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NBSIR 87-3626

An Overview of Smoke Control Technology

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John H. Klote

Abstract

Considerable advances in smoke control technology have occurred in the last few decades. However, smoke control is just beginning to take its proper place as a fire protection tool. This paper provides an overview of this technology, including discussions of the fundamental principles, stairwell pressurization, zoned smoke control, elevator smoke control, system activation and acceptance testing. In addition the problems of smoke purging are addressed.

Key words: acceptance testing, air conditioning, computer models, elevators, smoke control, smoke movement, stairwells.

1. INTRODUCTION

In building fire situations, smoke flows through numerous leakage paths to locations remote from the fire, threatening life and damaging property. These leakage paths can be open doors, gaps around closed doors, stairwells, elevators shafts and cracks or openings in construction. As a solution to the smoke problem, the concept of smoke control has developed. Smoke control makes use of fans to produce pressure differences and air flows that can control smoke movement.

The idea of pressurizing stairwells to provide a tenable environment within egress routes during building fires was first advanced in the late 1960's. At about the same time, the concept of the "pressure sandwich" evolved. This idea consisted of exhausting the fire floor and pressurizing surrounding floors with the intent of limiting smoke movement to the fire floor. The pressure sandwich concept has evolved into today's zoned smoke control systems.

Research and development of smoke control technology has been conducted worldwide, with the majority having been performed in Canada, England, France, Japan, United States and West Germany. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) published a design manual for smoke control systems (Klote and Fothergill, 1983). This ASHRAE Smoke Control Manual was the first document on the subject specifically intended for use by designers. However, the manual has been used extensively by fire protection professionals and code officials. Recently, the Smoke Management Systems Committee of the National Fire Protection Association (NFPA) has developed a smoke control document, NFPA 92A (1987). This document is in the NFPA review and approval cycle, and acceptance of it will be voted on by the NFPA membership at their annual meeting in November 1987.

The reason for this paper is to provide an overview of smoke control technology including discussions of the advances that have occurred since the publication of the ASHRAE Smoke Control Manual. In addition, the problems of smoke purging are addressed. Because smoke control is still in the early stages of development, no widely accepted view has emerged as to appropriate applications of this new fire protection tool. Much is known about the physical capabilities of smoke control technology, however there are still widely divergent opinions among the experts concerning many practical points of applying this technology. These areas of difference of opinion are identified as such and discussed in this paper. The paper is intended for members of the building design and construction community including HVAC designers, fire protection engineers and code officials. Design analysis methods are discussed in general terms only in this paper, since they are treated in detail in the ASHRAE Smoke Control Manual. Neither this paper nor the ASHRAE Smoke Control Manual address the problems of smoke management of atriums and other large spaces. However, the NFPA Smoke Management Systems Committee is developing a document to address the design of these systems.

In this paper the term "smoke" is used in accordance with the NFPA 92A definition which states that smoke consists of the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.

2. CONCEPT OF SMOKE CONTROL

Smoke control uses the barriers (walls, floors, doors, etc.) in conjunction with airflows and pressure differences produced by mechanical fans. Two basic principles of smoke control can be stated as follows:

- Airflow by itself can control smoke movement if the average velocity is of sufficient magnitude.

- An air pressure difference across a barrier can act to control smoke movement.

The use of air pressure differences across barriers to control smoke movement is frequently referred to as pressurization. Pressurization results in airflows in the small cracks and gaps in barriers, thereby preventing smoke back-flow through these openings. Therefore, in a strict physical sense, the second principle is a special case of the first principle. However, considering the two principles as separate is advantageous for engineering applications of smoke control. For a barrier with one or more large openings, air velocity is the appropriate physical quantity for both design and testing. When there are only small cracks, as around closed doors, designing to and testing for air velocities is impractical. In this case, the appropriate quantity is pressure difference.

The ASHRAE Smoke Control Manual discusses Thomas's methods of estimating the necessary critical air velocity needed to prevent smoke back-flow through a corridor, and this method can be used to obtain an rough estimate for an open doorway or other large opening. This critical velocity depends on the energy release rate and the width of the opening. A room fully involved in fire could have an energy release rate on the order of 8×10^6 Btu/hr (2.4 MW), and for this fire a critical velocity of about 800 fpm (4 m/s) would be needed in to prevent smoke back-flow through a 3 ft (0.9 m) wide doorway. A wastebasket fire might be on the order of 0.43×10^6 Btu/hr (125 kW). To protect against smoke back-flow during this smaller fire, a velocity of about 300 fpm (1.5 m/s) is needed for the same door width. Smoke from a sprinklered fire may be considered to be near ambient temperature due to the cooling effect of water spray. Thomas's method is not appropriate for the small temperature differences due to a sprinklered fire. Based on an analysis by Shaw and Whyte (1974), for a temperature difference of only 3.6 °F (2 °C), an average velocity of 50 fpm (0.25 m/s) would be needed to prevent smoke back-flow.

There are two problems with controlling smoke from unsprinklered fires by airflow: first the air flow rates are very great requiring expensive fans, and second the large flows can result in unacceptably large door opening forces. (What constitutes acceptable door opening forces is discussed later.) Therefore, airflow is not normally relied on as the primary means to achieve smoke control in buildings. Airflow is appropriate for special applications such as tunnels, but it is not discussed further in this paper.

Pressurization is almost always the means by which smoke control is achieved in building situations. However, the effect of open doors in these barriers must be considered. If doors are opened for only for the short time for a person to escape a smoke contaminated space, the resulting small amount of smoke infiltrating into the protected area probably will not adversely affect the performance of the smoke control system. The potential danger of open doors in smoke barriers needs to be evaluated for each application keeping in mind the fire evacuation plan and the total fire protection system of the building.

3. METHOD OF DESIGN ANALYSIS

The methods of design analysis presented in the ASHRAE Smoke Control Manual include applications appropriate for hand held calculators, and more complicated applications which for practical purposes require computer analysis. Chapter 3 of the manual describes the computer program for Analysis of Smoke Control Systems (ASCOS). Since publication of the manual, a version of ASCOS has become available for use on the IBM PC and compatible machines. A disk of this program plus example data files can be obtained for a modest price from the Society of Fire Protection Engineers (60 Batterymarch Street, Boston, MA 02110).

The methods of analysis in the ASHRAE Smoke Control Manual directly incorporate the effects of friction losses in shafts, temperature differences between the inside and outside of the building, and wind forces. The fire effect of smoke buoyancy is not directly incorporated in the methods of analysis. This fire effect is incorporated indirectly in the analysis by selection of the minimum design pressure differences as input parameters for the analysis. The selection of these pressure differences should be based on engineering understanding of fire protection and of fire growth and development. Later in the paper some suggested values of this parameter are presented. Because buildings have many leakage paths, the fire effect of gas expansion is not incorporated in the ASHRAE Smoke Control Manual methods of analysis. For unusually tight spaces, such as bank vaults or military ships, gas expansion should be considered.

An advantage of the analysis approach in the ASHRAE manual is that it is simple and direct lending itself to the time and cost constraints of the day-to-day design world. Further, this method lends itself to design of systems for which acceptance testing criteria is straight forward to establish and apply. Because fire effects are incorporated by the selection of design pressure differences, smoke control systems are designed for the same type of airflow conditions for which they operate during their acceptance tests. Thus acceptance criteria can consist of meeting specific pressure difference requirements as described later in this paper. Clearly, this analysis approach is superior to the rule-of-thumb methods that preceded it.

The results of two separate series of fire tests on pressurized stairwells (DeCicco 1973, Cresci 1973, Koplon 1973) tend to support the belief that the analysis approach of the ASHRAE manual is appropriate for design of building smoke control systems. To evaluate the analysis approach further and to study the interrelation between building fires and zoned smoke control systems, the Center for Fire Research at the National Bureau of Standards (NBS) is engaged in a project of full scale fires in a building scheduled for demolition. This project has been jointly funded by the U.S. Veterans Administration, ASHRAE, the New Jersey Bell Telephone Company, the Bell Atlantic Telephone Company, and the U.S. West Telephone Company.

4. PRESSURE DIFFERENCES

It is appropriate to consider both a maximum and a minimum allowable pressure difference across a barrier of a smoke control system. The values discussed in this section are based on the recommendations in the NFPA 92A. The maximum allowable pressure difference should be a value that does not result in excessive door opening forces, but, it is difficult to determine what constitutes excessive door opening forces. The force to open a door is the sum of the forces to overcome the door closer and to overcome the pressure difference across the door. Clearly, a person's physical condition is a major factor in determining a reasonable door opening force for that person. Section 5-2.1.4.3 of the Life Safety Code (NFPA 1985) states that the force required to open any door in a means of egress shall not exceed 30 lb (133N). For this limitation, maximum allowable pressure differences, calculated by the methods presented in the ASHRAE Smoke Control Manual, are listed in table 1.

Table 1. Maximum allowable pressure differences across doors (Inches Water Gage)

Door Closer Force (lb)	Door Width (inches)				
	32	36	40	44	46
6	0.45	0.40	0.37	0.34	0.31
8	0.41	0.37	0.34	0.31	0.28
10	0.37	0.34	0.30	0.28	0.26
12	0.34	0.30	0.27	0.25	0.23
14	0.30	0.27	0.24	0.22	0.21

Notes:

1. Total door opening force is 30 lb (133 N)
2. Door height is 7 ft (2.13 m)

Caution should be exercised in evaluating door closer force, because the force produced by the closer when the door is closing is often different from the force required to overcome the closer when opening the door. Many door closers require less force in the initial portions of the opening cycle than that required to bring the door to the full open position. The door closer force in table 1 is the force that the door closer exerts on the door at the very beginning of the opening cycle.

The previously described method of design analysis directly incorporates the effects of wind and stack action, but the fire effect is not directly included in this design analysis. The fire effect is addressed by selection of the minimum design pressure difference. The smoke control system should be designed to maintain this minimum value under likely conditions of stack effect and wind and when there is no building fire (such as during acceptance or routine testing). Some suggested minimum design pressure differences are listed in table 2. The values for nonsprinklered spaces are those that will not be overcome by the buoyancy forces of hot gases. These values were calculated for a gas temperature of 1700 °F, for a height above the neutral plane of 2/3 of the ceiling height, and with a safety factor of 0.03 inches water gage. If values are desired for other temperatures or ceiling heights, the calculation method presented in appendix A of NFPA 92A can be used.

Pressure differences produced by smoke control systems tend to fluctuate due to the wind, fan pulsations, doors opening, doors closing, and other factors. Short term deviations from the suggested minimum design pressure difference may not have a serious effect on the protection provided by a smoke control system. There is no clear cut value of allowable value of this deviation. It depends on tightness of doors, tightness of construction, toxicity of smoke, air flow rates, and on the volumes of spaces. Intermittent deviations up to 50 % of the suggested minimum design pressure difference are considered tolerable in most cases.

Table 2. Suggested Minimum Pressure Design Difference Across Smoke Barriers[1] (Inches Water Gage)

BLDG TYPE[2]	CEILING HEIGHT	DESIGN PRESSURE DIFFERENCE
AS	ANY	.05
NS	9 ft.	.10
NS	15 ft.	.14
NS	21 ft.	.18

NOTE 1: For design purposes, a smoke control system should maintain these minimum pressure differences under likely conditions of stack effect or wind.
NOTE 2: AS - Sprinklered, NS - Nonsprinklered.

5. PRESSURIZED STAIRWELLS

Many pressurized stairwells are designed and built with the goal of providing a tenable environment within the escape route in the event of a building fire. It is obvious that a pressurized stairwell can meet its objectives, even if a small amount of smoke infiltrates the stairwell. The three major design concerns with pressurized stairwells are:

- nonuniform pressure differences occur over the stairwell height,
- large pressure fluctuations caused by doors being opened and closed, and
- the location of supply air inlets and fans.

At first it might appear that the pressure differences from the stairwell to the building would be essentially the same over the height of the stairwell. Unfortunately, this is not the case. Figure 1 shows pressure profiles for stairwells located in buildings with three different leakage

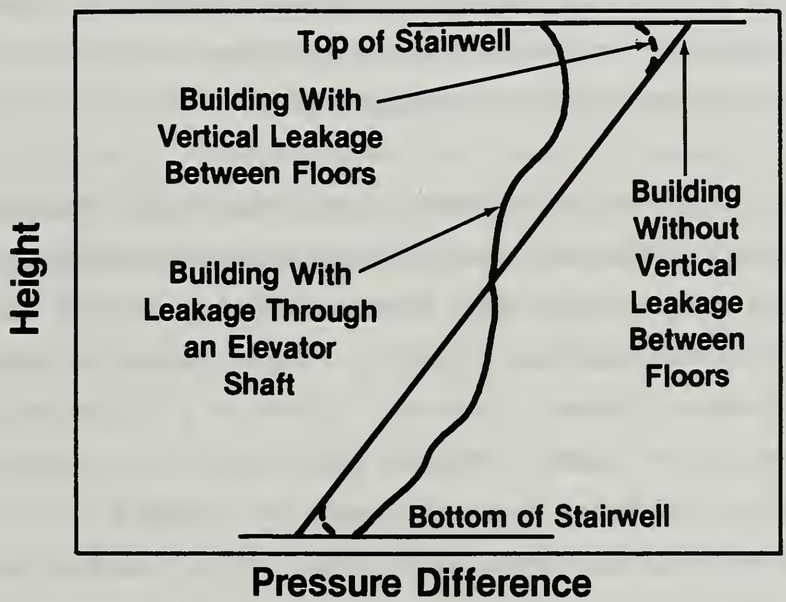


Figure 1. Pressure profiles for pressurized stairwells in three buildings with different leakage characteristics

characteristics, all with the same stairwell temperatures and building temperatures. These pressure profiles represent winter conditions, that is, an outside temperature less that the inside temperature.

For the building without vertical leakage through floors or shafts other than the stairwell, the pressure profile is a straight line. Of course, this leakage characteristic is not representative of many buildings. However, this case is useful because it has been analytically solved and it represents a worst case. The analysis is presented in section 4.3 of the ASHRAE Smoke Control Manual. It is a worst case in that it's minimum pressure difference is less than that for other, more realistic, leakage configurations; and it's maximum pressure difference is greater than that for these other leakage configurations. Computer analysis can be performed to include the effects of more complicated building leakage arrangements.

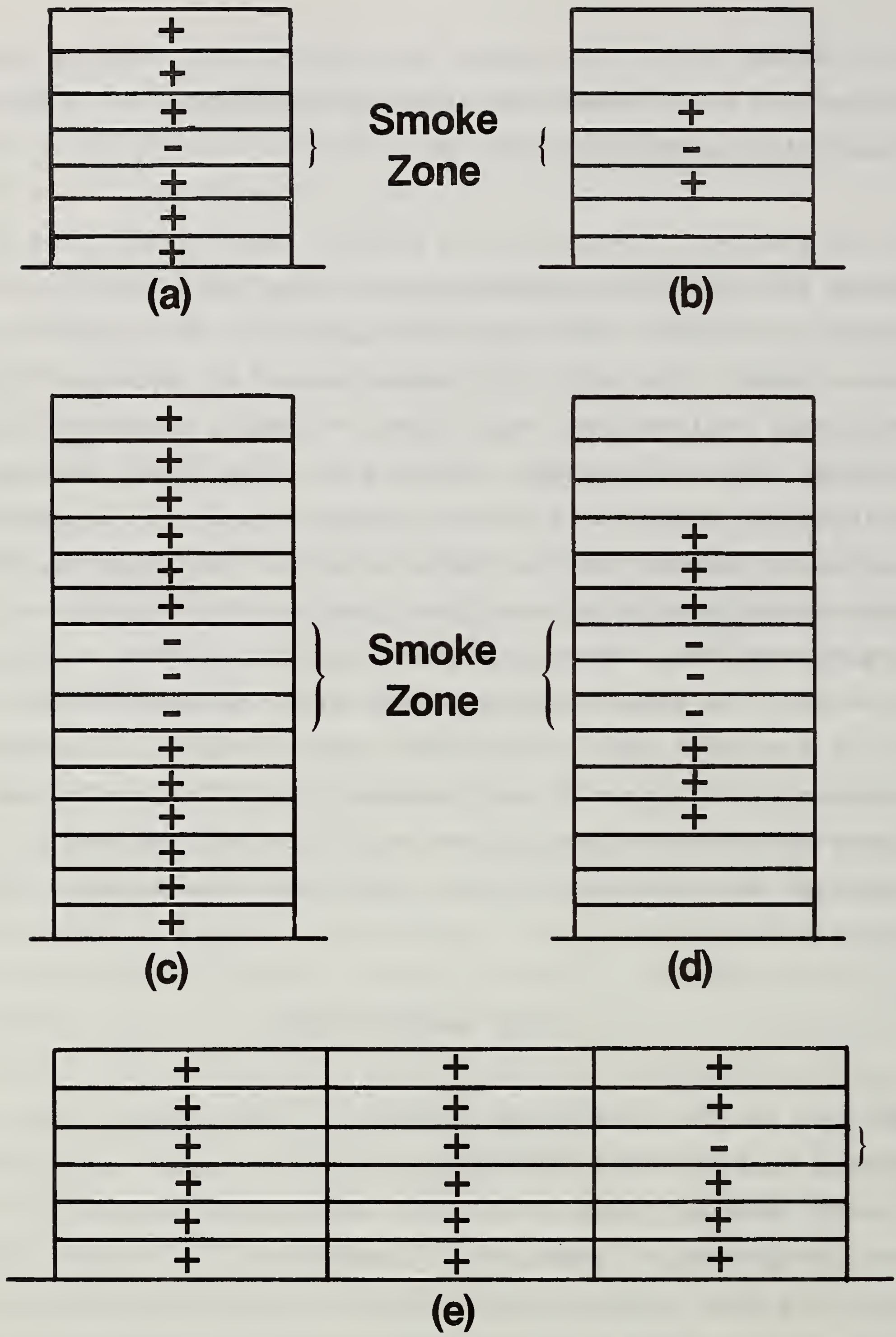
When a door is opened in a pressurized stairwell, the pressure difference across the remaining closed doors can drop dramatically. The two classes of design concepts that have been used to deal with this problem are over-pressure relief and feedback control. These concepts are described in the ASHRAE Smoke Control Manual, however, there is a difference of opinion as to the relative merits of each. This is the subject of a research proposal that the ASHRAE Fire and Smoke Control Committee (ASHRAE TC 5.6) has developed. It is anticipated that this project will lead to more effective and less complicated systems. An over-pressure relief system that has gained attention as being simple and cost effective is the "Canadian System." The essential features of this system are that air is supplied by one or more fans at relatively constant flow rates and the ground floor exterior stairwell door opens automatically upon system activation. This system eliminates the source of the most severe pressure fluctuations, that is the opening and closing of the exterior door.

There is concern with locating supply air inlets near the exterior ground floor doors of the stairwell. If a supply inlet is located near this door, the potential exists for much of the supply air to flow directly through the exterior doorway when it is opened thus effectively reducing stairwell pressurization. It is believed that locating inlets only one floor away from exterior doors eliminates this potential.

With any stairwell pressurization system, there is the potential for smoke feedback into the pressurized stairwell from smoke entering the pressurization fan intake. Therefore, the capability of automatic shutdown should be considered. The supply air intake should be separated from all building exhausts, outlets from smoke shafts, elevator vents and other openings through which smoke might flow in a building fire. Because hot smoke rises, consideration should be given to locating supply air intakes below such critical outlets. However, outdoor smoke movement that might result in smoke feedback depends on location of the fire, location of the points of smoke leakage from the building, wind speed and direction, and the temperature difference between the smoke and the outside air. At present, too little information ia available about such outdoor smoke movement to warrant general recommendations favoring ground level intakes rather that roof-level intakes. Some designers provide both ground level and roof-level intakes so that if smoke is detected in one intake that fan can be shut down without loss of stairwell pressurization.

6. ZONED SMOKE CONTROL

A Building can be divided into a number of smoke zones, each separated from the others by partitions and floors. A smoke control zone can consist of one floor, more than one floor, or a floor can consist of more that one smoke zone. Some arrangements of smoke control zones are illustrated in figure 2. In the event of a fire, pressure differences and airflows produced by mechanical fans can be used to limit smoke spread to the zone in which the fire initiated (the smoke zone). The concentration of smoke in this zone may render it untenable. Accordingly, in zoned smoke control systems, building occupants should evacuate the zone in which the fire occurs as soon as possible after fire detection.



Note: In the Above Figures the Smoke Zone Is Indicated by a Minus Sign and Pressurized Spaces Are Indicated by a Plus Sign. Each Floor Can Be a Smoke Control Zone as in (a) and (b) or a Smoke Zone Can Consist of More Than One Floor as in (c) and (d). All of the Non-Smoke Zones in a Building May Be Pressurized as in (a) and (c) or Only Non-Smoke Zones Adjacent to the Smoke Zone May Be Pressurized as in (b) and (d). A Smoke Zone Can Also Be Limited to a Part of a Floor as in (e).

Figure 2. Some arrangements of smoke control zones

7. ELEVATOR SMOKE CONTROL

A joint project to study elevator smoke control is being conducted by NBS and the National Research Council of Canada (NRCC). The intent of the project is to extend smoke control technology to elevators in an effort to help solve the fire evacuation problem of people who can not use stairs because of physical disabilities. Smoke protection is one of the many obstacles to the use of elevators for fire evacuation that are discussed by Klote (1984), and all of the obstacles other than smoke protection can be addressed by means of existing technology.

Elevator smoke control includes pressurization of the elevator shaft and lobbies. The lobbies must be protected from smoke for the time that people are waiting for elevators. Generally, pressurization of the elevator machinery room is not a concern, because it can be indirectly pressurized by air flowing from the elevator shaft through the large holes for elevator cables that connect the shaft to the machinery room.

The major design concern with elevator smoke control is the pressure fluctuations that result due to opening and closing of elevator doors and other building doors. A feedback control system was studied by computer modelling, and this study indicated that this system is capable of dealing with the pressure fluctuations problem (Klote and Tamura 1986). Also, this study indicated that elevator smoke control could be achieved by pressurizing the lobbies directly, pressurizing the shaft directly, or pressurizing both directly. These feedback controlled pressurization systems do not include air flow through vents from the elevator shaft to the outside. This can be achieved by elimination of these vents or by closing a damper in the vent during smoke control operations. Full scale fire experiments conducted at the 10 story fire research tower near Ottawa (Tamura and Klote 1987) verified the computer study and also showed that a pressure relief system was capable of dealing with the pressure fluctuation problem. This pressure relief system includes an elevator shaft vent to the outside.

Another concern is the transient pressures produced when an elevator car moves in its shaft. Some design engineers believed that this "piston effect" might overcome an elevator smoke control system. Analytical and experimental studies of piston effect have been conducted (Klote and Tamura 1987), and a simple relationship has been developed which is appropriate for design of systems that are not adversely effected by piston effect.

Before elevator smoke control can become a reality, the information developed about elevator smoke control by the NBS/NRCC joint project needs to be put in a form readily usable by design engineers.

8. SMOKE PURGING CAUTION

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

9. ACTIVATION OF ZONED SMOKE CONTROL SYSTEMS

Probably, system activation is the major area of disagreement in the field of smoke control. Primarily, this disagreement is about automatic activation versus manual activation. In the early days of smoke control, there was general agreement that activation of "pressure sandwich" systems should be automatic upon alarm from smoke detectors. Automatic activation by smoke detectors located in building spaces has the clear advantage of fast response.

Some building designers and fire service officials began to realize that smoke detectors could go into alarm on a floor far away from the fire. Thus automatic activation by smoke detectors could result in pressurization of the zone in which the fire occurred. This would result in the opposite of the desired operation, that is smoke would be forced into other zones. As a result, a vocal minority of officials feel that smoke control should only be activated manually by fire fighters after they are sure of the fire location. However, most involved professionals feel that such manual activation would be so late in the fire development that extensive hazard to life and property damage due smoke would have occurred.

The most recent view on the subject is that zoned smoke control should be automatically activated by an alarm from either heat detectors or sprinkler water flow. Obviously, this approach increases the likelihood of proper identification of the fire zone. For smoldering fires, this approach would result in significantly longer response time. However, for flaming fires, it is believed that the response time with this approach would be short enough so that significant benefit would be realized by the operation of the smoke control system. It is hoped that advances in smoke detector technology and application will improve significantly the ability of these detectors to positively identify the fire zone.

Throughout all this controversy, there was complete agreement that zoned smoke control should not be activated by alarms from pull boxes. The reason can be illustrated by the scenario of a man who observing a fire on an upper floor of a building decides that the first thing he should do is to get out of the building. On the way down the stairs, he thinks of his responsibility to the other occupants. He stops on a lower floor long enough to actuate a pull box. If that alarm activated the smoke control system, the wrong zone would identified as the fire zone.

Generally, it is agreed that stairwell pressurization systems can be activated by the alarm of any detector located within the building.

10. RELIABILITY OF POWER

Many designers and code officials feel that standby electrical generator sets should be provided for systems that are intended for the purpose of smoke control only. Generally, these dedicated systems have lower power requirements than systems that employ the building's HVAC system fans. Most pressurized stairwells are dedicated systems, and most zoned smoke control systems are non-dedicated systems. Some designers and code officials feel that standby power is not appropriate for non-dedicated systems, because of the costs associated with a standby generator set to provide all the power needed to operate all the HVAC fans in a large building. However, some HVAC systems are so arranged that out of the many HVAC fans only a few are needed for the smoke control operation. For such systems, standby power would be less expensive.

The considerations discussed above do not address the role of smoke control in a building's overall fire protection system. For buildings without fire suppression systems, smoke control can be a very important feature. Standby power for smoke control in such a building would be desirable. Further, the benefits of multiple power feeds should be considered either alone or in conjunction with standby power. Because smoke control is a new technology, no consensus has been reached concerning reliability of electric power; however, it is recommended that each case be evaluated individually considering the total fire protection system of the building.

11. ACCEPTANCE TESTING

Regardless of the care, skill and attention to detail with which a smoke control system is designed, an acceptance test is needed as assurance that the system, as built, operates as intended. Further, many smoke control systems will require adjustments of supply air flow rates or pressure relief vent openings to accommodate the particular leakage characteristics of the buildings they are part of. These adjustments can be made in conjunction with the acceptance test. All measurements made during acceptance testing should be recorded and saved for inspection.

NFPA 92A provides a general description of acceptance tests intended to demonstrate that the final integrated system installation complies with the specified design and functions properly. If standby power has been provided for the smoke control system, acceptance tests should be conducted with both normal power and standby power.

For zoned smoke control systems, one zone should be put into the smoke control mode, and the pressure differences at the boundaries of that zone should be measured. After smoke control operation in that zone has been deactivated, another zone should be tested in the same manner. This should be repeated until all smoke zones have been tested. Systems with automatic activation should be activated by putting an appropriate detector into alarm.

With all stairwell doors closed, pressure differences across each stairwell door should be measured. Then one door should be opened, and pressure difference measurements made at each closed stairwell door. This should be repeated until the number of doors opened equals the number of doors required by the code authority to be opened.

A caution needs to be given concerning the use of smoke bombs. The major problem with most smoke bomb tests of smoke control systems is that they are intended to test some improvement of smoke conditions in the zone where the fire is located. This is based on the mistaken belief that smoke control is capable of producing a significant improvement in tenable conditions within the zone where the fire is located. These tests are described here in general terms so that the reader can recognize this type of test and understand the problems with them. The smoke control system is put in operation. In the zone which is being exhausted, a number of smoke bombs are ignited. The smoke bombs produce all their smoke in a few minutes, and the zone rapidly fills with smoke. Because the smoke control system is exhausting air and chemical smoke from this zone, the concentration of chemical smoke decreases with time. If at some specific time after ignition, a specific object (such as an exit sign) is visible by a human observer at specific distance (such as 20 ft), the smoke control system is declared a success.

The problems with this type of smoke bomb test are numerous. The criterion for successful operation is not objective. Further, the potential danger of exposing the observer or other people to toxic chemical smoke must dealt with. The obscuration of smoke from a building fire is much different from that of chemical smoke. Most flaming fires produce a dense black smoke, while smoke bombs produce a white smoke. At present, no information is available relating smoke obscuration of chemical smoke to that of smoke from building fires. These problems can be overcome by modifications to the test method. However, this would not yield a test relevant for a smoke control system. Because a smoke control system is intended to maintain pressure differences at the boundaries of the smoke zone, the system should be tested by measuring pressure differences. A very serious problem with this type of smoke bomb test is that it can give building occupants and fire service officials a false sense of the security. The test can lead people to wrongly think that smoke control is capable of achieving a significant improvement in tenable conditions within the fire space.

Testing the performance of smoke control systems with chemical smoke from smoke bombs is not realistic for flaming fires in unsprinklered buildings. Probably the flow of unheated chemical smoke is similar to that of smoke from a sprinklered fire or a smoldering fire. However, the gases produced by a large flaming fire in a building are in the range of 1200 to 1800 °F. For chemical smoke to produce the same buoyant pressure differences as these gases, the chemical smoke would have to be heated to the same temperatures. Obviously, this is impractical because of the associated danger to life and property.

Chemical smoke or a tracer gas (such as sulfur hexaflouride) can be used to test for smoke feedback into supply air. The general procedure for testing with chemical smoke is described here. A number of smoke bombs are placed in a metal container, and all bombs are simultaneously ignited. The container is located near exhaust inlet in the smoke zone being tested so that all of the chemical smoke produced by the bombs is drawn directly into the exhaust air stream. If chemical smoke is detected in the supply air, its path should be determined, the path should be blocked, and then the smoke feedback test should be conducted again.

Smoke bombs can be useful in locating the leakage paths that sometimes defeat a smoke control system. For example, if the construction of stairwell is unusually leaky, pressurization of that stairwell may not be possible with fans sized for construction of average tightness. Chemical smoke generated within the stairwell will flow through the leakage paths and indicate their location so that they can be caulked or sealed.

12. SUMMARY

Smoke control makes use of mechanical fans to produce pressure differences and air flows that can control smoke movement. The methods of design analysis presented in the ASHRAE Smoke Control Manual directly incorporate the effects of friction losses in shafts, temperature differences between the inside and outside, and wind forces. Further, these methods of analysis indirectly incorporate fire effects by the selection of design pressure differences. Pressurized stairwells and zoned smoke control are the two smoke control systems in common use today, and research is ongoing to develop smoke control technology for elevator protection. It is generally believed that dilution of smoke by an HVAC system in the zone in which there is a fire will not result in any practical improvement in the tenable conditions in that zone.

Probably, activation of zoned smoke control systems is the major area of disagreement in the field of smoke control. The idea of automatic activation by smoke detectors became unpopular when it was realized that detectors could go into alarm on a floor far away from the fire. Many feel that zoned smoke control systems should be activated automatically by water flow from sprinklers or heat detectors, while a vocal minority feel that activation should only be manually by the fire service. There is general agreement that zoned smoke control should not be activated by alarms from pull boxes.

Generally, it is agreed that stairwell pressurization systems can be activated by the alarm of any detector located within the building.

There is considerable difference of opinion as to the circumstances under which standby power should be required for smoke control systems. It is recommended that the requirements for standby power for each case be evaluated individually considering the total fire protection system of the building. The acceptance tests evaluating the performance of smoke control systems should consist of pressure measurement tests. Chemical smoke from smoke bombs is not recommended for testing the performance of these systems. However, chemical smoke can be use to test for smoke feedback into supply air and to locate the leakage paths in construction that sometimes defeat a smoke control system.

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FORM NBS-114A (REV.11-84)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR-87/3626	2. Performing Organ. Report No.	3. Publication Date September 1987

4. TITLE AND SUBTITLE

An Overview of Smoke Control Technology

5. AUTHOR(S)

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6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

General Services Administration
Public Buildings Service
Office of Real Property Development
Buildings Technology and Standards Division

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Considerable advances in smoke control technology occurred in the last few decades. However, smoke control is just beginning to take its proper place as a fire protection tool. This paper provides an overview of this technology, including discussions of the fundamental principles, stairwell pressurization, zones smoke control, elevator smoke control, system activation and acceptance testing. In addition the problems of smoke purging are addressed.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

acceptance testing; air conditioning; computer models; elevators; smoke control; smoke movement; stairwells

13. AVAILABILITY

[X] Unlimited
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[X] Order From National Technical Information Service (NTIS), Springfield, VA 22161

14. NO. OF PRINTED PAGES

27

15. Price

$11.95