SCHULTE & ASSOCIATES
Building Code Consultants
880D Forest Avenue
Evanston, IL 60202
fpeschulte@aol.com
847/866-7479

TESTS P-1 AND P-4 (NISTIR 6196-1): AN ANALYSIS OF CEILING TEMPERATURE DATA

By Richard Schulte

A report titled "*Sprinkler, Smoke & Heat Vent, Draft Curtain Interaction – Large Scale Experiments and Model Development*" dated September 1998 contains a "treasure-trove" of information on the operation of sprinklers in storage occupancies. This report, also referred to as NISTIR 6196-1, includes the following excerpts:

> "*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, Illinois. The tests were designed to address relatively large, open-area buildings with flat ceilings, sprinkler systems, and roof venting with and without draft curtains. To simulate these conditions in the 37 m by 37 m by 15 m high (120 ft by 120 ft by 48 ft high) main test bay, the vents, draft curtains and sprinklers were installed on a 30 m by 30 m (100 ft by 100 ft) adjustable-height platform, 7.6 m (25 ft) off the floor. 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 spaced was continually exhausted through a smoke abatement system.*" (Page *i*)

> "*Recognizing that the resources in terms of funding and time were limited, the NFPRF Technical Advisory Committee reduced the number of parameters in this study by selecting one commodity, one rack configuration and ignition source, a single sprinkler system and one sprinkler discharge density, one commercial vent design, and one vent/draft curtain arrangement.*" (Page *i*)

> “*The significant cooling effect of sprinkler sprays on the near-ceiling gas flow often prevented the automatic operation of vents. . .In one cartoned plastic commodity experiment* [Test P-2]*, a vent did not open when the fire was ignited directly beneath it. The model simulations could not predict this phenomenon.*” *(*Page *ii)*

While the purpose of the research was to assess the impact of automatic smoke/heat vents on the operation of sprinklers, the research, in fact, determined that the activation of sprinklers significantly affects the operation of individually-activated automatic roof vents (when the temperature rating of the fusible element activating the vents has the same temperature rating as the sprinklers). After reviewing the data from the research work, even Dr. Craig Beyler (Hughes Associates, Inc.), a lobbyist who has represented the Smoke Vent Task Group (SVTG), a trade association of vent manufacturers, agreed that this was indeed the case.

In February 1999, Dr. Beyler and Leonard Y. Cooper published a paper titled “*Interaction of Sprinklers with Smoke and Heat Vents*”. The following is an excerpt from the Executive Summary of this paper:

> “*The experimental studies have 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.*” (Page 1)

Note: The Beyler/Cooper paper cited above was funded by the trade association representing the manufacturers of smoke/heat vents, the Smoke Vent Task Group.

Given that a lobbyist representing the vent manufacturers, Dr. Craig Beyler, has conceded that the operation of sprinklers interferes with the automatic opening of individually-activated vents (where the temperature rating of the fusible element activating the vents is the same temperature rating as the sprinklers), there should be no debate over whether or not this is indeed the case.

Note: The Beyler/Cooper paper cited above was funded by the trade association representing the manufacturers of smoke/ heat vents, the Smoke Vent Task Group.

In 2007, a proposal to prohibit the use of roof vents in buildings protected by a sprinkler system was introduced for consideration by a subcommittee of the NFPA 13 committee. This proposal was modified by the subcommittee and what resulted was a provision which mandated that roof vents either be manually-activated or be activated by a fusible element with a temperature rating one classification higher than the temperature classification of the sprinklers. The modified proposal was adopted and is now included in the 2010 edition of NFPA 13.

The end result of the new provisions addressing the installation of roof vents in buildings protected by a sprinkler system included in NFPA 13 is that roof vents must be manually opened in order to provide any venting. (Roof vents activated by a fusible element with a temperature rating one classification higher than the sprinklers means that the vents will not open automatically if the sprinkler protection is adequate for the hazard protected.)

(Roof vents activated by a fusible element with a temperature rating one classification higher than the sprinklers means that the vents will not open automatically if the sprinkler protection is adequate for the hazard protected.)

Given the fact that the vent provisions contained in the 2010 edition of NFPA 13, in effect, prohibits the automatic operation of smoke/heat vents, the effectiveness of operating sprinklers in reducing ceiling temperatures becomes a relevant issue in whether or not vents will be an effective form of fire protection in buildings protected by a sprinkler system.

NFPA 204, the Standard for Smoke and Heat Venting, addresses the issue of the effectiveness of smoke/heat vents based upon the temperatures of the hot gas layer which collects under the roof of a building provided with vents. Section A.4.4.3 in Annex A of the 2002 edition of NFPA 204 contains the following statement:

> "*Mass flow through a vent is governed mainly by the vent area and the depth of the smoke layer and its temperature. Venting becomes more effective with smoke temperature differentials between ambient temperature and an upper layer of approximately 110°C* [198°F] *or higher. Where temperature differences of less than 110°C* [198°F] *are expected, vent flows might be reduced significantly; therefore, consideration should be given to using powered exhaust. . .*"

The Beyler/Cooper paper from February 1999 also addresses the issue of the temperature of the combustion products layer which develops below the ceiling in the following excerpt:

> "*It is well known that vent flow rate is reduced at temperatures below 200°C (392°F) [Hinkley 1995] 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. . .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.*" (Pages 22 and 23)

With the above background, let's take a look at the temperature data recorded at the various sprinklers in Test P-1 and Test P-4 of the five large-scale tests conducted at Underwriters Laboratories as part of the research on the interaction between sprinklers and vents in 1997/1998. The reason that these two tests are of particular interest is that no vents opened in either of these two tests. Hence, the ceiling temperatures recorded were not influenced by the venting of combustible products.

The five large-scale tests, Tests P-1 through P-5, involved fires in Group A plastics stored in double-row racks. The height of the storage array was 20 feet with a ceiling height of 27 feet. In each test, the storage array was protected by ELO-231 upright ordinary temperature sprinklers manufactured by Central Sprinkler Corporation. The sprinklers used in the test had a temperature rating of 165°F and an RTI of 148 in metric units and 268 in English units.

> *"Where temperature differences of less than 110°C [198°F] are expected, vent flows might be reduced significantly; therefore, consideration should be given to using powered exhaust."*

Based upon the requirements contained in NFPA 13/NFPA 231C, a minimum density of 0.60 gpm/SF was required to protect this storage array. Rather than utilize the minimum density required, a density of 0.50 gpm/SF was actually utilized in each of the tests.

The sprinkler spacing utilized in the large-scale tests was 10 feet by 10 feet. A total of 100 sprinklers were utilized in each test. In other words, the area involved in each test was 10,000 square feet.

The following summarizes data from Test P-1 and Test P-4:

Table 1. Test Data Summary-Tests P-1 and P-4

	Test P-1	**Test P-4**
Draft Curtains	None	North/South and East/West
Number of Sprinkler Activations	20	5
Maximum Ceiling Temperature Recorded	234°C/453°F	175°C/347°F
Average Maximum Ceiling Temperature Recorded at All Sprinklers	81.3°C/178.3°F	56.8°C/134.3°F (100 temperature readings)
Average Maximum Ceiling Temperature Recorded at Sprinklers Within Curtained Area	81.3°C/178.3°F	96.4°C/205.5°F (56 temperature readings)

Notes:

Note 1: The maximum ceiling temperature recorded at each sprinkler did not occur at the same point in time. Hence, the maximum average ceiling temperature indicated above is a conservative estimate of the actual maximum average ceiling temperature which occurred.

Note 2: In Test P-4, there were three rows of sprinklers located to the west of the draft curtain which ran in the north-south direction and two rows of sprinklers located to the north of the draft curtain which ran in the east-west direction. There were a total of 56 sprinklers located to the east of the draft curtain running in the north-south direction and south of the draft curtain running in the east-west direction.

Table 2. Sprinkler Activation Times and Maximum Temperatures at Activated Sprinklers-Tests P-1 and P-4

	Test P-1		Test P-4	
Sprinkler Activations	**Activation Times**	**Maximum Temperatures at Sprinkler**	**Activation Times**	**Maximum Temperatures at Sprinkler**
1st	1:16 (76 seconds)	234°C/453°F	1:33 (93 seconds)	175°C/347°F
2nd	2:14 (134 seconds)	163°C/325°F	1:34 (94 seconds)	164°C/327°F
3rd	2:51 (171 seconds)	123°C/253°F	2:20 (140 seconds)	112°C/234°F
4th	5:03 (303 seconds)	110°C/230°F	3:19 (199 seconds)	109°C/228°F
5th	8:31 (511 seconds)	97°C/207°F	3:20 (200 seconds)	107°C/225°F
6th	8:35 (515 seconds)	100°C/212°F	-----	-----
7th	9:22 (562 seconds)	107°C/225°F	-----	-----
8th	10:19 (619 seconds)	105°C/221°F	-----	-----
9th	10:35 (635 seconds)	95°C/203°F	-----	-----
10th	11:08 (668 seconds)	105°C/221°F	-----	-----
11th	11:11 (671 seconds)	108°C/226°F	-----	-----
12th	12:23 (743 seconds)	98°C/208°F	-----	-----
13th	12:34 (754 seconds)	103°C/217°F	-----	-----
14th	12:45 (765 seconds)	99°C/210°F	-----	-----
15th	12:57 (777 seconds)	119°C/246°F	-----	-----
16th	13:09 (789 seconds)	104°C/219°F	-----	-----
17th	13:25 (805 seconds)	109°C/228°F	-----	-----
18th	13:30 (810 seconds)	107°C/225°F	-----	-----
19th	13:34 (814 seconds)	99°C/210°F	-----	-----
20th	13:41 (821 seconds)	107°C/225°F	-----	-----

Analysis

Test P-4 was designed to be identical to Test P-1, with the exception of the draft curtains provided at the ceiling in Test P-4. Obviously, the results of these two tests are markedly different. In Test P-1, 20 sprinklers activated, while in Test P-4 only 5 sprinklers activated.

The ignition point in Test P-4 was 30 feet from the nearest draft curtain and the sprinklers which activated in Test P-4 were located 25 feet or more from the nearest draft curtain. Further, the sprinklers which activated in Test P-4 were all in close proximity to the ignition point of the fire. Given these facts, it seems both reasonable and logical to conclude that the reason for the different number of sprinkler activations between these two tests was not the presence of draft curtains in Test P-4.

There are a number of possible explanations for different results between the tests. One explanation could be the manufacturing tolerances of the sprinklers utilized in the test. While the temperature rating assigned to the sprinklers used in the test was 165°F, almost certainly the actual temperature rating of sprinklers varies a few degrees above or below 165°F. The same could also be said about the RTI of the sprinklers used in the test. Most certainly, there is a slight variation in the RTI of the same model of sprinkler. What are the manufacturing tolerances of sprinklers with respect to temperature rating and RTI? It would appear that the answer to that question is unknown, at least at this point in time.

Another potential explanation for the variation in the test results between Test P-1 and Test P-4 is the temperature and humidity at the time of the tests. Data from the NISTIR 6186-1 report provides information regarding these variables:

Table 3. Initial Environmental Conditions-Tests P-1 and P-4

	Test P-1	**Test P-4**
Test Date	September 30, 1997	October 21, 1997
Outdoor Temperature	14°C/57°F	10°C/50°F
Indoor Temperature	20°C/68°F	17°C/63°F
Relative Humidity	51%	30%
Commodity Moisture Content	9%	6%

With indoor temperatures of both Tests P-1 and P-4 similar, it would seem unlikely that the indoor temperature of the test facility would have been a significant factor in the differing results of these two tests. The data above indicates that there was a significant difference in the humidity levels and moisture content of the commodity between these two tests, however, the effect due to differing humidity/moisture content was the opposite as would have been expected.

A third potential explanation for the differing results between Tests P-1 and P-4 is the temperature of the water used to supply the sprinkler system. Given the one month difference in the dates on which the tests were conducted, it is possible that the water temperatures in the underground water mains supplying the sprinklers may have been 10°F to 20°F lower for Test P-4 than in Test P-1. Obviously, sprinkler water spray discharge with a lower temperature would be better at absorbing heat generated from the fire than would warmer water, particularly given the flow rate of the sprinklers, 50 gpm.

Without information on the temperature of the water utilized in both tests, we can only speculate on whether or not this had any significant effect on the test results-the number of sprinklers which activated and the ceiling temperatures.

Table 4. Sprinkler Activation Times-Tests P-1 and P-4

Sprinkler Activation	Test P-1	Test P-4
1st Sprinkler	76 seconds	93 seconds
2nd Sprinkler	134 seconds	94 seconds
3rd Sprinkler	171 seconds	140 seconds
4th Sprinkler	303 seconds	199 seconds
5th Sprinkler	511 seconds	200 seconds

Table 5. Sprinkler Activation and Maximum Temperatures Recorded at Activated Sprinklers

Sprinkler Activation	Test P-1	Test P-4
1st Sprinkler	234°C/453°F	175°C/347°F
2nd Sprinkler	163°C/325°F	164°C/327°F
3rd Sprinkler	123°C/253°F	112°C/234°F
4th Sprinkler	110°C/230°F	109°C/228°F
5th Sprinkler	97°C/207°F	107°C/225°F

A comparison between the activation time of the first sprinkler to operate and the maximum temperature recorded at the first sprinkler indicates that the fire which developed in Test P-4 generated far less heat than the fire which developed in Test P-1. Although the first sprinkler activation in Test P-4 occurred 17 seconds later than in Test P-1, the maximum temperature at the first sprinkler to activate in Test P-1 was 234°C (453°F), while the maximum temperature at the first sprinkler to activate in Test P-4 was 175°C (347°F), 59°C (106°F) lower.

A second difference between Tests P-1 and P-4 is that the second sprinkler activation which occurred in Test P-4 occurred 1 second after the first sprinkler activation, while the second sprinkler activation which occurred in Test P-1 occurred 58 seconds after the first sprinkler activation.

A third difference between Tests P-1 and P-4 is that the four sprinkler activations which followed the first activation all occurred within 200 seconds in Test P-4, while the fifth sprinkler activation in Test P-1 did not occur until 511 seconds after ignition. In other words, there was a substantial delay in the activation of the second through fifth sprinklers in Test P-1 when compared to the activation times in Test P-4.

A comparison between the activation time of the first sprinkler to operate and the maximum temperature recorded at the first sprinkler indicates that the fire which developed in Test P-4 generated far less heat than the fire which developed in Test P-1.

Given the above, it appears that the prompt activation of five sprinklers in Test P-4 led to far better control of the fire in this test, even though the activation time of the first sprinkler to operate lagged the activation time of the first sprinkler in Test P-1 by 17 seconds.

While the information above is rather interesting from a standpoint of understanding how sprinklers gain control of a fire, what is more interesting from the standpoint of the capability of a venting system to perform its intended purpose is the temperature profiles after the first sprinkler activates and at sprinklers located away from the fire.

The time-temperature plots for Test P-1 shown in Figure 24 (Page 40) in NISTIR 6196-1 indicate that the temperature readings at the first sprinkler to activate immediately spiked upward after ignition and then immediately spiked downward after sprinkler activation. A similar spiking of temperatures upward and then downward also occurred at the 2nd, 3rd and 4th sprinklers which activated.

The time-temperature plots for Test P-4 shown in Figure 33 (Page 52) in NISTIR 6196-1 show a similar upward and then downward spiking of temperature readings for the first three sprinklers which operated in this test, while the temperature readings at the 4th and 5th sprinklers to activate reach a plateau roughly at the time of the activation of the first and second sprinkler activations and then spike downward after the activation of these sprinklers.

In the plots of time and temperature at the other 96 sprinklers in Test P-1, the effect on temperature caused by the first sprinkler activation can be clearly seen. The temperatures at these sprinklers peak briefly at the time when the first sprinkler activation occurs and then begin to slowly rise again until about 12 minutes after ignition. Between 12 and 16 minutes after ignition, the temperatures at the sprinklers located away from the fire begin a downward trend with the ceiling temperatures approaching ambient within 30 minutes after ignition.

As previously indicated, Test P-1 and Test P-4 were identical, with the exception that draft curtains were provided in Test P-4. The temperature profiles of the sprinklers on the side of the draft curtain opposite the fire clearly show that just how effective the draft curtains performed in Test P-4. The ceiling temperatures on the side of the draft curtains opposite the fire barely rise above ambient. Given this, only the temperatures on the fire side of the draft curtains are of interest.

In the plots of time and temperature at the 56 sprinklers located on the fire side of the draft curtain in Test P-4, the effect of the activation of the first two sprinklers within one second of one another is plainly obvious. The temperatures at the sprinklers which did not activate rise to their maximum at roughly the time the first two sprinklers activate and then begin to steadily fall. The ceiling temperatures reach ambient at these sprinklers at roughly 12 to 14 minutes after ignition.

Also of interest are the temperatures at sprinklers located remote from the ignition point. The following are tables which relate the maximum temperatures recorded at sprinklers based upon the location of the sprinklers with respect to the ignition point for Test P-1.

Table 6. Maximum Temperatures vs. Location-Test P-1
(North of Fire)

	Maximum Temperatures at Sprinklers	
Location of Sprinkler from Fire (North)	**5 Feet East of Fire**	**5 Feet West of Fire**
0 Feet	163°C/325°F	234°C/453°F
10 Feet	123°C/253°F	110°C/230°F
20 Feet	105°C/221°F	97°C/207°F
30 Feet	101°C/214°F	107°C/225°F
40 Feet	85°C/185°F	83°C/181°F
50 Feet	78°C/172°F	72°C/162°F

Table 7. Maximum Temperatures vs. Location-Test P-1
(South of Fire)

	Maximum Temperatures at Sprinklers	
Location of Sprinkler from Fire (South)	**5 Feet East of Fire**	**5 Feet West of Fire**
0 Feet	163°C/325°F	234°C/453°F
10 Feet	119°C/246°F	108°C/226°F
20 Feet	99°C/210°F	107°C/225°F
30 Feet	81°C/178°F	86°C/187°F
40 Feet	69°C/156°F	76°C/169°F

Table 8. Maximum Temperatures vs. Location-Test P-1
(North and South of Fire)

	Maximum Temperatures at Sprinklers			
	North		**South**	
Location of Sprinkler From Fire	**5 Feet East of Fire**	**5 Feet West of Fire**	**5 Feet East of Fire**	**5 Feet West of Fire**
0 Feet	163°C/325°F	234°C/453°F	163 °C/325°F	234°C/453°F
10 Feet	123°C/253°F	110°C/230°F	119 °C/246°F	108°C/226°F
20 Feet	105°C/221°F	97°C/207°F	99°C/210°F	107°C/225°F
30 Feet	101°C/214°F	107°C/225°F	81°C/178°F	86°C/187°F
40 Feet	85°C/185°F	83°C/181°F	69°C/156°F	76°C/169°F
50 Feet	78°C/172°F	72°C/162°F	-----	-----

Table 9. Maximum Temperatures vs. Location-Test P-1
(East of Fire)

Location of Sprinkler from Fire (East)	**Maximum Temperature at Sprinkler**
5 feet (2nd Sprinkler to Activate)	163°C/325°F
15 feet	107°C/225°F
25 feet	98°C/208°F
35 feet	72°C/162°F

Table 10. Maximum Temperatures vs. Location-Test P-1 (West of Fire)

Location of Sprinkler From Fire (West)	**Maximum Temperature at Sprinkler**
5 feet (1st Sprinkler to Activate)	234°C/453°F
15 feet	103°C/217°F
25 feet	100°C/212°F
35 feet	75°C/167°F
45 feet	68°C/154°F
55 feet	30°C/86°F Note 1 (59°C/138°F)

Note 1: It appears that the recorded temperature reading at this sprinkler is erroneous. The maximum temperature recorded at sprinklers located 10 feet to the north and to the south were 58°C and 59°C.

Table 11. Maximum Temperatures vs. Location-Test P-1 (East and West of Fire)

	Maximum Temperature at Sprinkler	
Location of Sprinkler from Fire	**East**	**West**
5 feet	163°C/325°F	234°C/453°F
15 feet	107°C/225°F	103°C/217°F
25 feet	98°C/208°F	100°C/212°F
35 feet	72°C/162°F	75°C/167°F
45 feet	-----	68°C/154°F
55 feet	-----	30°C/86°F Note 1 (59°C/138°F)

Note 1: It appears that the recorded temperature reading at this sprinkler is erroneous. The maximum temperature recorded at sprinklers located 10 feet to the north and to the south were 58°C and 59°C.

Based upon the data for Test P-1 above, it can be seen that the maximum temperatures recorded at sprinklers located 30 feet or further from the ignition source are roughly 200°F or less. (The temperature at the sprinklers located 30 feet north of the ignition point are 214°F and 225°F.)

Reviewing the time-temperature plots for the sprinklers located 30 feet or more from the ignition source in Test P-1 shows a gentle rise in temperature at these sprinklers and then a gentle drop in the ceiling temperatures. The maximum temperatures at sprinklers located 30 or more feet from the ignition source occurs between 10 and 14 minutes after ignition.

Given that the sprinkler operation in Test P-4 was so successful, it would be expected that the maximum temperatures recorded at sprinklers located away from the fire would also be less than 200°F. Given that Test P-4 included a draft curtain, it would also be expected that the temperature recorded along the draft curtain would be higher than sprinklers located in the same position without a draft curtain (since the function of a draft curtain is to prevent the spread of heat). The range of temperatures recorded at sprinklers located along the fire side of the draft curtains ranged from a low 66°C (151°F) to a high of 86°C (186°F). (The north-south draft curtain in Test P-4 was located 30 feet to the west of the ignition point and east-west draft curtain was located 35 feet north of the ignition point. The sprinklers located along the draft curtain were 5 feet from the draft curtain.)

Reviewing the time-temperature plots for all of the sprinklers on the fire side of the draft curtains in Test P-4, other than sprinklers which activated, shows a rapid rise in temperature at these sprinklers and then a gentle drop in the ceiling temperatures beginning at the activation times of the first two sprinklers to activate (93 seconds and 94 seconds). The ceiling temperatures recorded at the sprinklers which did not activate in this test reach ambient temperature at approximately 10 to 12 minutes after ignition.

The ceiling temperatures recorded at the sprinklers which did not activate in this test reach ambient temperature at approximately 10 to 12 minutes after ignition.

As explained previously, the application of the vent provisions contained in the 2010 edition of NFPA 13 means that roof vents must be manually opened, even if automatic vents are provided. Assuming that the activation time of the first sprinkler to operate is 60 seconds after ignition and that the delay in the activation of the sprinkler system water flow alarm is also 60 seconds, the fire department would not receive an alarm until 2 minutes. Assuming a fire department response time of 5 minutes, fire fighters would not arrive at a building fire until at least 7 minutes after fire ignition. With delays for size-up of the fire and for ground or aerial ladder deployment, it is unlikely that roof vents would be opened prior to 10 minutes after ignition of a fire, at best.

Based upon the data/analysis presented above, it should obvious that there will be a high probability that the 110°C (198°F) temperature differential between the gas layer which collects under the roof and ambient temperature will not exist 10 minutes after ignition. As the hot gases generated by a fire spread across the ceiling of a building, it can be expected that the temperature of the gases will cool even further than indicated in the data above. What all of this means is that manually opened vents will not function as anticipated. In simple terms, “cold smoke” doesn’t have sufficient buoyancy for manually-opened vents to function properly.

The analysis above assumes a fire department response of 5 minutes, however, the response time of many smaller fire departments, in particular volunteer fire departments, will likely be more on the order of 10, 20 or even 30 minutes. Based upon the above, it should be obvious that the usefulness of manually-operated roof vents dwindles as the fire department response time increases.

Tests P-1 and P-4 utilized the same storage array in each test and the above analysis is based upon the fires generated in these tests. The fires utilized in these two tests were intended to be severe and the sprinkler discharge density utilized in the tests was intentionally deficient (0.50 gpm/SF, rather than the minimum 0.60 gpm/SF required), however, it should be noted that not all fires which develop in industrial and storage occupancies will be as severe.

It should be obvious that the ceiling temperatures which develop as a result of less severe fires will be less than those observed above. If the efficacy of manual vents is questionable with the severe fires utilized in the large-scale tests, based upon the low temperature differential which develops, then surely vents will be useless should a less intense fire develop. From a probability standpoint, the probability of a less intense fire occurring in an industrial or storage building is far greater than the probability of a more severe fire. Given this, it can be stated that the probability that the manual operated vents will actually be useful is relatively low.

Should building codes require the installation of smoke/heat vents in sprinklered buildings where the probability that the vents will actually work as intended is small, or, perhaps even nil?

* * * * *