

## **NISTIR 6196-1: CEILING TEMPERATURE DATA TEST P-4**

By Richard Schulte

Section A.1.1. in Annex A of the 2002 edition of NFPA 204 provides a description of how roof vents work. The following is an excerpt from this section of NFPA 204:

*“The following list provides a general description of the significant phenomena that occur during a fire when a fire-venting strategy is implemented.*

*(a) Due to buoyancy, hot gases rise vertically from the combustion zone and flow horizontally below the roof until blocked by a vertical barrier (a wall or draft curtain), thus forming a layer of hot gases below the roof.*

*(b) The volume and temperature of gases to be vented are a function of the fire’s rate of heat release and the amount of air entrained into the buoyant plume produced.*

*(c) As the depth of the layer of hot gases increases, the layer temperature continues to rise and the vents open.<sup>1</sup>*

*(d) The operation of vents within a curtained area enables some of the upper layer of hot gases to escape and thus slows the thickening rate of the layer of hot gases. . . The rate of discharge through a vent of a given area is primarily determined by the depth of the layer of hot gases and the layer temperature. Adequate quantities of replacement inlet air from air inlets located below the hot upper layer are needed if the products of combustion-laden upper gases, are to be exhausted according to design.”*

Based upon the description of how roof vents operate contained in NFPA 204, it is clear that the temperature of the smoke/hot gas layer which collects under the roof is critical for the proper operation of vents.

This issue is further addressed in section A.4.4.3 in Annex A of the 2002 edition of NFPA 204:

*“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 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. . .”*

Given these two excerpts from NFPA 204 above, it can be concluded that the ceiling temperatures which develop in a fire should be of great interest when considering whether or not roof vents will perform their intended function when vents are utilized in a building protected by a sprinkler system. Fortunately, ceiling temperature data was collected in the research conducted at Underwriters Laboratories (UL) in 1997/1998 on the interaction between sprinklers and roof vents. The temperature data is included in the report on this research titled “*Sprinkler, Smoke & Heat Vent, Draft Curtain Interactioni – Large Scale Experiments and Model Development*” authored by Kevin B. McGrattan, Anthony Hamis and David Stroup dated September 1998. This report is referred to as NISTIR 6196-1.

The 1997/1998 research included a total of 5 large scale fire tests with Group A plastics stored in double row racks. In these five tests, the ceiling height was 27 feet and the storage height was 20 feet.

The storage array was protected by ELO-231 ordinary temperature (165°F) upright sprinklers manufactured by Central Sprinkler Corporation (CSC). These sprinklers had a response-time index (RTI) of 148 in metric units and 268 in English units.

The sprinkler spacing utilized in the tests was 10 feet by 10 feet and the water supply to the sprinklers was designed so that a density of 0.50 gpm/SF would be maintained. The required density for this storage configuration based upon NFPA 13 requirements was 0.60 gpm/SF.

In the fourth test, Test P-4, the ignition point was located half-way between two sprinklers. Test P-4 included a total of 5 roof vents installed in the ceiling with a vent spacing of 50 feet by 50 feet (measured from the vent centers). The fusible links in each of the vents had a temperature rating of 165°F. The RTI of the vent fusible links was calculated to be between 167 and 180 in metric units and between 302 and 326 in English units.

In addition to the roof vents, draft curtains were also included in this test. Draft curtains running in both the north-south and east-west directions were included.

In Test P-4, a total of 5 sprinklers activated. No roof vents operated during the test.

The following is a summary of the maximum temperature measurements at each sprinkler recorded during the test. It should be noted that these maximum temperature reading did not necessarily occur at the same point in time during the test.

### TEST P-4 Maximum Ceiling Temperature Measurements at each Sprinkler

	A	B	C	D	E	F	G	H	I	J
1	T <sub>max</sub> = 19°C T <sub>max</sub> = 66°F	T <sub>max</sub> = 19°C T <sub>max</sub> = 66°F	T <sub>max</sub> = 20°C T <sub>max</sub> = 68°F	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F
2	T <sub>max</sub> = 19°C T <sub>max</sub> = 66°F	T <sub>max</sub> = 19°C T <sub>max</sub> = 66°F	T <sub>max</sub> = 19°C T <sub>max</sub> = 66°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 28°C T <sub>max</sub> = 82°F	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 28°C T <sub>max</sub> = 82°F
3	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 23°C T <sub>max</sub> = 73°F	T <sub>max</sub> = 27°C T <sub>max</sub> = 81°F	T <sub>max</sub> = 69°C T <sub>max</sub> = 156°F	T <sub>max</sub> = 74°C T <sub>max</sub> = 165°F	T <sub>max</sub> = 75°C T <sub>max</sub> = 167°F	T <sub>max</sub> = 80°C T <sub>max</sub> = 176°F	T <sub>max</sub> = 83°C T <sub>max</sub> = 181°F	T <sub>max</sub> = 78°C T <sub>max</sub> = 172°F	T <sub>max</sub> = 71°C T <sub>max</sub> = 160°F
4	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 75°C T <sub>max</sub> = 167°F	T <sub>max</sub> = 83°C T <sub>max</sub> = 181°F	T <sub>max</sub> = 84°C T <sub>max</sub> = 183°F	T <sub>max</sub> = 96°C T <sub>max</sub> = 205°F	T <sub>max</sub> = 90°C T <sub>max</sub> = 194°F	T <sub>max</sub> = 79°C T <sub>max</sub> = 174°F	T <sub>max</sub> = 67°C T <sub>max</sub> = 153°F
5	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 26°C T <sub>max</sub> = 79°F	T <sub>max</sub> = 86°C T <sub>max</sub> = 187°F	T <sub>max</sub> = 99°C T <sub>max</sub> = 210°F	T <sub>max</sub> = 112°C T <sub>max</sub> = 234°F	T <sub>max</sub> = 112°C T <sub>max</sub> = 234°F	T <sub>max</sub> = 90°C T <sub>max</sub> = 194°F	T <sub>max</sub> = 78°C T <sub>max</sub> = 172°F	T <sub>max</sub> = 67°C T <sub>max</sub> = 153°F
6	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 27°C T <sub>max</sub> = 81°F	T <sub>max</sub> = 83°C T <sub>max</sub> = 181°F	T <sub>max</sub> = 86°C T <sub>max</sub> = 187°F	T <sub>max</sub> = 164°C T <sub>max</sub> = 327°F	T <sub>max</sub> = 175°C T <sub>max</sub> = 347°F	T <sub>max</sub> = 88°C T <sub>max</sub> = 190°F	T <sub>max</sub> = 74°C T <sub>max</sub> = 165°F	T <sub>max</sub> = 67°C T <sub>max</sub> = 153°F
7	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 27°C T <sub>max</sub> = 81°F	T <sub>max</sub> = 70°C T <sub>max</sub> = 158°F	T <sub>max</sub> = 82°C T <sub>max</sub> = 180°F	T <sub>max</sub> = 107°C T <sub>max</sub> = 225°F	T <sub>max</sub> = 109°C T <sub>max</sub> = 228°F	T <sub>max</sub> = 89°C T <sub>max</sub> = 192°F	T <sub>max</sub> = 78°C T <sub>max</sub> = 172°F	T <sub>max</sub> = 68°C T <sub>max</sub> = 154°F
8	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 27°C T <sub>max</sub> = 81°F	T <sub>max</sub> = 72°C T <sub>max</sub> = 162°F	T <sub>max</sub> = 79°C T <sub>max</sub> = 174°F	T <sub>max</sub> = 81°C T <sub>max</sub> = 178°F	T <sub>max</sub> = 86°C T <sub>max</sub> = 187°F	T <sub>max</sub> = 84°C T <sub>max</sub> = 183°F	T <sub>max</sub> = 76°C T <sub>max</sub> = 169°F	T <sub>max</sub> = 69°C T <sub>max</sub> = 156°F
9	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 25°C T <sub>max</sub> = 77°F	T <sub>max</sub> = 26°C T <sub>max</sub> = 79°F	T <sub>max</sub> = 68°C T <sub>max</sub> = 154°F	T <sub>max</sub> = 76°C T <sub>max</sub> = 169°F	T <sub>max</sub> = 80°C T <sub>max</sub> = 176°F	T <sub>max</sub> = 80°C T <sub>max</sub> = 176°F	T <sub>max</sub> = 76°C T <sub>max</sub> = 169°F	T <sub>max</sub> = 73°C T <sub>max</sub> = 163°F	T <sub>max</sub> = 65°C T <sub>max</sub> = 149°F
10	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 24°C T <sub>max</sub> = 75°F	T <sub>max</sub> = 26°C T <sub>max</sub> = 79°F	T <sub>max</sub> = 66°C T <sub>max</sub> = 151°F	T <sub>max</sub> = 69°C T <sub>max</sub> = 156°F	T <sub>max</sub> = 73°C T <sub>max</sub> = 163°F	T <sub>max</sub> = 71°C T <sub>max</sub> = 160°F	T <sub>max</sub> = 63°C T <sub>max</sub> = 145°F	T <sub>max</sub> = 68°C T <sub>max</sub> = 154°F	T <sub>max</sub> = 64°C T <sub>max</sub> = 147°F

5 sprinkler activations (shown in red)

**Average Maximum Ceiling Temperature: 56.8°C/134.3°F**  
(100 temperature readings)

**Average Maximum Ceiling Temperature-South and East of Draft Curtains: 96.4°C/205.5°F**  
(56 temperature readings)

In Test P-4, one of the draft curtains was positioned such that there were 3 rows of sprinklers located to the west of the curtain running in the north-south direction and 7 rows on the east side of this curtain. The curtain running in the east-west position was positioned such that there were two rows of sprinklers located to the north of this curtain and eight rows of sprinklers located to the south of this curtain. The location of the draft curtains is easily discernable in a review of the temperature data above.

<b>Sprinkler Activation</b>	<b>Activation Time</b>	<b>Maximum Ceiling Temperature at Sprinkler</b>
1 <sup>st</sup>	1:33 (93 seconds)	175°C (347°F)
2 <sup>nd</sup>	1:34 (94 seconds)	164°C (327°F)
3 <sup>rd</sup>	2:20 (140 seconds)	112°C (234°F)
4 <sup>th</sup>	3:19 (199 seconds)	109°C (228°F)
5 <sup>th</sup>	3:20 (200 seconds)	107°C (225°F)
<b>Average</b>		<b>133°C (272°F)</b>

**Notes:**

<sup>1</sup> Research conducted at Underwriters Laboratories in 1997/1998 demonstrates that the activation of sprinklers delays or prevents the activation of individually-activated automatic roof vents where the activation temperature of the vent is the same as the temperature rating of the sprinklers.

Provisions addressing the use of roof vents in buildings protected by a sprinkler system included in the 2010 edition of NFPA 13 require that the vent activating devices be one temperature classification higher than the temperature classification of the sprinklers.

Based upon the above, it can be concluded that there is a high probability that individually-activated automatic roof vents will not open automatically in a building provided with sprinkler protection. If the roof vents do not open automatically, smoke and heat generated by the fire will not be vented until the vents are opened manually.

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