#3459

Full scale smoke control tests at the Plaza Hotel building

Experiments with zone smoke control with and without stairwell pressurization

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FREQUENTLY in building fires, smoke flows through many leakage paths to remote locations, threatening life and damaging property. These leakage paths can be open doors, gaps around closed doors, stairwells, mechanical shafts, elevator 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. Primarily smoke control is achieved by pressure differences acting across the barriers of buildings.

Theoretically, air flow at open doorways can control smoke movement. However, the problems of very large air flow rates and flow control in situations of opening and closing doors make smoke control by air flow impractical in most building applications.

There have been no major fires in buildings with zoned smoke control systems. Further, there are no reported fire tests of engineered smoke control systems other than pressurized stairwells. Some new systems have been tested with smoke bombs, however such tests are not conclusive because the resulting smoke is cold. The National Institute of Standards and Technology (NIST), formerly National Bureau of Standards, is engaged in a project to evaluate the basic concept of smoke control. A series of full scale fire tests will be conducted in the Plaza Hotel Building in Washington, D.C.

The project is sponsored by NIST, ASHRAE, Bell Atlantic Telephone Company, New Jersey Bell Telephone Company, the U.S. Fire Administration, the U.S. Veterans Administration and US West Inc. Member companies of the Air Movement and Control Association (AMCA) have donated fans for this project.

This paper presents a general overview of this project, and more detailed information is provided in the project plan (Klote 1988a). The test facility for the project is the seven-story Plaza Hotel Building scheduled for demolition. Accordingly, the project will be limited to work that needs to be studied in a multistory building. This consists of zone smoke control experiments with and without stairwell pressurization. Additionally, smoke movement without smoke control will be studied. Corridor pressurization, system activation, air flow control strategies and many other worthy topics of smoke control research will not be addressed in this project, because they can more effectively and more economically be researched in laboratory facilities.

PROJECT OBJECTIVE

The objective of this project is to evaluate the current approach to achieve smoke control for zoned smoke control systems with and without stairwell pressurization. This approach is described in the following sections on pressure difference and air changes. Also, the interaction between smoke control and the fire will be studied.

Pressure Differences

It is appropriate to consider both a maximum and a minimum allowable pressure difference across a barrier of a smoke control system. A general discussion of these pressure differences is provided (Klote 1988b). The maximum allowable pressure difference should be a value that does not result in excessive door opening forces. Recommended values of maximum pressure difference are listed in NFPA 92A (1987) for different door sizes based on a 30-pound door opening force. However, for this project the minimum pressure difference is the major focus of attention.

For nonsprinklered fires, the minimum pressure differences discussed in the ASHRAE Smoke Control Manual (Klote and Fothergill 1983) and NFPA 92A (NFPA 1988) are based on the buoyancy of fire gases. In order to define the minimum pressure difference, a discussion of buoyancy is needed. The buoyancy pressure difference between a space filled with hot fire gases and its surroundings can be expressed as

$$P = 7.64\, P_t \left(\frac{1}{T_O} - \frac{1}{T_F} \right) P_t h$$

where:

P = pressure difference due to buoyancy of smoke, in H_2O

T_O = absolute temperature of the surroundings, 'R

T_F = absolute temperature of fire gases, 'R

h = distance between the neutral plane and the ceiling, ft

The neutral plane is a horizontal plane at which the pressure inside the space filled with fire gases equals the pressure of the surroundings. The preceeding equation is for constant values of fire compartment temperature and surrounding temperature.

The minimum pressure difference is the buoyancy pressure difference likely to be caused by some fire conditions plus a safety factor. The smoke control system should be designed to maintain this minimum pressure difference across the boundaries of the smoke control system under likely conditions of stack effect and wind when there is no building fire (such as during acceptance or routine testing). As can be seen from the equation, the buoyancy pressure difference depends on the fire gas temperature and the location of the neutral plane. If the fire compartment is some distance away from the barriers of the smoke zone, the fire gases reaching these barriers will be cooled due to heat transfer and dilution. Thus, the actual fire gas temperature can vary over a wide range. NFPA 92A lists recommended values of minimum pressure difference based on a fire gas temperature of 1700° F, a distance between the neutral plane and the ceiling of 2/3 of the floor-to-ceiling height and a safety factor of 0.03 inches water gage. These values of minimum pressure difference are listed in *Table 1.*

The approach above assumes that pressure differences due to expansion of fire gases are not significant. If there are large openings between the smoke zone and its surroundings, expansion pressure differences will be negligible. It is generally believed that any adverse smoke flows due to expansion will be of short duration and insignificant for zoned smoke control systems in typical buildings. The term "typical building" is used to mean a building with leakage in the range listed in Appendix C of the *ASHRAE Smoke Control Manual.* This research project will examine the appropriateness of the preceeding approach to minimum pressure difference with special attention to the effect of expansion.

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

Bldg Type[2]	Ceiling Height	Design Pressure Difference[3]
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.

NOTE 3: The pressure difference measured between the smoke zone and adjacent spaces, while the affected areas are in the smoke control mode.

NOTE 4: This table taken from NFPA 92A (1988)

Air Changes

In order to achieve pressure differences, the smoke zone is exhausted and surrounding zones are pressurized. The flow rates of exhaust and pressurization air must be sufficient to produce at least the minimum pressure difference across the barriers of the smoke zone.

Exhausting air from the smoke zone results in air from outside and from other zones being pulled into the smoke zone. This air flowing into the smoke zone can provide oxygen to the fire. Smoke control systems frequently are designed to exhaust and supply air at six air changes per hour. (As is common practice, air change rates are on a per hour basis, even though this is not explicitly stated in the text.) Most commercial air conditioning systems are capable of moving about four to six air changes. This fact probably accounts for the popularity of six air changes in smoke control applications. Current designs are based on the assumption that the adverse effect of supplying oxygen at six air changes is not significant in comparison with the benefit of smoke control. This project will evaluate this assumption.

Tests will be conducted with smoke control at flow rates of six air changes under various conditions of open and closed burn room window and a closed and cracked open fire floor stairwell door. The cracked open stairwell door is selected to simulate a door that has been jammed about an inch open. Similar tests will be conducted without smoke control allowing evaluation of the effect of the six air changes of the energy release rate of the fire.

Extent of effort

The work in the Plaza Hotel Building will have a duration of about three months and will consist of the following tasks:

- Modify test building
- Install instrumentation
- Install smoke control systems
- Calibrate building leakage
- Conduct tests

The first four tasks will be conducted during the first two months, and the tests will be conducted during the last month.

Plaza Hotel Building

The Plaza Hotel building is a masonry structure consisting of two wings, one three stories and the other seven stories tall. The two wings were built at different times, and were constructed some time before the turn of the century. The wings are connected at only one location on each floor *(Figures 1 through 5).* The building has no central forced air HVAC system, but is heated by steam radiators and cooled by window air conditioners. Thus, dedicated smoke control systems will be installed as described later.

The connections between the wings at each floor will be sealed off, and the tests will be conducted in the seven-story wing, using the shorter wing as an instrumentation area. The second floor will be the fire floor, and fires will be built in a room and in the corridor as shown by the fire hardening shown on *Figure 3.*

Based on visual inspection, the building is much more leaky than typical for most buildings. To tighten the building, gaps around doors and windows, holes in floors and other construction cracks will be caulked and sealed. This caulking and sealing will be done in conjunction with a leakage calibration effort (discussed later) to assure that the building is in the range considered typical.

The building was used, most recently, as the headquarters of the Capitol Police, and is located near the U.S. Capitol Building in Washington, D.C. The Architect of the Capitol has obtained official approval of the U.S. Senate Committee on Rules and Administration for NIST to use the Plaza Hotel Building for this fire research project. The stipulations of this approval are:

- All activities of the project will be coordinated with the Office of the Architect of the Capitol.
- The project will not interfere with the normal functions of the Senate.

Further, the Office of the Architect of the Capitol has agreed to coordinate communications and requests for service with the D.C. Fire Department.

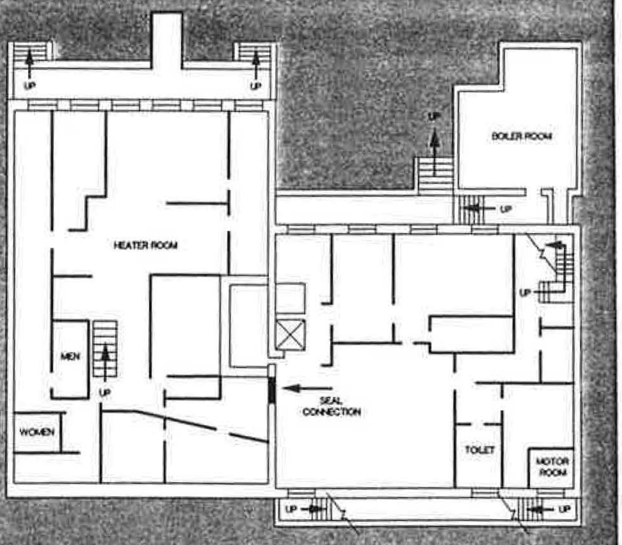

Figure 1. Plaza Hotel building basement floor plan.

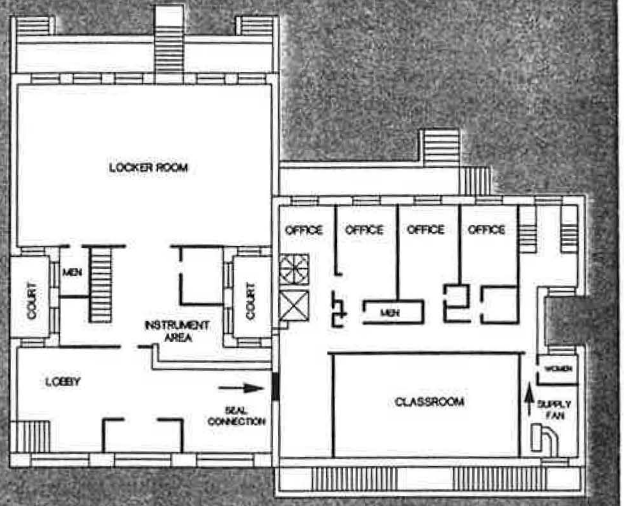

Figure 2. Plaza Hotel building first floor plan.

Instrumentation

Instrumentation will consist of thermocouples, gas analysis (O_2, CO_2 and CO), differential pressure transducers, smoke meters and a load platform. Over 100 thermocouples will be made using well over two miles of thermocouple wire. Smoke meters will be used to measure smoke obscuration. The load platform will be used to measure the weight loss from wood fires.

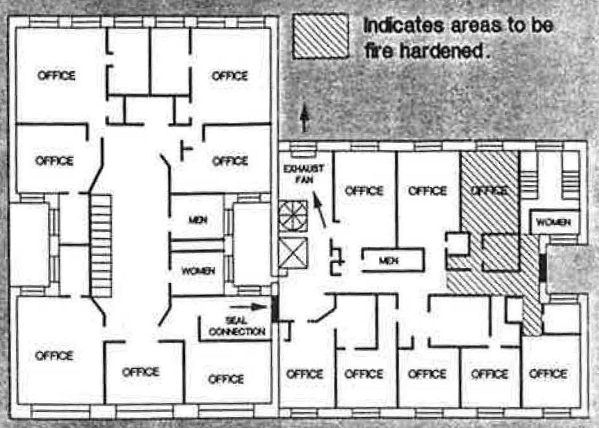

Figure 3. Plaza Hotel building second floor plan.

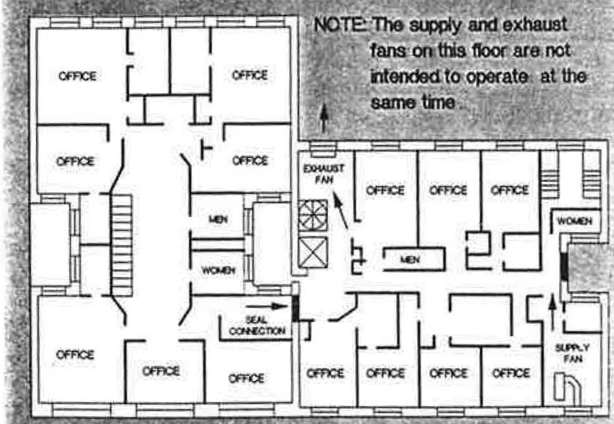

Figure 4. Plaza Hotel building third floor plan.

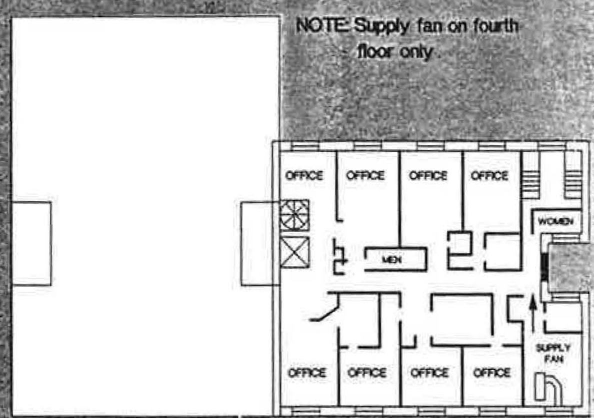

Figure 5. Plaza Hotel building typical floor plan for floors four through seven.

Video cameras will be located on the floors and in the stairwell. Instruments and video cameras on the fire floor and in the stairwell will be protected from heat damage. Wires from the instruments and video cameras will be run to the instrument area on the first floor of the three-story wing of the building. In this area there will be a microcomputer, channel scanner and digital voltmeter for data acquisition. Also, video recording.

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processing and viewing equipment will be located in the instrument area.

Smoke Control Systems

This project will test the two most common types of smoke control systems: pressurized stairwells and zoned smoke control. In the zoned smoke control concept, a building is divided into a number of smoke control zones, each zone separated from the others by partitions, floors and doors that can be closed to inhibit the movement of smoke. Frequently, these zones are floors of a building, but they may be more than one floor or even part of a floor. In the event of a fire, pressure differences produced by mechanical fans are used to restrict the smoke spread to the zone where the fire started. The concentration of smoke in this smoke zone goes unchecked. Therefore, in zoned smoke control systems it is intended that building occupants evacuate the smoke zone, as soon as possible, after fire detection.

The primary reason stairwells are pressurized is to provide an essentially "smoke free" exit path during building fires. The zoned smoke control will be tested with and without stair pressurization. The concepts of stairwell pressurization and zoned smoke control are discussed in greater detail in the *ASHRAE Smoke Control Manual* and in *NFPA 92A*.

For both zoned smoke control and stairwell pressurization, air is supplied from the outside, and exhaust air goes to the outside. The location of the stairwell pressurization fan will be outside the building near grade level. The locations of the fans for zoned smoke control are shown on *Figures 2, 3, 4 and 5.* The fans can be used so that the smoke zone is either the fire floor or both the fire floor and the floor above.

Calibrate building leakage

To assure that the building leakage is in the typical range after caulking and sealing, a series of tests will be conducted to evaluate the leakage areas between floors and in exterior walls. The technique used is illustrated by the following example. All leakage paths on the third floor to the stairwell, elevator shaft and other shafts are sealed. The second, third and fourth floors are pressurized, and the supply flow rates are adjusted so pressure differences to the floors above and below the third floor are zero. Within the limits of accuracy of this test, all of the air supplied to the third floor flows out through the exterior walls. The mass flow rate, $\dot{m}$, of air to the third floor and the pressure difference, P_{BO3}, from the building to the outside are measured. The leakage area, A_{BO3}, between the building and the outside at the third floor is calculated as

$$A_{BO3} = \frac{\dot{m}}{C_{BO3}\,(2\,\rho\,P_{BO3})^{1/2}}$$

The value of the flow coefficient, C_{BO3}, is approximately 0.65 for gaps around doors, construction cracks and other small leakage paths in walls and floors. The density, ρ, of air in the third floor space is calculated from the perfect gas law. Then the fan on the second floor is shut off, and the supply rates of the other fans are adjusted so the pressure difference between the third and the fourth floors is zero. The total mass flow rate, $\dot{m}$, of air from the fan to the third floor; the pressure difference, P_{F3}, from the third floor to the second floor; and the pressure difference, P_{BO3}, from the building to the outside are measured. Within the limits of accuracy of this test, all of the air supplied by the fan to the third floor flows through the exterior walls and through the third floor leakage paths. This can be expressed as

$$\dot{m} = C_{BO3}\,A_{BO3}\sqrt{2\,\rho\,P_{BO3}} + C_{F3}\,A_{F3}\sqrt{2\,\rho\,P_{F3}}$$

The flow coefficients and density are evaluated as before, and the flow area, A_{F3}, is obtained from this equation. The preceeding example evaluates the flow areas by measurements at one set of flow conditions. If possible, several measurements will be conducted and the flow areas will be evaluated statistically. Further, several measurements could give an indication of the applicability of the constant flow coefficient assumption.

Fires

Initially, gas fires were planned because of their ease and high repeatability. Further, because gas fires are well understood, they lend themselves to computer simulation. However, for conditions of depleted oxygen, gas fires require automatic shut-down for safety reasons. To learn about the interaction of the fire and the smoke control system, the fire must behave realistically under depleted oxygen conditions. Thus, it was decided to use a solid fuel rather than a gaseous fuel. Wood crib fires are a good choice because they are repeatable and fairly well understood (Gross 1962, Block 1971). The crib fires will be made of nominal 2 by 2's, and each fire will consist of either 300, 400 or 600 pounds of wood. All of these fires will have a duration of about a half hour, provided there is sufficient oxygen.

All of the fires, with the possible exception of the last one, will be unsprinklered because the long drying out time between sprinklered tests is prohibitive for a project of limited testing time. Because the fuel will be limited, the fires will be allowed to burn until all the wood is burned out. For safety reasons, the fire tests will be coordinated with the D.C. Fire Department.

Summary

No zoned smoke control system has been tested under real fire conditions. The objective of the full scale fire tests in the Plaza Hotel Building is to evaluate the current approach concerning minimum pressure difference to achieve smoke control for zoned smoke control systems with and without stairwell pressurization. Also, the interaction between smoke control and the fire will be studied. Air will be exhausted at six changes per hour from the fire floor to evaluate the effect of this common exhaust rate on the fire energy release rate. ■

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