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The Plaza Hotel fire experiments

The effectiveness of zoned smoke control systems was demonstrated by these smoke movement experiments

By John H. Klote
Member ASHRAE

Smoke is recognized as the major killer in building fires. Smoke often migrates to building locations remote from the fire space, threatening life and damaging property. Stairwells and elevator shafts frequently become smoke-clogged, thereby blocking evacuation and inhibiting rescue and firefighting.

The MGM Grand Hotel fire (Best, Demers 1982) is an example of the smoke problem. There, the fire was limited to the first floor, but smoke spread throughout the building. Some occupants on upper floors were exposed to smoke for hours before rescue. The death toll was 85, and the majority of the deaths were on floors far above the fire. (It is a credit to the Clark County Fire Department that during such a complex firefighting operation, the location of exposure is known for all but six of the fatalities.)

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The MGM Grand Hotel fire is not unique in this respect as is illustrated by the fires at the Roosevelt Hotel (Juillerant 1964) and the Johnson City Retirement Center (Steckler *et al.* 1990). All these fires were located on the first floor, but the majority of deaths were on upper floors, as shown in *Figure 1*. As a solution to the smoke problem, the concept of zoned smoke control was developed.

A series of full-scale fire experiments of zoned smoke control was conducted at the seven-story Plaza Hotel in Washington, D.C. A zoned smoke control system uses pressurization produced by fans to restrict smoke flow to the zone of fire origin. The benefit of this system is that other zones in the building remain essentially "smoke free," reducing property loss and hazard to life.

Before this project, no zoned smoke control system had been tested under real fire conditions as part of an organized,

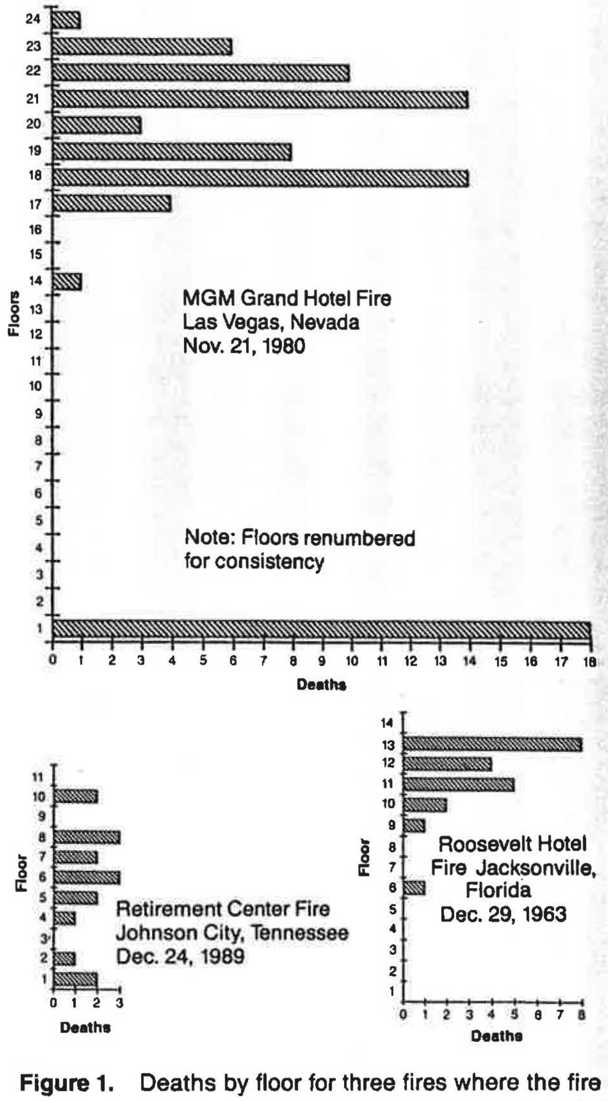

Figure 1. Deaths by floor for three fires where the fire was located on the first floor.

About the author

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analytical engineering research project. However, such experimental programs of smoke control systems for stairwells and elevators have been conducted.

The intent of this article is to qualitatively describe some of the results of the Plaza Hotel experiments that are relevant to smoke control design and testing. A total of 12 tests were conducted to study smoke movement due to unsprinklered wood fires, sprinklered wood fires and smoke bombs (*Table 1*).

Based on tests by Walton (1988), the 300-lb unsprinklered wood fires burned at the Plaza Hotel had an approximate heat release rate of 5×10^6 Btu/h. The temperatures from these fires were about 1200°F in the corridor 20 ft away from the fire. The smoke bomb tests were conducted to evaluate the extent to which smoke bombs are appropriate for acceptance testing of these systems.

Because of space limitations, the sprinklered tests are not discussed here. However, it should be noted that sprinklered fires produce such small pressure differences that they are not much of a challenge for a smoke control system. Smoke movement in these experiments was evaluated from smoke obscuration measurements, gas concentration (CO, CO_2 and O_2) measurements, and video recordings. Further results and experimental details are presented in Klote (1990).

The Plaza Hotel Building was a masonry structure consisting of two wings, one three stories tall and the other seven stories tall. The wings were connected to each other at only one location on each floor as can be seen from the second floor plan (*Figure 2*).

The connections between the wings at each floor were sealed off, and the fires were set on the second floor of the seven-story wing, using the shorter wing as an instrumentation area. The areas of the second floor indicated in *Figure 2* were fire hardened to minimize structural damage to the building.

SYMBOLS:

UP	Up	S	Smoke Meter
DN	Down	P	Differential Pressure Probe at Floor to Ceiling Below
Elev	Elevator		
Φ	Thermocouple Tree	P/P	Differential Pressure Probe Across Wall
G	Gas Probe (CO, CO_2, O_2)		

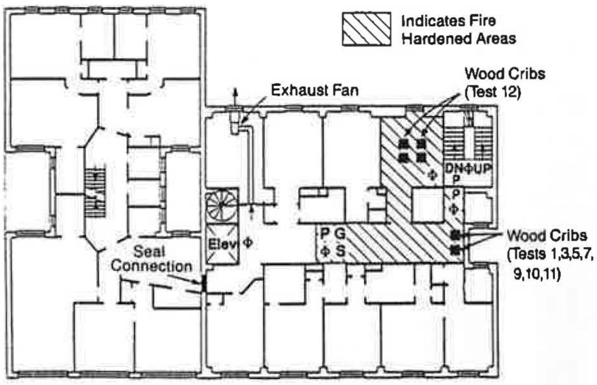

Figure 2. Second floor plan of the Plaza Hotel.

Smoke control systems

The smoke control system was designed using the methods of the ASHRAE smoke control manual (Klote, Fothergill 1983). The design analysis is discussed in detail by Klote (1988). The minimum design pressure difference was 0.10 in. w.g. This level of pressurization is recommended by the National Fire Protection Association (1988) for smoke control in unsprinklered buildings.

A dedicated system of fans and ducts was installed for zoned smoke control and stairwell pressurization. The smoke control system is shown in *Figure 3*, and the intent of the sys-

Table 1. Test Schedule

Test	Test Type	Fire Load[2] (lb)	Zoned Smoke Control[3]	Stairwell Pressurization[4]	Activation Time[5] (min.)	Condition of Stairwell Doors at: Basement to Outside	2nd Floor[6]	7th Floor
1	Wood Fire	300	off	off	–	closed	closed	closed
2	Smoke Bomb	–	on	off	0	closed	closed	closed
3	Wood Fire	200	on	off	0	closed	1/2 in.	closed
4	Smoke Bomb	–	off	off	–	closed	1/2 in.	open
5	Wood Fire	300	off	off	–	closed	1/2 in.	open
6	Smoke Bomb	–	on	on	0	open	1/2 in.	open
7	Wood Fire	300	on	on	0	open	1/2 in.	open
8	Smoke Bomb	–	on	on	4	open	1/2 in.	open
9	Wood Fire	300	on	on	4	open	1/2 in.	open
10	Sprinklered	300	off	off	–	closed	1/2 in.	open
11	Sprinklered	300	off	off	–	closed	1/2 in.	open
12	Wood Fire	600	on	on	0	open	1/2 in.	closed

[1]All fires in the second floor corridor and all windows closed except for test 12 where: the fire was in the fire hardened room on the second floor; and the window in that room was open.

[2]Fire load is approximate.

[3]Zoned smoke control consisted of pressurization of first and third floors at 2,000 cfm (0.94 m^3/s) each, and exhaust of the second floor at the same rate.

[4]Stairwell pressurization consisted of supplying 9,000 cfm into the stairwell at the first floor with the exterior basement door open.

[5]Activation time is the time after ignition that the smoke control system and stairwell pressurization system are turned on.

[6]Second floor door designation 1/2 in. indicates that the door was cracked open 1/2 in.

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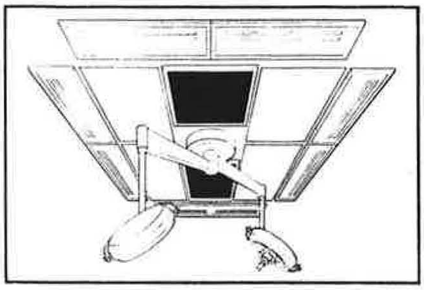

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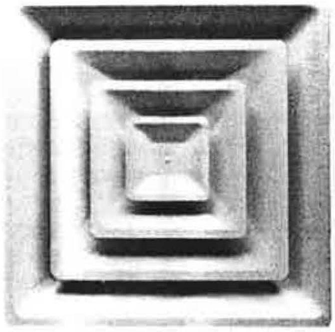

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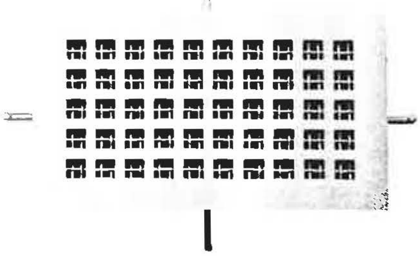

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tem is to prevent smoke escape from the fire floor. This type of system is not intended to improve tenability conditions on the fire floor.

The smoke control system consisted of a 2,000 cfm exhaust fan on the fire floor (*Figure 3*), a 2,000 cfm pressurization fan on the first floor, a 2,000 cfm pressurization fan on the third floor, plus another centrifugal fan located outside that supplied 9,000 cfm of pressurization air to the stairwell at the first floor. The 2,000 cfm amounts to about six air changes of each of these floors.

Unsprinklered fires

The unsprinklered fires without smoke control (tests 1 and 5, see *Table 1*) resulted in smoke movement to the stairwell and the upper floors of the building. For test 1, all stairwell doors were closed throughout the fire, and the smoke concentrations were relatively low in the stairwell and on the upper floors.

Pressurization produced by the smoke control system during test 3 resulted in essentially no smoke in the stairwell and other floors. The low smoke concentrations away from the fire floor during test 1 indicate that significant benefits can result from tight compartmentation.

Frequently in building fires, there are larger openings for smoke flow than there were for tests 1 and 3. To evaluate some of these openings, several tests were conducted with the fire floor stairwell door 1/2-in. open and the seventh floor stairwell door completely open. The fire floor stairwell door was open to simulate the gap of a door warped due to high differential temperatures, and the completely open door simulated a door that was accidentally blocked open.

Test 5 had this condition of open doors and was without smoke control. During this test, significant levels of smoke flowed through the 1/2-in. gap into the stairwell, and from the stairwell through the open seventh floor door onto that floor. The other floors had lower levels of smoke. Even with the same open door conditions, pressurization by the smoke control system (tests 7 and 9) prevented such smoke movement to the stairwell and upper floors.

Fan temperatures. Concern is frequently expressed about problems of fan reliability at elevated operating temperatures. However, analysis of the Plaza Hotel experiments showed that this should not be the major concern about fan temperature.

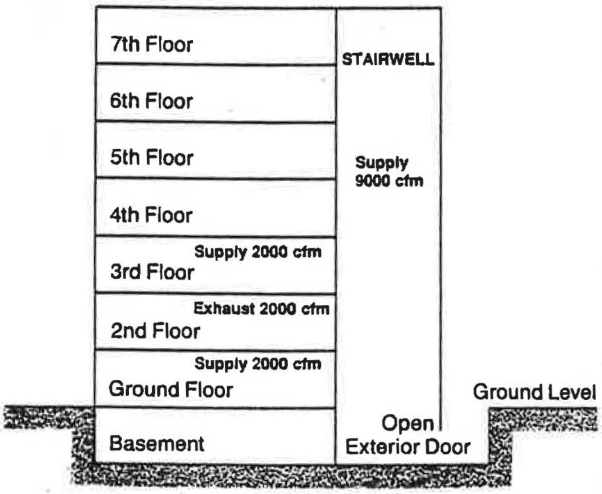

Figure 3. Schematic of the smoke control system.

The volumetric flow through the exhaust fan is nearly constant, and the mass flow through the exhaust fan decreased as the temperature of the exhaust gases increased. Because the mass flow of the fan causes the pressure difference at the fire floor boundary, reduction in fan mass flow results in reduction in smoke control system pressurization.

The pressure difference across the boundary of the smoke control zone is proportional to the square of the mass flow rate through the fan. Because of the buoyancy of fire gases, this pressure difference varies with elevation above the floor. The full analysis (Klote 1990) explains to what extent such a reduction in mass flow rate affects the pressure differences produced by the smoke control system.

The reduction in mass flow rate through the fan can be expressed in terms of pressure difference as:

$$\phi = 1 - (\Delta P_{min}/\Delta P_r)^{1/2}$$

where,

- ϕ = allowable fraction reduction in mass flow rate through the fan
- ΔP_{min} = minimum allowable average pressure difference across the boundary of the smoke zone, in. w.g.
- ΔP_r = pressure difference across the boundary of the smoke zone for normal conditions, in. w.g.

If the minimum average pressure difference is 0.10 in. w.g., and the pressure difference across the boundary of the smoke zone for normal conditions is 0.16 in. w.g., then the allowable mass fraction reduction in mass flow through the fan is 21 percent.

The maximum allowable fan temperature can be calculated as:

$$T_{fan} = \frac{(T_r + 460)}{(1 - \phi)} - 460$$

where,

- T_{fan} = maximum allowable temperature of the fan, °F
- T_r = temperature of the fan for normal conditions, °F

For example, if a reduction of 21 percent in the mass flow rate is acceptable and T_r is 70°F, the maximum allowable fan temperature is 211°F.

Smoke bomb tests

These experiments supported the belief that smoke bombs should not generally be used for acceptance testing of smoke control systems. Smoke produced by smoke bombs is very different from the hot smoke produced by flaming fires.

The real smoke obscured light much more than the chemical smoke, and it would obscure vision much more as well. The chemical smoke was at room temperature, so it did not result in buoyancy pressures like those of hot smoke from a flaming fire.

Smoke bombs generate most of their chemical smoke during the first few minutes after ignition, but real fires generate more and more smoke as the fire develops. A few minutes after the bombs burned out, the smoke control system purged the chemical smoke from the fire floor.

People who do not have an understanding of fire science could easily believe that a smoke control system would result in similar performance for a large flaming fire. The results of the unsprinklered fire tests indicate that this is not so.

Even with smoke control, the levels of smoke on the fire floor were significant for the unsprinklered fires. Smoke bombs should not be used for acceptance tests that are intended to simulate system performance under unsprinklered fire conditions.

Summary

This article qualitatively describes some of the results of the Plaza Hotel fire experiments that are relevant to smoke control design and testing. Further information about these experiments are provided by Klote (1990).

For the fires of this experimental series, the zoned smoke control system effectively maintained positive pressurization and restricted smoke to the fire floor. High temperature exhaust fan gases can result in a significant loss of system pressurization. The equations presented in this article can be used to evaluate this effect.

Smoke bombs should not be used for acceptance tests that are intended to simulate system performance under unsprinklered fire conditions. Chemical smoke from smoke bombs is very different from smoke due to a flaming fire, so persons observing a smoke bomb test can develop a false sense of security.

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