

Smoke Control Tests at the Plaza Hotel in Washington DC

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1. INTRODUCTION

In the spring of 1989, a series of full scale fire experiments of zoned smoke control were conducted at the seven story Plaza Hotel in Washington, DC. A zoned smoke control system is a system that uses pressurization produced by fans to restrict smoke flow to the zone of fire origin. The benefit of these systems is that other zones in the building remain essentially "smoke free" reducing property loss and hazard to life. No zoned smoke control system has been tested under real fire conditions either by a research effort or an accidental fire. However, fire experiments of smoke control systems for stairwells and elevators have been conducted.

This project was sponsored by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE); Bell Atlantic Telephone Company; New Jersey Bell Telephone Company; U.S. Fire Administration; U.S. Veterans Administration, and US West Incorporated. Member companies of the Air Movement and Control Association (AMCA) donated fans for this project. The Architect of the Capitol obtained approval of the U.S. Senate Committee on Rules and Administration for NIST to use the Plaza Hotel building for this project.

The objective of this effort is to evaluate the current approach to zoned smoke control systems. Accordingly, the smoke control system was designed using the calculational methods of the ASHRAE Smoke Control Manual (Klote and Fothergill 1983) and it was designed to produce the levels of pressurization recommended by the National Fire Protection Association (NFPA 1988). This zoned smoke control system was designed to operate along with a stairwell pressurization system. The design analysis of both of these systems are discussed in detail by Klote (1988). Data analysis is ongoing for this project, and a detailed report will be published in the near future. This paper is an initial discussion of the tests.

2. DESCRIPTIONS OF TESTS

The Plaza Hotel building is a masonry structure consisting of two wings, one three stories and the other seven stories tall. Fires were set on the second floor of the seven story wing. The areas of the second floor indicated on figure 1 were fire hardened by covering the walls, floor and ceiling with calcium silicate board to minimize structural damage to the building. Other floors of the seven story wing are of similar size and layout to that shown in figure 1.

The building had no central forced air heating system, so a dedicated system of fans and ducts was installed for zoned smoke control and stairwell pressurization. The zoned smoke control system consisted of three 0.94 m³/s (2000 cfm) centrifugal fans: one for pressurization of the first floor, one for exhaust of the fire floor (second floor), and one for pressurization of the third floor. Another centrifugal fan, located outside, supplied 3.3 m³/s (7000 cfm) of pressurization air to the stairwell at the first floor. The exterior basement door of the stairwell was open during operation of the stair pressurization fan. This was done to simulate a system for which the exterior door opens upon system activation to eliminate the pressure fluctuations due to opening and closing the exterior door.

The test series consisted of chemical smoke tests and wood fires, and the test schedule is listed in table 1. Two of the wood fires (tests 10 and 11) were sprinklered. The chemical smoke was produced by three smoke bombs rated by the manufacturer for a three minute duration. The smoke bomb tests were included to evaluate the extent to which smoke bombs are appropriate for acceptance testing of smoke control systems.

Wood was selected for these urban area experiments because it produces relatively light smoke. Wood sticks were arranged in geometric piles called cribs, because these crib fires are repeatable and fairly well understood (Gross 1962, Block 1971). The cribs, illustrated in figure 2, were constructed of fir sticks 38 mm (1.5 in) by 38 mm (1.5 in) by 0.61 mm (2 ft) long. The sticks were fastened together with 8d common nails. The crib illustrated in figure 2 consisted of 24 layers and weighted approximately 68 kg (150 lbs), and these cribs were used for most of the tests. The exception was test 3 for which a smaller crib of 18 layers weighing about 45 kg (100 lb) was used because of concern about possible damage to the buildings structural system. Each fire used two cribs located in the corridor as illustrated in figure 1. By extrapolation of data (Walton 1988) for similar cribs, it is estimated that two 24 layer cribs would have a peak energy release rate of 1.5 MW, and two 18 layer cribs would have a peak energy release rate of 1.0 MW. A 0.13 m (5.0 in) diameter metal pan with 100 ml of heptane was centered under each crib as an ignition source. The cribs were stored in a room in the Plaza Hotel without humidity control, however, all the cribs had a moisture content less than 6 percent.

3. DISCUSSION OF WOOD FIRE TESTS

During test 5 which was without zoned smoke control and stair pressurization, significant amounts of smoke infiltrated the seventh floor and lesser amounts reached the third floor as illustrated by figure 3. For this test the second floor door was cracked ½ inch open simulating the gap of a door warped due to high differential temperatures. Video recordings also showed smoke flowing through the door gap and into the stairwell. Smoke was also observed on floors 4 and 7 of the stairwell. Test 1 was similar except that the stairwell doors were closed. As expected the smoke obscuration away from the fire was considerably lower for test 1.

For the tests with smoke control, the spaces away from the fire floor were essentially smoke free. This was observed on the video for floors 3 through 7

and for the stairwell. Figure shows that essentially no smoke reached the third and seventh floors during test 9, which was the same as test 5, except that zoned smoke control and stair pressurization were operating.

To obtain an idea of the relative effect of sprinklers, tests 10 and 11 were sprinklered. Test 10 was with a conventional sprinkler and test 11 was with an on-off head. In both tests, the sprinkler was located just below the ceiling and directly over the fire. During test 10, the sprinkler extinguished the fire shortly after it activated, and the smoke levels were very low on the fire floor. Other floors were essentially smoke free. This indicates that when a fire is rapidly extinguished, smoke spread away from the fire is slight. The sprinkler was ideally located for test 10, and for less ideal location considerably more smoke might have been generated. The on-off sprinkler used in test 11 failed to extinguish the fire, but it resulted in a cycling of the water spray with fire growth when the spray was off. This resulted in considerable smoke as can be seen from figure 5. Further study is needed concerning the effect of sprinklers on smoke generation.

Figure 6 shows the concentrations of carbon monoxide (CO) on the second floor during the wood fires. For the fires without smoke control (tests 1 and 5), CO on the fire floor approached 2 percent. For these tests, the oxygen levels decreased to about 10 percent and remained at that level until the end of the test. For the non-sprinklered fires with smoke control (tests 3, 7 and 9), CO concentrations were much lower. Possibly the lower CO levels are because the smoke control system pulled air into the fire floor. The lower CO levels with smoke might appear to be a possible benefit of smoke control. However, caution should be exercised in this regard, because greater fuel loads could also result in the high levels of CO for non-sprinklered fires.

4. DISCUSSION OF CHEMICAL SMOKE TESTS

As with the wood fires, some smoke moved beyond the fire floor for the non-sprinklered fire (test 4) without smoke control. During this fire, the video showed smoke in the stairwell as it did for the wood fire (test 5) with similar conditions. For tests 2, 6 and 8 with smoke control, the spaces away from the fire floor were essentially smoke free as is illustrated for test 6 in figure 8. However, the smoke concentrations due to smoke bombs tests are considerably different from those due to the wood fires. The chemical smoke is produced over a short time (3 minutes according to the smoke bomb manufacturer). However, the fire burns for nearly a half an hour. The chemical smoke results in lower obscuration. With smoke control, obscuration due to chemical smoke decreases rapidly at about 5 minutes after ignition. This is believed to be the result of the smoke control system purging the chemical smoke. Further, this chemical smoke does not develop the buoyancy pressures of the hot fire gases from the wood fires. It is possible that persons only observing the chemical smoke in an acceptance test could develop unrealistic expectations about improvements in smoke conditions on the fire floor.

5. SUMMARY

During the fires for which the smoke control system was not operating, there was significant smoke movement into the stairwell and to other floors

especially the seventh floor. When the smoke control system was operating, the stairwell and floors away from the fire remained essentially smoke free. These results demonstrated that zoned smoke control systems can achieve the objective of preventing smoke infiltration beyond the smoke zone. The experimental data is being analyzed to evaluate the underlying assumptions of zoned smoke control, and a detailed report will be published in the near future.

6. REFERENCES

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Table 1. Test Schedule

Test	Test Type	Fire Load ¹ lb (kg)	Zoned Smoke Control ²	Stairwell Pressurization ³	Activation Time ⁴ (min)	Condition of Stairwell Doors at:		
						Basement to Outside	2nd Floor ⁵	7th Floor
1	Wood Fire	300 (136)	off	off	-	closed	closed	closed
2	Smoke Bomb	-	on	off	0	closed	closed	closed
3	Wood Fire	200 (91)	on	off	0	closed	closed	closed
4	Smoke Bomb	-	off	off	-	closed	½ inch	open
5	Wood Fire	300 (136)	off	off	-	closed	½ inch	open
6	Smoke Bomb	-	on	on	0	open	½ inch	open
7	Wood Fire	300 (136)	on	on	0	open	½ inch	open
8	Smoke Bomb	-	on	on	4	open	½ inch	open
9	Wood Fire	300 (136)	on	on	4	open	½ inch	open
10	Sprinklered	300 (136)	off	off	-	closed	½ inch	open
11	Sprinklered	300 (136)	off	off	-	closed	½ inch	open

¹Fire load is approximate.

²Zoned smoke control consisted of pressurization of first and third floors at 2000 cfm (0.94 m³/s) each, and exhaust of the second floor at the same rate.

³Stairwell pressurization consisted of supplying 7000 cfm (3.3 m³/s) into the stairwell at the first floor with the exterior basement door open.

⁴Activation time is the time after ignition that the smoke control system and stairwell pressurization system are turned on.

⁵Second floor door designation ½ inch indicates that the door was cracked open ½ inch.

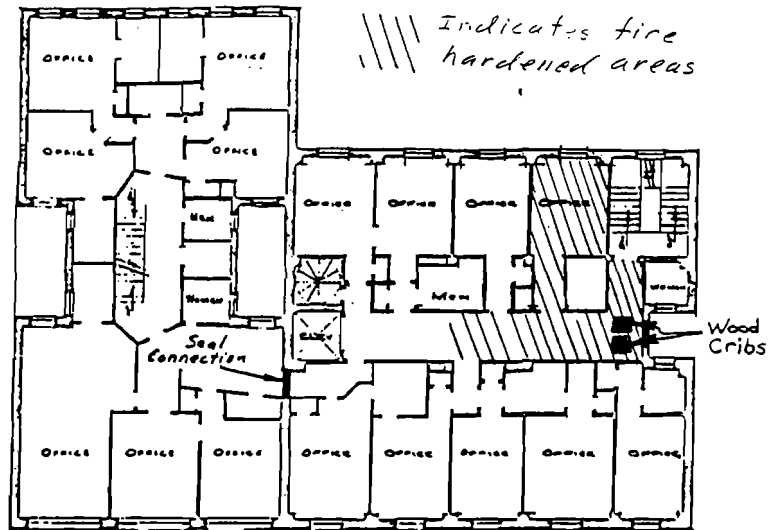


Figure 1. Second floor plan of Plaza Hotel

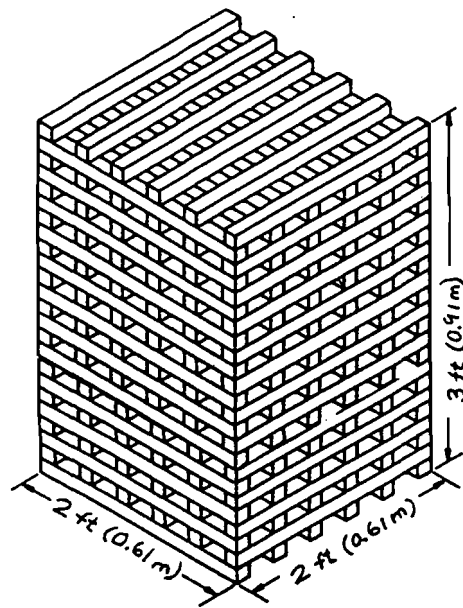


Figure 2. Crib configuration

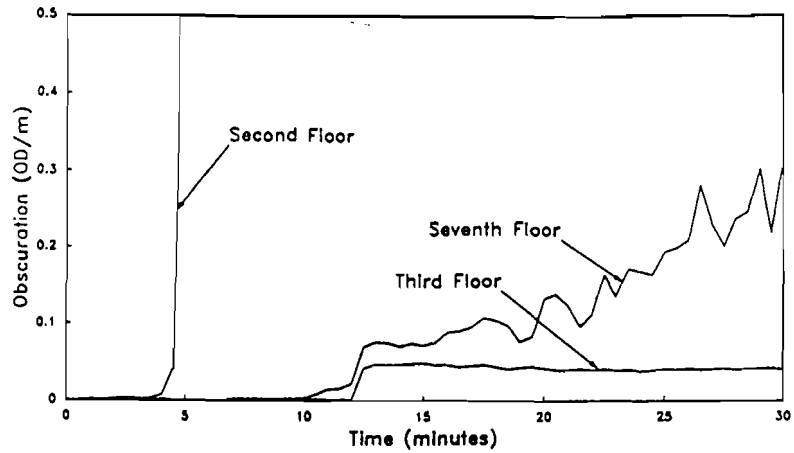


Figure 3. Smoke obscuration for wood fire without smoke control (test 5)

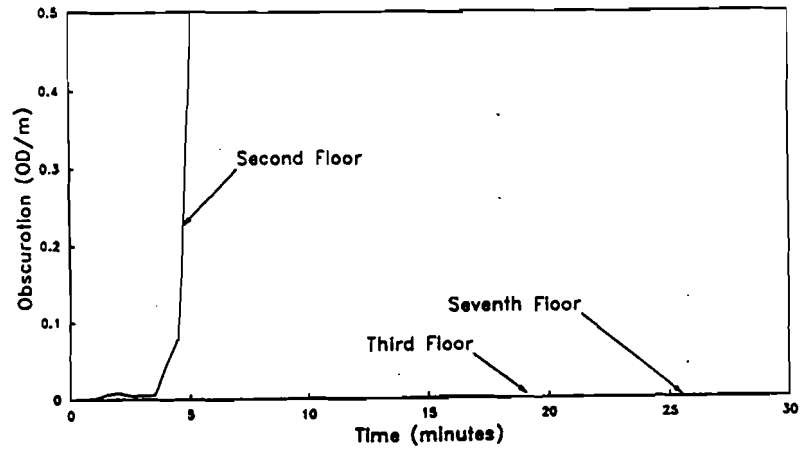


Figure 4. Smoke obscuration for wood fire with smoke control (test 9)

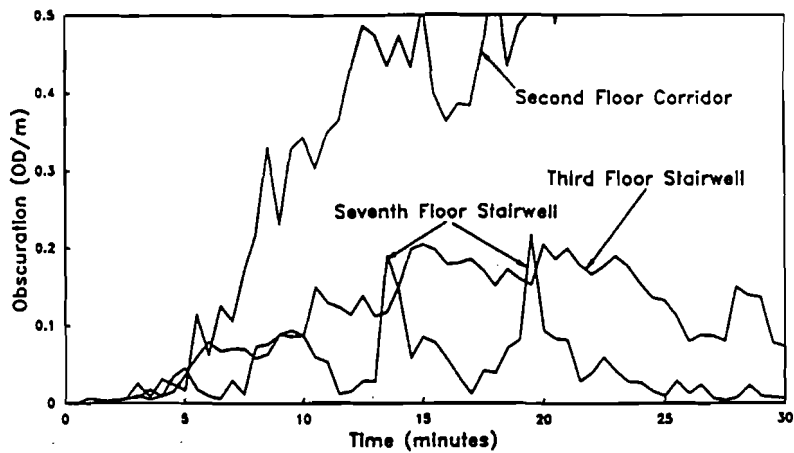


Figure 5. Smoke obscuration for wood fire without smoke control and sprinklered by on-off sprinkler (test 11)

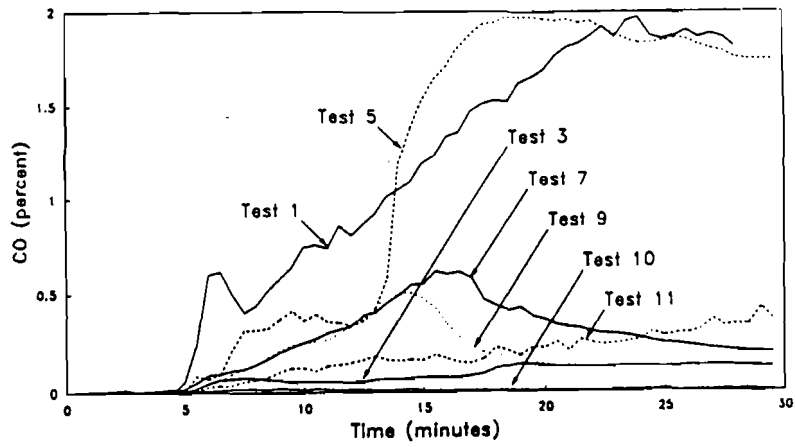


Figure 6. Second floor CO concentrations for wood fires

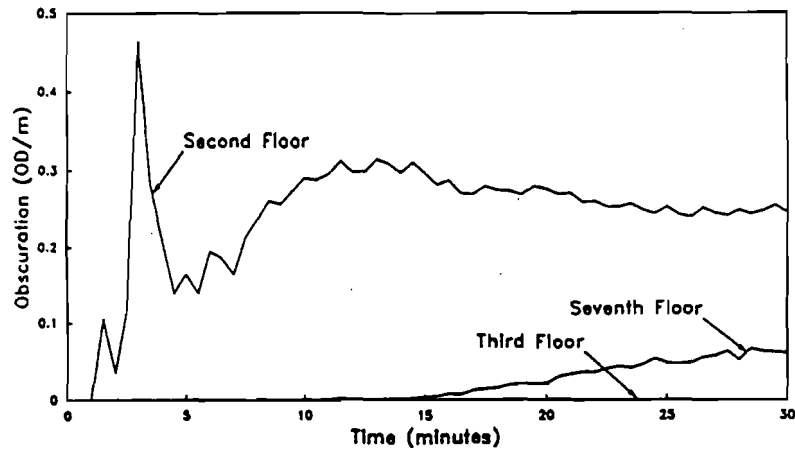


Figure 7. Smoke obscuration for smoke bomb test without smoke control (test 4)

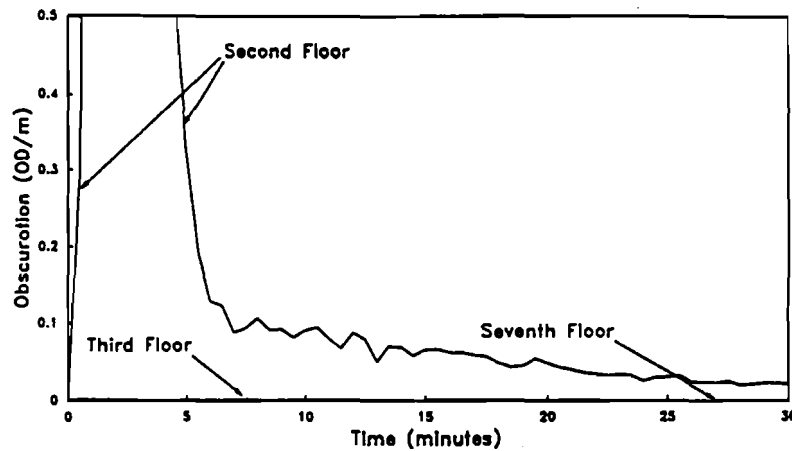


Figure 8. Smoke obscuration for smoke bomb test with smoke control (test 6)