrium. Calculations for the second approach are more complex, and these calculations can be done by computer zone models.

SMOKE FILLING

While smoke exhaust is probably the most common form of atrium smoke management in the United States, some atriums are of such size that no smoke exhaust is needed to keep the occupants from contacting smoke throughout a fire evacuation. This form of smoke management is called *smoke filling* and 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 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 see *The SFPE Handbook of Fire Protection Engineering.*[20]

GRAVITY VENTING

In the United Kingdom and Australia, *gravity venting* is often used where we in the U.S. would use fan-powered smoke exhaust. This natural method consists of opening vents in the atrium ceiling or high on the atrium walls to let the smoke flow out without the aid of fans. The proposed *NFPA 92B* addresses gravity venting systems.

The flow rate through a gravity vent can be calculated, and it depends on the (1) size of the vent, (2) depth of the smoke layer, and (3) temperature of the smoke. When smoke is detected, all the vents need to be opened at one time. Thermally activated vents, like those often used for industrial heat and smoke venting, are inappropriate for gravity venting of atria because of the time delay in opening the vents.

The applicability of gravity venting depends primarily on the (1) size of the atrium, (2) outside design temperatures, and (3) wind conditions. Gravity venting is simpler and less costly than fan-powered exhausting. Because loss of power can occur during fire situations, there is a significant advantage to a smoke management system that requires no power for fans.

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

MAKE-UP AIR

For smoke exhaust systems and gravity venting systems, air must be supplied to the atrium to make up for the smoke exhaust. A few months ago, an engineer erroneously indicated to the author that he thought that make-up air would not be needed for large atria, because they already have such a large volume of air. This is not so. Make-up air is essential for all smoke exhaust systems and gravity venting systems. Make-up air can be either fan powered or nonpowered. The network computer program, CONTAM96,[21] can be used to analyze nonpowered make-up airflows.

VELOCITY LIMIT

There is a concern that air velocity could disrupt the structure of the plume resulting in failure of the smoke management system. The best current information available is that a velocity of 1 m/s (200 fpm) or less will not cause such disruption. For this reason, *NFPA 92B* indicates that velocities should not exceed 1 m/s (200 fpm) in the atrium where there could be a plume. This applies to any air velocity whether it is for make-up air or for some other purpose.

STRATIFICATION AND DETECTION

The issue of smoke stratification is included in the proposed *NFPA 92B*. 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 hot air layer, many professionals believe that such layers are often in excess of 50 °C (120 °F) (Figure 7). When the temperature of the smoke plume is less than that of the prestratified layer, the smoke cannot reach the ceiling. In this situation, the smoke cannot activate ceiling-mounted smoke detectors (Figure 8).

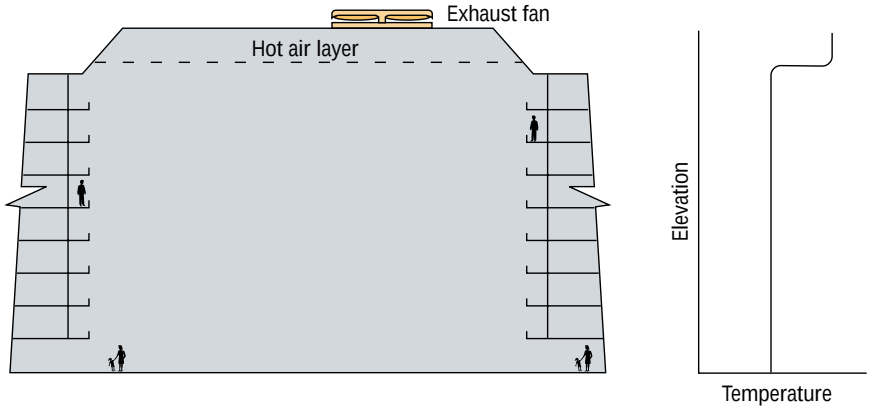
Beam smoke detectors can be used to overcome this detection difficulty, and the proposed *NFPA 92B* describes three methods of using beam detectors for this purpose. Two of the methods employ horizontal beams with the intent of (1) detecting the smoke layer or (2) detecting the plume.

The third method uses upward-angled beams with the intent of detecting the development of a smoke layer at whatever stratification conditions exist. In this third approach, one or more beams are aimed at an upward angle to intersect the smoke layer regardless of the level of smoke stratification. For redundancy when using this approach, more than one beam smoke detector is recommended.

NUMBER OF EXHAUST INLETS

When the smoke layer depth below an exhaust inlet is relatively shallow, a high exhaust rate can lead to entrainment of cold air from the clear layer (Figure 9). This phenomenon is called "plugholing," and it is addressed in the proposed *NFPA 92B*. To prevent plugholing, more than one exhaust inlet point may be needed. The maxi-

Figure 7. Hot layer of air under atrium ceiling (a) sketch and (b) temperature profile



(a) Sketch of hot air layer

(b) Temperature profile

mum mass flow rate, which can be efficiently extracted using a single exhaust inlet, is given as:

$$\dot{V}_{max} = C_1 \beta d^{5/2} \sqrt{T_o(T_s - T_o)} \qquad (1)$$

where:

$\dot{V}_{max}$ = maximum volumetric flow rate at T_s, m³/s (cfm)

T_s = absolute temperature of the smoke layer, K (R)

T_o = absolute ambient temperature, K (R)

d = depth of smoke layer below exhaust inlet, m (ft)

β = exhaust location factor (dimensionless)

C_1 = 0.00887 (0.537)

The above equation is consistent with the approach of *CIBSE* (1995). Based on limited information, suggested values of β are 2.0 for a ceiling exhaust inlet near a wall, 2.0 for a wall exhaust inlet near the ceiling, and 2.8 for a ceiling exhaust inlet far from any walls. It is suggested that d/D be greater than 2, where D is the diameter of the inlet. For exhaust inlets, use $D = 2ab/(a + b)$, where a and b are the length and width of the inlet. The results of experiments conducted at the National Research Council of Canada are consistent with this approach to avoiding plugholing.[22, 23, 24]

SEPARATION BETWEEN INLETS

When the exhaust at an inlet is near this maximum flow rate, adequate separation between exhaust inlets needs to be maintained to minimize interaction between the flows near the inlets. This separation is also addressed in the proposed *NFPA 92B*. One criterion for the separation between inlets is that it be at least the distance from a single inlet that would result in an arbitrarily small velocity based on sink flow. Using 0.2 m/s (40 fpm) as the arbitrary velocity, the minimum separation distance for inlets located in a wall near the ceiling (or in the ceiling near the wall) is:

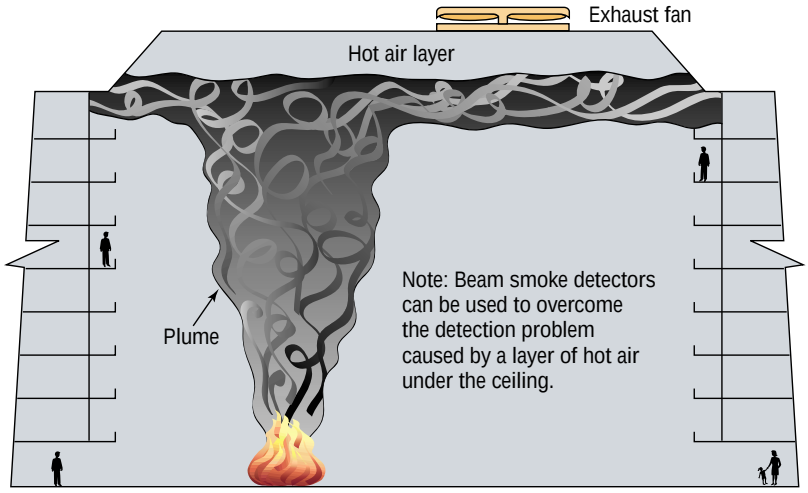


Figure 8. Stratified smoke in an atrium with a hot layer of air under the ceiling

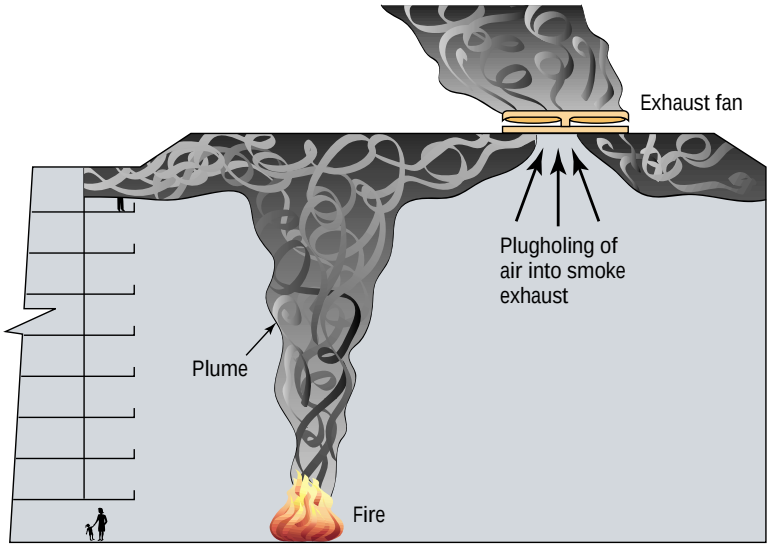


Figure 9. Plugholing of air into smoke exhaust inlets can result in failure of a smoke exhaust system

$$S_{min} = C_2 \beta \sqrt{\dot{V}_e} \qquad (2)$$

where:

S_{min} = minimum separation between inlets, m (ft)

$\dot{V}_e$ = volumetric flow rate, m^3/s (cfm)

β = exhaust location factor (dimensionless)

C_2 = 0.32 (0.023)

SMOKE LAYER DEPTH

The proposed *NFPA 92B* clearly indicates that the smoke layer must be designed to be deep enough to allow for a ceiling jet.

WHEN EQUATIONS DON'T APPLY

As a general rule, it can be stated that equations don't apply when the assumptions behind those equations are not appropriate. For example, the equation for the mass flow of an axisymmetric plume does not apply if obstructions break up the plume flow. Also the basic zone model approach does not apply if the smoke plume cools so much that there is no well-defined smoke layer under the ceiling. Another example would be that the balcony spill equations of *NFPA 92B* do not apply when the fire is on the balcony. It is not possible to catalog all possible situations for which equations don't apply, because of the variety and complexity of buildings. Practitioners need to understand the assumptions behind the equations they use to be sure that the equations apply.

Techniques that can be used when the equations don't apply are (1) scale modeling and (2) 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[10]).

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.

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MODELING SPOT-TYPE SMOKE DETECTOR RESPONSE

Currently Available Methods and Their Merits for Everyday Use

By William E. Pucci, P.E.

INTRODUCTION

Members of the fire protection community are often faced with predicting the response time of spot-type smoke detectors. Many studies have been done and many papers written, but the fact still remains that such predictions are, at best, approximate. This article summarizes the methods currently available with a focus on what everyone should know about smoke detector use.

MOTIVATION

Understanding how smoke detectors react to fire is of utmost importance in meeting fire safety objectives. Early detection of smoke plays a key role in the life safety of building occupants. Many times, smoke detector response is the first indication of a fire in a building. As a result, it would be ideal for design engineers to be able to demonstrate that this response allows occupants sufficient time to safely evacuate before untenable conditions are reached. Similarly, report reviewers, such as Authorities Having Jurisdiction (AHJs), need assurance that smoke detector response calculations are soundly based. They also need to be able to determine whether or not the input to the prediction model was accurate and whether or not a sufficient safety margin was included based on the limitations of the prediction method used. Finally, whether or not spot-type smoke detectors responded properly and promptly is also important to those involved in post-fire reconstruction.

Many professionals oppose the theoretical modeling of smoke detector response altogether. In some respects this opposition is warranted, as the methods commonly used to predict response are not even consistent with the detection mechanism. However, numerous studies have been done for specific situations which, when used as part of an overall analysis, have some merit. This article focuses on conventional, spot-type smoke detectors commonly found in commercial, nuclear, industrial, and residential applications.

REASONS FOR LACK OF ACCURATE MODELS

Despite a fair amount of research on the subject, modeling of smoke detector response is still far from refined. The reason for this lies in the large number of interrelated variables that come into play. These variables include those that affect conditions in the room (which in turn affect operation of detectors) and those that affect the response of a particular detector to those conditions.

Examples of variables that affect conditions within the room include but are not limited to the size and geometry of the room and building, the ambient conditions, the type and arrangement of combustibles, and the nature of fire spread and growth. Since detector response is contingent on conditions within a room, even the slightest change in a single variable can significantly affect detector response.

As far as variables that affect the response of a particular detector, different detectors respond differently to different types of fires. First, photoelectric (light-scattering) smoke detectors use a different operating principle than ionization detectors. Second, small changes in design features between two detectors of the same type can result in different response characteristics. The data reported by manufacturers and testing laboratories are extremely limited in terms of characterizing the response of an individual detector to the many different types of fires that it may be exposed to during its lifetime.

CURRENT METHODS

In short, there are no practical methods for directly modeling the response of photoelectric or ionization spot-type smoke detectors. It isn't that theories don't exist, but the uncertainly in the calculations and the lack of pertinent data make these methods unusable in most cases. What remains then are methods to estimate the response of

spot-type detectors. "Estimate" is defined in *Webster's Ninth New Collegiate Dictionary* as "to judge tentatively or approximately the value, worth, or significance of; to determine roughly the size, extent, or nature of." Thus, anyone who writes a report or makes a statement that a smoke detector "WILL go off at x seconds" is misrepresenting the facts.

KEY POINTS OF SMOKE DETECTOR MODELING

- **There are no practical methods for directly modeling the response of spot-type detectors.**
- **The methods that do exist are merely estimates, and the results from using these methods are approximate at best.**

Photoelectric detectors operate by projecting a light source into a sensing chamber and positioning a light receiver at some angle to that source. If smoke is present, light is reflected and refracted (bent) by the smoke onto the receiver to produce a signal. Ionization detectors rely on a small radioactive source to produce an electrical current between two oppositely charged plates. When smoke enters the chamber of an ionization detector, some ions attach to the smoke particles. The increased mass of the ion slows it down and may allow the small air currents to carry the particle/ion out of the chamber before it reaches the plate on the other side. This reduces the net current flow between the electrical plates. Also, the particle/ion combination is a larger target for collision with an oppositely charged particle. When a positive ion collides with a negative ion, they recombine and further reduce the current flow in the chamber.[1]

The purpose of this article is not to go into detail on the operating principles of the different types of spot-type detectors. However, it is important to recognize that the most widespread method for estimating the response of spot-type detectors is by comparing the amount of smoke (obscuration, or optical density per unit length) at a detector location to the amount of smoke required for that detector to go into alarm. While this concept seems straightforward, neither photoelectric nor ionization detectors use obscuration as a detection method. Nevertheless, optical density is the only practical parameter for estimating the response of spot-type detectors. Two methods on how to predict optical density are discussed below.

TEMPERATURE APPROXIMATION

The most common way that optical density is predicted is through what is know as the "temperature approximation method". In this theory, the optical density in the vicinity of a detector is postulated to be directly proportional to the temperature rise at that location. While the operation of smoke detectors is independent of temperature rise, a temperature rise indicates that combustion products necessary for activating the smoke detectors are present. Because models for estimating temperature rise are fairly well developed, users need only know the temperature rise required for smoke detector activation.

Unfortunately, the principle by which smoke detectors sense fire in a room is considerably more complex than simply monitoring the temperature rise in the vicinity. The temperature approximation method completely ignores several phenomena that affect the response of the detector and therefore cannot be expected to give accurate response times. That being said, due to a lack of other available methods, there is some merit to using this method, if done properly.

First and foremost, the type of fuel that is being burned must be known. As an example, the study that first documented the temperature approximation approach[2, 3] demonstrated that a certain ionization detector required a temperature rise of 14 °C (25 °F) for a wood fire but only 1.7 °C (3 °F) for a cotton fire. Similarly, there are many different kinds of ionization detectors, all of which can alarm at different levels.

In 1985, one study[4] showed how a particular combination of ionization detector and wood crib fuel would result in a temperature rise at response of 13 °C (23 °F). This value has become a common benchmark for detector response since that time. More recent work[5] has proposed a temperature rise of 5 °C (9 °F) for hydrocarbon fires and ionization detectors responding to an obscuration level of 2.5% per meter (i.e., their reported sensitivity). The choice of a certain temperature rise criteria should be carefully selected and justified (see references for limited available data).

MASS OPTICAL DENSITY METHOD

The second method available to predict the optical density in a space is called the mass optical density (D_{mass}) method[1]. In this method, the following equation is used to estimate the optical density per unit length:

$$D_u = \frac{D}{L} = D_{mass}\left(\frac{W_f}{V_c}\right) \qquad (1)$$

where:

D_u = optical density per unit length (m^{-1})
L = path length (m)
D_{mass} = mass optical density (m^2/g)
W_f = mass of fuel burned (g)
V_c = volume in which the smoke is dissipated

Cone and furniture calorimeters are used to experimentally determine values of D_{mass}.

The method requires the user to select a value of D_{mass} for the particular fuel and burning mode. The most complete set of data is available in the *SFPE Handbook of Fire Protection Engineering.*[6] However, not all fuels and burning modes have been tested and reported. Also, while only one value of D_{mass} can be specified, many fuel packages are actually combinations of several different fuel types.

In addition to reported values of D_{mass}, Tewarson[7] examined data from several sources and developed the following equations for when the smoke yield (Y_s) is available:

$D_{mass} = 0.10 \times \ln(Y_s) + 0.52$ (for flaming fires)
$D_{mass} = 0.10 \times \ln(Y_s) + 0.65$ (for smoldering fires)

Regardless of what method is used to determine D_{mass}, the mass optical density method assumes that the smoke produced is uniformly distributed throughout the specified volume. Called a zone model, this, too, introduces error into the results, as optical density can vary from point to point within the volume. Also, not all smoke ends up in the volume, as some is typically deposited on walls, ceilings, and objects within a room as soot. These limitations of zone models, as well as the fuel-specific nature of D_{mass}, should be recognized when making estimates of detector response using mass optical density.

LIMITATIONS ON THE USE OF OPTICAL DENSITY

Neither photoelectric nor ionization detectors use obscuration as a detecting mechanism. Some other important limitations on the use of optical density, the most widespread method of estimating the response of spot-type smoke detectors, are discussed below.

Sensitivity Ratings

Spot-type smoke detectors are labeled by testing laboratories with a single calibration point in obscuration – specifically the response to a smoldering, cotton lamp wick in a chamber with a forced-air current. Fuels other than lamp wicks have different values of obscuration at response, as do different burning modes (i.e., flaming versus smoldering). For example, a detector labeled with a sensitivity of 2.5% per meter may respond at a different obscuration level for a flammable liquid pool fire. Those predicting smoke detector response should consider that the labeled sensitivity does not represent the obscuration level at response for all fuels and burning modes.

Fuel Characteristics

The two most common types of spot-type detectors, ionization and photoelectric, respond differently to different types of fires. All of the work done to date on establishing temperature-rise criteria has been done for flaming fires. A smoldering fire might generate considerably more smoke in the early stages, when the temperature in the room may not necessarily be significantly elevated.

While there are values of D_{mass} reported for pyrolysis (i.e., smoldering combustion), values for flaming fires are more widely reported. An additional limitation of using mass optical density is that the reported values are for specific fuel. In an actual fire, the item first ignited may actually be comprised of several different fuels. The user of this model must therefore determine what value of D_{mass} to use – certainly a subjective determination.

Although little work has been done with smoldering fires, anyone predicting smoke detector response should at least subjectively consider the potential for smoldering fires and their effects on predictions. As a rule of thumb, ionization detectors generally respond more quickly to flaming fires, and photoelectric detectors respond more quickly to smoldering fires.

Wavelength of Light

The value of optical density measured in a test depends on the wavelength of light used. For a given set of test conditions, if the wavelength of the measuring light beam is reduced, the measured optical density will increase. Since the wavelength of the light source in a detector may not be the same as the wavelength of the measuring light beam in a given test, error will be introduced into calculations where the wavelength of light is not considered. This can have a significant impact on the results and is present whenever test data are used to represent potential future fires.

Smoke Entry Resistance

It is possible to take one step beyond the conventional optical density methods, as proposed by Heskestad[8] and further pursued by researchers at the VTT Research Institute in Finland[9] and by Marrion[10] and Oldweiler[11]. This method recognizes the fact that spot-type smoke detectors experience a time lag, as the smoke outside of the detector must penetrate to the inside where the detection mechanism is located. In other words, just because the optical density outside a detector has reached the alarm threshold does not necessarily mean that the optical density inside the detector has reached that level.

Called "smoke entry resistance", the concept is very similar to the RTI of heat detectors in that it identifies a time constant for the lag time associated with entry of smoke into the detection chamber. Items such as insect screens and the geometry of the detector itself contribute to smoke entry resistance. Heskestad proposed that the time lag could be represented by a time constant using the following relaton:[8]

$$L = \tau \times U \qquad (2)$$

where:

L = characteristic length (also known as "L-number") (meters)
τ = detector time constant (seconds)
U = ceiling jet velocity flowing past the detector (m/sec)

In short, the L-number, which has units of length, is interpreted as the distance the smoke would travel at a given velocity before the optical density inside the detector reaches the value outside of the detector. The L-number is thought to be a property of the detector that is independent of the smoke and ceiling jet properties. While this theory holds promise, the data are sparse, and the effect of velocity needs further evaluation. However, the phenomenon has been observed, and particularly for smoldering fires with low gas velocities, users of models should give consideration to its possible influence on results.

CONCLUSIONS

Due to the uncertainty involved in predicting smoke detector response, a range of potential detection times should generally be provided. Additionally, the limitations of the models being used should always be stated, and the applicability of input data to the postulated fire scenario should be considered.

It is clear that more data are needed to be able to predict smoke detector response more accurately. For photoelectric detectors, more information is needed on the optical characteristics produced by different fuels, specifically, how the smoke produced by certain fuels reflects and refracts light at the wavelength used by detectors, and how much reflected/refracted light is

required for response. For ionization detectors, data are needed on the number and size of smoke particles produced by different fuels. Also, data on the velocity of airflow/currents through the detection chamber and its effect on response are needed.

Despite the aforementioned limitations, the past performance of both photoelectric and ionization detectors should not go unnoticed. If installed in accordance with their listing and manufacturer's installation instructions, both types have demonstrated the ability to provide sufficient time for occupants to safely egress. The merits of modeling their response quantitatively will see greater attention as performance-based requirements replace prescriptive ones in model building codes and as owners begin to establish fire safety objectives that include preservation of property and continuity of operations in addition to the life safety of the building occupants.

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Career center

Fire protection engineering is a growing profession with many challenging career opportunities. Contact the Society of Fire Protection Engineers at www.SFPE.org or the organizations below for more information.

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Fire Protection Engineers

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Fire Protection Engineers

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ASCE/SFPE Standard Calculation Methods for Structural Fire Protection, 2000.

In 1997, SFPE began a collaborative activity with the American Society of Civil Engineers and structural material trade associations to develop a series of standards on the calculation of structural fire resistance. The first of these standards, developed under ASCE's ANSI-approved standards development procedures, is a collection of the various methods now available to predict the performance of steel, concrete, masonry, and timber structures in response to the standard fire-resistance test.

SFPE/ASCE Member Price: $28.50 Nonmember Price: $38.00

Enclosure Fire Dynamics, by Bjorn Karlsson and James G. Quintiere, 1999. This 300-page text has been developed to serve as a framework and reference for how to estimate the environmental consequences of a fire in an enclosure. It is based in part on the work in this area developed by Professor Magnusson, Lund University, and is expanded upon with new topics and information from the authors. Ten chapters and three appendices cover such subjects as fire plumes and flame heights, pressure profiles and vent flows, heat transfer, and computer modeling, as well as suggestions for educators.

SFPE Member Price: $59.95 Nonmember Price: $79.95

Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings,

by the SFPE Task Group on Performance-Based Analysis and Design, 2000. This guide outlines a process for carrying out these designs and is essential for anyone who will apply, approve, or be affected by performance-based codes and standards. Chapters cover such topics as: defining your project scope and identifying goals; specifying stakeholders and design objectives; developing performance criteria; creating design fire scenarios and trial designs; evaluating trial designs; and documentation and specifications. Equip yourself for the coming era of performance-based codes with this unique guide!

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Resources

Skin Burn Guide. The SFPE *Engineering Guide to Predicting 1st and 2nd Degree Skin Burns* summarizes accepted calculation methods for predicting pain and first- and superficial second-degree skin burns from radiant heat transfer. Calculation methods are presented that range from simple algorithms to more detailed calculation methods. For each method, the data requirements, possible data sources, inherent assumptions, and limitations are presented. The *Guide* also provides an overview of the physiology of the skin as it relates to thermal injury.

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Sprinkler Hydraulics and What It's All About,

2nd Edition, by Harold S. Wass, Jr. Significantly expanded and updated to the 1999 edition of NFPA 13©, this comprehensive reference on sprinkler hydraulics contains practical information on all aspects of hydraulic design including: sprinkler discharge; friction losses; backflow prevention; relationships to water supply; examples of dead-end, loop, grid, and in-rack sprinkler designs; and inspection and reliability. Written in an easy-to-understand format by one of the industry's acknowledged experts on sprinkler hydraulics.

SFPE Member Price: $50.00 Nonmember Price: $60.00

Fire Sprinkler Systems Video Series,

Protection Knowledge Concepts, Inc., 1999. This four-tape series is designed for anyone who designs, specifies, inspects, buys, approves, or maintains these vital systems. This series covers the basics of fire sprinkler systems, hazard classification, water supplies, and care and maintenance. The set includes a set of 40 test questions and certificates for those who successfully complete the series.

SFPE Member Price: $349.00
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BRAIN TEASER

A grocer purchased 100 kg of potatoes. When they were purchased, the moisture content of the potatoes was 99.0%. Prior to selling the potatoes the grocer checked the moisture content of the potatoes and determined that it was now 98.0%. How many kilograms of potatoes did the grocer now have to sell?

Thanks to Merritt Bauman, P.E., for providing this issue's Brain Teaser.

Solution to last issue's Brain Teaser

The demand for a fire protection system is 0.0576 m^3/s. For this same system, the design area divided by the density is 1,000,000 m × s. What is the system density and design area?

$$D \times A = 0.0576 m^3 / s$$

$$A/D = 1{,}000{,}000 m \times s$$

Solving the second equation for A and substituting it into the first yields

$$1{,}000{,}000 D^2 = 57{,}600 m^2 / s^2$$

Therefore, the density, D, is 0.00024 m/s = 0.24 mm/s, and the design area, A, is 240 m^2.

CORPORATE 100

The SFPE Corporate 100 Program was founded in 1976 to strengthen the relationship between industry and the fire protection engineering community. Membership in the program recognizes those who support the objectives of SFPE and have a genuine concern for the safety of life and property from fire.

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Marsh Risk Consulting
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National Electrical Manufacturers Association
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Sprinkler Design and Layout

Morgan J. Hurley, P.E.
Technical Director
Society of Fire Protection Engineers

Over the last two years, there have been a number of legislative proposals in the State of Florida that were aimed at modifying the statutory relationship between engineers and technicians within the state. Some of these legislative proposals, if implemented, would have reduced the role of the fire protection engineering community in the design of fire protection systems and would have been a disservice to the public at large.

The State of Florida presently requires that engineers design sprinkler systems with 50 or more sprinklers. Sprinkler systems with fewer than 50 sprinklers could be designed either by an engineer or by a technician. This 50-sprinkler threshold is consistent with the SFPE White Paper[1] which states that, for "limited projects," a technician could execute a design concept; and 50 sprinklers would be the definition in the State of Florida of a "limited project."

The SFPE White Paper provides the following examples of "design concepts" for sprinkler systems: determining the density, water flow, and pressure requirements; classification of hazards and commodities to be protected; preparing a preliminary hydraulic design; and confirmation of hydraulic data for the water supply. Similarly, the White Paper lists as examples of "layout" determining the layout of risers, cross mains, branch lines, and sprinklers heads; sizing of pipe; determining hanger locations and; performing detailed hydraulic calculations.

In the State of Florida, "design" has traditionally been defined to include locating sprinklers and piping, sizing sprinkler piping, and performing hydraulic calculations in addition to developing the sprinkler system design concepts. This arrangement is consistent with the SFPE White Paper if the engineer has the necessary education and experience to perform these tasks. In some states, these layout tasks are typically delegated to technicians who work for contractors.

Recent legislative changes in Florida, which are scheduled to become effective in June 2001, add a definition of "layout" to the statutes. Their definition of "layout" is consistent with the definition in the SFPE White Paper.

An owner of a structure has a legal and ethical responsibility to ensure that the structure is designed, constructed, and operated in a safe manner. Building owners typically engage fire protection engineers, among other professionals, to assist the owner in meeting this responsibility. In addition to having a contractual responsibility to an owner, engineers also have a responsibility to the public at large.

While an engineer's clients expect engineers to develop designs that are functional and meet the client's goals, the public also has expectations of engineers. The public places a trust in engineers to develop designs that provide an acceptable level of safety. To this end, states license engineers, and professional societies publish codes of ethics.

Compliance with a code or standard in itself is not sufficient for public safety. It is also necessary to consider any unique features or conditions present and analyze if they warrant consideration beyond what a code or standard requires.

REFERENCES

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