FEMTC 2022

"CFD ANALYSIS OF FIRE PROTECTION SPRINKLER SYSTEM ADAPTED FOR A STORAGE/SALE RACK OF FLAMMABLE LIQUIDS"

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OUTLINE OF PRESENTATION

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- Introduction
- Main Goal
- Methodology
- Information Review
- Full Scale Test Results
- Sprinklers System Adaptation
- CFD Simulation
- Results & Discussion
- Conclusions
- Further Study

INTRODUCTION

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- A Chilean store retail presents a fire safety concern regarding to the combustible and flammable liquids organized in racks and arranged for sale.
- Racks are protected by a pre-engineered dry chemical system.
- Dry chemical system didn’t pass fire full-scale test.




INTRODUCTION

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- Store´s management has decided to install an in-rack sprinkler solution according NFPA 30.
- Modification of rack geometry or flammable and combustible liquids (plastic bottles), it would impact negatively in the sales of the products.
- Store´s management decision is to follow the NFPA 30 rules as much as possible without significantly impacting the racks or the plastic bottles.
- “Adaptation”

INTRODUCTION & MAIN GOAL

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Introduction

- IDIEM in advance indicated that the solution proposed to protect the rack does not fulfill an important part of the code.
- Therefore, IDIEM has developed a CFD analysis of fire protection sprinkler system proposed, to demonstrate that the adaptation of the design is incapable of controlling or extinguishing the fire.

Main Goal

- Investigate through a CFD analysis if a sprinkler system partially designed from the NFPA codes would be able to control or extinguish a fire on a storage/sale rack of flammable liquids.

METHODOLOGY

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INFORMATION REVIEW

FIRE FULL SCALE TEST RESULTS

SPRINKLERS SYSTEM ADAPTATION

CFD SIMULATIONS

METHODOLOGY

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- INFORMATION REVIEW
- FIRE FULL SCALE TEST RESULTS
- SPRINKLERS SYSTEM ADAPTATION
- CFD SIMULATIONS

It's reviewed the information regarding to the stored flammable and combustible items in the rack, rack configuration, materiality, geometry, among others technical characteristics.

NFPA 30: Flammable and Combustible Liquids Code is reviewed.

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METHODOLOGY

- INFORMATION REVIEW
- FIRE FULL SCALE TEST RESULTS
- SPRINKLERS SYSTEM ADAPTATION
- CFD SIMULATIONS

- Test if the actual fire extinguishment system would control or extinguish a fire
- Investigate the fire dynamics in the current rack arrangement
- Represent a reliable CFD simulation of the fire dynamics in the flammable rack

METHODOLOGY

1. INFORMATION REVIEW
2. FIRE FULL SCALE TEST RESULTS
3. SPRINKLERS SYSTEM ADAPTATION
4. CFD SIMULATIONS

- Sprinkler system designed based on NFPA 13 and NFPA 30.
- Due to operational and commercial reasons, the arrangement of the rack and the vessels or containers of liquids do not fulfill any design codes such as NFPA 30.
- Due to the store requirements, an adaptation of a sprinkler system will be designed, trying to fulfill the code as much as possible.

METHODOLOGY

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INFORMATION REVIEW

FIRE FULL SCALE TEST RESULTS

SPRINKLERS SYSTEM ADAPTATION

CFD SIMULATIONS

- Performance evaluation
- Assumptions and considerations regarding with fire dynamics
- Fire scenarios
- Sensitivity analysis
- Modelling Configuration

INFORMATION REVIEW

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- The storage rack for combustible and flammable liquids is constructed of bolted metal profiles, with 7 storage levels.

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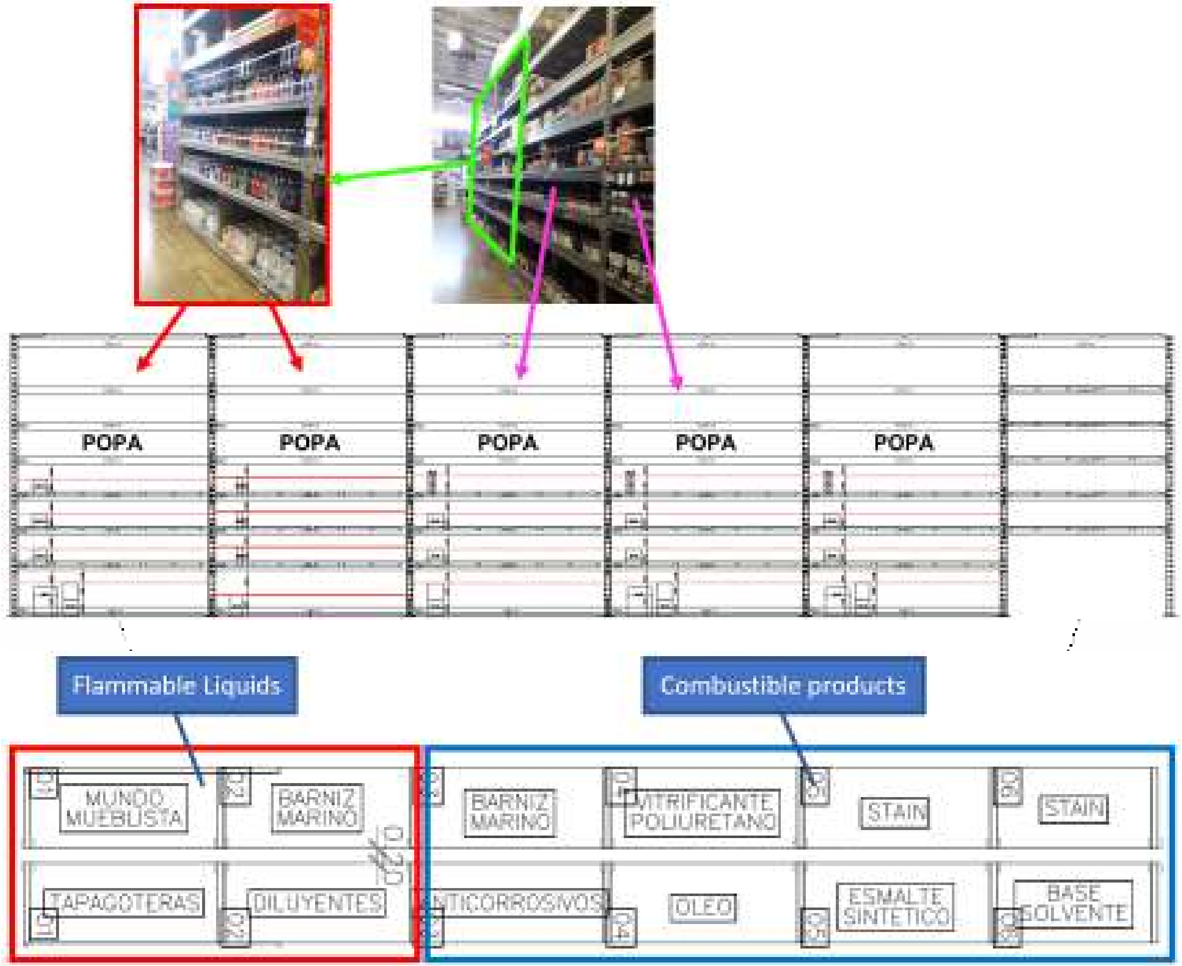
INFORMATION REVIEW

- Distribution of the products.

Product	Flash point (°C)	Boiling point (°C)	Water Solubility
Synthetic thinner	< 0	255	Insoluble
White gasoline	< -18	288	Insoluble
Solvent	11	464	Miscible
Thinner	-3,3	535	Insoluble
Thinner type “duco”	-3,3	535	Insoluble
Polyurethane thinner	36	498	Insoluble
Pyroxylin thinner	-3,3	535	Insoluble
Acrylic thinner	-3,3	400	Insoluble
Solvent	11	464	Miscible
Thinner for pool paint	27	527	Insoluble
White spirit	38	275	Insoluble



FULL SCALE TEST RESULTS

177 units:
49 bottles 1 L Synthetic thinner
38 bottles ½ L White gasoline
19 bottles 1 L White gasoline
20 bottles 1 L Synthetic thinner
25 bottles 1 L Solvent
22 bottles 1 L Thinner for pool paint
4 bottles 1 L Polyurethane thinner

214 units:
50 bottles 1 L Synthetic thinner
48 bottles 1 L Solvent
25 bottles 1 L Pyroxylin thinner
23 bottles 1 L Polyurethane thinner
29 bottles 1 L Acrylic thinner
15 bottles 1 L Solvent
21 bottles 1 L Thinner for pool paint
3 bottles 1 L Thinner type "duco"

37 bottles 5 L per unit
White spirit – Synthetic thinner

FULL SCALE TEST RESULTS

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SPRINKLER SYSTEM ADAPTATION

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- The main liquids stored in the racks correspond to **Heptane, Methanol, Toluene, Isopropanol, Ethanol**, among others.
- According to NFPA 30 Handbook, very thin-walled plastic containers not intended for reuse, should not be used for routinary and repeated storage of flammable products and combustible liquids.
- Therefore, the actual plastic bottles do not fulfil NFPA 30.

Liquid	Boiling Point (°C)	Flash Point (°C)	Classification
Methanol	64,7	12	IB
Ethanol	78,4	12,7	IB
Isopropanol	82,5	11,2	IB
Toluene	110	4,4	IB
Etan	98,4	-3,8	IB

SPRINKLER SYSTEM ADAPTATION

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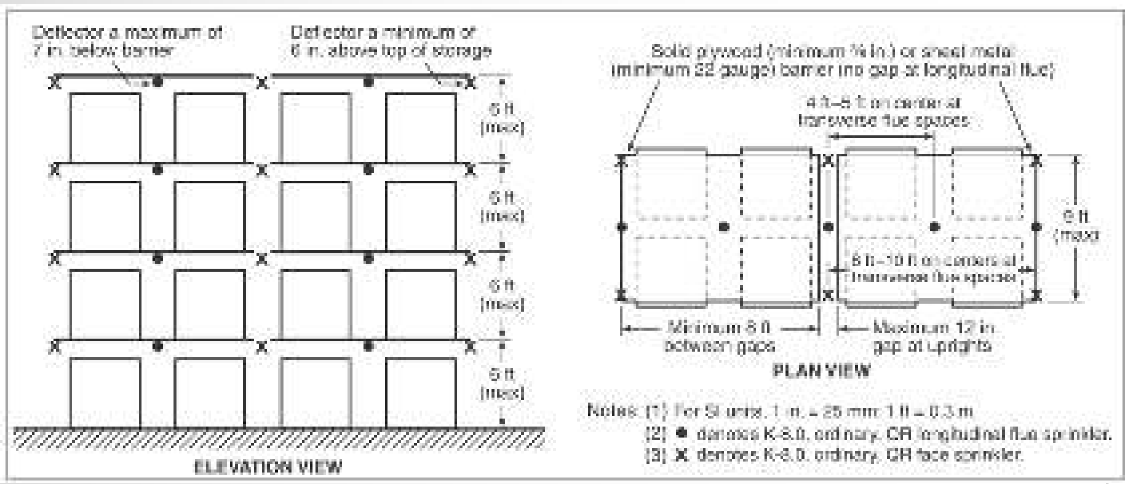
- The racks do not fit in the category of fuel and flammable storage racks approved to be protected with automatic sprinklers (its more a retail aisle).

- Due to the client´s requirement the protection will be assimilated to one of "flammable liquids in rack storage".

- NFPA 30 Ed. 2012 indicate that the In-rack sprinkler system shall provide that the 8 most remote sprinklers at operating pressure of 50 psi, while the ceiling sprinklers shall discharge 600 gpm.



Rack Sprinkler		
K Factor	8	
Op. Pressure	50	Psi
Flow	56,7	gpm
Response	Quick	
Temperature	68	°C

Ceiling Sprinkler		
Density	0,2	gpm/ft2
Design Area	3000	ft2
Total Flow Requirement	600	gpm
K Factor	25,2	
Op. Pressure	15	psi
Flow per Sprinkler	97,2	gpm

CFD SIMULATIONS

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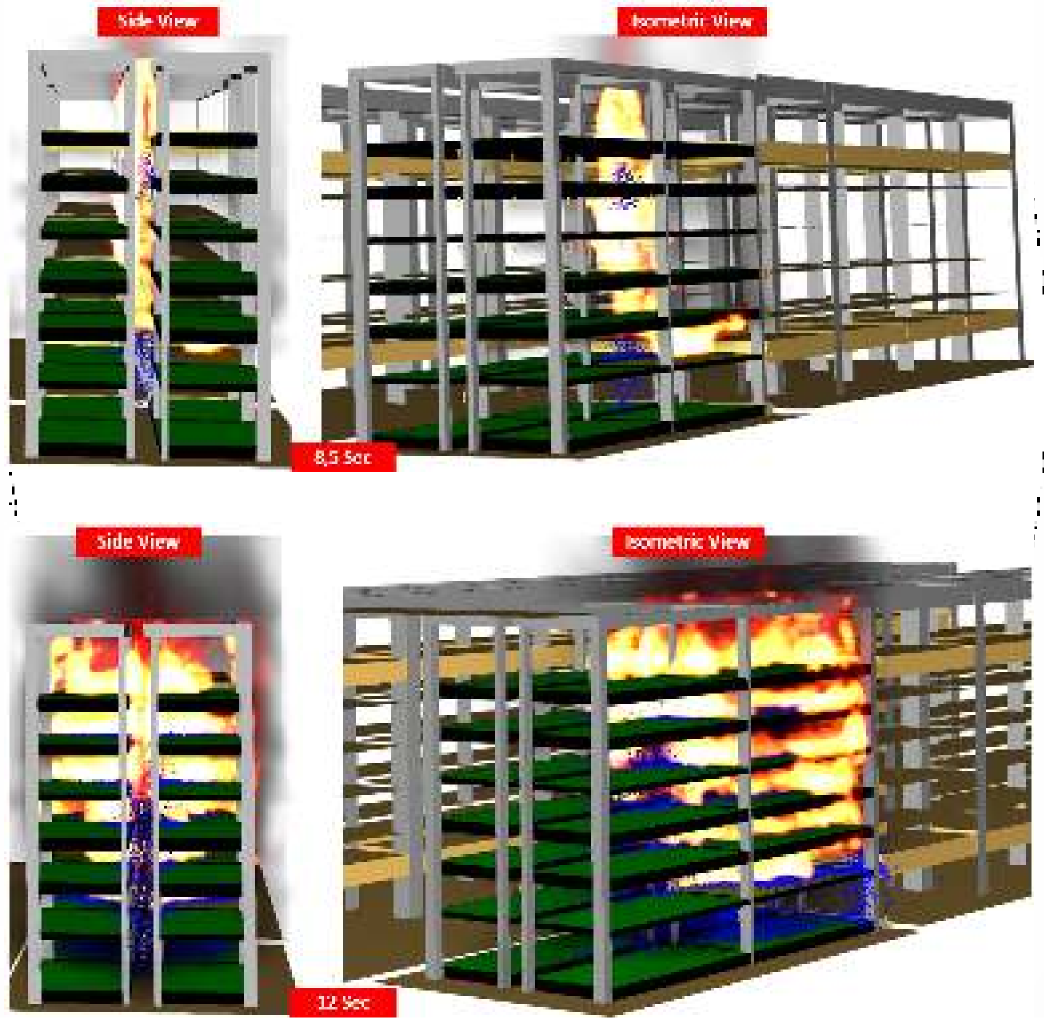
Performance Criteria

- Flame propagation
- Presence of combustion
- Gas Temperature
- Sprinklers operation and water discharged
- Thermal radiation

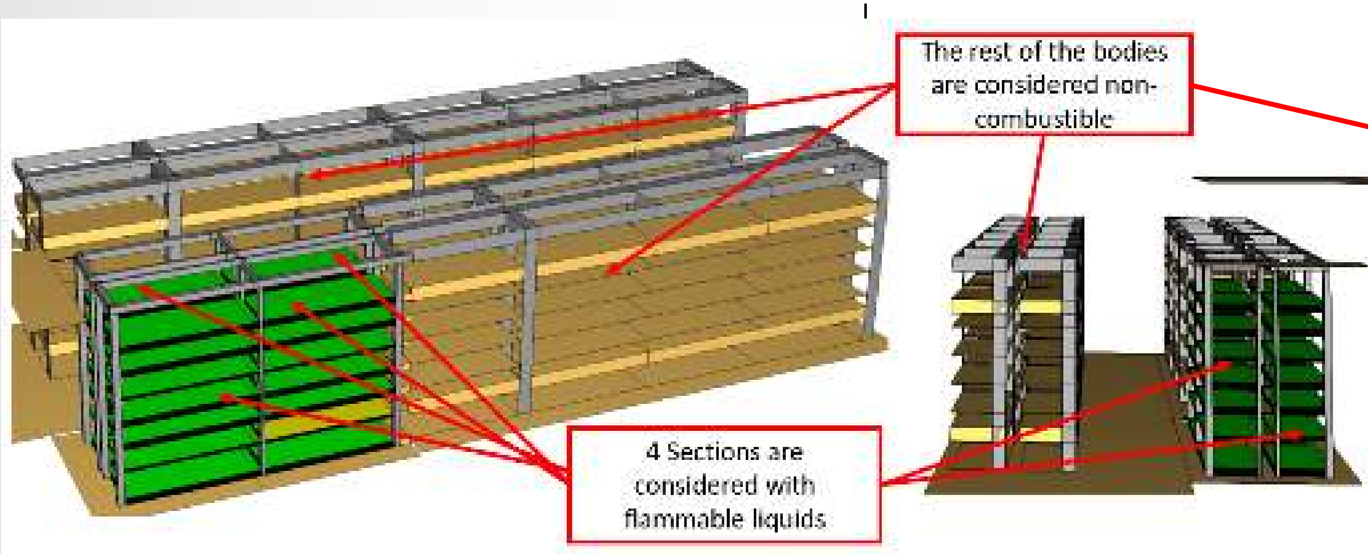


CFD SIMULATIONS

Fire Scenarios

- The analyzed rack considers 4 bodies containing liquids that are assimilated to Ethanol and representative of the full-scale test.

- Therefore, the simulation of fire propagation will be in the first 4 bodies of the rack.



CFD SIMULATIONS

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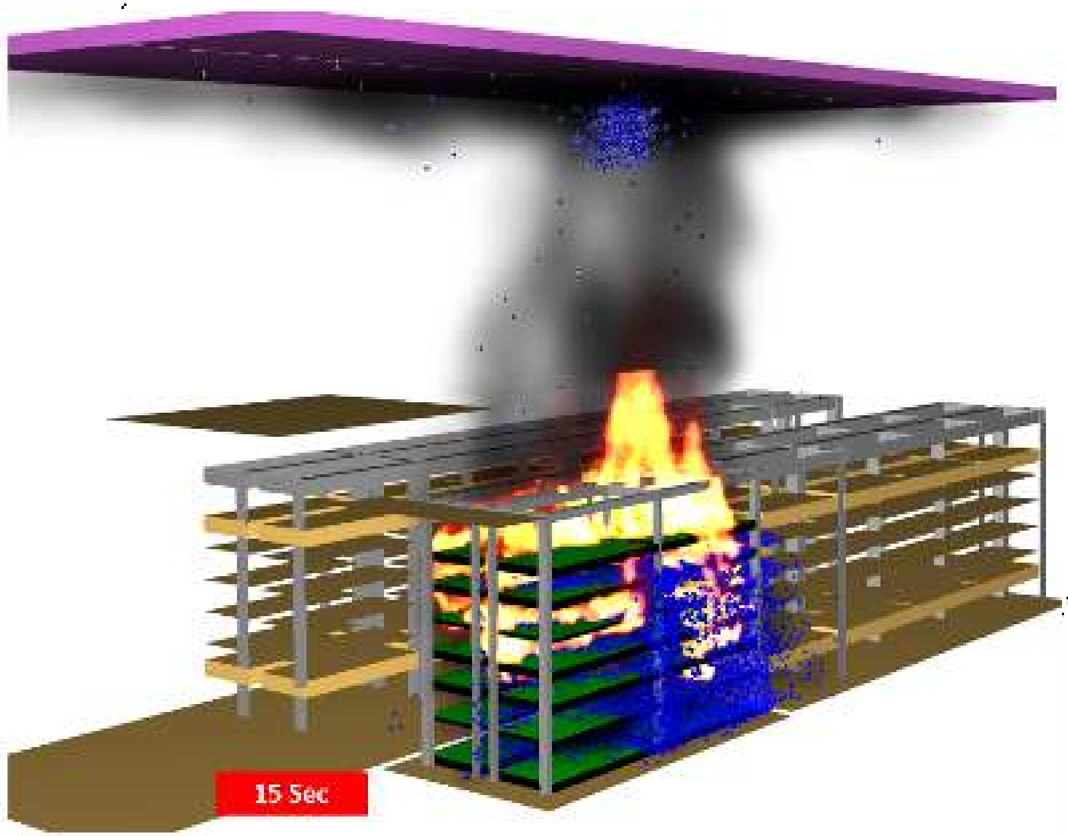
Fire Scenarios

2 Scenarios

- First scenario **without** sprinklers
- Second scenario **will consider** sprinklers.



CFD SIMULATIONS

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Assumptions and Configurations

BLEVE and Jet Fires

This condition generates jet fires, spreading the fire to adjacent places and lower levels.

This fire condition it is not considered in the modelling due to:

- There is no information to model the mechanical deformation of plastic bottles.
- This condition increases the complexity of the model.
- The consideration of this condition does not have a significant impact on the objectives of the fire modeling.

CFD SIMULATIONS

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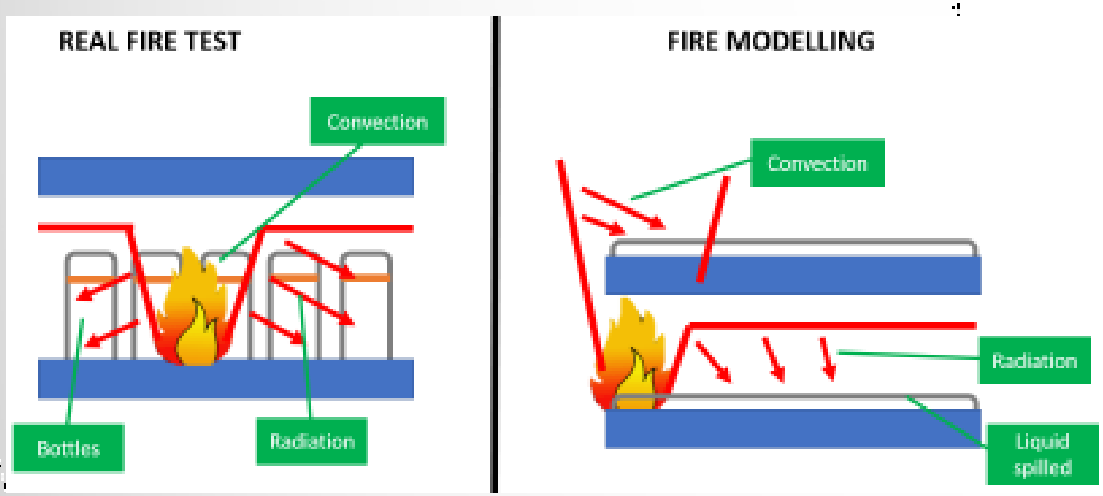
Assumptions and Configurations

Fire Spreading

- Condition is particularly complex to model and significantly increases the computational costs of the model.
- Therefore, its assumed that the metal trays in the rack contain flammable liquid (ethanol) already spilled.
- Condition considers the probable worst scenario an also generates a simplified model.
- From the full-scale test, the bottles does not act as a barrier anymore



CFD SIMULATIONS

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Assumptions and Configurations

Fire Ignition

- Full-scale test considers an open flame (torch lighter).
- Ignition particle configured and positioned at the same place where the fire in the full-scale test was lit.
- The ignition particle has been configured through a timer deactivation (10 seconds).

Fire Extinguishment

- The autoignition temperature assigned to the Ethanol correspond to 360°C.

Fire Combustion

- Substances used correspond to Ethanol (fuel) and water (sprinklers).
- The complex pyrolysis model has been used.

Material	ΔH_T (kJ/g)	y_{CO_2} (g/g)	y_{CO} (g/g)	y_{ch} (g/g)	y_s (g/g)	ΔH_{ch} (kJ/g)	ΔH_{con} (kJ/g)	ΔH_{rad} (kJ/g)
Ethyl alcohol	27.7	1.77	0.001	0.001	0.008	25.6	19.0	6.5

Combustible	Ethanol	
Density	794	kg/m3
Cp	2,44	kJ/ (kg °K)
Heat of Vaporization	837	kJ/kg
Heat of Combustion	27474	kJ/kg
Thermal Conductivity	0,17	W/ (m °K)
Radiative Fraction	0,25	
Boiling Temperature	78,5	°C

CFD SIMULATIONS

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Assumptions and Configurations

Sprinklers System

- 5000 droplets per second will be used.
- For fire suppressing in shelf storage items, it is useful to consider the water droplets moving horizontally along the bottom of a solid object. Therefore, the parameter ALLOW_UNDERSIDE_PARTICLES=.TRUE. is configured.
- A study of Sheppard indicated that sprinklers with similar characteristics than the used in the research were tested and measured, indicating Dv50 droplet size between 700 to 1000 μm.

In Rack Sprinklers		
Density	1000	kg/m3
Surface Tension	0,0728	N/m
Dn	20	mm
	0,02	m
Sprinkler Surface	0,00031415	m2
Sprinkler Flow	56,7	gpm
	3,5721	L/s
	0,0035721	m3/s
Water Velocity	11,370683	m/s
Weber Number	35520	
Dv50	0,00152106	m
	1,52105915	mm
	1521,05915	um

Celling Sprinklers		
Density	1000	kg/m3
Surface Tension	0,0728	N/m
Dn	25,4	mm
	0,0254	m
Sprinkler Surface	0,00050669	m2
Sprinkler Flow	97	gpm
	6,111	L/s
	0,006111	m3/s
Water Velocity	12,060568	m/s
Weber Number	50750	
Dv50	0,00171512	m
	1,71511967	mm
	1715,11967	um

CFD SIMULATIONS

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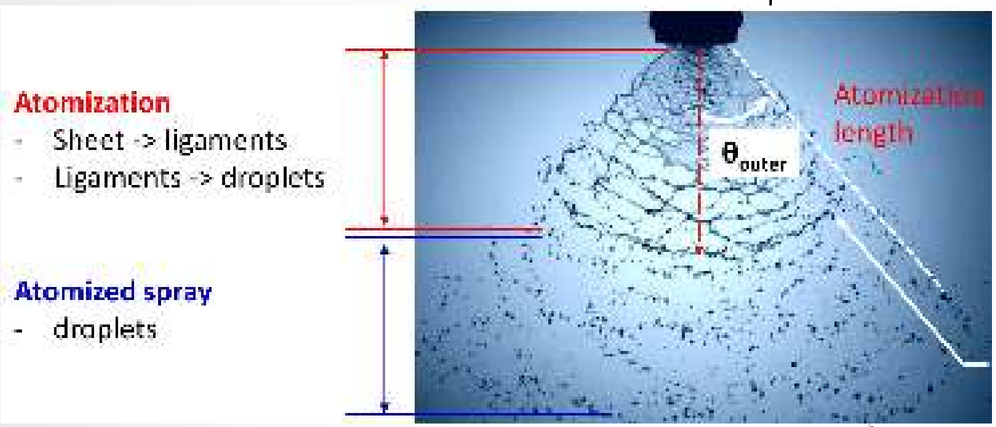
Assumptions and Configurations

Sprinklers System

- An offset value of 0.01m and 0.02m is considered for the simulation.



In Rack Sprinkler		
Droplet Diameter	1520	um
Activation Temperature	68	°C
RTI	25	(m*s)^1/2
Offset	0,01	m
Water flow	214,6	L/min
Droplet Velocity	11,3	m/s
Cone Angle	75°	
Droplet per second	5000	
K Factor	8	US

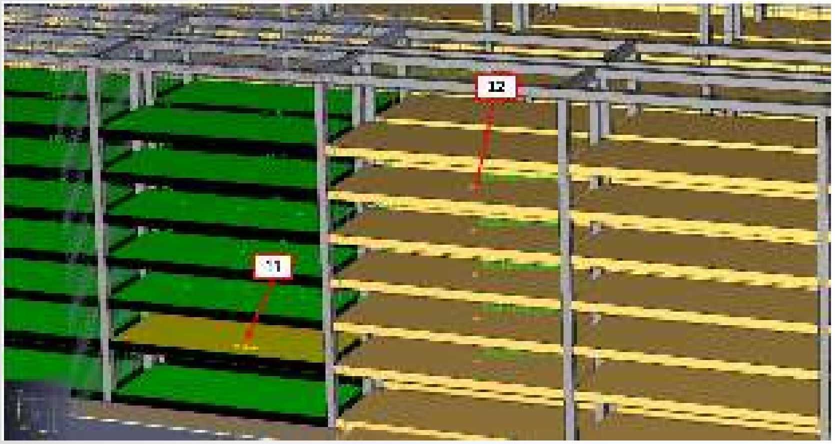
Ceiling Rack		
Droplet Diameter	1715	um
Activation Temperature	74	°C
RTI	50	(m*s)^1/2
Offset	0,02	m
Water flow	366	L/min
Droplet Velocity	12	m/s
Cone Angle	85°	
Droplet per second	5000	
K Factor	25,2	US

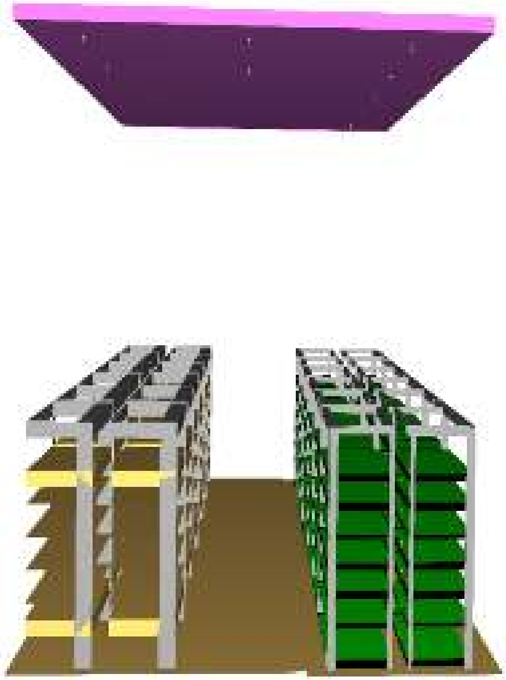
CFD SIMULATIONS

Assumptions and Configurations

Solids and Obstructions

- The structure of the rack have been considered as inert.
- The heat transfer in the metal trays is considered, therefore the material characteristics are considered.





Material	Steel	
Emissivity	1	
Density	7850	kg/m3
Conductivity	45,8	W/(m°K)
Specific heat	0,46	kJ(kg°K)

RESULTS & DISCUSSION

Sensitivity Analysis

Mesh type	HRR (kW)	D*	Cellsize (m)	Cellsize (mm)	$D^*/\delta x$
Coarse	1000	0,6094	0,08	80	8
Fine	1000	0,6094	0,0625	63	10
Re-fined	1000	0,6094	0,04	40	15

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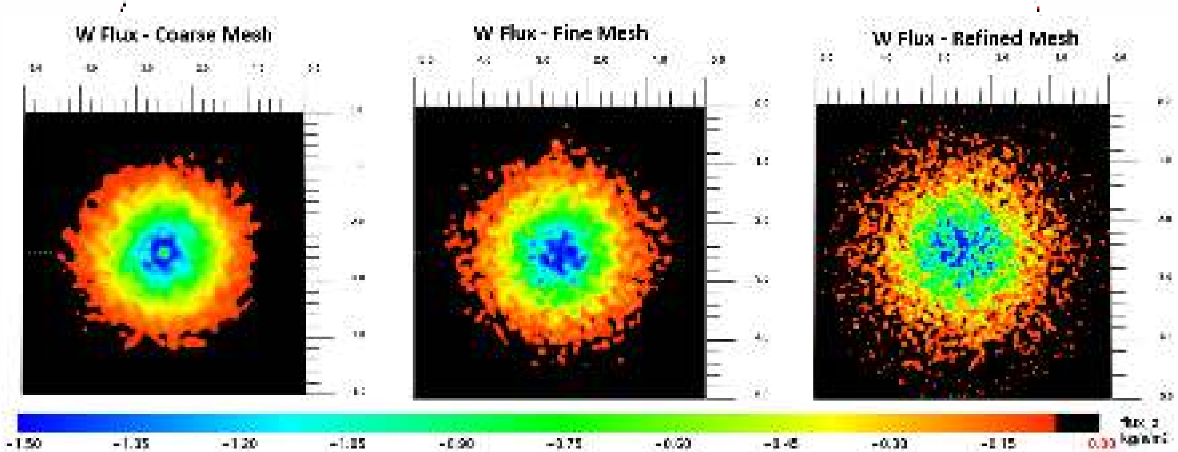

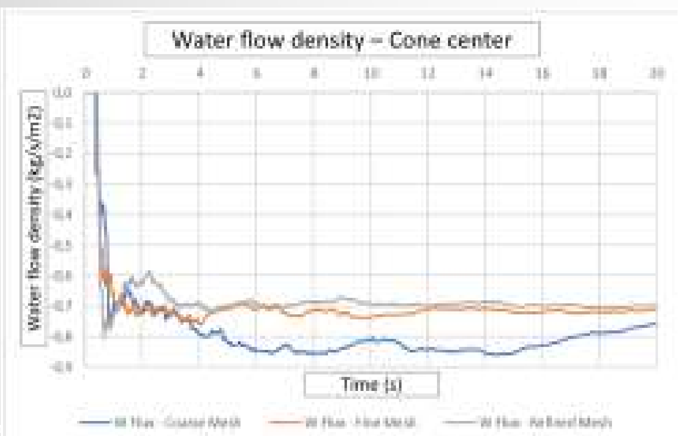

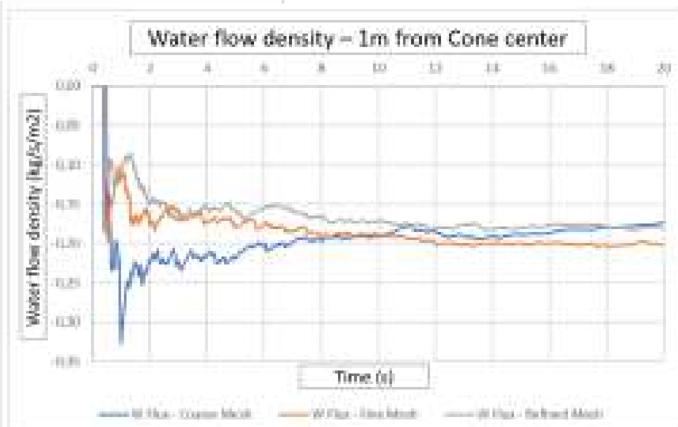

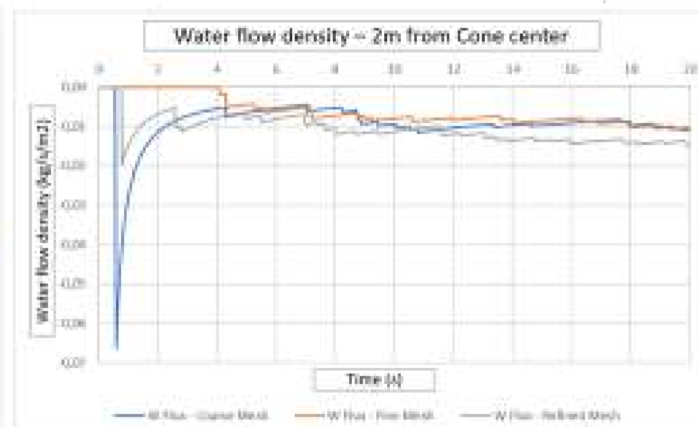

RESULTS & DISCUSSION

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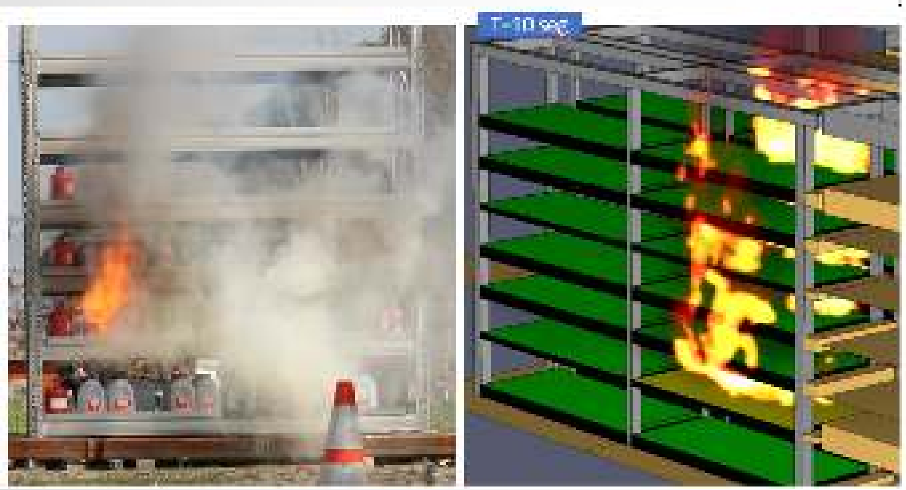
Model Validation



RESULTS & DISCUSSION

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Model Validation

RESULTS & DISCUSSION

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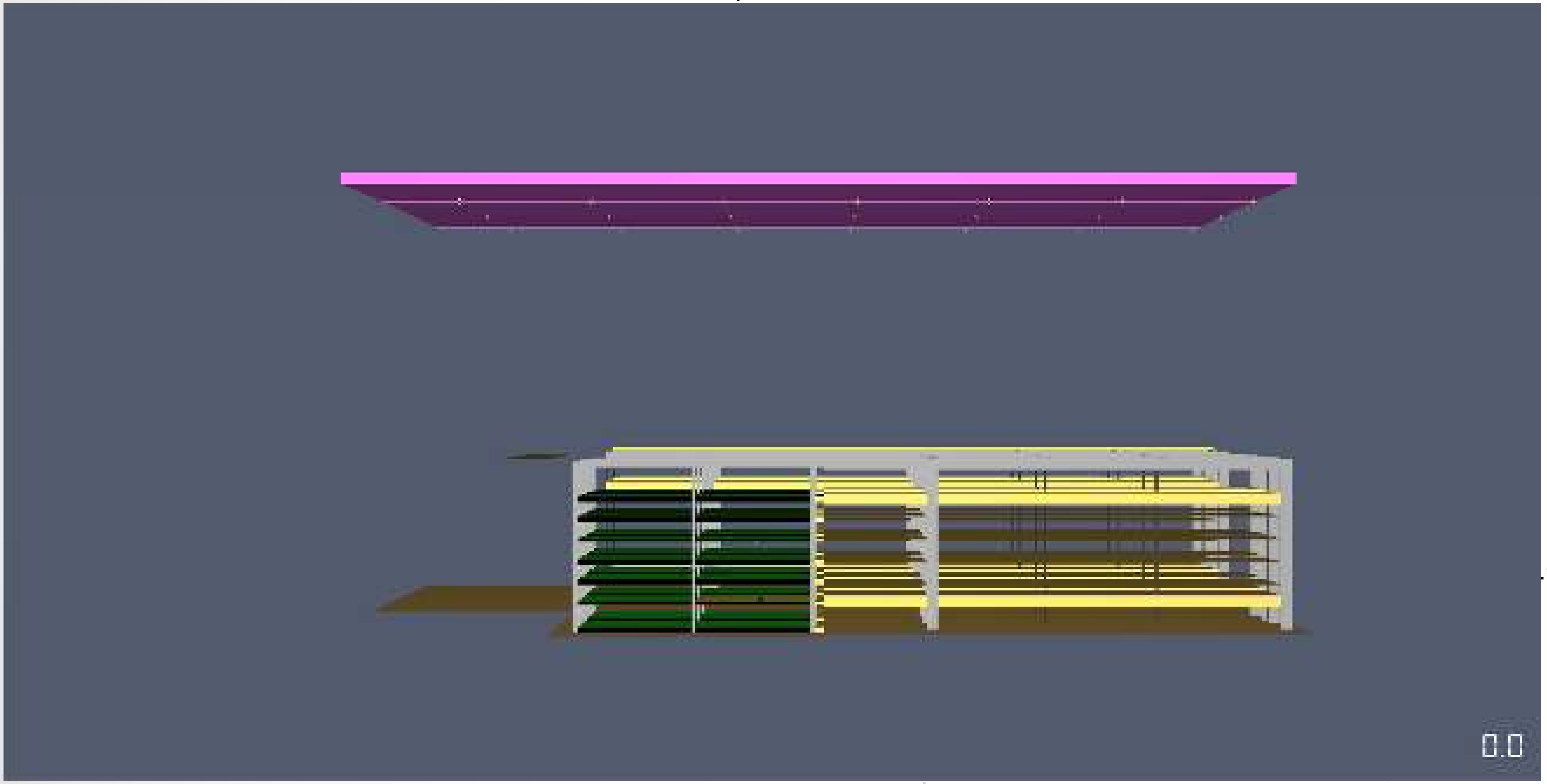
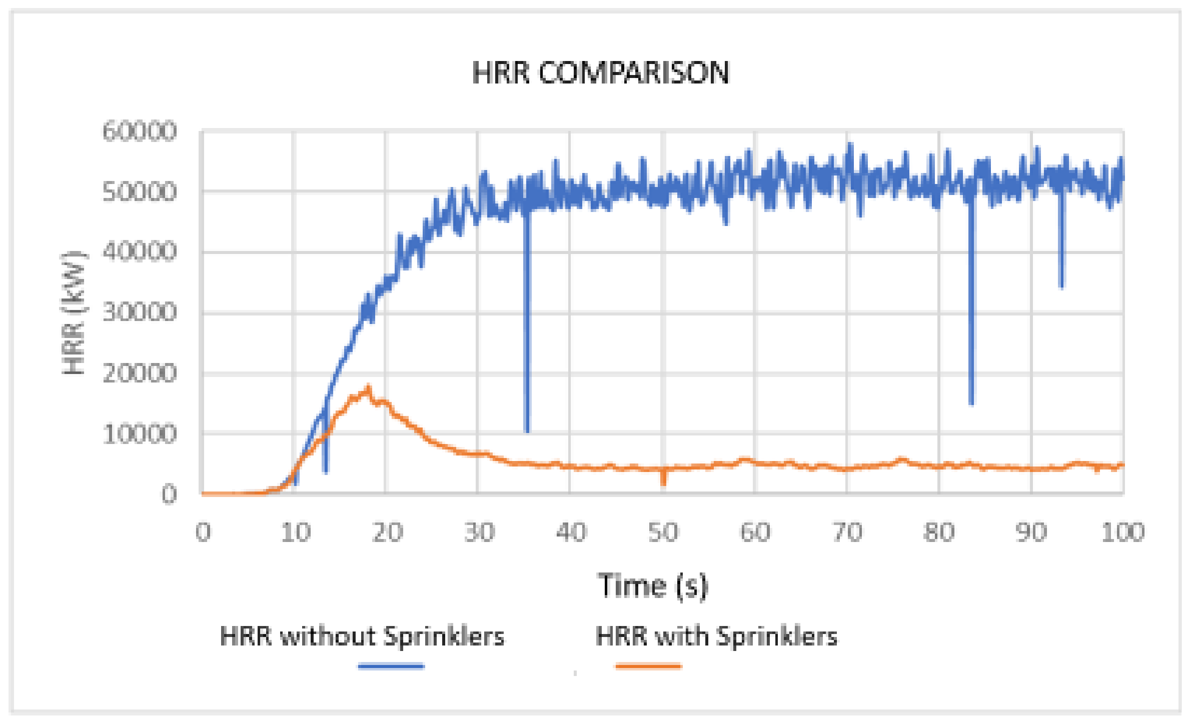
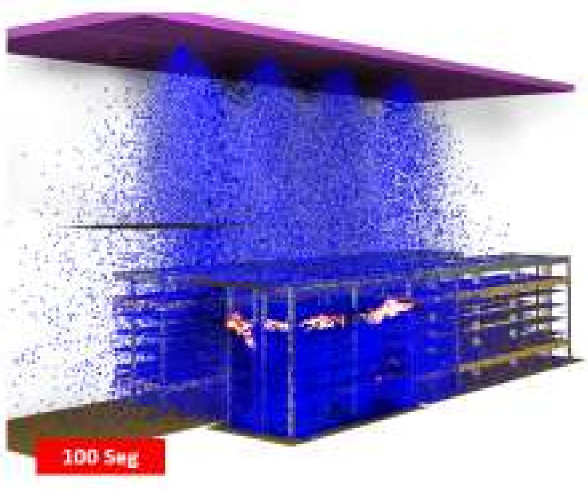
Sprinklers System Performance



RESULTS & DISCUSSION

Sprinklers System Performance





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RESULTS & DISCUSSION

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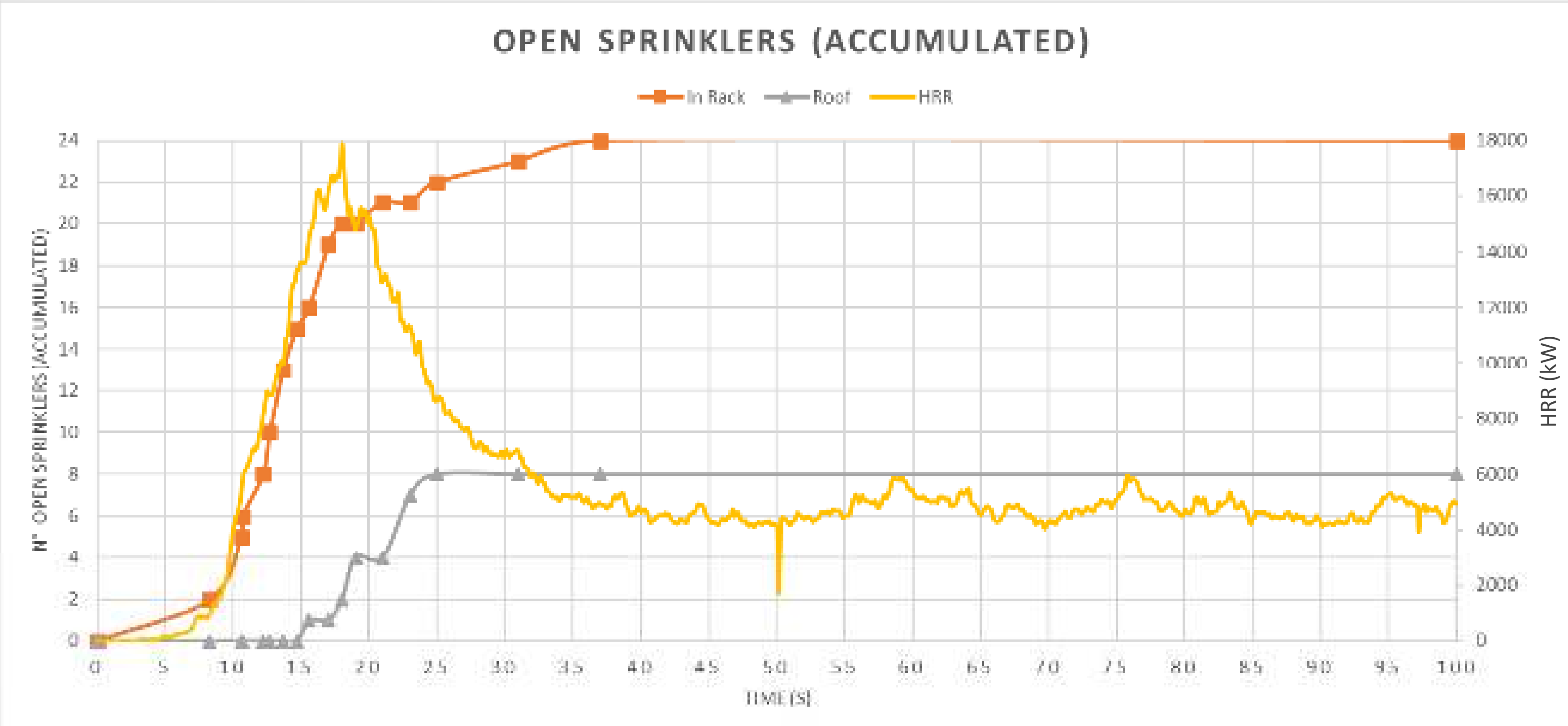
Sprinklers System Performance



RESULTS & DISCUSSION

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Sprinklers System Performance

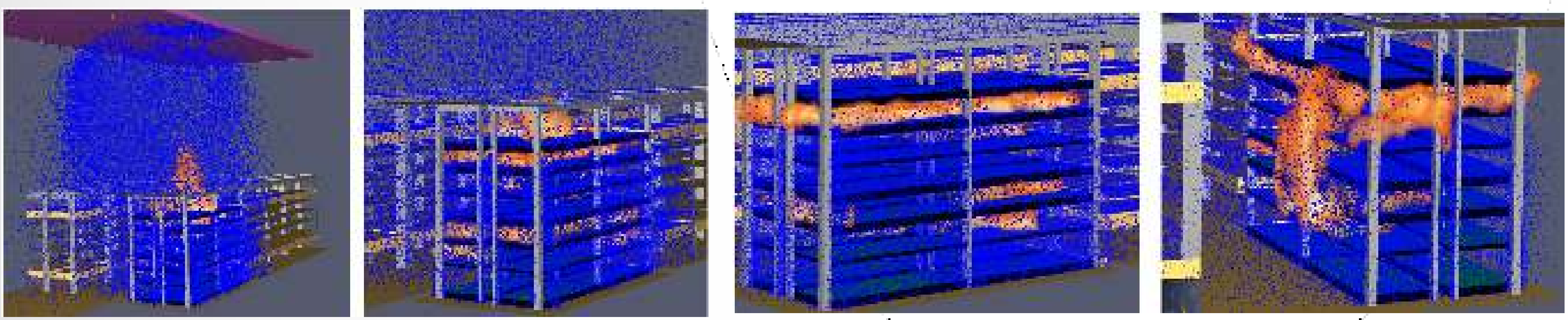
- Despite the extra amount of water discharged by the arrangement of sprinklers, the fire has not been extinguished and the HRR has been decreased to an average of 4 MW.

Flow required by NFPA 30

Activated Sprinklers		Flow per Sprinkler (gpm)	Flow Total (gpm)
In Rack	8	56,7	453,6
Roof	6	97,2	583,2
Hose Stream (gpm)			250
System Total Flow (gpm)			**1286,8**

Flow discharged by the CFD simulation

Activated Sprinklers		Flow per Sprinkler (gpm)	Flow Total (gpm)	% Difference from NFPA 30
In Rack	24	56,7	1360,8	300
Roof	8	97,2	777,6	133
Hose Stream (gpm)			250	0
System Total Flow (gpm)			**2388,4**	



RESULTS & DISCUSSION

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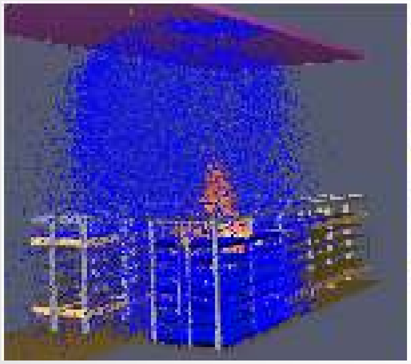
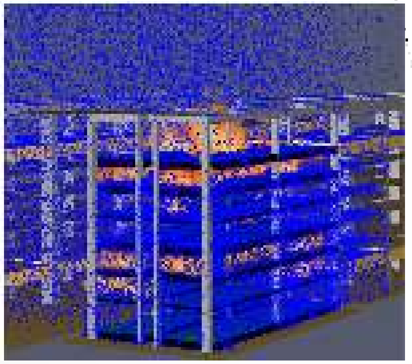
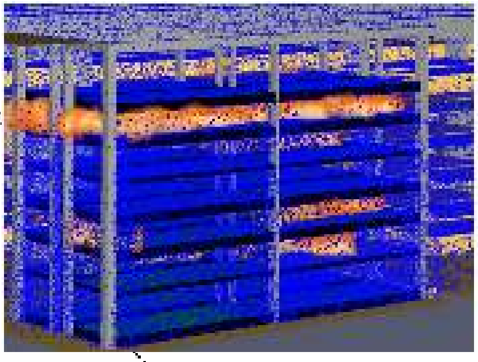
Sprinklers System Performance

- It is possible to argue that the phenomenon of skipping is presented.
- Its occurs when a sprinkler activates significantly sooner than a neighboring sprinkler that is closer to the fire plume (random activation).
- Skipping reduces the amount of water delivered to the fire and therefore reduces the effectiveness of the sprinkler to extinguish the fire.
- Unfortunately, it is challenging to establish the reason of sprinkler skipping experimentally.


CONCLUSIONS

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- The proposed adaptation of the sprinkler system according NFPA 30 standard, does not extinguish the fire. The proposed system can control the fire, reducing the HRR to an average value of 4 MW (assimilable to a light vehicle in a tunnel), which it's still a "considerable" high value for a fire inside of a store.

- The impossibility of extinguish the fire is due to the rapid propagation of the flames generated by the non-compliance of the bottles according NFPA 30.

- The fast spreading due the thin wall bottles produces the effect of skipping (random operation) in the sprinkler system.

- The water discharged by the in-rack sprinklers is 300% more than the theoretical (NFPA 30) flow required to control or extinguish a fire.

- The geometry and the bottle´s construction are main factors to control or extinguish a fire in a storage/sale rack of flammable liquids, protected by a sprinklers system.

CONCLUSIONS

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Further Studies

- It is posible to modify the rack geometry and the type of vessels or plastic bottles.
- As an alternative, it is possible to install "Safety Storages", according 14470-1, FM 6050, UL/ULC 1275, GS, EN 16121/16122 (among others).

CONCLUSIONS

THUNDERHEAD ENGINEERING
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Final Remarks

- As the store indicates that a re-arrangement of the rack geometry or an exchange of the format to store flammable and combustible liquids (plastic bottles), it would impact negatively in the sales of the products.
- It is **unacceptable** that the profit of a store or a shop is above the fire safety.
- Occasionally, the CFD are an influential tool to demonstrate results, due to the images are more trustworthy than the words.

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Thank you!

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