



Maximizing installation flexibility and storage capacity using Tyco® ESFR Storage Sprinklers



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Introduction

Johnson Controls has been a pioneer in developing Early Suppression Fast Response (ESFR) Sprinklers for storage applications, beginning with the introduction of the first ESFR sprinkler, the K-14.0 ESFR-1, in the late 1980s and the K-25.2 ESFR-25 in the late 1990s. This line has expanded in the decades since and with the addition of the K-33.6 Tyco® Model ESFR-34 in 2020, Johnson Controls now has the most complete ESFR line of storage sprinklers. This portfolio provides the most installation flexibility and maximum potential storage capacity when compared to other ESFR sprinklers.

The Tyco Model ESFR-22 and Model ESFR-25 are Early Suppression Fast Response Sprinklers for High-Piled Storage Occupancies in accordance with the National Fire Protection Association NFPA 13:2019. The Tyco Model ESFR-22, Model ESFR-25 and Model ESFR-34 are "Storage Sprinklers" in accordance with FM Global Loss Prevention Data Sheets 2-0 and 8-9.

Background

Providing maximum flexibility for sprinkler system design, installation and maintenance is a major goal in developing fire protection products and protection schemes. This is particularly important in warehouse applications where an effective fire sprinkler system can minimize construction and installation costs while maximizing the economic benefit for the warehouse operator.

There has been significant progress in fire sprinkler capabilities since the 1990s. ESFR sprinklers can provide flexibility through ceiling-only storage protection – which, as the term implies, means there are no automatic fire sprinklers in the storage racks and automatic fire sprinklers installed at the ceiling provide fire protection. While in-rack sprinklers are capable of providing effective fire protection, having the sprinklers and piping located within the racks reduces storage and rack flexibility, takes up volume from valuable commodity and increases the risk of damage to a sprinkler or piping. Ceiling-only protection schemes using ESFR automatic fire sprinklers now exist for ceiling heights up to 55 feet (16,8m) and 50 feet (15,2m) of storage with commodities as hazardous as cartoned non-expanded plastic.

This paper will analyze two important factors: (1) the distance the automatic fire sprinkler is located below the ceiling and (2) the minimum aisle width – and demonstrate why these factors can allow for greater flexibility for installation and storage.

Sprinkler-to-Ceiling Distance

The late 1980s brought about the development of the first ESFR sprinkler. This sprinkler, the ESFR-1, launched by Johnson Controls (formerly Grinnell®) had a K-factor of 14.0 (200) and was able to provide ceiling-only protection up to a 40 foot (12,2m) ceiling height. Approximately ten years later, the company developed the K-25.2 Model ESFR-25 automatic fire sprinkler that increased ceiling-only protection to 45 feet (13,7m). In addition to the increased ceiling height, the Model ESFR-25 provided another significant improvement over the Model ESFR-1: the ESFR-25 increased the deflector-to-ceiling distance from 14 inches (350mm) to 18 inches (450mm). NFPA 13:2019 section 14.2.10.1.3 states, "Pendent sprinklers with a nominal K-factor of K-22.4 (320) and K-25.2 (360) shall be positioned so that the deflectors are a maximum 18 inches (450mm) and a minimum 6 inches (150mm) below the ceiling."

There are two major benefits of the additional deflector distance. First, is increased installation flexibility with respect to allowing the pipe centerline to be lower and second, is maximizing the ability to avoid roof support structures and equipment from other building systems such as ductwork from heating, ventilation and air conditioning (HVAC) equipment.

Whether installing per NFPA13:2019 or FM 8-9, ESFR sprinklers have some of the most stringent obstruction rules, in order to maintain proper response time and spray distribution pattern. These rules are essential for ESFR sprinklers installed at the ceiling to address a fire effectively. This means ESFR sprinkler installations must avoid obstructions such as ceiling support structures and HVAC ducts that could slow sprinkler response time or negatively affect spray distribution.

Table 1 – K-22.4 and K-25.2 ESFR Deflector-to-Ceiling Distance (in/mm)

Ceiling Height (ft/m)	Tyco ESFR-25	Alternative A ESFR-25	Alternative B ESFR-25	Tyco ESFR-22	Alternative A ESFR-22	Alternative B ESFR-22
45/13,7	18/450	14/350	18/450	18/450	18/450	18/450

Although NFPA 13:2019 requires K-22.4 and K-25.2 ESFR sprinklers to have an 18 inch (450mm) deflector-to-ceiling distance, not all K25.2 sprinklers meet this requirement.

Table 1 shows the currently listed and approved K-22.4 and K-25.2 ESFR sprinklers along with their UL Listed deflector-to-ceiling distance used in conjunction with a 45 foot (13,7m) ceiling height.

As shown in Table 1, Tyco Model ESFR-22 and ESFR-25 sprinklers are UL Listed with an 18 inch (450mm) deflector-to-ceiling distance as specified by NFPA 13:2019. The sprinklers are also FM Approved. It should be noted that

FM Global in Loss Prevention Datasheet 2-0 addresses sprinkler location using the thermal element-to-ceiling dimension.

In addition to approving the aforementioned sprinklers to a 45 foot (13,7m) ceiling height, the January 2020 edition of FM Global Loss Prevention Datasheet 8-9 approves ESFR or Storage Sprinklers up to a ceiling height of 55 feet (16,8m). Table 2 shows the thermal element-to-ceiling distance for FM Approved Storage Sprinklers at ceiling heights of 45 feet (13,7m), 50 feet (15,2m) and 55 feet (16,8m).

Table 2 – K22.4, K25.2, K28.0 and K33.6 Storage (ESFR) Thermal Element-to-Ceiling Distance (in/mm) at 45 foot (13,7m), 50 foot (15,2m) and 55 foot (16,8m) Ceiling Heights

Ceiling Height (ft/m)	Tyco ESFR-22	Alternative A ESFR-22	Alternative B ESFR-22	Tyco ESFR-25	Alternative A ESFR-25	Alternative B ESFR-25	ESFR-28	Tyco ESFR-34
45/13,7	17/431,8	17/431,8	17/431,8	17/431,8	13/330,2	17/431,8	N/A	N/A
50/15,2	13/330,2	13/330,2	13/330,2 17 ¹ /431,8	13/330,2 17 ¹ /431,8	13/330,2 17 ¹ /431,8	13/330,2 17 ¹ /431,8	13/330,2	17/431,8
55/16,8	N/A	N/A	N/A	N/A	N/A	N/A	13/330,2	17/431,8

¹13 inches with 50 psi design, 17 inches with 75 psi design

As shown in Table 2, Tyco Model ESFR-34, Model ESFR-25 and ESFR-22 sprinklers are FM Approved with the maximum thermal element-to-ceiling distance at each ceiling height.

Aisle Width

In addition to sprinkler-to-ceiling distance, aisle width is another key factor for an automatic fire sprinkler protection scheme for a warehouse. NFPA 13:2019 section 3.3.4 defines aisle width as “the horizontal distance between the face of loads in racks under consideration.” Figure 1 depicts an overhead view of a typical double row rack storage array separated by aisles. Storage fire protection schemes shown in NFPA 13:2019 and FM Global Loss Prevention Data Sheet 8-9 identify the minimum aisle width allowed based on ceiling height, storage height, commodity type and sprinkler type.

Aisle width is an important factor in determining the amount of commodity a warehouse can store, which directly impacts warehouse economics. The more commodity that can be stored, the more potential to generate revenue. With regards to K-22.4 and K-25.2 ESFR sprinklers, minimum aisle width is consistent among all UL Listed or FM Approved sprinklers under ceilings with heights up to 45 feet (13,7m); however, for K-22.4 and K-25.2 ESFR sprinklers UL Listed and FM Approved over 45 feet (13,7m) there are minimum aisle width differences. Table 3 lists K-22.4, K-25.2 and K-28.0 sprinklers that currently have a UL Specific Application Listing up to a 48 foot (14,6m) ceiling and 43 feet (13,1m) of storage along with their minimum listed aisle width.

Figure 1 – Overhead view of typical double row racks separated by aisles

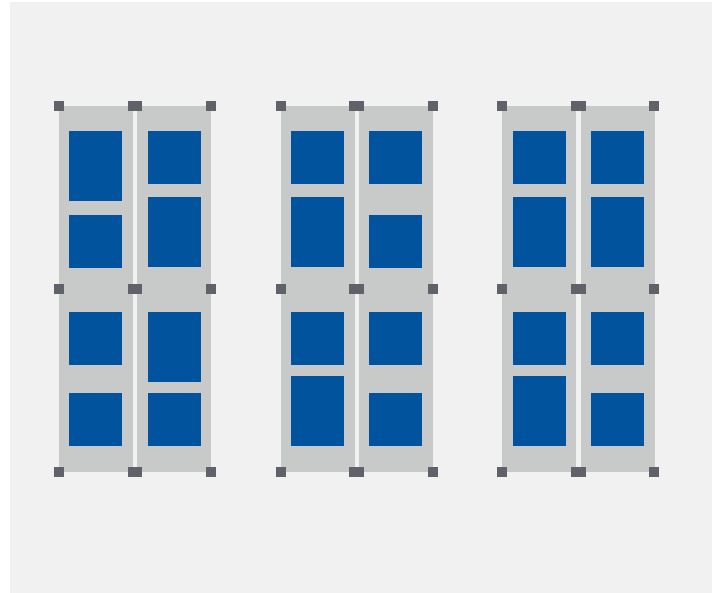
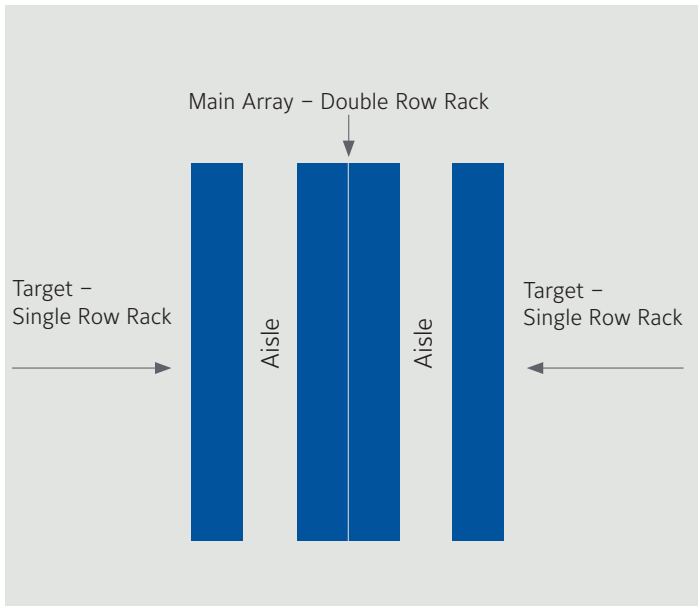


Figure 2 - Plan view of a full scale fire test arrangement



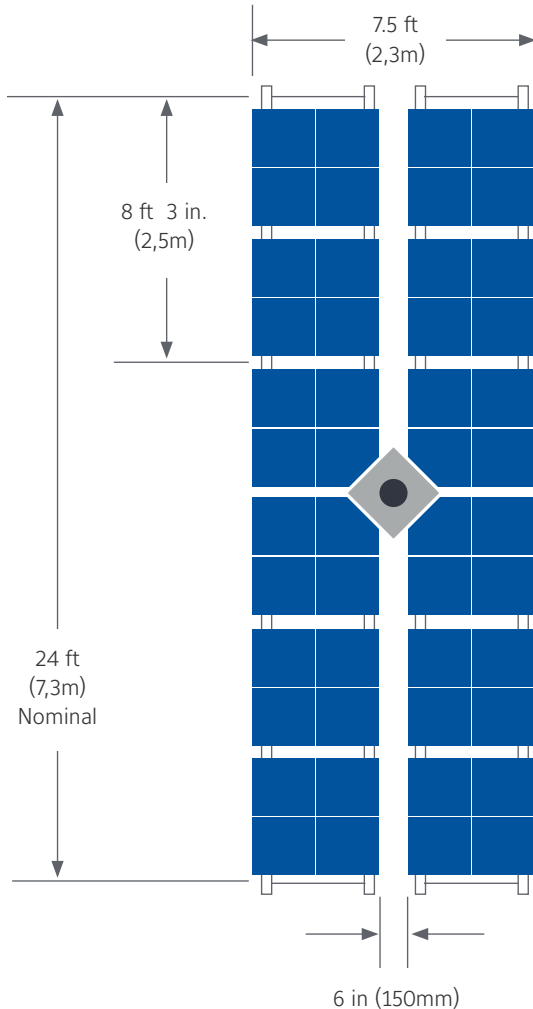
Commodity ignition in the target array significantly increases the fire's heat release rate and increases the challenge to sprinklers' distribution patterns. The high intensity fire can redirect the water spray upwards and towards surrounding sprinklers, cooling them and delaying or preventing their operation – a phenomenon called "skipping." The combination of aisle jump and sprinkler skipping typically leads to an unsuccessful fire test. Increased aisle width mitigates the risk of a fire test failure by making aisle jump more difficult.

While the increased aisle width can improve the chances of a successful fire test, it can have a negative impact on the amount of commodity a warehouse can store. Warehouse capacity is estimated by calculating the number of double row racks that can be placed in a given area of the warehouse and subsequently calculating the number of pallet loads that can be stored in the double row racks. Figure 3 depicts a theoretical warehouse that has a floor space used to house double row racks. For the purpose of simplicity, the space used for the calculation is a 200 feet (61m) by 200 feet (61m) area. Dimension B is the dimension available for the length of the racks and Dimension A is the dimension used to determine the number of racks that can be placed in the area.

Figure 3 - Plan view of placing double row racks separated by aisles



Figure 4 – Plan view of a typical double row rack



From rack height we can estimate the number of tiers the rack will have. Typically a tier is about 5 feet (1,5m) in height, therefore a storage rack that is 40 feet (12,2m) in height can have 8 tiers.

$$\#Tiers = \frac{\text{Storage Height}}{5}$$

Pallets are typically 42 inches (1066mm) wide and are separated by a 6 inch (152mm) flue space, meaning a pallet can be stored lengthwise every 48 inches (1219mm) or 4 feet (1,2m). Given the rack length of 24 feet (7,3m) from Figure 4, there are 6 pallets (24 divided by 4) per each single. Since this is a double row rack, 6 is multiplied by 2, meaning 12 total pallets for each tier in a double row rack that is 24 feet long. The number of pallets per linear foot of a tier of a double row rack can be determined to be 12 pallets/24 feet or 0.5 pallets/feet.

$$\text{Pallets per linear ft per tier} = 0.5$$

The number of double row racks is based on Dimension A, the aisle width and the width of the double row rack.

$$\# \text{ of Double Row Racks} = \frac{\text{Building Dimension A}}{\text{Aisle Width} + \text{DRR Width}}$$

The total number of pallets is calculated based on the following equation:

$$\text{Total \# of Pallets} = (\# \text{ Tiers}) (\# \text{ Double Row Racks}) (0.5 * (\text{Building Dimension B} - 8))$$

Example:

- Warehouse floor area:
Dimension A: 200 ft / 61m; Dimension B: 200 ft / 61m
- Storage height: 40ft / 12,2m
- Double row rack width: 7.5ft / 2,3m
- Aisle Width: 4 ft / 1,2m
- Number of Tiers = $40/5 = 8$
- Number of Double row racks = $200/(4+7.5) = 17.4$ or 17
- Total Number of Pallets = $8 \times 17 \times (.5 \times (200-8)) = 13,056$

Given these parameters, for K-22.4 and K-25.2 ESFR sprinklers UL Listed and FM Approved to a 45 foot (13,7m) ceiling and 40 foot (12,2m) storage height, the theoretical maximum warehouse capacity is the same regardless of the sprinkler model.

We will next examine the effect aisle width has on ceiling heights greater than 45 feet (13,7m). As shown in Table 3, different sprinkler models are UL Listed with different aisle widths at the 48 foot (14,6m) ceiling height. Table 5 below shows the theoretical number of pallets that can be stored in a warehouse that has a 200 foot x 200 foot (61m x 61m) area and a 48 foot (14,6m) ceiling.

Table 5 – Total number of pallets for ESFR sprinklers listed with a 48 foot (14,6m) ceiling

Sprinkler Model	Aisle width (ft/m)	# of Pallets	% Decrease from Maximum
ESFR-22	8/2,4	10,608	-18.75%
Tyco ESFR-25	5/1,5	13,056	--
ESFR-28	6/1,8	12,240	-6.25%



It is interesting to note that given the same area:

- Total capacity with a 45 foot ceiling (13,7m) and a 4 foot (1,2m) aisle (13,056 as shown in the aforementioned example) is essentially the same as the total capacity with a 48 foot ceiling (14,6m) and a 5 foot (1,5m) aisle
- The calculation demonstrates that by increasing the aisle width to 6 feet (1,8m) there is a reduction of about 6% compared to what can be stored with the 5 foot (1,5m) aisle at 48 feet (14,6m) or a 4 foot (1,2m) aisle at 45 feet
- Increasing the aisle width to 8 feet (2,4m) decreases storage capacity by nearly 19%

The January 2020 edition of FM Global Loss Prevention Datasheet 8-9 now identifies FM Approved ceiling-only protection schemes at ceiling heights of 50 feet (15,2m) and 55 feet (16,8m) using quick response pendent storage sprinklers. The capacity calculation for these ceiling heights was performed based on FM approved aisle widths and the results are shown in Table 6.

The results of this calculation show that at the current FM Approved 6 foot (1,8m) aisle width and the 50 foot (15,2m) ceiling height:

- The maximum storage capacity based on number of pallets is essentially the same as what can be stored with a 4 foot (1,2m) aisle under a 45 foot (13,7m) ceiling or a 5 foot (1,5m) aisle under a 48 foot (14,6m) ceiling
- The 6 foot (1,8m) aisle under a 55 foot (16,8m) ceiling can increase the capacity by more than 10% over protection schemes available at 45 feet (13,7m), 48 feet (14,6m) and 50 feet (15,2m)
- The 8 foot aisle width under a 55 foot (16,8m) ceiling actually accommodates 13% less commodity than the scheme with 6 foot (1,8m) aisles and about 5% less than the Listed and Approved schemes at 45 foot (13,7m), 48 foot (14,6m) and 50 foot (15,2m) ceiling heights

While the above storage capacity calculations are based on a 200 foot x 200 foot (61m x 61m) warehouse space, the relative difference in percent basis will remain approximately the same given a fixed rack length and varying the length across the racks. Table 7 summarizes the pallet calculation on varying space lengths.

Table 6 – Total number of pallets for ESFR sprinklers approved with 50 foot (15,2m) and 55 foot (16,8m) ceiling heights

Ceiling height (ft/m)	Aisle Width (ft/m)	K-22.5 and K25-2 ESFR	K-28.0 ESFR	K-33.6 ESFR
50/15,2	6/1,8	12,960	12,960	12,960
55/16,8	6/1,8	N/A	N/A	14,400
55/16,8	8/2,4	N/A	12,480	N/A

Table 7 – Calculation of pallet capacity in various length warehouse spaces

Note: See Figure 3 for plan view visual of the calculations below

Building Dimension A (ft/m)	Building Dimension B (ft/m)	FM Approval 55' (16,8m) Ceiling 50' (15,2m) Storage 6' (1,8m) Aisle (ESFR-34)		UL Spec App 48' (14,6m) Ceiling 43' (13,1m) Storage 5' (1,5m) Aisle (ESFR-25)			FM Approval 55' (16,8m) Ceiling 50' (15,2m)Storage 8' (2,4m) Aisle (ESFR-28)		
		# of Racks	# of Pallets	# of Racks	# of Pallets	% Decrease From Max Storage	# of Racks	# of Pallets	% Decrease From Max Storage
50 / 15,2	200 / 61	4	3,840	4	3,264	-15.0%	3	2,880	-25.0%
100 / 30,5		7	6,720	8	6,528	-2.9%	6	5,760	-14.3%
150 / 45,7		11	10,560	12	9,792	-7.3%	10	9,600	-9.1%
200 / 61		15	14,400	16	13,056	-9.3%	13	12,480	-13.3%
250 / 76,2		18	17,280	20	16,320	-5.6%	16	15,360	-11.1%
300 / 91,4		22	21,120	24	19,584	-7.3%	19	18,240	-13.6%
350 / 106,7		26	24,960	28	22,848	-8.5%	23	22,080	-11.5%
400 / 122		30	28,800	32	26,112	-9.3%	26	24,960	-13.3%
450 / 137		33	31,680	36	29,376	-7.3%	29	27,840	-12.1%
500 / 152,4		37	35,520	40	32,640	-8.1%	32	30,720	-13.5%
600 / 182,9		44	42,240	48	39,168	-7.3%	39	37,440	-11.4%
700 / 213,4		52	49,920	56	45,696	-8.5%	45	43,200	-13.5%
800 / 234,8		59	56,640	64	52,224	-7.8%	52	49,920	-11.9%
900 / 274,3		67	64,320	72	58,752	-8.7%	58	55,680	-13.4%
1000 / 304,8		74	71,040	80	65,280	-8.1%	65	62,400	-12.2%

Summary



In summary, Tyco Models ESFR-34, ESFR-25 and ESFR-22 automatic fire sprinklers provide for the most installation flexibility and offer the ability to maximize warehouse storage capacity

- Tyco Models ESFR-22 and ESFR-25 automatic fire sprinklers are UL Listed with a deflector-to-ceiling distance of 18 inches (457mm) and FM Approved with a thermal element-to-ceiling distance of 17 inches (432mm), providing the most installation flexibility to avoid obstructions that are currently allowed under a 45 foot (13,7m) ceiling
- The Tyco Model ESFR-34 automatic fire sprinkler is FM Approved for use in ceiling-only fire protection schemes under both 50 foot (15,2m) and 55 foot (16,8m) ceilings with a thermal element-to-ceiling distance of 17 inches (432mm), which provides four (4) additional inches (102mm) of flexibility compared to other ESFR sprinklers approved at the same heights
- The Tyco Model ESFR-25 automatic fire sprinkler is UL Specific Application Listed for ceiling-only fire protection to ceiling heights of 48 feet (14,6m) with a 5 foot (1,5m) aisle width—this sprinkler:
 - Provides for more potential storage capacity than other similarly Listed specific application sprinklers with aisle widths greater than 5 feet (1,5m)
 - Allows as much potential storage capacity as sprinklers approved with a 6 foot (1,8m) aisle under a 50 foot (15,2m) ceiling

- The Tyco Model ESFR-34 automatic fire sprinkler is approved for ceiling-only protection under a 55 foot (16,8m) ceiling with a minimum 6 foot (1,8m) aisle, which allows the most potential storage capacity of any Listed or Approved ceiling-only fire protection scheme
- Warehouses using the Tyco Model ESFR-34 automatic fire sprinkler at the maximum ceiling height of 55 feet (16,8m) and minimum aisle width of 6 feet (1,8m) can store approximately:
 - 10% more commodity than ceiling-only schemes Listed or Approved at 45 feet (13,7m), 48 feet (14,6m), and 50 feet (15,2m)
 - 13% more commodity than other schemes approved with a 55 foot (16,8m) ceiling and an 8 foot (2,4m) aisle

To learn more about how you can use Tyco Models ESFR-34, ESFR-25 and ESFR-22 automatic fire sprinklers to maximize installation flexibility and storage capacity, visit www.tyco-fire.com to view technical data sheets, product information, or to request more information.

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With over 30 years of engineering experience, Mr. Silva is the Chief Engineer for JCI's Fire Suppression Products business. For more than 19 years he has developed numerous products for use in fire sprinklers systems and is named on 30 U.S. Patents related to fire suppression devices. In his current role as Chief Engineer, Mr. Silva is involved with the research and development of new fire protection products and is a member of the NFPA 13, 30B and 1925 Technical Committees.

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