Fire Technology, 37, 9–35, 2001

Interaction of Sprinklers with Smoke and Heat Vents

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Abstract. There has been an ongoing controversy about the use of sprinklers and smoke/heat vents together, and dozens of position papers have been published over the decades. This paper reviews 13 experimental studies that have some relevance to the claims posed for and against the combined use of sprinklers and smoke/heat vents. These studies are used to evaluate the positive and negative claims that have been made with regard to the combined use of sprinklers and smoke/heat vents. Three of the studies investigate the use of smoke/heat vents alone. Four investigations include sprinklers, but do not include roof vents. Three of these are test series in which perimeter vents were used in the test facility, and the fourth included sprinklers, a partial draft curtain, and no smoke/heat vents. Four test series included sprinklers, smoke/heat vents, and draft curtains, but utilized spray or pool fires which were not subject to extinguishment by the sprinklers. Four test series included sprinklers, smoke/heat vents, draft curtains, and used Class A fuels which were subject to extinguishment.

The studies of smoke and heat venting used in conjunction with sprinklers show clearly that venting does not have a negative effect on sprinkler performance. Experimental studies have shown that venting does limit the spread of products of combustion by releasing them from the building within the curtained compartment of fire origin. This improves visibility for building occupants and firefighters who need to find the seat of the fire to complete fire extinguishment. Limiting the spread of smoke and heat also reduces smoke and heat damage to the building. In the event that sprinklers do not operate, venting remains a valuable aid to manual control of the fire.

The experimental studies have shown that early vent activation has no detrimental effects on sprinkler performance and have also shown that current design practices are likely to limit the number of vents operated to one and vents may in fact not operate at all in very successful sprinkler operations. Design practices should move to methods that assure early operation of vents, and vent operation should be ganged so that the benefit of roof vents is fully realized. Sprinkler design with vents and draft curtains needs to take full account of draft curtains as obstructions. Curtains should be placed in aisles rather than over storage.

Key words: sprinklers, vents, smoke, heat

Introduction

The importance of sprinklers as a tool in fire safe building design is universally recognized. Development of this technology has been ongoing since the early 1800s [1]. In the absence of sprinklers, it is also well recognized that smoke and heat vents can play an important role in the fire safety design of buildings. The development of the technology of smoke and heat vents has been ongoing since 1954 when the first significant research on smoke and heat vents [2] was initiated in response to a disastrous fire which destroyed the Livonia automobile factory in 1953 [3, 4] and a similar automobile factory in Saginaw where manually opening skylights allowed an effective attack on the fire. Heat activated smoke and heat vents have been listed by UL and FM since the early 1970's. However, there are ongoing controversies regarding the use of these two well established fire protection technologies together. The goal of this paper is to assess our current state of knowledge regarding the interactions of sprinklers and smoke/heat vents through a review of the experimental research that has been performed. The review focuses on the use of sprinklers and smoke/heat vents in storage/warehouse facilities.

Overview of the Issues/Claims—Positive and Negative

Background

Significant research and development of heat and smoke vent technology was initiated in 1954. While this first study involved testing of vents in the absence of sprinklers, experimental studies that followed one year later represented the first investigations into aspects of the interaction of vents, draft curtains, and sprinklers [2, 5]. Since that time, there have been a variety of other studies that addressed the sprinkler/vent interaction problem.

Published and often unpublished reports of the results of combined sprinkler/vent studies typically conclude that certain enhanced or reduced benefits accrue from combining the two technologies, i.e., positive and/or negative claims. Also, over the years, many analyses of the results of these studies by people not directly involved in the work have also been published. These analyses invariably conclude with opinions on positive or negative claims for the combined technologies, opinions that are partly, and at times entirely, different from the opinions espoused in the corresponding original report of the work in question. Finally, published opinions on the effects of combining vents with sprinklers are often based on simple logical arguments. At times, even these latter opinions can appear to be contradictory. Thirty-four "position" papers on the subject were identified, and a separate list of these is presented in the Appendix. The next two sections list and describe briefly the physical basis for the various positive and negative claims relative to the impact of combining vents and sprinklers.

Issues/Claims—Positive

It is claimed in the literature that, when used with sprinklers, vents lead to enhanced fire safety over that attained by sprinklers alone in the following ways:

- ***Positive Claim: Smoke and heat vents improve visibility:*** The benefit of *improved visibility* is a result of the fundamental action of the venting. Smoke that is vented from the building does not contribute to the reduction of visibility within the building. Because the buoyancy and smoke concentration is greatest in the curtained area of the fire, smoke and heat vents provided within the draft curtain area of fire origin will most effectively vent the smoke and heat of the fire, hence improving visibility with the building. The enhanced visibility benefits escaping occupants of the building and firefighters who need to locate the fire to complete fire extinguishment.

- ***Positive Claim: Smoke and heat vents reduce temperatures and hazardous gas concentrations:*** The above explanation for *improved visibility*, i.e., removal through vents of the smoke, and replacement with cool, uncontaminated air, also explains how vents generally lead to reduced temperatures and reduced toxic and combustible gas concentrations within the space. The reduction in temperatures and hazardous gas concentrations benefit escaping occupants of the building and firefighters who need to locate the fire to complete fire extinguishment.
- ***Positive Claim: Smoke and heat vents contain damage to the curtained space:*** The combined action of draft curtains and smoke vents not only allows for the removal of smoke and heat from the building but also acts to limit the spread of heat and smoke outside the curtained area. The smoke and heat are trapped within the curtained area and are directly vented to the outside. In the absence of the curtains and vents, the smoke would spread throughout the facility, causing additional damage to the building contents.
- ***Positive Claim: Smoke and heat vents assist the fire department to identify the location of the fire within the facility and reduce the need for hazardous manual roof venting:*** The opening of the vents will lead to a flow of smoke through the roof of the facility, but only within the bounds of this curtained compartment of fire origin. Thus, the location of the fire *inside* the facility is revealed to the fire department, from *outside* the facility. In the absence of the curtain/vent system, the smoke would spread through the volume of the entire facility and flow to the outside through all randomly spaced leaks in the upper building envelope. These smoke leaks would not reveal the fire's location, requiring the fire department to search throughout the building to find the fire before completing the extinguishment of the fire. In addition, deployment of a curtain/vent system provides additional assistance in locating the fire once the fire department is *inside* the facility by virtue of the above-discussed benefit, *improved visibility*.

  The second of the fire department benefits is related to manual venting, i.e., the common firefighter practice of venting the fire by manually cutting holes in the roof of a facility. This is well known to be a particularly dangerous activity. With ceiling vents in place and available for firefighter use, the need for manual venting may be eliminated altogether. If additional venting is required, the practice is accomplished more quickly and safely than it would be possible in the absence of automatic roof vents, which can be easily and quickly operated manually.
- ***Positive Claim: Smoke and heat vents provide protection even if the sprinklers do not work:*** It is generally recognized that sprinkler systems are operational and effective in 90 to 99 percent of the fires, depending on the statistical source used and the definitions and qualifications applied. If the sprinkler system is not operational or effective, then manual firefighting needs to be relied upon for fire control. The smoke and heat vents will be effective in limiting damage to the building, providing firefighter access to the fire, and aiding in the escape of building occupants. In short, the benefits of heat and smoke vents can be realized in the absence of an effective sprinkler system.
- ***Positive Claim: Smoke and heat vents prevent an excessive number of sprinklers from operating:*** By limiting the spread of heat and smoke to the curtained area of fire origin, the operation of sprinklers remote from the fire is prevented. While sprinkler systems are designed to perform adequately without the benefit of smoke vents and

draft curtains, in marginal fire control situations, the prevention of the activation of remote sprinklers can allow successful fire control by the sprinklers where control might otherwise not be achieved.

Issues/Claims—Negative

When used with sprinklers, it is claimed in the literature that vents lead to reduced fire safety over that attained by sprinklers alone in the following ways:

- ***Negative Claim: Smoke and heat vents will cause enhanced burning rates:*** By definition, successful venting requires that the smoke that flows through the vents and out of the facility be continuously replaced via low-level supply-air vents. Therefore, with successful venting, virtually all the gases entrained into the combustion zone of the threatening fire will be fresh air, and the burning rate will be maintained at “free-burn” levels. In contrast, without roof vents or other natural or forced fresh air ventilation, a threatening fire in a facility will continuously consume the available oxygen in the entire space. The reduced oxygen concentration will reduce the burning rate of the fire. Thus, relative to the closed compartment fire scenario, the use of smoke and heat vents will lead to enhanced burning rates.
- ***Negative Claim: Smoke and heat vents will delay sprinkler activation:*** The venting of heat and smoke through roof vents will result in lower gas temperatures at ceiling level and will cause the early sprinkler activations to be delayed. This will result in a larger fire at the time of the early sprinkler activations, which could cause the fire to not be controlled by the sprinkler system.
- ***Negative Claim: Smoke and heat vents increase the number of activated sprinklers:*** The claim that vents cause an increased number of discharged sprinklers, in a way that is deleterious to success of sprinkler control of the fire, can be explained in two different ways, both of which are invoked in the position papers.

  The first explanation is that the delay in the activation of the first sprinklers will cause the fire size at first sprinkler activation to be larger. This in turn causes more sprinklers to be activated during fire control. In effect, fire control may not be realized and the number of sprinklers activated will exceed the design area.

  The second explanation is that the confinement of heat and smoke by the draft curtains will increase the temperatures at remote sprinklers within the curtain area, and this will increase the number of sprinklers activated.
- ***Negative Claim: Smoke and heat vent flow rates are insufficient to realize any benefit:*** The claim here is that the action of discharging sprinklers is so effective in cooling the smoke that the remaining forces of buoyancy will not be strong enough to successfully drive a significant amount of smoke out of the roof vents. As such, the benefits posed for smoke and heat venting will not be realized.
- ***Negative Claim: Smoke and heat vents are not cost effective:*** This claim is that smoke and heat vents are not sufficiently effective to justify the additional costs. It is sometimes suggested that the money would be better spent on other fire protection measures.

TABLE 1
Summary of Experimental Programs

Test Program (Chronological Order)	Roof Vents	Draft Curtains	Sprinklers	Fuel	Scale
1. Armour Research Foundation 1995 Reduced-Scale Vent Tests	Yes	Yes	No	NS	Small
2. FMRC 1956 Tests on Vents, Curtains, and Sprinklers	Yes	Yes	Yes	NS	Large
3. Fire Research Station Fire Vent Research	Yes	Yes	No	NS	Small, Large
4. UL 1964 Tests on Effects of Vents on Sprinkled Fires	Yes	Yes	Yes	S	Large
5. Colt International, Ltd. 1966 Portsmouth Fire Tests	Yes	Yes	No	NS	Large
6. FMRC 1970 Rubber Tire Fire Test	Perimeter	No	Yes	S	Large
7. FMRC 1971 Rack Storage Tests	Perimeter	No	Yes	S	Large
8. FMRC Model Study of Venting Performance in Sprinklered Fires	Yes	Yes	Yes	NS, S	Small
9. FMRC 1975 Stored Plastics Test Program	Perimeter	No	Yes	S	Large
10. IITRI 1980 Full-Scale Vent/Sprinkler Research	Yes	Yes	Yes	S	Large
11. 1989 Ghent Vent/Sprinkler Tests	Yes	Yes	Yes	NS	Large
12. FMRC 1994 Protection of Warehouse Retail Occupancies	No	Partial	Yes	S	Large
13. UL 1998 Sprinkler, Vent, Draft Curtain Fire Tests (NFPRF)	Yes	Yes	Yes	NS, S	Large

NS—fire is not suppressible (i.e., spray or flammable liquid pool fire), S—fire is suppressible (e.g., Class A fuels).

Overview of Tests and Summaries of Results

In order to evaluate these positive and negative claims, it is useful to review the research that has been conducted. The following is a summary of experimental investigations that have had some measure of influence on claims that the combining of vents and sprinklers leads to a positive or negative impact on fire safety. The summaries are arranged in chronological order to facilitate an understanding of the progression of the work in the field. Table 1 summarizes the investigations and their characteristics.

Armour Research Foundation 1955 Reduced-Scale Vent Tests [2]

In response to the Livonia fire, General Motors sponsored a research program to study venting, which was conducted by the Armour Research Foundation of the Illinois Institute of Technology (IIT) [2]. The purpose of the work was to establish a basis for vent design that would be expected to remove most of the heat and smoke generated in industrial plant fires. The study involved 1/8 and 1/16 scale models of factory-like buildings. Equivalent full-scale fire sizes of 13.6 MW (12,900 Btu/s) were used as the fire threat; these were intended to simulate 10.2 m^2 (110 ft^2) gasoline spill fires. Most of the experiments involved steady-state tests. For the fire threat evaluated, it was found that a vent area to floor area of 1:30 was adequate for a successful design.

Some combined sprinkler/vent tests with water density of 10.2 Lpm/m^2 (0.25 gpm/ft^2) were performed. From these tests, it was determined that the cooling action of the sprinklers was effective in reducing the gas temperature and in removing about 35 percent of energy released by the fire. The 1:30 unsprinklered vent design area was found to be effective in removing most of the remaining fire energy release. The results of this study provided much of the basis for the original NFPA 204 [3, 6].

FMRC's 1956 Tests on Vents, Curtains, and Sprinklers [5]

In 1956, FMRC ran a series of large-scale tests to study the effects of combining sprinklers, vents, and draft curtains. The tests were conducted in a 36.6 m × 18.3 m (120 ft × 60 ft) test building. A 20 Lpm (5 gpm) gasoline spray fire (~10 MW) was used as the fire threat. Automatic sprinklers were 71°C (160°F) heads installed on a 3 m × 3 m (10 ft × 10 ft) spacing. In the tests where draft curtains and vents were used, the draft curtains were 1.5 m (5 ft) deep, and vent areas were 1.5 m^2 (16 ft^2) or 3.0 m^2 (32 ft^2), within a curtained area of 212 m^2 (2280 ft^2), i.e., vent area to floor area of 1:140 or 1:70, respectively. Water application densities used were 0, 6.1, and 10.2 Lpm/m^2 (0, 0.15, and 0.25 gpm/ft^2). The tests in the series were conducted using various combinations of vents, draft curtains, and sprinklers. Six of these tests were sprinklered.

The test results provided in this study were for steady fire sources, which cannot be suppressed. As such, they did not provide insights into the full transient interactions of fire growth, fire suppression, and remote sprinkler activations. Nonetheless, these tests provided insights into the fluid dynamics interactions of fire flows and sprinkler flows. Comparison of average temperatures indicated that vents contributed significantly to temperature reductions in the unsprinklered tests in the series; however, they were of modest value in reducing temperatures in the sprinklered tests.

Even without venting, draft curtains significantly reduced the number of operating sprinklers from 48 to 28 sprinklers in the case of a 57 Lpm (15 gpm) sprinkler discharge rate, limiting the discharged sprinklers to those located within the curtained compartment of fire origin. Venting reduced the number of operating sprinklers, but only marginally for 57 Lpm (15 gpm) sprinkler discharge from 48 to 44 sprinklers in the case of no draft curtains, and from 28 to 24 sprinklers in the case with draft curtains. With draft curtains but no vents, the number of operating sprinklers was reduced from 28 to 15 sprinklers when the sprinkler discharge was increased from 57 Lpm (15 gpm) to 95 Lpm (25 gpm). With draft curtains but no vents, changes in sprinkler discharge from zero to 57 Lpm (15 gpm) to 95 Lpm (25 gpm) resulted in significant corresponding reductions in temperatures in the curtained spaces. For the sprinklered scenarios studied, venting performed a positive, but modest role in reducing temperatures [7].

While venting had only modest impacts on temperatures in sprinklered tests, venting did have a positive effect on visibility in building bays adjacent to the fire area. In unvented tests, visibility was generally reduced to zero after about six minutes. In vented tests, visibility in bays remote from the fire was improved as compared to the unvented tests [8].

Test results showed that, while vents are effective in reducing temperatures, sprinklers are even more effective in this regard. Draft curtains were shown to play a major role in controlling the maximum number of operating sprinklers to only those in the curtained space, but it would appear that success in this can only be assured if vents are available to keep the smoke/high-temperature gases from flowing out to adjacent curtain-compartmented spaces. Venting had a positive effect on visibility in building bays adjacent to the fire area in sprinklered fires.

Fire Research Station's (FRS) Fire Vent Research [9, 10]

In 1958, Colt International, Ltd. sponsored a four-year fire ventilation research program conducted by the FRS, Building Research Establishment in the United Kingdom (UK). This was a combined experimental/analytic investigation of unsprinklered fires. Nomographs were developed relating required area of venting to fire size, building height, depth of draft curtains and permissible depth of smoke and hot gases. This work provided the basis for the engineering design of smoke and heat venting (for example, see Hinkley [11]).

Underwriters Laboratories Inc.'s (UL) 1964 Tests on Effects of Vents on Sprinklered Fires [12]

In 1964, UL conducted an experimental program to study effects of automatic roof vents on sprinklered fires. The first of two series of experiments involved three tests: one with a 3.3 m^2 (36 ft^2) vent and 74°C (165°F) sprinklers, one without vents and 74°C (165°F) sprinklers, and one without vents and 100°C (212°F) sprinklers.

The first test series was performed in an 18 m × 18 m × 5 m high (60 ft × 60 ft × 16 ft high) room, i.e., vent area to floor area in the vented test of 1:100. Sprinklers were installed on a 3 m × 3 m (10 ft × 10 ft) spacing, 0.3 m (1 ft) below the roof. Water to the sprinklers was supplied from a 30 m (100 ft) high tower. The fire threat was a 1.8 m (6 ft) high crib, constructed of 32 layers of 5, 0.05 m × 0.10 m × 0.91 m long (2 in × 4 in × 3 ft long) wood sticks. The crib was placed over a gasoline nozzle burner with a flow rate of 1.1 Lpm (0.3 gpm).

The fire was centered between four sprinklers and was about 6 m (20 ft) from two of the walls. Automatic vent action was simulated by manually opening the vent after fusing a 74°C (165°F) link. The vent was located approximately 6 m (20 ft) from the fire.

Comparing the vented and unvented test, the corresponding tests with the 74°C (165°F) sprinklers, it was found that the effect of the vent was to decrease the number of operating sprinklers from 13 to 9, decrease the total water demand, improve the water density on fire, modestly decrease crib weight loss, and increase roof temperatures.

The second series of experiments involved six larger-scale tests. The larger space used in this series included two contiguous areas of differing roof heights. Also, multiple vents were used, one of which, but not all, was open at the start of several tests. In some tests, remote sprinklers were not supplied with water. The results suggested that venting decreased the number of operating sprinklers (the total water flow rate), caused no significant difference in damage to the test array of combustibles (cardboard or polystyrene boxes on pallets), and increased severity of the structural exposure. Two tests with polystyrene boxes had the remote vent closed and the nearer vent in automatic mode. For these, the test with a 2.2 m^2 (24 ft^2) vent area activated 12 sprinklers; 11 sprinklers were activated when the vent area was increased to 4.5 m^2 (48 ft^2) [3].

Colt International, Ltd.'s 1966 Portsmouth Fire Tests [13]

In 1966, FRS and Colt International, Ltd. conducted a series of four unsprinklered tests, with and without vents, in Victoria Barracks, Portsmouth, United Kingdom. The test space was 18 m × 11 m × 8 m high (60 ft × 36 ft × 27 ft high). The conclusions were as follows: (1) Within the test space, temperature increases without vents were over three times the temperature increases with vents, and without vents, the temperature exceeded that at which structural steel would fail. This was not the case with vents. (2) In the vented tests, the low temperature and smoke levels near the ground were such that firefighters could locate the fire and extinguish it rapidly. (3) While use of vents reduced temperatures in the test space, the reduction was not low enough to prevent timely operation of fusible links in the vicinity of the fire, which were deployed in a way as to simulate the operation of first sprinkler discharge [3].

FMRC's 1970 Rubber Tire Fire Test [14]

In 1970, FMRC conducted sprinklered fire tests of rubber tire rack storage in a closed facility. In one test, sprinklers apparently controlled the fire within 8 to 14 minutes, with 43 sprinklers activated by 8 min and 44 sprinklers activated by 28 min. At 60 minutes into the test, all doors and windows were opened to ventilate the building. At 87 minutes, with the number of activated sprinklers still at 44 and after all roof temperatures had apparently been maintained at relatively low levels, from 40 to 90°C (100 to 200°F) since the time the sprinklers first established control of the fire, near-roof gas temperatures at one end of the rack storage started to increase rapidly. Fifty sprinklers were activated by 94 minutes, and 94 sprinklers were activated at 117 minutes, at which time all doors and windows were again closed. After the closing of the doors and windows, one additional sprinkler activated at 118 minutes. A final maximum of 95 sprinklers activated.

At the time the doors and windows were opened at 60 minutes, the oxygen concentration in the test building was 19 percent. At the time the doors and windows were closed at 117 minutes, the oxygen concentration was 21 percent. On closing the doors, the oxygen concentration was reduced to 15 percent for a short time before increasing again. Temperature data were apparently not obtained from approximately 18 minutes to 80 minutes into the test. Sequencing of sprinkler activations was not reported. Temperatures measured at roof level indicate that the fire reignited around 87 minutes when additional sprinklers began to operate well away (to the south) from the fire origin. The ultimate damage is consistent with this observation. It appears that the fire burned inside the array and spread to a remote location. This behavior is consistent with the burning behavior observed in landfills and other disposal sites for discarded tires [3, 15].

Although it is clear that this test is not well understood, it has been widely cited as an example of the detrimental effect of ventilation [8, 16]. Similarly, the significance of the test and its interpretation as a ventilation-related phenomenon have been strongly countered by others [3, 15].

FMRC's 1971 Report on Rack Storage Tests [17]

The test report covers a series of 6.1 m (20 ft) high rack storage tests carried out at FMRC between 1968 and 1970. Some of these tests are considered to be relevant to the question of combined sprinklers and (roof) vents because of comparisons between tests in a fully closed facility and in one that was vented with doors and/or eaveline windows open from the start of the test (i.e., perimeter vents). However, the action of actual roof vents was not evaluated in any of these tests. Only three tests employed perimeter ventilation, and only one of these was replicated without the ventilation feature. Reference is to vented Test 72, which, except for the ventilation, was identical to replicate Tests 65 and 66.

Comparing Tests 65 and 66 (without vents) to Test 72 (with vents), it was found that with the vents, there was more than twice the damage to the commodities (22 percent of the boxes consumed in both Tests 65 and 66 with no significant damage to the racks versus 50 percent for Test 72 with damage to the central part of the racks) and more than twice the sprinklers activated (45 and 48 for Tests 65 and 66, respectively, versus 98 for Test 72). In the vented test, first sprinkler activation occurred earlier than in the unvented tests (3 min 15 s and 3 min 11 s for Tests 65 and 66, respectively, versus 2 min 35 s for Test 72). Finally, it is noted that vented Test 72 had a significantly different initial fire growth behavior compared to that of Test 65 and 66, and that this may have affected the outcome. FMRC's position on the effects of ventilation in these tests is that they are not conclusive.

Alternative opinions have been offered in the interpretation of the results of these tests. Waterman *et al*. [3] have emphasized the inappropriateness of interpreting the action of perimeter ventilation with that of roof vents and the significant problems of reproducibility in apparently similar tests.

FMRC's Model Study of Venting Performance in Sprinklered Fires [18]

In the early 1970s, an FMRC small-scale experimental study was conducted. The objective was to investigate experimentally the performance of automatic heat and smoke vents in sprinklered fires in one-story buildings, principally in terms of sprinkler water demand, but also in terms of visibility conditions and fuel consumption. The study was performed at FMRC's Norwood, MA, laboratory and involved a 1:12.5 scale model of FMRC's fire test facility at West Gloucester, RI. In the following discussion of the tests, all dimensions are reported as the full-scale configuration that the scale model is intended to represent. To determine the physical dimensions of the scale model experiments, all lengths should be divided by 12.5.

The overall scale of the experiment is 76 m × 61 m (250 ft by 200 ft), i.e., 4,650 m^2 (50,000 ft^2), with a single roof elevation for the entire space. Experiments were conducted in the 9 m (30 ft) tall portion of the facility (i.e., a raised floor) though approximately, half the facility has a roof height of 18 m (60 ft) (i.e., a lower floor). Automatic, individually-fused vents on 15.2 m (50 ft) spacing were employed with vent areas up to 9.3 m^2 (100 ft^2). The draft curtain area was 30 m × 30 m (100 ft × 100 ft), yielding a curtained area of 929 m^2 (10,000 ft^2). The draft curtains were aluminum sheets 1.8 m (6 ft) deep. Vent ratios of 1:25, 1:50, and 1:100 were tested. Spray nozzles were used to represent sprinklers. Rather than employing individual fusible links, simulated 100°C (212°F) sprinkler links were used to cause activation of zones of spray nozzles via solenoid valves. Zones included four to ten spray nozzles. The first ring of spray nozzles was a single zone, and beyond the first ring, zones included the nozzles in a quadrant of the ring. Sprinkler application densities of 11 and 18 Lpm/m^2 (0.27 and 0.45 gpm/ft^2) were used in the testing.

High piled combustible materials were simulated through the use of vertical 152 mm (6 in.) thick triwall cardboard arrays with a scaled height of 6.1 m (20 ft) and a scaled spacing of 152 mm (6 in.). Alternate scaled heights ranged from 3.6 to 7.9 m (12 to 26 ft) were employed. The vertical array had no aisles, and central ignitions were always used. A square heptane pool fire with a scaled edge length of 3.6 m (12 ft) was used in some tests.

Measurements during the testing included temperatures of the simulated sprinkler link and gas temperatures near the roof. The optical density of smoke and oxygen concentrations at eye level was measured in the curtained area. The obscuration produced by the water spray was subtracted from the measurement in an attempt to isolate smoke obscuration from water spray obscuration. Water spray corrections were based on measurements of obscuration with only the water spray nozzles operating. The total sprinkler flow rate of the system was measured during the test.

The testing included 24 different sets of conditions. Variables included the fuel array, the sprinkler density, the vent ratio, and the presence or absence of draft curtains. The number of replicate tests ranged from one to nine.

For the cardboard tests, the addition of vents and draft curtains increased the fuel consumed by about 65 percent. The water demand was increased by about 35 percent. At the same time, the time to the loss of visibility in the curtained area was delayed from 13 minutes to 20 minutes by the addition of vents and curtains. Since no smoke measurements were made outside the curtained area of fire origin, the effect of vents and curtains on the remainder of the building where additional benefits would be expected are not known. In these tests, all the vents within the curtained area opened except for three tests in which three of four opened. The reproducibility of the cardboard tests in terms of the number of sprinkler activations was about ±20 percent (e.g., for unvented cardboard tests, 44 sprinklers were activated on average with a standard deviation of about 7 sprinklers). These fires were placed at the center of the curtained area which maximizes the distance to the vents. When the fire was directly below a vent, the number of sprinklers activated was reduced relative to the no vent case, and times to loss of visibility were increased.

When the water application density was increased to 18 Lpm/m^2 (0.45 gpm/ft^2), the number of sprinklers activated was reduced markedly to less than 20, and the vents did not operate. Fires were centered on the curtained area that maximized the distance to the vents.

For the larger heptane pool fires, vents and draft curtains reduced the water demand by about 20 percent and improved the visibility by as much as a factor of two though total loss of visibility was not realized in this series even without vents. Of course, since the heptane pool fire could not be suppressed, there was no effect on fuel consumed.

In cardboard tests in which all vents were opened at first sprinkler activation, the number of sprinklers activated was unchanged relative to the no vent case, and visibility was not lost at any time during the tests. The minimum oxygen concentration for unvented tests was generally about 18 percent while for vented tests the concentrations were 20 to 21 percent.

FMRC's 1975 Stored Plastics Test Program [19]

The FMRC fire test facility at West Gloucester was used for a test series that included 23 full-scale sprinklered tests involving plastics stored in a variety of configurations. It is of interest to note that, in contrast to the relatively small number of vented tests in the FMRC [17] study and despite the concern of FMRC of the effects of ventilating sprinklered fires, all 23 of these tests were conducted with 82 m^2 (882 ft^2) of open eaveline perimeter windows and with 34 m^2 (368 ft^2) additional venting from open doorways. No roof vents were included. It is also noteworthy that similar perimeter window and door ventilation was always used in a subsequent three-phase series of 17 full-scale FMRC tests of stored plastic commodities [20–22].

For the tests, first sprinkler activation ranged from 46 s to 3 min 6 s, and total number of sprinklers activated ranged from 3 to 76. The minimum oxygen concentration of the air as it entered the fuel arrays at the 5 ft elevation ranged from 18 percent to 21 percent by volume for 20 of the 23 tests and 11.9 percent for 1 test. For the remaining two tests, this datum point was not reported. No trends in the results of the testing can be linked to the oxygen concentration [3].

IITRI's 1980 Full-Scale Vent/Sprinkler Research Tests [3, 4, 23]

In 1977, the intra-industry Fire Venting Research Committee sponsored IITRI (IIT Research Institute) to review past research and fire experience related to vent/sprinkler interactions in large-area single-story structures. Based on the review and other considerations, the committee funded IITRI to conduct 45 large-scale experiments. This was done in 1980–1981. The experiments were conducted in a 23 m × 7.6 m × 5.2 m high (75 ft × 25 ft × 17 ft high) test space. Fires were placed in a corner to represent one-quarter of a larger fire in the center of a 46 m × 15.2 m (150 ft × 50 ft) room. Thus, the simulated curtain area was 700 m^2 (7500 ft^2). To simulate the test area as part of an even larger area, two garage doors on the wall farthest from the fire were partially opened to represent a draft curtain. The area beyond the curtains was also enclosed by vertical air stacks to minimize extraneous wind effects. Up to four 3.0 m^2 (32 ft^2) automatic roof vents were included in the tests. The activation temperature of their fusible links was 74°C (165°F). The sprinklers used in the tests were deployed with spacing of 3 m (10 ft) approximately, and they had activation temperatures of 74°C (165°F) or 141°C (286°F). The system was designed for water deliveries of up to 24 Lpm/m^2 (0.6 gpm/ft^2).

The activation time of each vent and sprinkler was determined, and the temperature of dummy links adjacent to each sprinkler and vent were instrumented for temperature. Gas temperatures at roof level and a thermocouple tree was placed in the curtained area well away from the fire source. Oxygen, carbon dioxide, and carbon monoxide were measured near the floor next to the fire to monitor the air quality of the air entrained into the fire.

The propane fires had heat release rates of 3470 kW (197,500 Btu/min). Tests with both 74°C (165°F) sprinklers and 141°C (286°F) sprinklers showed that the time to first sprinkler activation and the total number of sprinklers activated were not affected by the roof vents. The roof vents did improve the visibility in the curtained area away from the fire. Oxygen concentrations were all in the range of 18 to 21 percent with lower values associated with fewer vents and more sprinkler activations.

The wood pallet tests used only 74°C (165°F) sprinklers. In preliminary tests, it became clear that the tests were not sufficiently reproducible to allow clear and easy interpretation of results. The lack of reproducibility was most easily seen in the number of sprinklers activated. As a result, it was decided to perform five replicate tests with and without roof vents. Each of these tests involved four abutted stacks of wood pallets (0.91 m ×

1.22 m × 0.12 m high (3 ft × 4 ft × 4.62 in. high)) piled five pallets high. The average number of sprinklers activated was found to be 17 for both the vented and unvented cases. The standard deviations were 6 and 3 for the unvented and vented tests, respectively. The oxygen concentrations measured during the tests ranged from 17 to 21 percent, but there was no clear effect of venting upon the oxygen concentration measurements. No clear statements concerning the effects of vents on visibility can be made based on the IITRI test results. Since the facility did not include building areas outside the curtained area, the tests provide no insights into visibility in these areas.

1989 Ghent Tests [24–27]

In 1989, the FRS, Colt International, Ltd., and the City of Ghent Fire Brigade undertook a collaborative test program in a test building constructed in Ghent, Belgium, the Multifunctioneel Trainingcentrum. The main objective was develop a database with which to validate the capability of the fire model presented in Hinkley [28–30] to simulate the test fire scenarios. The data acquired were also used to evaluate the effectiveness of vents in sprinklered fires.

The test building involved a single space 50 m × 18 m × 10 m high (164 ft × 59 ft × 33 ft high). For the tests, a 3.1 m (10 ft) deep draft curtain was hung from the roof, creating a curtained, flat-roof area of 27 m × 18 m (89 ft × 59 ft) under which test fires were burned. A total of 20 roof vents, each with an area of 1.67 m^2 (18 ft^2) were installed in this area, centered on a grid measuring 4.8 m × 4.5 m (16 ft × 15 ft). Sprinklers on a spacing of 3.7 m × 2.4 m (12 ft × 8 ft) were also installed in this area. The sprinklers had fusible links with temperature ratings of 68°C (155°F). The roof area on the other side of the draft curtain was also provided with 20 roof vents, and these were always open. A total of 16 inlet vents were installed at ground level in the sides of the building, each having an aerodynamic free area of 3.1 m^2 (34 ft^2).

Test fires were pool fires with hexane floating on water near the floor level. One source had a steady output of 5.4 MW (5100 Btu/sec). The other source provided approximately an exponentially growing heat release rate, reaching 10 MW (9500 Btu/sec) in 2.5 min. In one group of tests with the growing fire, the growth rate was continued until the first sprinkler activated, at which time the heat release rate was kept constant until the end of the test. For the later tests, the energy release rate during the constant portion of the tests ranged from 9 MW to 13 MW (8,700 Btu/s to 12,300 Btu/sec). In a second group of tests with the growing fire, the growth rate was continued until the first sprinkler activated, at which time the heat release rate was kept constant for 30 s and then reduced by 20 percent to the end of the test.

In the steady fire experiments, prescribed numbers of vents (0, 10, or 20) and sprinklers (1 or 5) were used. While vents reduced the temperatures in the upper portion of the curtained area, in all cases, temperature distributions reflect a well defined stratified upper layer. Measured velocities in the vents were unaffected by the operation of the sprinklers.

In the growing fire tests, the time to first sprinkler activation was increased an average of 12 seconds over the 150 second nonvented baseline. Increasing the number of vents reduced the number of sprinklers ultimately activated. In as much as the test fires were limited to about 10 MW, in all cases, the additional sprinklers operating without vents were providing water to areas where no fire was present or would be expected to be present for realistic fuels. The number of sprinklers activated was reduced as the applied water density increased. Some local smoke logging was observed for the higher applied water densities.

FMRC's 1994 Tests of Protection of Warehouse Retail Occupancies [31–34]

The FMRC fire test facility at West Gloucester was used for a full-scale test program to determine if existing or new technology fire sprinkler systems are capable of providing acceptable protection for storage found in warehouses and warehouse-type retail stores. Nine large-scale fire tests were conducted with double-row rack storage arrangements containing a cartoned Group A Unexpanded Plastic commodity. Partial cross-aisle arrays of the combustibles were included to evaluate the possibility of cross-aisle fire spread. Sprinkler protection was provided by Extra Large Orifice upright sprinklers, with 16 mm (0.64 in) diameter orifice, deployed at the roof only, i.e., no in-rack sprinklers. The deflectors and the fusible links were approximately 0.18 m (7 in) and 0.20 m (8 in), respectively, from the roof. Test variables included spacing of sprinklers (2.4 m × 3.0 m (8 ft × 10 ft) or 3.0 m × 3.0 m (10 ft × 10 ft) grid), floor-to-roof spacing (6.7 m to 8.2 m (22 ft to 27 ft)), storage height (4.2 m to 6.1 m (14 ft to 20 ft)), ignition location (between two sprinklers in the case of low-roof clearance and directly below a sprinkler in the case of high-roof clearance), sprinkler temperature rating (74°F (165°F) or 141°C (286°F)), sprinkler discharge density (18 mm/min to 24 mm/min (0.45 gpm/ft^2 to 0.60 gpm/ft^2)), number of storage tiers (3 to 6); type of shelving (slatted wood, solid wood or wire mesh), flue spacing, and the presence of draft curtains.

Partial draft curtains were installed in two of the nine tests to assess their effects on fire development and sprinkler performance. Two intersecting 19.8 m long × 1.8 m deep (65 ft long × 6 ft deep) draft curtains were installed over the storage arrays. As such, the draft curtains were only included in the context of their role as an obstruction and no smoke vents were included in any of the tests. Draft curtains are not normally used in the manner tested. Curtain locations were coordinated with ignition locations to provide worst-case conditions, i.e., fire initiation below the curtain and just inside a curtain corner. In terms of the two tests with draft curtains (Tests 6 and 7), one was an otherwise replicated test with 74°F (165°F) sprinklers, but with no draft curtains (compare Tests 1 and 6) and one with 141°C (286°F) sprinklers (compare Tests 3 and 7), but with no draft curtains. No replicate tests were performed.

Criteria for successful sprinkler action used to evaluate results of the tests were (1) magnitude of the water demand—a maximum 186 m^2 (2000 ft^2) design area was desired, i.e., more than 25 discharged sprinklers constituted failure; (2) magnitude and duration of high roof level steel and gas temperatures—temperatures sustained at levels that would result in damage to exposed structural steel would be unacceptable (e.g., steel temperatures in excess of 638°C (1180°F) and gas temperatures sustained at or above 538°C (1000°F) for more than 7 minutes were unsafe); and (3) extent of fire damage—confinement of the fire within the limits of length of the test storage array was required (fire spread to the end of the array was allowed). The application of Criterion 3 also differed from the historical approach. Historically, it would have been judged that if the fire jumped an aisle or if the fire reached the end of the fuel array, the fire would not be judged to have been confined within the limits of the test array. In this work, the authors deemed that tests where the flames spread to the end of the array were successes. The historical view arises, of course, out of the realization that if the fire reaches the end of the array, the test provides no basis for assuming that fire propagation will be limited, and as such, the protection cannot be viewed as adequate. Using historical acceptance criteria, six of the nine tests would have been classified as failures, rather than three of the six tests as reported by the authors.

The authors indicated that neither of the two tests with draft curtains met the above criteria. In Test 6 (origin below the curtain), 35 sprinkler heads operated over an area of 260 m^2 (2800 ft^2). There were two instances of sprinkler skipping in the area of the draft curtain that may have caused this result. In Test 7 (origin at the corner of the curtain), the fire spread across the aisle. It was concluded that draft curtains were detrimental to sprinkler performance in sprinklered warehouses and warehouse retail stores. It was also concluded that to further understand the effects on sprinkler performance caused by the presence of draft curtains, additional testing should be considered.

UL's 1998 Sprinkler, Vent, Draft Curtain Fire Tests [35, 36]

The International Fire Sprinkler, Smoke and Heat Vent, Draft Curtain Fire Test Project organized by the National Fire Protection Research Foundation (NFPRF) brought together a group of industrial sponsors to support and plan a series of large scale tests to study the interaction of sprinklers, roof vents, and draft curtains of the type found in large warehouses, manufacturing facilities, and warehouse-like retail stores. A Technical Advisory Committee consisting of representatives from the sponsoring organizations, the National Institute of Standards and Technology (NIST), and other interested parties planned 39 large-scale fire tests that were conducted in the Large Scale Fire Test Facility at Underwriters Laboratories (UL) in Northbrook, IL.

The tests were designed to address relatively large, open area buildings with flat roofs, sprinkler systems, and roof venting with and without draft curtains. To simulate these conditions in the 37 m × 37 m × 15 m high (120 ft × 120 ft × 48 ft high) main test bay, the vents, draft curtains, and sprinklers were installed on a 30 m × 30 m (100 ft × 100 ft) adjustable-height roof-like platform, 7.6 m (25 ft) or 8.2 m (27 ft) off the floor. When draft curtains were used, the curtained area was 21.7 m × 20.5 m (71.2 ft × 67.1 ft), 455 m^2 (4780 ft^2). The depth of the draft curtains was 1.8 m (6 ft). Each vent had an area of 3.0 m^2 (32 ft^2), and there were four vents in the curtained area, i.e., a vent-area-to-floor-area of 1:37. In most tests, the smoke vents were activated by 74°C (165°F) fusible links. During the tests, smoke and hot gases filled the volume enclosed by the draft curtains, and the excess smoke flowed around the edges of the platform into a plenum space above. The smoke in the plenum space was continually exhausted through a smoke abatement system. Because of the need to exhaust all tests, it was not possible to assess the effects of vents and curtains except with regard to local effects as all the tests conducted were vented via the plenum.

The sprinkler protection was provided by 74°C (165°F) Extra Large Orifice, 16 mm (0.64 in.), sprinklers installed at the roof only, using a 3.05 m (10 ft) by 3.05 m (10 ft) spacing. The application density was set at 20.4 Lpm/m^2 (0.5 gpm/ft^2), somewhat less than the normal design value of 24.5 Lpm/m^2 (0.6 gpm/ft^2) for unexpanded plastic commodities stored in double rack tiered storage up to 6.1 m (20 ft).

The testing included 34 heptane spray fire tests and five high rack storage tests. Tests were performed with and without draft curtains and with and without operational smoke vents. The heptane spray fire tests were divided into two test series. Both series used fires which grew as t-squared fires designed to reach 10 MW in 75 s (in one test, 10 MW in 150 s). The growth curve in the first series was followed until the first sprinkler activated (typically at somewhat over one minute when the fire was approximately 5 MW), at which time the fire was maintained steady for the duration of the test. In the second test series, the heptane fire followed the t-squared curve to reach 10 MW in 75 seconds and was then kept steady at 10 MW for the duration of the 16 test. The five rack storage tests used the FM standard plastic commodity, consisting of unexpanded polystyrene cups in triwall cartons stacked on standard pallets. The storage was two wide racks, four tiers tall with a total height of 6.1 m (20 ft). Aisle widths were 2.4 m (8 ft). The plenum exhaust system flowed at 11 m^3/s (24,000 cfm) during heptane tests and 23 m^3/s (60,000 cfm) during rack storage tests.

The first series of 22 heptane spray fire (approximately 5 MW) tests was performed with a single vent which was alternately closed, manually activated, and thermally activated, with and without draft curtains. The fire location was varied with respect to the vent and draft curtains. The second series of 12 heptane spray fire (10 MW) tests were performed with closed vents, manually activated vents, and thermally activated vents. Draft curtains were in place for all the 10 MW tests. The rack storage tests included two tests without draft curtains and three tests with draft curtains. Vents were in place and thermally activated in all rack storage tests except the final test when all four vents were manually activated at the time of the first sprinkler operation.

The first heptane test series showed no effect of vent operation on the time to first sprinkler operation or the ultimate number of sprinklers activated. Draft curtains increased the total number of sprinklers activated from 4–6 sprinklers to 8–13 sprinklers, but had no effect on first sprinkler activation.

The second heptane test series showed that the operation of vents had no effect on the time to first sprinkler activation or the total number of sprinklers operating, including tests in which all the vents were open at the start of the test. The total number of sprinklers operating varied from 13 to 28 depending upon the position of the fire. When the fire was placed directly below the curtain, 23 sprinklers were operated, less than in tests with the fire centrally located in the curtained area. When the fire was placed below the corner of the curtained area, 19 sprinklers operated, but these included sprinklers at the edge of the array so more sprinklers may have operated if the test facility were larger.

The rack storage test results are summarized in Table 2. Test 1 is the base case of no vents operating and no curtains present. The results are acceptable in the context of test criteria historically applied to such testing. Test 2 was designed to determine the effect of a vent directly over the fire. In fact, it appears that the fusible link for the vent cold soldered (as in the case of sprinkler skipping, while the solder of the vent link was in the process of melting, cooling by water droplets was apparently initiated and fusing of the link, i.e., melt-through of the solder, never occurred) and did not operate during the test. Rather, an adjacent vent operated later. Nonetheless, the performance is not much changed from Test 1. Two sprinklers at the edge of the test area activated, but based on the symmetry of the sprinkler operations, it appears unlikely that additional sprinklers would have activated if the test area were larger. Test 3 was designed to examine the worst case scenario for draft curtains/vents. While more boxes were damaged

TABLE 2
Rack Storage Results

Test #	1	2	3	4	5
Draft Curtains	No	No	Yes	Yes	Yes
Fire Position*	C	V	DC	C	C
Vents Opened	0	1	1	0	4**
Time(min:sec)		6:04	4:11		1:14
Sprinklers Operated	20	23+	19+	5	7
Damaged Boxes	117	127	184	103	81

*Fire Position: C—center of the curtained area, V—directly beneath a vent, DC—at the draft curtain.

**Vents opened manually at first sprinkler operation.

+ indicates that a sprinkler at the edge of the test area operated so it is possible more sprinklers would have operated.

and three sprinklers at the edge of the test array were activated, by historically applied criteria (FMRC [17]), the test results were satisfactory. Test 4 was representative of the more typical condition of fire originating within the curtained area and not in close proximity of any vent. In fact, no vents operated and the fire was very quickly and efficiently controlled. The first activation was slightly slower than other tests, but the second sprinkler operated only 1 second after the first. Test 5 was devised to maximize the effect of vent operation on sprinkler performance. Like Test 4, the performance was excellent. Once again, the first and second sprinklers activated within one second of each other.

Based on these rack test results, it is not possible to identify any adverse effects of smoke vents and draft curtains on sprinkler performance. Obscuration measurements were made in the plenum, at the height of the base of the draft curtains, and at eye level within the curtained area. The plenum obscuration is a general measure of the total smoke produced by the fire and generally follow the test to test damage trends, i.e., Tests 4 and 5 were less than the remaining tests. The eye level obscuration measurement showed that in all tests visibility was maintained in the curtained area for about 12 minutes except in Test 2 where the obscuration climbed at about 6 minutes. Optical densities always remained low until after the last sprinkler activated in the tests, indicating that during the active burning period the smoke remained buoyant. After the fire was controlled, the downward momentum of the sprinklers appears to be able to dominate the flow within the curtained area, causing smoke drag down. No eye level optical density measurements were made outside the curtained area.

Based on the collective results of the heptane and rack testing in this project, few conclusions can be drawn. All of the testing indicated that if the fire is not directly under a vent, vents have no effect on the activation of sprinklers. When the fire was directly beneath a vent, the first sprinklers activation times were somewhat longer. In the first heptane series, draft curtains increased the number of sprinklers activated though not to unacceptable numbers. In the rack storage testing, no such effect could be observed. When fires were initiated at the curtain, no effect on the number of sprinklers activated was seen in the second heptane series. In the rack storage tests, 19+ sprinklers were activated, but given the activation of 20 and 23+ sprinklers in noncurtained tests, it is difficult to attribute any negative effects on sprinkler activations. However, the rack storage test under the draft curtain did lead to more damage to goods. Given the poor reproducibility of the tests and the satisfaction of historically applied test criteria, it is difficult to assign a negative significance to this single test result. A notable result in the testing was the small number of thermally activated vent operations. There were no tests in this program where more than one smoke vent operated thermally, and there were many tests where no vents operated thermally. The smoke vents used in the tests had a relatively slow response fusible link system. The rack fire tests series further demonstrates the previously recognized fact that individual tests cannot be relied upon due to the limited reproducibility of this type of test.

Evaluation of Claims

The work reviewed in the prior section provides the basis for the evaluation of the claims in favor and against the use of smoke and heat vents with sprinklers. While there have been many attempts to model all or part of the interactions of sprinklers and vents, the issues are more complex than can be dealt with using even the most sophisticated modeling methods available today. The most clear indication of this is the recent NPPRF research project. While modeling of the fluid mechanical aspects of the problem were quite successful in predicting aspects of sprinkler activation in the first heptane spray fire series, the model was unable to predict the corresponding results in the rack storage tests beyond first sprinkler activation. Similarly, there have been many studies of portions of the problem through experimentation and analysis. None of that work is sufficiently comprehensive to rise to the level of insight provided by the experimental studies in the prior section.

The experiments reviewed in the prior section include a wide range of study approaches, none of which are complete and comprehensive. The testing includes those using spray or pool fires which while being well controlled fire sources are not realistic in the sense that they do not react to the water spray as normal Class A fuels do. Thus, though certain interactions are well controlled, a key interaction is lost. Some studies were small-scale investigations. In particular, the FMRC model study attempted a comprehensive approach to modeling. However, in spite of some attempt to empirically model fire growth and extinction, the modeling methods used in that study are only valid for the fluid mechanical portions of the problem [37]. Compromises like the use of ganged spray nozzles instead of individually operated automatic sprinklers and the representation of rack storage arrays with vertical arrays of cardboard limit the value of the results.

None of the testing programs reviewed used a test building of sufficient size to fully evaluate the interactions of sprinklers and roof vents. As large as some of the test facilities were, they are dwarfs beside the buildings in which sprinklers and vents are used. The FMRC facility (4650 m^2 (50,000 ft^2)) has no capabilities to include roof vents, and as such, FMRC has never performed a full-scale sprinklered test with roof vents. The UL facility has a test area of only 1393 m^2 (15,000 ft^2), only about three times a typical curtained area, and that facility cannot be operated without ventilation due to environmental concerns. As such, we must realize that the data available to us at this time are not complete and require great care in assessing our understanding of the issues.

Reproducibility is a significant issue in this type of testing. The 1974 FMRC [18], 1989 IITRI [3], and 1998 UL [36] tests clearly indicate that suppression tests with Class A fuels are not highly reproducible. In the small-scale work at FMRC where control and hence reproducibility are expected to be enhanced, errors about the mean of ±20 percent in the number of sprinklers operated were typical. In the large-scale IITRI work, errors about the mean of ±35 percent in the number of sprinklers operated were apparent. Indications in the 1998 UL study were that even larger deviations were present. As such, reaching conclusions based on individual tests cannot be justified.

Evaluating Claims in Favor of Smoke and Heat Vents in Sprinklered Facilities

The claims made in favor of smoke and heat venting in sprinklered facilities were summarized in an earlier section. In many cases, these claims have similar roots and consequences. For purposes of evaluation, the claims can be simplified to the following four claims:

1. Smoke and heat vents limit the distribution of products of combustion in the facility;
2. Smoke and heat vents decrease the number of discharged sprinklers;
3. Smoke and heat vents assist the fire department identify the location of the fire within the facility and reduce the need for hazardous manual roof venting; and
4. Smoke and heat vents limit the distribution of products of combustion in the facility if the sprinklers are inoperative.

Limiting the extent of smoke spread is the key physical process that allows emergency egress, firefighter access, and limits spatial extent of smoke and heat damage. The studies which provide information regarding this claim include 1956 FMRC [5], 1994 FMRC [18], Ghent [24–27], and UL [36]. The limitations on the spread of products of combustion were noted by observation of the visibility during these tests. In the 1956 FMRC [5] spray fire tests, the visibility outside the curtained area was improved by venting. In the 1974 FMRC model study, the time to the loss of visibility was extended by venting, and in the case of ganged operation of all vents, fire control was achieved without the loss of visibility. In the Ghent study, during steady fires, products of combustion remained stratified and were contained to the draft curtain reservoir in vented tests. In growth fires, the smoke distribution was limited by the draft curtains, but some local smoke logging occurred near the fire in some tests. In the 1998 UL tests, visibility was maintained during the active burning period, but smoke logging was observed after fire control was achieved. Due to limitations in facilities or instrumentation, only the 1956 FMRC and Ghent studies address the movement of products of combustion outside the curtained area of the fire. Both report improvements in visibility outside the curtained area of the fire. Other studies are unable to provide any information on the spread of products of combustion in tests with smoke and heat vents used in conjunction with sprinklers. None of the studies reviewed provide data that show that the vents do not act to limit the spread of products of combustion.

The claim that smoke and heat vents will limit the number of sprinklers activated was most clearly supported by the 1956 FMRC [5] study where the use of vents and draft curtains halved the number of sprinklers activated (mainly as a result of the action of the draft curtains). This was due to the unusual configuration of the test wherein the draft curtain area was only about 186 m^2 (2000 ft^2). In normal practice today, the sprinkler design area is a fraction of the curtained area. Under these circumstances, the effects observed in the 1956 FMRC [5] tests would not be relevant. However, in the 1964 UL tests [12], the use of vents and curtains reduced the number of operating sprinklers from 13 to 9. In the 1974 FMRC model study [18], the number of operating sprinklers was increased by vents and curtains for the cellulosic fuels, and decreased for the heptane fuels. Because these small scale tests do not represent real burning behavior of real fuels and their suppression, the mixed model results should be discounted in considering this claim. The IITRI study [3, 4] found no effect of vents on either propane or wood pallet fires though draft curtains were used in all tests. The Ghent study [24–27] found that for the growing fires, the number of sprinklers activated was reduced by the addition of venting though again draft curtains were used in all tests. The 1998 UL tests [36] showed a clear increase in the number of operating sprinklers due to vents and draft curtains for the 5 MW heptane fires, but no clear trend could be established in the rack tests due to the lack of reproducibility and replicates. Due to the limitations of the tests and the somewhat conflicting results, the claim that smoke vent will reduce the number of sprinklers activated cannot be clearly substantiated.

The claim that venting assists the fire department in locating the fire and reduces the need for manual venting relates to operational characteristics of vents. That automatically operated vents or even manually operable vents reduce the demands on firefighters venting the building has not been experimentally evaluated. Similarly, that fire plumes are visible from roof vents has not been assessed through research. If vents operate in the vicinity of the fire, they will be observable from outside the building. The results of some of the test series raise questions if even one vent will reliably be operated in a fire. The FMRC model study [18] found that if the fire was remote from the vents and the number of sprinklers activated was limited to less than 20, then vent operation did not occur. In the IITRI study [3, 4] vents did operate reliably even though the vents were remote from the fire. In the 1998 UL tests [36], vents did not operate reliably when fires were remote from the vent in both heptane fires and rack fires. Indeed, no more than one vent operated in any test, and in a number of tests, no vents operated. In one extreme case, where the rack fire was started directly below the vent, the vent failed to operate due to cold soldering though a neighboring vent did operate. This raises legitimate concerns with this claim, but further raises concerns with the effectiveness of vents in general. The issue of reliable vent operation will be revisited in conjunction with the negative claims.

The claim that smoke and heat vents operate effectively when sprinklers do not operate is clearly a valid one. The smoke venting studies reviewed in this paper and others clearly provide the basis for the claim. The real question here is how relevant is the claim, i.e., how reliable are sprinkler systems. While it is outside the scope of this paper to review sprinklers system reliability studies, sprinkler systems are widely reported to be 90 to 99 percent reliable [38]. In the remaining cases, manual firefighting must be relied upon, and the support of an automatic venting system has clear value in these cases.

Evaluating Claims Against the Use of Smoke and Heat Vents in Sprinklered Facilities

The claims made against the use of smoke and heat venting in sprinklered facilities were summarized in an earlier section. The list is reproduced here for reference.

1. Smoke and heat vents will cause enhanced burning rates;
2. Smoke and heat vents will delay sprinkler activation;
3. Smoke and heat vents increase the number of operated sprinklers;
4. Smoke and heat vents flow rates are insufficient to realize any benefit;
5. Smoke and heat vents are not cost effective.

The claim that the use of smoke and heat vents will enhance burning rates has been actively made by Factory Mutual (e.g., [8, 16]). This view has also been the basis for advising firefighters to not enter or vent a building protected by sprinklers, but rather the building should be "buttoned up," and the sprinkler system should be left to do its work. Entry should only be attempted after the fire is clearly controlled though guidance on how this is to be determined is not clearly given. This guidance clearly contradicts normal fire service practices, and the FM guidance does not seem to be followed in general. The testing shows that sprinklered fires in buildings result in oxygen concentrations at the base of the fire of 17 to 21 percent by volume. The 1974 FMRC model study [18] indicated that venting increased the oxygen concentration from about 18 percent to near 21 percent near the base of the fire. The IITRI tests [3, 4] showed no clear correlation of oxygen concentration, and the venting, with all concentrations in the 17 to 21 percent range near the base of the fire. The 1975 FMRC plastics tests [19] yielded oxygen concentrations in the 18 to 21 percent range near the base of the fire. It is well established that reduced oxygen levels in the range of 18 to 21 percent are not low enough to lead to significant variations in burning. Large-scale fires will certainly not be extinguished by these oxygen concentrations. It is significant to note that all the test work was performed in relatively small buildings. As such, leakage in larger, more realistic buildings will be greater and this will tend to increase oxygen concentrations over those observed in smaller test buildings. Work by NIST [39], Peatross and Beyler [40], Tewarson *et al.* [41], and Santo and Tamanini [42] show that burning rates at 18 percent are generally only 10 to 30 percent less than at the normal 21 percent. Suppression of flaming combustion generally requires oxygen concentrations of 12 to 14 percent [43]. Further, it is universally acknowledged that sprinklers are effective by cooling the fuel surfaces and not by gas phase mechanisms processes. The claim that burning rates are materially enhanced by venting is not supported by the fire science literature.

The claim that smoke and heat vents will delay sprinkler activation is not supported by the available data except when the fire is directly below the vent. Tests in which vents were manually operated at the start of the test by FMRC [18], IITRI [3, 4], Ghent [24], 1998 UL [36] all showed no effect on the activation of early sprinklers. Similarly, the 1998 UL rack tests, where vents were opened at the first sprinkler activation, showed no effect on the timing of subsequent sprinkler operations. Where the fire is not directly beneath the vent, there are no data which indicate this claim is valid. When the fire is directly beneath the vent, the FMRC tests [18] found no notable effect of the vent on sprinkler activations. In the 1998 UL heptane tests, some delays in early sprinkler activations were noted. No serious effects were noted. The 1998 UL rack tests intended to explore this phenomenon, but the vent fusible link failed to operate the vent due to cold soldering. The overwhelming evidence is that vents do not affect sprinkler operations even if opened at the start of the test. This is consistent with the European practice of ganging the vents and operating them by smoke detector or first sprinkler activation [44]. This result relates to the concerns over the reliable operation of smoke vents. Current U.S. practice is to impede the operation of vents to assure that sprinklers operate first. This concern is unwarranted based on the data. Early activation of vents and ganging vents are viable strategies which should be employed to improve venting reliability.

The claim that smoke and heat vents will lead to increased numbers of sprinkler activations is not supported by the data. The results cited above in the positive claim that venting will reduce the number of sprinklers are all applicable here. Just as these studies did not support the positive claim that vents reduce the number of sprinklers activated, the data do not support the negative claim that venting will increase the number of sprinkler activations. While the testing shows that there are instances of both increases and decreases, there is no evidence that either trend is generally valid.

The negative claim is that smoke and heat vent flow rates are insufficient to realize any benefit. In some sense, this negative claim can be taken as the converse of the positive that venting will limit the distribution of products of combustion. The evidence in favor of this positive clearly contributes to refuting this negative claim. However, there are other aspects to be considered. It is well known that vent flow rate is reduced at temperatures below 200°C (392°F) [28] and that sprinklers can cause cooling of upper layer smoke to well below this level. For example, in sprinklered fires, it would not be unreasonable for smoke layer temperatures to be 70°C (158°F). At such a temperature, the theoretical flow rate relative to the maximum possible high temperature flow rate would be halved. The only experimental program which addressed the actual flow through the roof vents was the Hinkley *et al.* [24] steady fire testing. These tests showed no effect of 1 or 5 sprinklers on vent flow velocities. This result is somewhat remarkable in the light of the above discussion of temperature effects on flow rates. Despite these results, it must be acknowledged that there may be a reduction in vent flows due to sprinklers both in terms of reduced temperatures and direct spray effects. Nonetheless, improvements in visibility were observed in the testing which indicate that there are benefits which result from venting sprinklered fires (see discussion of the improved visibility claim for additional details).

The final negative claim that smoke and heat vents are not cost effective has never been seriously studied. Any such study would need to consider the cost of installation, the energy/lighting savings which may be realized through natural lighting, and the reduction in heat, smoke, and fire damage which results from the use of vents. While the first two are reasonably well known, the latter has not been studied in any investigation reported in the fire literature. As such, this claim has no clear basis and must be regarded as mere speculation.

Fire Protection Design Issues

The review of the studies relevant to venting sprinklered fires gives rise to two design issues for smoke and heat venting systems. First, it is clear that the current focus on assuring that vent operation is delayed has an adverse effect on system performance. It is important that design attention be paid to causing vents to operate more rapidly and in greater numbers. The data indicate that the European approach of ganged operation of vents based on early detection is a viable and desirable strategy. Second, it has been noted that draft curtains represent obstructions and should be dealt with in sprinkler design as obstructions. Draft curtains should be provided in the center of aisles and not directly over the storage. Dealing with these issues will improve fire protection design.

Conclusions

The studies of smoke and heat venting used in conjunction with sprinklers show clearly that venting does not have a negative effect on sprinkler performance. Successful performance of sprinklers does not rely upon reduced oxygen concentrations. Venting has been shown to have no effect on the activation times of early sprinklers and does not affect the total number of sprinklers activated. If the fire is directly beneath a vent, activations of the first sprinklers may be delayed slightly, but there is no evidence that this will have a significant impact on sprinkler performance.

Experimental studies have shown that venting does limit the spread of products of combustion by releasing them from the building within the curtained compartment of fire origin. This improves visibility for building occupants and firefighters who need to find the seat of the fire to complete fire extinguishment. Limiting the spread of smoke and heat also reduces smoke and heat damage to the building. In the event that sprinklers do not operate, venting remains a valuable aid to manual control of the fire.

The experimental studies have shown that early vent activation has no detrimental effects on sprinkler performance and have also shown that current design practices are likely to limit the number of vents operated to one and vents may in fact not operate at all in very successful sprinkler operations. Design practices should move to methods which assure early operation of vents, and vent operation should be ganged so that the benefit of roof vents is fully realized. Sprinkler design with vents and draft curtains needs to take full account of draft curtains as obstructions. Curtains should be placed in aisles rather than over storage.

Appendix—List of Position Papers

1. P. Battrick, (1986), “Venting Plus Sprinklers—The Case Against,” *Fire International*, October/November 1986.
2. J.G. Degenkolb, “Roof Vents and the Fire Fighter,” *Fire Service Today*, vol. 48, no. 11, 1981, pp. 17–19.
3. “Designing for Protection—When and How to Use Heat and Smoke Vents,” *Record*, vol. 56, no. 4, 1979, pp. 11–13; *Building Standards*, vol. 11, no. 2, 1980, pp. 14–16.
4. J. Edwards, “Vents and Sprinklers—Controversy Resolved,” *Fire Prevention*, vol. 211, July/August 1988, p. 39.

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6. J.C. Fulton, "Roof Vents Function in Buildings with Sprinklers Explained," *Fire Engineering*, vol. 125, no. 6, 1972, p. 43.
7. J. Gardner, "Comparing Smoke Vent Systems in Shopping Malls," *Fire Prevention*, vol. 236, January/February 1991, pp. 23–27.
8. N.E. Gustafsson, (1989), "Smoke Ventilation of Sprinklers Compartments," in *Proceedings of the Fifth International Fire Protection Engineering Institute* (IFPEI), Section 4, Ottawa, Canada, May 22–31, 1989, pp. 1–33.
9. N.E. Gustafsson, "Sprinklers vs Smoke Vents—Are They Compatible?" *Fire Protection*, vol. 16, no. 4, 1989, pp. 5–10.
10. G. Hansell, "The Problems of Effective Venting in Warehouses," *Fire Prevention*, vol. 262, September 1993, pp. 40–42.
11. "Heat and Smoke Venting," *The Sentinel*, vol. 36, no. 4, 1980, p. 15.
12. A.J.M. Heselden, "Taking a New Look at Combining Sprinklers Systems with Venting," *Fire*, October 1985, pp. 42–43.
13. A.J.M. Heselden, "The Interaction of Sprinklers and Roof Venting in Industrial Buildings: The Current Knowledge," Building Research Establishment (BRE), Fire Research Station (FRE), Department of the Environment, Garston, Watford, United Kingdom, 1984.
14. A.J.M. Heselden, "The Interaction of Sprinklers and Fire Venting," *Fire Surveyor*, vol. 11, no. 5, 1982, pp. 13–28.
15. P.L. Hinkley, *et al.* "Sprinklers and Vents Interaction—Experiments at Ghent," *Fire Surveyor*, October 1992, pp. 18–23.
16. P.L. Hinkley, "Fire Venting," *Fire Surveyor*, vol. 15, no. 4, 1986, pp. 5–12.
17. P.L. Hinkley, "The Case for Combining Venting and Sprinkler Systems," *Fire Engineering Journal*, vol. 47, no. 145, 1987, p. 20.
18. J.E. Holt, "Sprinklers and Fire Venting," *Fire Surveyor*, vol. 11, no. 6, 1982, pp. 13–18.
19. R. Johnson, "Controlling Plastic Materials Fires in Warehouses," *Fire Journal*, May 1977, PP. 43–45, 125–128.
20. T. Lenton, "SPI Tests of Stored Plastics in Warehouses," *Fire Journal*, May 1979, pp. 30–35.
21. E.E. Miller, "Study Notes and Graphical Analysis of: Model Study of Automatic Heat and Vent Performance in Sprinklered Fires—Sept. 1974," FMRC Technical Report No. 21933, Report to NFPA Smoke and Heat Venting Subcommittee, February 1980.
22. E.E. Miller, "Fire Venting of Sprinklered Property," Position Paper to 204 Subcommittee, National Fire Protection Association, Quincy, MA, March 1980.
23. E.E. Miller, "Automatic Fire Venting in Sprinklered Buildings," NFPA 1981 Fall Meeting, Toronto, November 17, 1981.
24. E.E. Miller, "Fire Venting Mini-Study No. 8: Reappraisal of Vented Rubber Tire Fire Tests," Appendix E of T.E. Waterman, *et al.* "Fire Venting of Sprinklered Buildings," IITRI Project No. 8385, prepared by IIT Research Institute, Chicago, for the Fire Venting Research, July 1982.

25. H.P. Morgan, “Combining Sprinklers and Vents: An Interim Approach,” *Fire Surveyor*, April 1993, pp. 10–14.
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27. H.P. Morgan, “Sprinklers and Smoke Exhaust Ventilation: When They Can Be Used Together?” Fire Asia’98, Hong Kong, China, 1998.
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