Case Study: Separation of electronic and ESFR sprinklers in a warehouse facility

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Recent studies have shown that electronically activated sprinklers (EAS) can provide adequate fire protection for high hazard commodities such as exposed expanded group-A plastics stored on racks in warehouse applications, with up to 55% lower total water demand and fewer additional engineering controls than existing alternatives [1]. These performance enhancements are made possible through the simultaneous activation of multiple sprinklers surrounding the point of fire origin by an “intelligent” fire detection and control system that uses electronic sensors that are much more sensitive to heat than early suppression fast response (ESFR) sprinklers. However, due to the complexity and cost of an electronic sprinkler system, there is a desire to identify options that would allow electronic and ESFR sprinklers to be used in a single warehouse where high hazard commodities can be sequestered to a specific section of the facility protected by EAS.

Problem Overview:

To ensure proper hydraulic performance of a system using both EAS and ESFR in the same fire area, it is necessary to prevent a fire located beneath ESFR sprinklers from activating the EAS system in another part of the facility. The focus of this study is to identify and validate draft curtain design criteria – including depth, location, and configuration – that will enable one or more standard temperature 68°C (155°F) or intermediate temperature 100°C (212°F) ESFR sprinklers to operate well before the EAS algorithm operating conditions are met. While the specifics of the EAS control algorithm are not discussed, the system evaluated utilizes a combination of 11°C/min (20°F/min) rate of rise (ROR) detection criteria, either 68°C (155°F) or 88°C (190°F) fixed temperature (FT) detection criteria, and the quantity of confirmed detections to determine where and when sprinklers should operate and the total number of sprinklers to operate. A relatively large number of sensors must register a ROR or FT and specific triggering criteria must be met before EAS will operate. It should be noted that the ROR criteria used by the system requires a 11°C (20°F) increase over the ambient temperature in 60 seconds or less to register a confirmed detection.

Draft curtain design criteria:

The idea of using draft curtains to separate sprinklers of differing temperature ratings or thermal sensitivities is not novel. For example, NFPA 13 allows the use of a 0.6 m (2 ft) deep draft curtain centered over a 1.2 m (4 ft) aisle to separate ESFR sprinklers from standard response sprinklers in the same fire area [2]. Additionally, FM Property Loss Prevention Data Sheet 1-10 allows the use of a 0.6 m (2 ft) deep curtain separating quick-response and special-response sprinklers from
standard response-sprinklers. FM 1-10 also provides an alternative approach specifying that a
draft curtain depth of at least 1.2 m (4 ft) or 1/8 the maximum building height, whichever is greater,
centered over an aisle of at least 1.5 times the sprinkler spacing be used where required [3]. While
these design approaches are assumed appropriate for existing automatic sprinkler systems,
additional analysis is necessary to determine their effectiveness with EAS.

Furthermore, several design challenges must be considered in the selection of draft curtain criteria.
Draft curtains must be deep enough to prevent heat propagation while not obstrucitng sprinkler
spray from protected hazards. Also, negative impact on warehouse operations should be
minimized. For example, an excessively deep curtain can obstruct access to the top level of racking
and large aisle width requirements may reduce overall storage capacity. Additionally, the design
approach should be scalable to address buildings of different heights and sprinkler system
configurations.

**Solution approach and simulation framework:**

Considering the above, simulations conducted using Fire Dynamics Simulator (FDS) version 6.6.0
are used to determine if existing prescriptive draft curtain design criteria as stated, or with minor
changes, can prevent or delay activation of the first EAS ROR sensor until operation of at least
one 100°C (212°F) ESFR sprinkler. The simulation framework is based on the FDS validation
cases modeled after the UL/NFPRF Sprinkler, Vent, and Draft Curtain study [4, 5]. This basis is
appropriate for the analysis because it has been used to validate the ability of FDS to predict the
conditions within the fire plume, ceiling jet / hot gas layer, and sprinkler activation times in a
warehouse type environment. During the UL/NFPRF study, tests and simulations were conducted
using both a heptane spray burner and standard cartoned unexpanded group-A plastic commodity
(CUP). Details on the accuracy of the predictions for the convective heat release rate for CUP
commodity have been found to be within 20% of large-scale calorimeter tests conducted at both
UL and FM [6].

For this study, the base FDS validation case input files are modified as follows:

- The ceiling height is extended from 7.6 m (25 ft.) to 10.6 m (35 ft.).
- A draft curtain of varying depth constructed of 16 cm (5/8 in.) thick gypsum board is
centered within the domain separating it into two halves and centered between two rows of
sprinklers.
- A 3 by 6 grid of ESFR sprinklers with an RTI value of 25 (m*s)^{0.5} at a distance of 30 cm
(12 in) below the ceiling surface are included on the ignition side of the draft curtain with
operating temperatures of both 68°C (155°F) and 100°C (212°F).
• A 3 by 6 grid of EAS sensors with an RTI value of \(7 \text{ (m s)}^{0.5}\) located 30 cm (12 in) below the ceiling surface are included opposite the ignition side of the draft curtain with an operating temperature of 30°C (86°F). This corresponds to an approximate 12°C (21.6°F) increase above the simulation starting ambient temperature of 18°C (64.4°F) to reasonably approximate the ROR response of the electronic sprinkler detection and control system. The sensor RTI was determined experimentally utilizing the plunge tunnel test described in FM 2000 section 4.28 at an operating temperature of 68°C (155°F) [7].

• Water spray and water-based suppression performance are not simulated as this is not a well validated capability of FDS. The sprinklers are modeled as heat sensors and relative activation times were measured.

• The fire scenario consists of the simulated CUP commodity from the UL/NFPRF FDS validation case arranged in a double row rack configuration, 8 pallet loads long, 2 loads deep, and of varying height. The location of the rack and ignition orientation with respect to the sprinkler system is determined as the result of the relative distance from the face of the rack to the draft curtain.

An example rendering of the computational domain showing the orientation of the draft curtain and the fire scenario can be found in figure 1.

![Figure 1: Rendering of the computational domain showing the fire scenario, draft curtain, sprinkler configuration, and sprinkler / EAS sensor activation temperatures at first 100°C ESFR sprinkler activation for simulation CASE 2. ESFR sprinklers are on the left side of the curtain and EAS sensors are located on the right.](image-url)
Results and discussion

A summary of the simulation cases and the related results are shown in Table 1.

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3</th>
<th>CASE 4</th>
<th>CASE 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft curtain depth</td>
<td>0.6 m (2 ft)</td>
<td>1.2 m (4 ft)</td>
<td>1.33 m (4.4 ft)</td>
<td>1.33 m (4.4 ft)</td>
<td>1.33 m (4.4 ft)</td>
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<tr>
<td>Curtain distance from rack face</td>
<td>0.6 m (2 ft)</td>
<td>0.6 m (2 ft)</td>
<td>2.0 m (6.5 ft)</td>
<td>3.2 m (10.5 ft)</td>
<td>2.0 m (6.5 ft)</td>
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<td>Storage height</td>
<td>6.1 m (20 ft)</td>
<td>6.1 m (20 ft)</td>
<td>6.1 m (20 ft)</td>
<td>6.1 m (20 ft)</td>
<td>4.6 m (15 ft)</td>
</tr>
<tr>
<td>Sprinkler spacing</td>
<td>3.0 m x 3.0 m (10 ft x 10 ft)</td>
<td>3.0 m x 3.0 m (10 ft x 10 ft)</td>
<td>2.4 m x 3.0 m (8 ft x 10 ft)</td>
<td>2.4 m x 3.0 m (8 ft x 10 ft)</td>
<td>2.4 m x 3.0 m (8 ft x 10 ft)</td>
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<tr>
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<td>between 2</td>
<td>among 4</td>
<td>between 2</td>
<td>among 4</td>
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<tr>
<td>Basis of design</td>
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<td>NFPA 13 with deeper curtain</td>
<td>FM 10-1</td>
<td>FM 10-1 B2 ignition</td>
<td>FM 10-1</td>
</tr>
</tbody>
</table>

| RESULTS                    |                 |                 |                 |                 |                 |
| First 68°C (155°F) ESFR    | 80 s            | 83 s            | 101 s           | 77 s            | 111 s           |
| First 100°C (212°F) ESFR   | 103 s           | 104 s           | 114 s           | 102 s           | 120 s           |
| First EAS detection        | 73 s            | 112 s           | 114 s           | 109 s           | 119 s           |
| Max EAS sensor temp at ESFR operation | 41°C (106°F) | 29°C (84°F) | 31°C (88°F) | 31°C (88°F) | 34°C (93°F) |
| EAS system activation before ESFR operation | YES | NO | NO | NO | NO |

Table 1: Simulation cases and associated variables. Note that EAS system activation requires a relatively large number of sensors to register a ROR or FT condition and other specific triggering criteria to be achieved.

The simulation results from CASE 1 suggest the 0.6 m (2 ft) deep draft curtain design criteria specified in NFPA 13 and FM 1-10 will slow, but not prevent, the propagation of heat between areas. While this is a viable strategy for separating sprinklers of different sensitivity types, it is ineffective at delaying EAS sensor activation beyond either of the ESFR temperature ratings and is the only case that results in the EAS system algorithm conditions to be met before ESFR operation. Extending the draft curtain from 0.6 m (2 ft) to 1.2 m (4 ft) in CASE 2 is effective at reversing the trend and produces a considerable margin between the activation times of both ESFR sprinkler types and the EAS sensors. In both CASE 1 and 2, the draft curtain is located close to the rack face placing ignition between two sprinklers.

To investigate the alternative FM 10-1 criteria, CASE 3 places the racking a bit further from the draft curtain and moves the ignition location to among four sprinklers. The draft curtain is also extended slightly to 1.33 m (4.4 ft) to comply with the 1/8 maximum ceiling height rule, and the sprinkler spacing is revised to 2.4 m x 3.0 m (8 ft x 10 ft) to place sensors closer to the curtain face. This appears to delay initial ESFR sprinkler activation and results in a smaller overall margin between first ESFR and EAS sensor activations.
To determine if this is the effect of the ignition location or the result of a thermally driven flow effect produced by the increased distance from the curtain, the rack is moved to place ignition between two sprinklers on the second row from the draft curtain in CASE 4. While this results in a slightly faster EAS sensor activation time overall, it significantly increases the margin with respect to both ESFR sprinkler types – resulting in a trend similar to CASE 2. Subsequently, the among four ignition scenario in CASE 3 is determined to be the worst case.

The impact of ceiling clearance is investigated in CASE 5. The rack is reduced in height by one tier resulting in 6.1 m (20 ft) of clearance between the commodity and the ceiling, and ignition is moved back to the among 4 ignition location from CASE 3. The lower commodity height and increased clearance results in a slightly longer activation time for both the ESFR sprinklers and EAS sensors. The relative timing is similar to CASE 3 with the first EAS sensor activating 1 second before the first 100°C (212°F) ESFR sprinkler, and well before EAS system activation conditions are achieved. Also, under no circumstances does an EAS sensor register a reading approaching the 68°C (155°F) fixed temperature threshold.

**Conclusions:**

Overall, the results suggest that the draft curtain design criteria modeled after the alternative method in FM 1-10 should provide adequate means to prevent premature activation of EAS systems when used within the same fire area as intermediate temperature ESFR sprinklers. It should be noted that the study focuses on a maximum ceiling height of 10.6 m (35 ft) which is assumed worst case for the specific application. Alternative design guidelines at lower ceiling heights and related scalability criteria are not directly evaluated. The selected design method limits the minimum draft curtain depth to 1.2 m (4 ft), providing a reasonably conservative approach for lower ceiling heights.

Finally, the evaluation of sprinkler system performance using simulation tools such as FDS are largely relegated to determining the time and location of first sprinkler activation for a given scenario. This is primarily due to the limited capability of these tools to adequately simulate impact of water spray and water-based suppression. A benefit of the simultaneous activation principle employed by EAS systems is that fire detection and full system activation are separated into two discrete events. This supports the idea that simulation methods like those used in this study can be an effective option for evaluating the impact of building geometry, obstructions to heat flow, and even commodity configuration on the hydraulic performance of EAS systems.

**Acknowledgements:**

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REFERENCES:


3. FM Global Loss Prevention Data Sheet 1-10 Interaction of Sprinklers, Smoke and Heat Vents, and Draft Curtains, January 2011, Factory Mutual Insurance Company, Johnston, RI.


