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FIREFIGHTING TACTICS AND NISTIR 6196-1

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The practice of providing automatic smoke and heat (roof) vents in industrial and storage buildings protected by a sprinkler system has been the subject of rather intense debate in the fire protection field for more than three decades. The principal reason for the debate is over the concern that roof vents which open automatically will have a significant adverse impact on the ability of sprinklers to control a fire. Despite this concern, provisions which require roof vents in sprinklered storage buildings were included in the Uniform Fire Code (UFC) in the 1980's. When the three regional code groups merged and developed a single model building code and fire code, the provisions for roof vents in sprinklered buildings contained in the UFC (and also the Standard Fire Prevention Code) were included in the new codes, the International Building Code (IBC) and the International Fire Code (IFC).

Just prior to the publication of the first edition of the International Codes, new research on the issue of the use of roof vents and draft curtains in sprinklered buildings sponsored by the National Fire Protection Research Foundation (NFPRF) was conducted at Underwriters Laboratories. The results of this research were published in September 1998. As a result of this research, code changes to delete the requirements for roof vents in sprinklered buildings have been introduced into the code change process at least four times since 1999.

The latest code change proposals to delete the requirements for roof vents contained in the IBC and IFC are code changes F130-06/07 and F158-06/07. (These code changes were proposed by Schulte & Associates.) The proposals were “disapproved” by the Fire Code code change committee at public hearings in Lake Buena Vista, Florida in late September 2006. The following is an excerpt from the code change committee’s rationale for disapproval of these code changes:

"*. . . .There was no definitive information presented that smoke and heat vents do not contribute to fire control. The issues of interaction between smoke and heat vents and sprinklers have not been examined in detail and solutions proposed, such as was done with the issue of ESFR sprinklers vs smoke and heat vents. . . . .In cases where the sprinkler system does not suppress the fire but, rather, controls it, smoke continues to be generated. The discussions have focused on everything but the safety of the occupants, including firefighters. Smoke and heat vents provide the fire department with an important tool to remove the smoke for occupant safety and enhanced fire attack access, especially in very large area buildings where access from the exterior is limited at best. . . . .The current text presents a balanced approach between firefighter safety and building safety. . . .*"

In an apparent response to the publication of the NFPRF sponsored research in 1998, the American Architectural Metals Association (AAMA) announced a new research project on the interaction of sprinklers and roof vents in September 1999, however, this research was never conducted. Given the limitations of the code change process (where it is difficult to discuss complex technical justifications for a code change in two minutes), it was proposed that the International Code Council's Code Technology Committee (CTC) study code change proposals regarding roof vents in December 2005. After holding a public hearing on the issue in late October 2006, the CTC voted to study the issue. Once again, the AAMA announced a research project on the interaction of sprinklers and roof vents in the summer of 2006, apparently in response to the CTC's discussions of the sprinkler/vent issue.

The announcement of the new research project on roof vent/sprinkler interaction appeared in the summer 2006 issue of the AAMA newsletter, AAMAnet.work. This announcement included the following excerpt:

"*Smoke and Heat Vents (S&HV) on building roofs not only improve fire protection, they also improve the level of safety for firefighters. Prompt venting has been proven to reduce dangerous heat, vision-obscuring smoke, and toxic or potentially explosive products of combustion. And, by preventing heat from mushrooming over the fire area and heating other materials to the point of ignition, fire venting has a marked effect on reducing the lateral spread of fire.*"

Do automatic roof vents actually perform as indicated in the AAMA's announcement of their new research project? The results of the NFPRF research on the interaction of sprinklers, roof vents and draft curtains conducted in 1997/1998 seem to challenge the AAMA's assertions. The following are excerpts from a report titled *"Sprinkler, Smoke & Heat Vent, Draft Curtain Interaction - Large Scale Experiments and Model Development"* authored by Kevin B. McGrattan, Anthony Hamins and David Stroup and dated September 1998. (The entire report can be downloaded from the National Institute of Standards and Technology (NIST) website. This report is referred to as NISTIR 6196-1.)

"*The tests and model simulations showed that when the fire was not ignited directly under a roof vent, venting had no significant effect on the sprinkler activation times, the number of activated sprinklers, the near-ceiling gas temperatures, or the quantity of combustibles consumed.*" (Executive Summary)

'*The tests and model simulations showed that when the fire was ignited directly under a roof vent, automatic vent activation usually occurred at about the same time as the first sprinkler activation, but the average activation time of the first ring of sprinklers was delayed. The length of the delay depended on the difference in activation times between the vent and the first sprinkler.*" (Executive Summary)

"*The tests and model simulations showed that when draft curtains were installed, up to twice as many sprinklers activated compared to tests performed without curtains.*" (Executive Summary)

"*In one rack storage test where the ignition of the fire took place near a draft curtain and the fuel array extended underneath the curtain, disruption of the sprinkler spray and delay in sprinkler operation caused by the draft curtain led to a fire that consumed more commodity compared to the other tests where the fires were ignited away from the draft curtains. This result was demonstrated by the model simulation, as well.*" (Executive Summary)

"*The significant cooling effect of sprinkler sprays on the near-ceiling gas flow often prevented the automatic operation of vents. This conclusion is based on thermocouple measurements within the vent cavity, the presence of drips of solder on the fusible links recovered from unopened vents, and several tests where vents remote from the fire and the sprinkler spray activated. In one cartoned plastic commodity experiment, a vent did not open when the fire was ignited directly beneath it. The model simulations could not predict this phenomenon*." (Executive Summary)

"*Model simulations showed how the activation times of the first and second sprinklers had a substantial impact on the overall number of activations in the plastic commodity tests. In the simulation of one test, it was shown that a delay of approximately one minute in the activation of the second sprinkler led to the activation of four times as many sprinklers as in a simulation of a test with no delay. It had been suggested that these different outcomes were due to the presence of draft curtains in the tests with the sprinkler delay, but the simulations showed that the curtains had no effect because they were over 9 m (30 ft) away from the ignition point.*" (Executive Summary)

"*The objective of the project was to investigate the effect of roof vents and draft curtains on the time, number, and location of sprinkler activations; and also the effect of sprinklers and draft curtains on the activation time, number, and discharge rates of roof vents.*" (Page 1)

"*In all, 39 tests were specified by the committee. All 39 tests were conducted in the Large Scale Fire Test Facility at Underwriters Laboratories (UL) in Northbrook, Illinois.*" (Page 1)

"*The Large Scale Fire Test Facility at UL contains a 37 m by 37 m (120 ft by 120 ft) main fire test cell, equipped with a 30.5 m by 30.5 m (100 ft by 100 ft) adjustable height ceiling. The height of the ceiling may be adjusted by four hydraulic rams up to a maximum height of 14.6 m (48 ft).*" (Page 2)

"*Draft curtains . . . 1.8 m (6 ft) deep were installed . . . .The curtains were constructed of 1.4 m (54 in) wide sheets of 18 gauge sheet metal. The seams in the draft curtains were connected with aluminum tape. The area of the largest quadrant in Fig. 2 was selected to provide a larger vent to floor ratio (1:42) than called for by the Uniform Fire Code (1:50 for up to 6.1 m (20 ft) of storage height and less then 560 m^2 (6000 ft^2) of curtained area) [4].*" (Page 2)

"*The sprinklers used in all the tests were Central ELO-231 (Extra Large Orifice) uprights. The orifice diameter of this sprinkler was reported by the manufacturer to be nominally 16 mm (0.64 in), the reference actuation temperature was reported by the manufacturer to be 74°C (165°F). The RTI (Response Time Index) and C-factor (Conductivity factor) were reported by UL to be 148 $(m\text{-}s)^{1/2}$ (268 $(ft\text{-}s)^{1/2}$) and 0.7 $(m/s)^{1/2}$ (1.3 $(ft/s)^{1/2}$), respectively [1]. When installed, the sprinkler deflector was located 8 cm (3 in) below the ceiling. The thermal element of the sprinkler was located 11 cm (4.25 in) below the ceiling. The sprinklers were installed with 3 m by 3 m (10 ft by 10 ft) spacing in a system designed to deliver a constant 0.34 $L/(s\text{-}m^2)$ (0.50 gpm/ft^2) discharge density when supplied by a 131 kPa (19 psi) discharge pressure.*" (Page 3)

"*UL-listed double leaf fire vents with steel covers and steel curbs were installed in the adjustable height ceiling. . . .The vents were designed to open manually or automatically. In tests where automatic operation of the vents was desired, UL-listed fusible links rated at either 74°C (165°F) or 100°C (212°F) were installed. In most tests, the 74°C link was used.*" (Page 3)

"*The Factory Mutual Research Corporation (FMRC) Standard Plastic test commodity, a Cartoned Group A Unexpanded Plastic, served as the fuel for the cartoned plastic commodity series.*" (Page 3)

"*Draft curtains are usually installed to aid roof vents by creating a deeper layer of smoke and hot gases than would otherwise be formed in large, open area buildings. Recent experiments at Factory Mutual [21] investigated the effect of draft curtains on a sprinkler system without roof vents. . . . .The report concluded that ". . .the presence of draft curtains close to the fire origin will (1) result in the development of a more severe fire and (2) deleteriously affect sprinkler protection.*"" (Page 5)

"*There has been much less work examining the effects of sprinklers on vents. . . .*" (Page 5)

"*A commodity storage height of 6 m (20 ft) with a ceiling height of 8.2 m (27 ft) represents one of the most severe arrangements allowable under NFPA 231C without requiring in-rack sprinklers. Under the Uniform Fire Code, storage of the test commodity is required to be protected using sprinklers, vents and draft curtains when the size of the high piled storage area exceeds 230 m^2 (2,500 ft^2).*" (Pages 33 and 34)

"*Even though UL listing and FM approval of this sprinkler with this type of storage arrangement are based on a minimum density requirement of 0.6 gpm/ft^2, the lower density of 0.5 gpm/ft^2 was used to allow for more challenging, but still controllable, fires and more sprinkler activations.*" (Page 34)

"*It had become clear by this time in the project that the vents were unlikely to open when the fire was ignited more than about 4.6 m (15 ft) away.*" (Page 54)

"*Draft curtains also had an effect on sprinkler activation times. Given two sprinklers equidistant from a fire, the one nearer to a curtain showed a tendency to activate sooner.*" (Page 62)

"*Based on the test data collected in this study, it is difficult to assess how, in general, sprinklers affect the activation of vents because . . . .it appears from the data below that the sprinkler spray influenced the thermal response characteristics of this particular vent, and it is believed that sprinklers could have a similar influence on similar vent designs.*" (Page 64)

"*In the one unsprinklered test of the study (Test I-11), the vent opened at 4:48. The heptane spray burner was 8.6 m (28 ft) from the vent center. Six other tests were performed with the fire at this distance from the vent when the vent was equipped with a fusible link, and in none of these tests did the vent open. In the unsprinklered Test I-11, the temperature near the vent was about 170°C (338°F), whereas in Test I-10, with the fire at the same location, the temperature near the vent was about 90°C (194°F) after the sprinklers had activated around the fire (Figs. 94 and 95). Examination of the near-ceiling temperatures from all the tests indicates that sprinklers of this type have a significant cooling effect, and this will certainly have an effect on thermally-responsive, independently-controlled vents.*" (Page 64)

"*In Plastic Test P-2, the fire was ignited directly under a vent. In the experiment, flames reached the top of the central array at about 65 s and the vent cavity at about 70 s. The first sprinkler activated at 100 s. The vent did not open at any time during the 30 min test even though another vent 6 m (20 ft) to the west of the unopened vent opened at 6:04. The temperature history of the brass disks within the cavity of the unopened vent is given by Fig. 39. After the test, the fusible link was examined, and it was observed that the solder holding the two strips of metal together had begun to melt. This observation had been made when examining the links after several of the heptane spray burner tests, as well.*" (Page 64)

"*This data, along with the plunge tunnel measurements reported in Section 3.1.4, suggests that the fusible link reached its activation temperature before or at about the same time as the first sprinkler activated, but the link did not fuse. It is not clear whether the link did not fuse because it was cooled directly by water drawn upwards into the vent cavity, or whether the sprinkler spray simply cooled the rising smoke plume enough to prevent the link from fusing. In any event, this phenomenon deserves further study.*" (Page 64)

"*A sensitivity analysis was performed to determine what parameters had the most impact on the results of the calculations, and droplet size was shown to be one of the more important. The reason for this is because the heat transfer between the hot gases and the droplet is directly proportional to the surface area of the droplet. Thus doubling the size of the droplets reduces the number of droplets by a factor of 8 and reduces the heat transferred from the gas by a factor of 4.*" (Page 83)

"*Similar calorimetry experiments have been performed at Factory Mutual. There are two differences between the tests performed at FM and those at UL. The first is that the first pallet in the FM tests is raised 23 cm (9 in) off the floor whereas the first tier at UL is on the floor. Second, the FM burns are centrally ignited with four half-ignitors arranged in a pinwheel pattern at the intersection of the four pallets, whereas the UL burns are ignited in the center of one of the lateral flues with two half-ignitors, one on each side of the flue. As a result, the fire growth with the FM configuration is more rapid because of the fire has access to more fresh air from all four flues and from beneath. Figures 47 and 48 present the results of the FM burns, compared with the corresponding simulations.*" (Page 84)

"*A drawback of large scale testing is that this type of sensitivity analysis usually requires more tests than can be afforded. If a sufficient number of replicates cannot be performed, then the outcomes of the experiments are often subject to debate as to whether differences in test results were due to changes in test parameters or due to random variations.*" (Page 90)

"*If the increased number of sprinkler activations of Test P-1 over Test P-4 can be attributed to the delay of the second nearest sprinkler, did the draft curtains have any effect at all? Comparing the simulation of Test P-4 with the 'no delay' simulation of Test P-1, there is not much difference in heat release rates. The overall temperatures near the ceiling are slightly higher in Test P-4, most likely due to the containment of the hot gases by the curtains. This was seen in the analysis of the first series of heptane spray burner tests.*" (Page 90)

"*Another interesting case to examine with the numerical model is Test P-2, where the ignition point was directly under the vent, but the vent did not open.*" (Page 90)

"*There is certainly plenty of evidence from the heptane spray burner tests indicating that when the fire was placed directly beneath an opened vent, the number of activations was significantly reduced.*" (Page 93)

"*Clearly, the draft curtains had an effect on the performance of the sprinkler system. The draft curtains delayed the opening of the two sprinklers directly north of the first two sprinklers to activate. Less obvious, the draft curtains changed the near-ceiling flow pattern of both the sprinkler spray and the fire plume.*" (Page 95)

"*An important assumption made is that the temperature rise ΔT in Eq. 47 is equal to the ambient temperature on the Kelvin (Rankine) scale. Thus, if the ambient temperature were 20°C (68°F), then the temperature rise ΔT near the vent would be assumed to be 293°C (559°F). At this temperature, the mass flow through the vent would be very near its theoretical maximum. Of course, this analysis does not take into account the effect of sprinkler sprays because it is stated in Chapter 6-1 of the 1991 edition of 204M that the document ". . . .represents the state of technology of vent design in the absence of sprinklers." Indeed, the test data and the model predictions reported here indicate that the temperature increase over ambient in the vicinity of an opened vent in a sprinklered facility would be far less than 293°C.*" (Page 100)

"*The mass flow rates for Test I-10 and P-5 are relatively low compared with the theoretical maximum because the near-ceiling gas temperatures are greatly reduced by the sprinklers. . . . The simulation of Test II-2 was rerun with the draft curtains removed. The computed mass flow from the numerical simulation dropped into a range of 1.5 kg/s to 2.0 kg/s. In terms of Eq. (47), this reduction in mass flow rate is due to the decrease in the smoke layer depth, d, but another contribution is the change in ceiling jet dynamics caused by the draft curtain removal. This latter effect is not accounted for in Eq. (47), but it is in the numerical model.*" (Page 100)

"*The significant cooling effect of sprinkler sprays on the near-ceiling gas flow often prevented the automatic operation of vents. This conclusion is based on thermocouple measurements within the vent cavity, the presence of drips of solder on the fusible links recovered from unopened vents, and several tests where vents remote from the fire and the sprinkler spray activated. In one cartoned plastic commodity experiment, a vent did not open when the fire was ignited directly beneath it. The model simulations could not predict this phenomenon.*" (Page 101)

Discussion

Based upon the NFPRF research published in 1998, it appears that many of the AAMA's "*proven*" assertions of "*improved fire protection*" provided by roof vents and draft curtains simply do not occur in buildings protected by standard (control mode) sprinklers. While the NFPRF research did not completely resolve the long-standing debate over whether automatic vents have a detrimental impact on the operation of sprinklers, the research clearly demonstrated that the operation of sprinklers has a significant adverse impact on the operation and effectiveness of smoke/heat vents and that draft curtains can have a significant adverse impact on the operation of a sprinkler system.

If you compare the requirements for roof vents and draft curtains contained in the Uniform Building and Fire Codes with the provisions for vents and draft curtains in the International Codes, you will note one striking difference-the requirements for draft curtains have essentially been removed in the International Codes. It appears that the reason why the requirements for draft curtains was eliminated in the IBC/IFC is the NFPRF (and also 1994 FMRC) research findings regarding draft curtains and the operation of sprinkler systems. What may not be clear, however, is that the elimination of the requirements for draft curtains has a negative impact on the operation of smoke/heat vents.

The combined effect of not providing draft curtains and the activation of sprinklers means that automatic smoke/heat vents will provide little, if any, automatic venting in a fire where the sprinkler system is operational. In other words, automatic vents will likely have to be opened manually in order for venting to occur and that the venting which will be provided by the manually opened vents will be significantly impaired by both the lack of the draft curtains and also by the cooling effects of operating sprinklers. Of course, once the sprinklers begin to gain control of the fire, the smoke will lose its buoyancy, and roof vents will be of little use.

Given the above, it would appear that the only case where providing smoke/heat vents in a building is actually beneficial is where the sprinkler system fails to discharge water due to a closed water supply valve, broken supply piping or a pump which doesn't start. In this case, smoke/heat vents may indeed prove effective in venting smoke and heat from the building, but will smoke/heat vents installed per the requirements contained the IBC and IFC be adequate to reduce the ceiling temperatures sufficiently to prevent the collapse of a non-rated roof structure? (A roof deck supported on non-rated steel bar joists or steel trusses only provides a nominal fire resistance rating.) Given that the roof vent-to-floor area ratios presently required in the IBC are the same as the ratios contained in the 1970's versions of the UBC, it certainly seems reasonable to at least question whether or not fire-fighters can safely operate in buildings provided with smoke/heat vents per the IBC when there is a complete failure of the sprinkler system.

Conclusion

Section 101.3 in the 2006 edition of the International Building Code indicates that one of the purposes of the building code is "*to provide safety to fire fighters and emergency responders during emergency operations*". Obviously, large industrial and storage buildings present an extreme challenge to firefighters which is why the IBC requires that sprinkler protection be provided in single story industrial and storage buildings which exceed 12,000 square feet in floor area. In the event of a complete failure of a sprinkler system protecting a large industrial or storage building, should fire departments still utilize interior manual fire-fighting tactics (depending solely upon the roof vents to prevent the collapse of the roof structure) or should firefighters switch to an exterior attack?

NIOSH 2005-132 titled "*Preventing Injuries and Deaths of Firefighters Due to Truss System Failures*" provides a definitive answer to that question. The following are four quotes from NIOSH 2005-132:

> "*Fire fighters should be discouraged from risking their lives solely for property protection activities.*"
>
> "*. . . however, under uncontrolled fire conditions, the time to truss failure is unpredictable.*"
>
> "*Lives will continue to be lost unless fire departments make appropriate fundamental changes in fire-fighting tactics involving trusses.*"
>
> "*Use defensive strategies whenever trusses have been exposed to fire or structural integrity cannot be verified.*"

Switching from interior firefighting to exterior firefighting tactics in the event of a complete failure of a sprinkler system protecting a large industrial or storage building as recommended by NIOSH 2005-132 appears to be just common sense. Common sense also tells us that the most effective way to protect firefighters is to periodically inspect and test sprinkler systems to insure that the sprinkler protection is being properly maintained. (The National Fire Protection Association (NFPA) indicates that no firefighter fatalities occurred in a building protected by a sprinkler system in 2005.) Perhaps it's time for the fire service to rethink its strategies about firefighting in large industrial and storage buildings.

Roof vents are not the answer to protecting firefighters in large industrial and storage buildings which are protected by a sprinkler system. Inspection, testing and maintenance of the sprinkler system is.

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