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THE INTERACTION OF ROOF VENTS AND DRAFT CURTAINS WITH STANDARD SPRINKLERS

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Section 910.1 in the International Building Code (IBC) requires that automatic smoke and heat (roof) vents be provided in single story portions of buildings with an undivided room or space which exceeds 50,000 square feet in floor area which is classified as either a moderate hazard industrial (F-1) or storage (S-1) occupancy. This section further requires that smoke and heat vents also be provided in buildings which contain high-piled storage per the International Fire Code. Given that IBC requires that sprinkler protection be provided in fire areas which contain moderate hazard industrial or storage occupancies which exceed 12,000 SF in floor area, the IBC in effect mandates that smoke and heat vents be provided in large single story industrial and storage buildings which are protected by standard sprinklers.

The issue of whether or not smoke and heat vents should be provided in buildings which are protected by standard sprinklers has been the subject of debate in the fire protection field for well over 30 years. The debate is over whether open roof vents will delay the operation of sprinklers in the vicinity of a fire and whether this delay in sprinkler operation will be detrimental to the ability of the sprinkler system to achieve control of the fire. While the interaction of sprinklers and smoke and heat vents is still debated, two other issues regarding the interaction of sprinklers and smoke and heat vents have been resolved. These issues are whether the operation of sprinklers affects the opening of automatic roof vents and whether the use of draft curtains affects the operation of the sprinklers.

Despite containing numerous obvious flaws in logic, a paper titled "*Interaction of Sprinklers with Smoke and Heat Vents*" is an excellent overview of the issue of installing roof vents and draft curtains in buildings which are protected by standard sprinklers. This paper is dated February 1999 and authored by Craig L. Beyler and Leonard Y. Cooper of Hughes Associates, Inc.[1] The paper reviews research projects which has been conducted on the interaction of sprinklers, roof vents and draft curtains since ~~1955~~ 1956 and also discusses the various pros and cons of using roof vents and draft curtains in buildings protected by sprinklers. The following are excerpts from the Beyler/Cooper paper:

"*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.*"

"***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*[in] *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 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. . . .* "

“***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 95 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.*”

“***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.*”

“*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 warehousetype retail stores. . . . The authors indicated that neither of the two tests with draft curtains* [without roof vents] *met the above criteria.*”

“*. . . . 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 NFPRF 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. . . . . It is notable that in the time since the 1974 FMRC model study, FMRC has conducted hundreds of full-scale sprinkler tests and have published no additional modeling studies of the type used in the 1974 report.*”

"*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.*"

"*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 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 are not matters for fire research. Similarly, that fire plumes are visible from roof vents is not a matter for research.*"

"*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 sprinkler system reliability studies, sprinkler systems are widely reported to be 90-95 percent reliable, with strong indications that the actual reliability is even lower. In the remaining cases, manual firefighting must be relied upon, and the support of an automatic venting system has clear value in these cases.*"

"*The claim that the use of smoke and heat vents will enhance burning rates has been actively made by Factory Mutual (e.g., Battrick 1986; Ward 1985]. 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 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 [Heskestad 1974], IITRI [Waterman et al. 1982; Waterman 1984], Ghent [Hinkley et al. 1992a], 1998 UL [McGrattan, Hamins, and Stroup 1998] 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 [Heskestad 1974] 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. . . .Early activation of vents and ganging vents are viable strategies which should be employed to improve venting reliability.*"

"*The negative claim is that smoke and heat vent flow rates are insufficient to realize any benefit. . . . 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.*"

"*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.*"

"*First, it is clear that the current focus on assuring that vent operation is delayed has an adverse effect on* [vent] *system performance. It is important that design attention be paid to causing vents to operate more rapidly and in greater numbers. . . .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.*"

In order to understand the interaction between sprinklers, roof vents and draft curtains, it is first necessary to understand the mechanisms of how sprinklers control and extinguish a fire. The following description of how sprinklers work is contained in an article titled "*Meeting the Challenges of an Ever-Changing Storage Industry*" written by James Golinveaux and Joe Hankins of Tyco Fire Protection. The article appeared in the Winter 2006 issue of *Fire Protection Engineering* magazine.

"*Cooling takes place at the roof/ceiling, where relatively small drops are lifted by the fire plume and cool the gas layer at the ceiling. This has the positive effect of preventing collapse of the building structure and sprinkler piping, but also can delay operation of adjacent sprinklers (commonly known as "skipping").*"

"*Prewetting takes place away from the actual fire area, where discharge from sprinklers falls onto unburned combustibles, preventing ignition.*"

"*Penetration of the fire plume by water is the only one of the three mechanisms that actually reduces the heat release rate (HRR) of a fire and, if sufficient, can completely extinguish a fire. Penetration is a function of the momentum of water discharge from sprinklers and drop size, as well as the intensity of the fire plume.*"

"*Control mode (CM)* [standard] *sprinklers are designed to rely on cooling and prewetting, allowing the fire to continue to burn in the area of ignition while controlling roof/ceiling temperatures and preventing fire spread until firefighters arrive or until the fire burns itself out. Control mode sprinkler protection is characterized by a relatively large area of sprinkler operation (15 – 50 sprinklers)* [in storage occupancies]."

In addition to understanding the mechanisms of how sprinklers control and extinguish a fire, it is also helpful to understand the capabilities of sprinklers with respect to controlling fires in storage occupancies. The following excerpts are from explanatory material regarding the requirements for sprinkler systems protecting storage racks contained in NFPA 13:

"*Sprinkler protection installed as required in this standard is expected to protect the building occupancy without supplemental fire department activity. Fires that occur in rack storage occupancies are likely to be controlled within the limits outlined in B-1.1, since no significant building damage is expected. The first fire department pumper arriving at a rack storage-type fire should connect immediately to the sprinkler siamese fire department connection and start pumping operations.*"

"*During the testing program, the installed automatic extinguishing system was capable of controlling the fire and reducing all temperatures to ambient within 30 minutes of ignition. Ventilation operations and mop-up were not started until this point.*"

An understanding of firefighting tactics for large buildings is also useful in determining the need for roof vents and draft curtains. A recent publication issued by the National Institute for Occupational Safety and Health (NIOSH) titled *"Preventing Injuries and Deaths of Fire Fighters due to Truss System Failures*" (NIOSH 2005-132) dated April 2005 contains the following excerpts regarding firefighting tactics in :

"*Steel trusses are also prone to failure under fire conditions and may fail in less time than a wooden truss under the same conditions.*"

"*The number of fire fighter fatalities related to structural collapse could be significantly reduced through proper education and information concerning truss construction. Fire fighters should be discouraged from risking their lives solely for property protection activities.*"

"*Lives will continue to be lost unless fire departments make appropriate fundamental changes in fire-fighting tactics involving trusses.*"

"*NIOSH recommends that fire departments, fire fighters, building owners, and managers take steps to minimize the risk of injury and death to fire fighters during fire fighting operations involving structures with truss roof and floor systems.*"

"*Use defensive strategies whenever trusses have been exposed to fire or structural integrity cannot be verified. Unless life-saving operations are under way, evacuate fire fighters and use an exterior attack [Brannigan 1999; Dunn 2001].*"

Since most large single story industrial and storage buildings utilize the unlimited area building provisions contained in the IBC, these buildings are normally constructed utilizing unprotected noncombustible (Type 2B) construction. (The term “unprotected” refers to the lack of protection of the structural members by fire resistive materials, not whether or not the building is protected by a sprinkler system.) Given this, large industrial and storage buildings are typically constructed utilizing steel bar joists and steel trusses to support the roof construction. Hence, the NIOSH recommendations would be applicable to most buildings where roof vents are required by the IBC/IFC.

Discussion

Perhaps the most important point made in the Beyler/Cooper paper is the admission “*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.*”

While the issue of whether the operation of smoke and heat vents will affect the activation of sprinklers is still the subject of debate, there is no debate about the significant impact that sprinkler activation has on the operation of automatic roof vents. This point was clearly demonstrated in the research sponsored by the National Fire Protection Research Foundation (NFPRF) at Underwriters Laboratories (UL) in 1997 and 1998 and also in a fire which occurred in a bulk retail store in Tempe, Arizona on March 19, 1998.

In the NFPRF fire tests, an automatic roof vent located directly over a fire failed to operate. The failure of the roof vent was attributed to the “cooling effect” of the sprinkler spray discussed by Golinveaux and Hankins in the excerpts above. Droplets of water from the sprinkler spray collected on the vent fusible links and prevented the link from operating. (The same “cooling effect” would also occur with plastic smoke and heat vents which operate by shrinking and then falling out.)

In the bulk retail store fire in Tempe, the sprinkler protection was inadequate for the hazard protected and the system was clearly failing to gain control of the fire. Although three of the 29 automatic roof vents provided had operated at the time of the arrival of the fire department, the building, which was 100,000 square feet in floor area with a height varying from 24 to 29 feet, was filled with smoke from the floor to the roof. A ladder company had to be dispatched to the roof to manually open the other vents which had not operated. Obviously, sending firefighters to the roof to manually open the vents violated the precautions contained in the NIOSH publication. Interestingly enough, the fusible links for the roof vents had a temperature rating of 165°F, while the temperature rating of the sprinklers was 286°F.

Among the "positive claims" included in the Beyler/Cooper paper are that the use of roof vents in sprinklered building allow the venting of the combustion products, smoke, heat, toxic gases and combustible gases, generated by the fire. The issue that Beyler and Cooper fail to address is how this venting will occur if no vents operate, or whether the venting will be sufficient if only one vent operates. Logic tells us that if the vents don't operate due to the activation of sprinklers, then venting will not occur.

The Beyler/Cooper paper also makes frequent reference to the positive effects of draft curtains which will contain the combustion products. What Beyler and Cooper don't say in their paper is that the IBC/IFC provisions for roof vents (which were under development in 1999) only require draft curtains to be provided in industrial and storage buildings without high-piled storage and that, even when draft curtains are required, the IBC permits the curtained area to be 50,000 square feet in floor area. In other words, all of the benefits attributed to draft curtains by Beyler and Cooper don't apply to buildings constructed to comply with the IBC/IFC provisions for roof vents. So much for the containment of the combustion products by draft curtains.

The Beyler/Cooper paper makes reference to fire tests conducted by Factory Mutual Research Corporation (FMRC) in 1994. Two tests included a combination of sprinklers and draft curtains (without roof vents). Based upon the results of these tests, FMRC concluded "*that the presence of curtain boards can cause increases in sprinkler operation, smoke production, and fire damage (i.e. sprinklers opened well away from the fire).*" In response to FMRC's conclusion, Beyler and Cooper state that "*since draft curtains are not normally used in the manner tested* [without roof vents]*, the goal of the testing is unclear.*" Once again, the logic of the Beyler/Cooper response is flawed based upon the statement "*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."*

If no vents operate due to the activation of sprinklers, a test of sprinklers and draft curtains without roof vents should yield the same results as a test of sprinklers, roof vents and draft curtains. It certainly doesn't take a PhD to figure that one out. (Interestingly enough, another engineer retained by the manufacturers of roof vents, William Koffel of Koffel Associates (a former president of the Society of Fire Protection Engineers (SFPE) and member of the NFPA 13 and NFPA 204 committees) also made the exact same point as Beyler and Cooper about FMRC's conclusions from their tests with draft curtains at the ICC code change hearings in Orlando in late September 2006.)

While Beyler and Cooper tout the benefits of the use of draft curtains in conjunction with roof vents (and sprinklers), the one issue that is not mentioned in the paper is the interference with "pre-wetting" caused by draft curtains. This interference with pre-wetting was demonstrated in the NFPRF's fire tests at UL and also in the fire at the bulk retail facility in Tempe previously mentioned. In the fire in Tempe, a draft curtain provided in an aisle (as recommended by Beyler and Cooper) prevented sprinklers on the side of the draft curtain opposite of the fire from operating and pre-wetting combustibles. This lack of pre-wetting allowed the fire to spread across an aisle which was 10 feet in width.

Another issue which Beyler and Cooper raise in their paper is "*that smoke and heat vents operate effectively when sprinklers do not operate*" also appears to challenge logic and common sense. Obviously, a fire which occurs in a building which contains an undivided space which is 50,000 square feet or larger, or in a building which contains high-piled storage, will be difficult for most U.S. fire departments to control without sprinkler protection. (That's why building codes require sprinkler protection in industrial and storage buildings which have fire areas exceeding 12,000 SF.) Given the typical delays in reporting a fire and in fire department response, a fire in these types of buildings would typically be too large for interior manual firefighting to be successful by the time firefighters arrive at the fire. With normal fire department response times, the building structure will have been exposed to fire for more than 5 minutes by the time firefighters arrive and the integrity of the structural members supporting the roof will most probably be questionable. Under these circumstances, committing fire personnel to perform interior firefighting would be extremely risky at best.

Per the recommendations contained in NIOSH 2005-132, the failure of the sprinkler system caused by a closed water supply control valve, pump failure or a break in the main supply piping in the sprinkler system should result in a change of tactics from interior firefighting to an exterior attack. There is no need to send firefighters to the roof to ventilate the fire if there is a complete failure of the sprinkler system. The fire itself will perform the ventilation function in short order with a partial or total collapse of the roof structure and roof vents will do little to prevent the relatively rapid collapse of the roof structure.

Conclusion

In September 1999, the American Architectural Metals Association (AAMA) announced a new research project on the use of smoke and heat vents in sprinklered buildings. Given the timing, the announcement appears to have been in response to the research findings in the sprinkler/vent tests sponsored by the National Fire Protection Research Foundation (published in September 1998) and code change proposals to delete the requirements for roof vents based upon the NFPRF research.

After a delay of almost 7 years, the AAMA has finally announced that Hughes Associates, Inc. has been retained to perform a modeling study of the interaction between sprinklers and roof vents. According to the AAMA newsletter (Summer 2006), the purpose of the modeling study is "*to concretely demonstrate the value of S&HV* [smoke and heat vents] *in terms of property protection, occupant safety, firefighter safety, and firefighter effectiveness*". The newsletter further states that the "*test results will provide data for an optimized S&HV design approach suitable for inclusion in Chapter 8 of NFPA 204, "Guide for Smoke and Heat Venting," or in model building codes.*" It's rather interesting that the AAMA would announce the results of the Hughes' study prior to Hughes even beginning work on the project.

Considering that the results of the Hughes' study have already been announced by the AAMA and the statement in the Beyler/Cooper paper that *"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* [February 1999]", hopefully the AAMA has also allocated funds for a peer review of Hughes' research. One can only wonder what will happen if the Hughes' research doesn't "*concretely demonstrate the value of S&HV*". My guess is that the Hughes' study will "never see the light of day" if this happens.

[1] This paper was later published in *Fire Technology*. See Beyler, C.L., and Cooper, L.Y., "Interaction of Sprinklers with Smoke and Heat Vents," *Fire Technology*, 37 (1), 2001, pp. 9–35.

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