2012 Chicago Symposium
Fire Safety Design and Sustainable Buildings: Challenges and Opportunities

Research Efforts in Fire Protection Engineering are Contributing to Sustainability Goals

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AON **Fire Protection Engineering**

Today's Topics & Sustainability Themes

- Storage in Offices

- Airfoils / HVLS Fans

(Photo: courtesy of Big Ass Fans Co.)

- Optimizing Fire Safety Equipment

- Saving water resources
- Protecting built assets
- Energy Savings - lower operating costs
- Effective use of built resources
- Reduce greenhouse gas emissions

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Storage in Offices

- Compact Mobile Shelving Systems
  - High density, space saving storage
  - Eliminate aisles, save 50 % of floor space
  - 80% of systems used in offices, 200 ft² in area
- Sustainable Advantages
  - Reduce the size of building footprint
  - Savings on construction materials
  - Reduced floor area means lower operational costs
- Conflicts with fire protection goals
  - High density storage concept poses fire risks
  - Sprinklers – are they capable or do we risk building loss
  - How much water is needed to protect
  - Is space saving advantage lost to rooms need for fire pumps, water tanks

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FPRF Research Project – Initiated 2006

- History
  - 2002 ed. Of NFPA 13 lacked criteria, some suggested
    - Rack storage with in-rack sprinklers
    - Extra hazard
  - 2006 NFPA 13 – attempted to set criteria (0.30 gpm/ft² over 1500-2500 ft²)
  - Literature review initiated in 2006
- Full scale testing recommended and funding obtained
  - Evaluate NFPA 13 Light Hazard – 0.10 gpm/ft² over 1500 ft²
  - Focused on paper packed inside file folders
  - Bench-scale tests with various shelf fuel loading densities
  - Full-scale test at UL's norhbrook facility

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Bench Scale Tests

Test ID	Packing Density	Moisture Content	Peak Heat Release Rate (kW)
B-1	All sections 100%	5.6%	1.3
B-2	All sections 70%	5.6%	16.5
B-3	All sections 85%	5.6%	8.9
B-4	All sections 100%	5.4%	7.4
B-5	Left section = 100% Left-center section = 100% Right-center section = 57% **Right section = 29%**	5.4%	38.4

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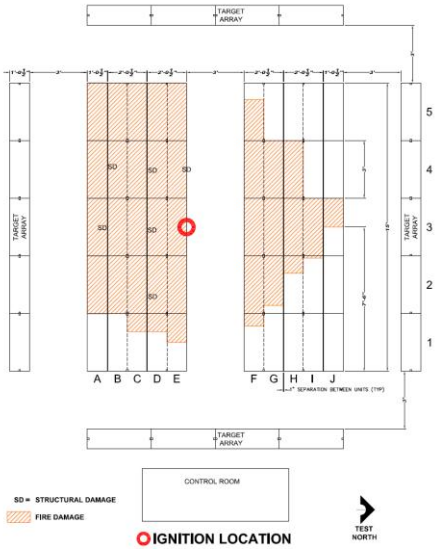
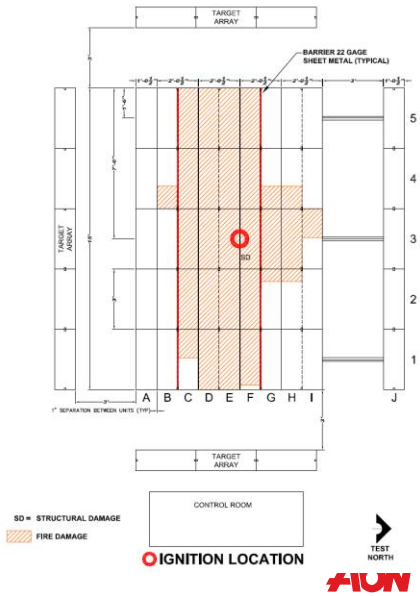
Open Array and Closed Array Tests





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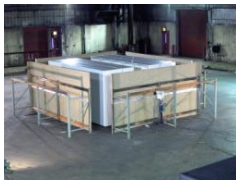
Results – Long Sprinkler Operation Times, Steel < 1000˚F



Photos: Courtesy of UL

Parameter	Spacesaver 3 (open)	NFPA 1 (open)	Spacesaver 2 (closed)	NFPA 2 (closed/barriers)
1st sprinkler operation	01:43:42	00:36	00:51:37	00:1:21
Ceiling steel temp (F)	210 (Max)	902 (1 min avg.) (30 minutes after 1st sprinkler op)	Not recorded	846 (1 min avg.)
Ignition to test term	02:14:00	01:30:00	01:22:00	01:22
Aisle Jump	No	Yes(00:54)	No	No
Number of sprinkler operated	4	13	6	4

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Summary - Compact Mobile Storage

- NFPA 13 Revised
  - Compact storage typical in offices up to 8 ft.
  - Light Hazard acceptable
    - Paper, magazines , books, plastics < 5%
    - 18 in. clearance to sprinkler deflector
    - Sprinklers – ordinary Temp., Q.R., Standard upright or pendent

- Sustainability Outcome
  - High-Density mobile storage an effective design solution
  - Does not represent threat to existing Light Hazard sprinkler systems
  - No inherent disadvantage relative to fire protection needed – rooms for pumps, water supplies

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Optimizing Fire Safety Equipment

- Smoke Detector Application Example
  - Valuable fire safety product
  - NFPA 72 standards address installation and use when required
- Sustainable Advantages
  - Early, or very early warning of potentially threatening fire
  - Prevented or Reduced fire loss
  - Preserve life, property and mission
- Conflicts with Sustainability Goals when
  - Code or standards mandatory requirements are not adequately justified
  - Research stopped short of fully answering questions (money, time)
  - Not used in optimal fashion with other fire protection features

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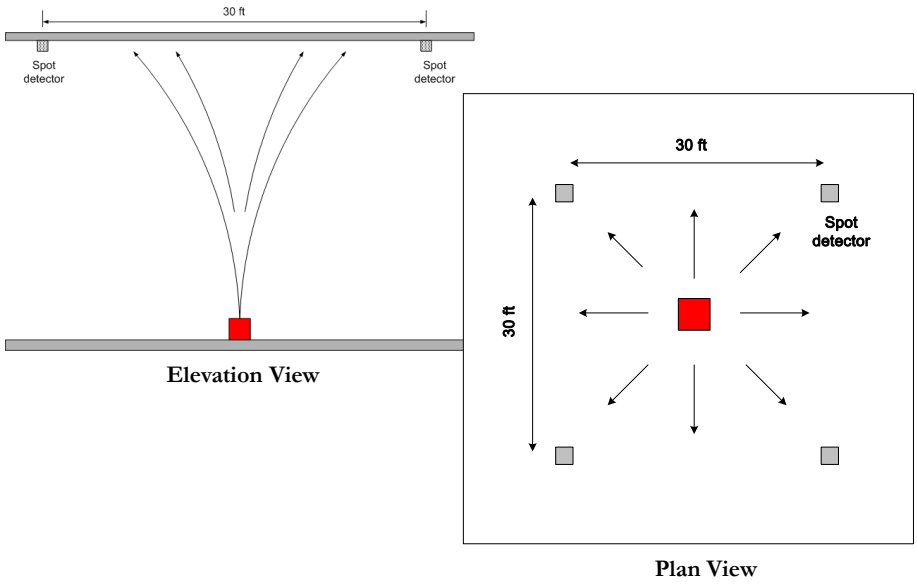
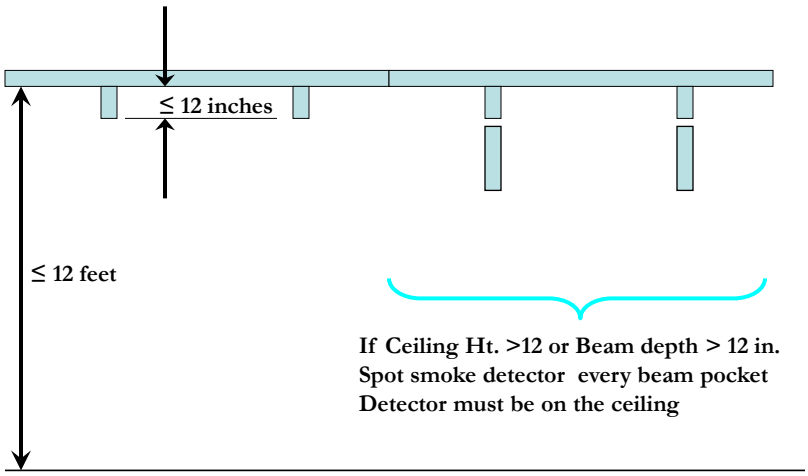
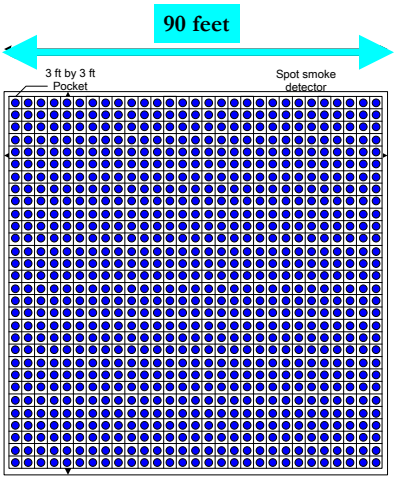
Baseline – 30 ft. Guideline Spacing



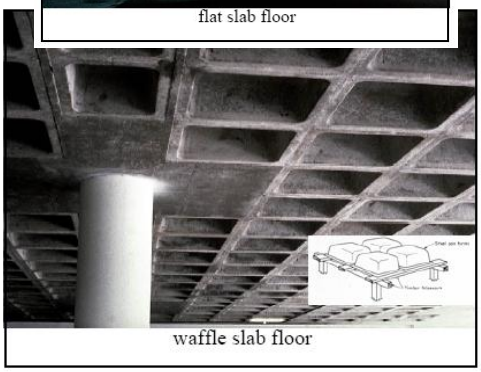
2002 Edition NFPA 72 Spot Smoke Detector Rules for Solid Beams



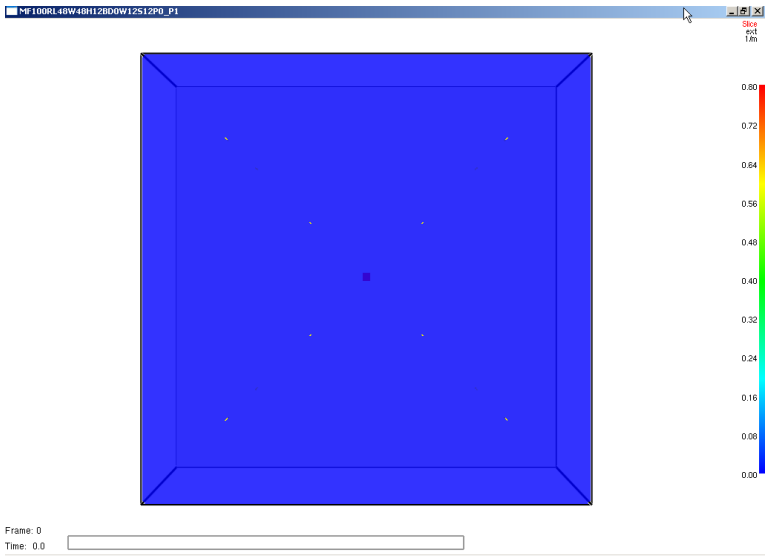
Why Most Questioned Requirement



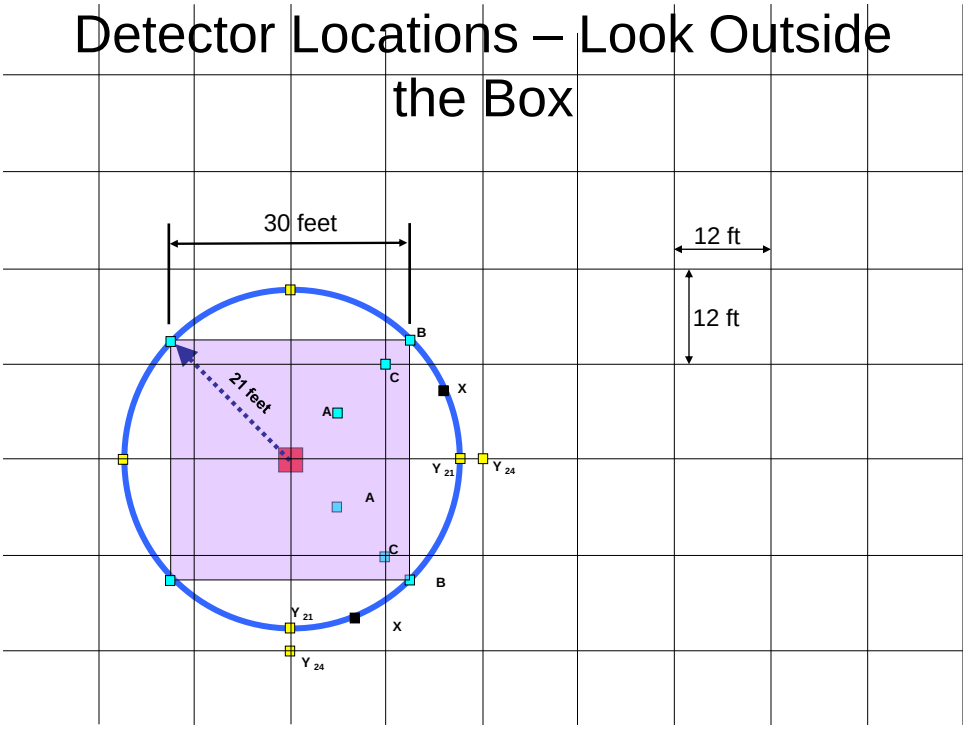

flat slab floor


waffle slab floor

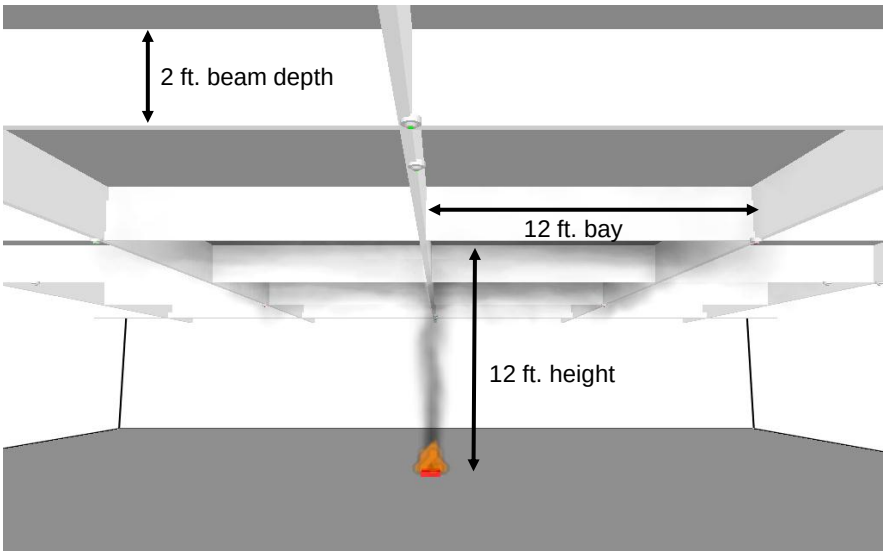
Baseline – Smooth Unconfined Ceiling



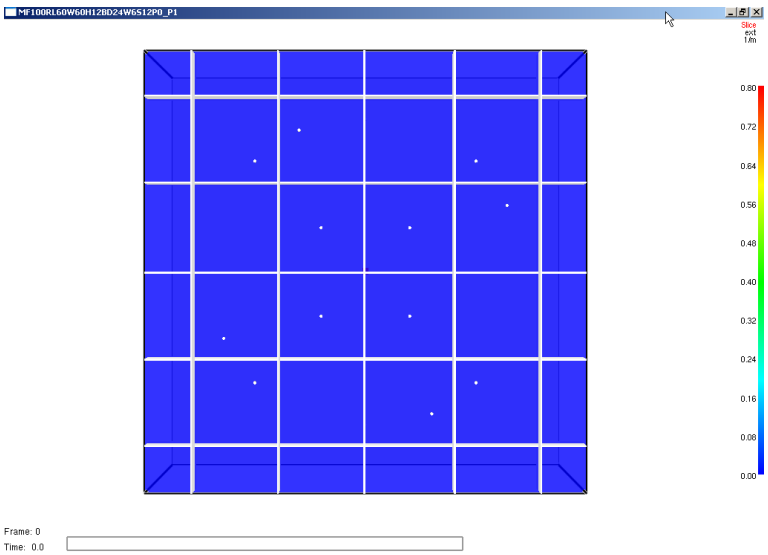
Detector Locations – Look Outside the Box



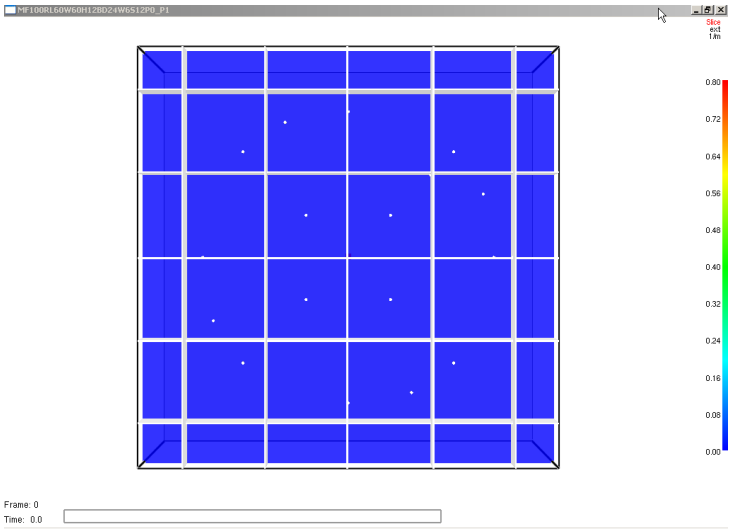
12 Ft. x 12 Ft. Beam Pockets

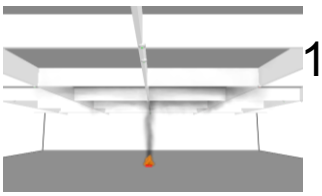


12’ x12’ Pockets - Medium Fire, Slice at Ceiling

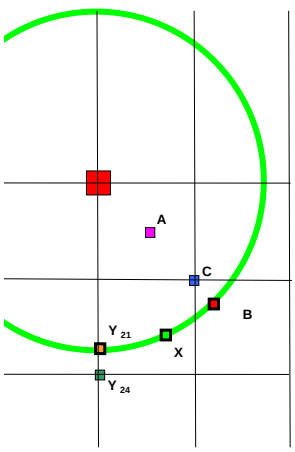


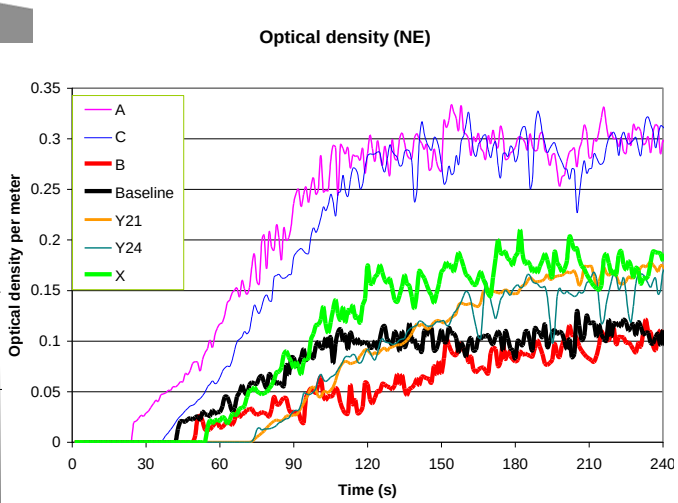
12’ x12’ Pockets - Medium Fire, Slice at Beam Bottom



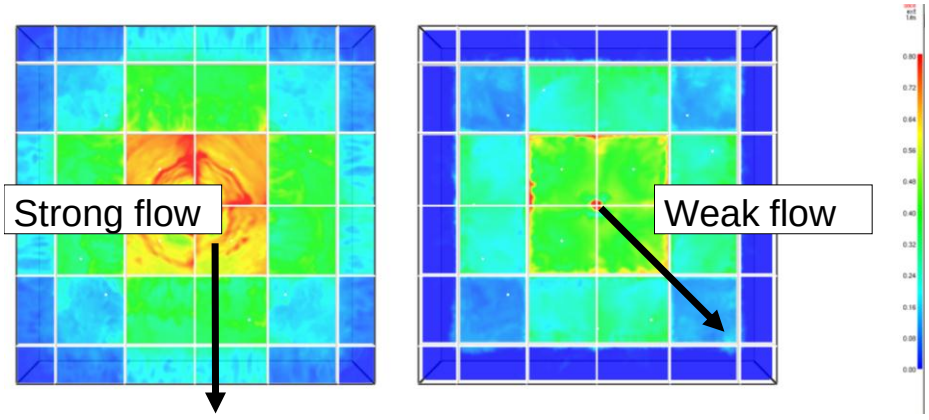


12’x12’ Beam Pocket Results



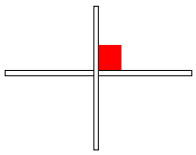


12’ x 12’, 2’ Deep Beams, 180s

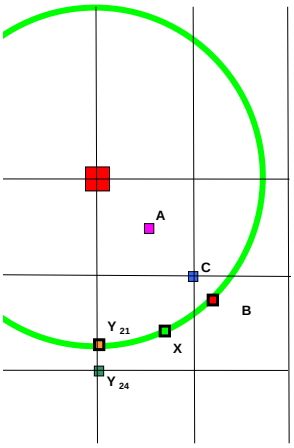


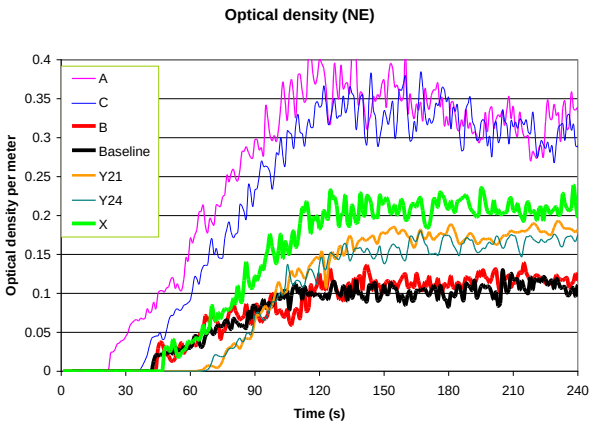
Slice under ceiling

Slice at bottom of beam

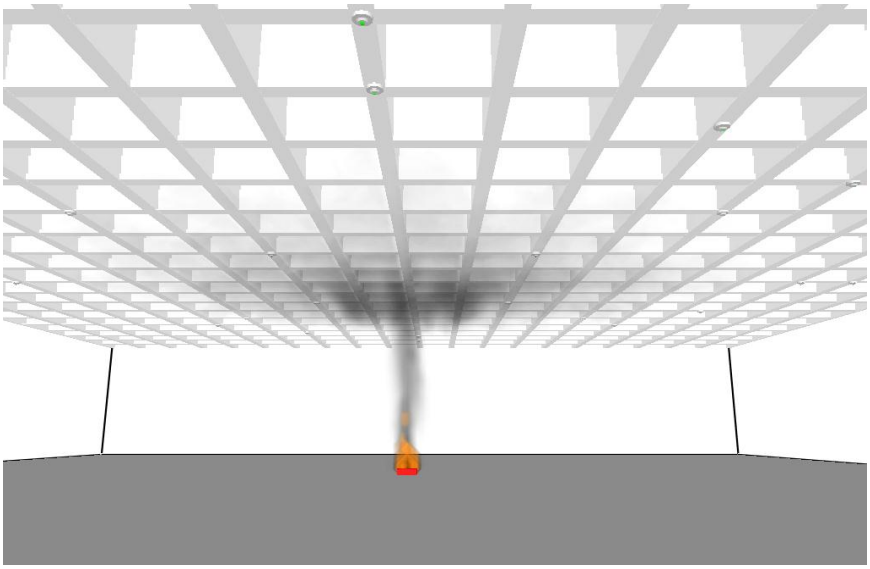


12 ft Beam Pockets, 2 ft Deep Beams, Medium t^2 Fire to 100 kW, Fire in a Position 8.5” Diagonal Shift

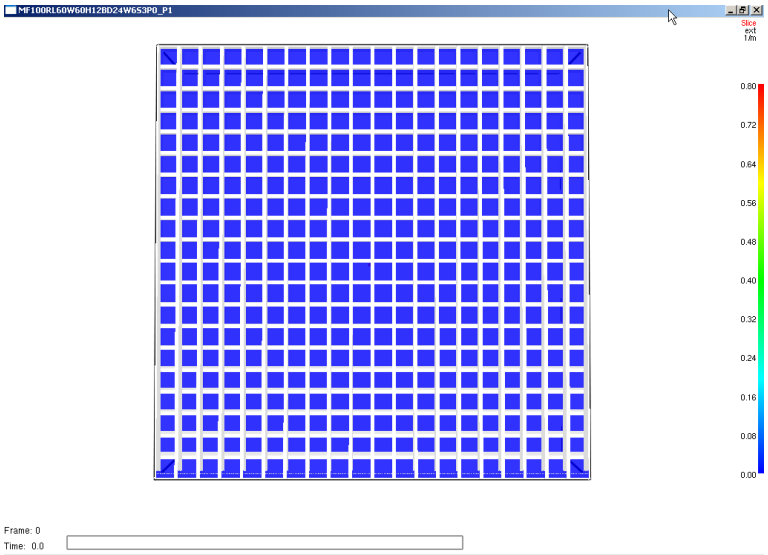


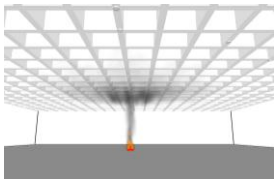


Waffle Ceiling

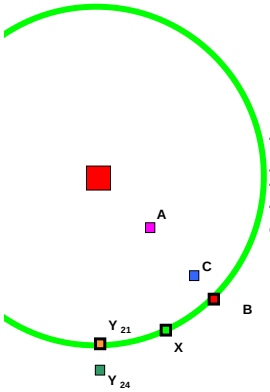


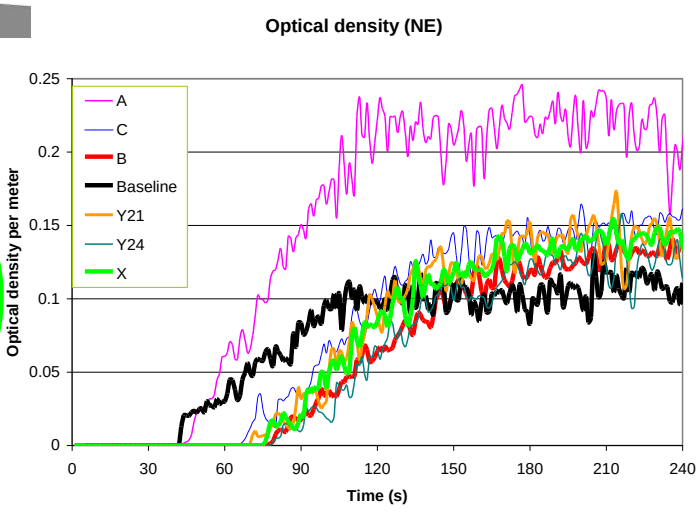
Waffle – Medium Growth Fire, Slice at Ceiling





Waffle Results





Summary – Smoke Detector Optimization

- NFPA 72 Revised
  - Detector can be effectively used in waffle or pan type at a spacings of 15 -30 ft.
  - In corridor situations smoke detectors can be effective at spacing of ~40 ft
  - Mounting the detector on the ceiling in beam pockets or the bottom of the beams is acceptable
  - Keeping smoke detector locations 4 inches below or away from a beam-ceiling corner appears unsubstantiated. No stagnant zone or locations were observed that would preclude smoke detector alarm.

- Sustainability Outcome
  - Smoke detector application is optimized
  - Carbon footprint of the manufactured product in buildings is reduced
  - Smoke detectors continue to provide for early warning, prevention/reduction of fire loss

High Volume Low Speed Fans

- High Volume Low Speed Fans
  - Blades with unique large diameter Airfoil designs
  - Provides for cooling or heating
- Sustainable Advantages
  - Energy cost savings
  - Reduction in CO_2 and carbon emissions
  - Example: two 20-ft. 1 HP HVLS fans ≈ twelve 3-ft. high speed fans and an 86 % reduction in electricity consumption
  - LEED credits
- Conflicts with fire protection goals
  - Downward airflow disrupting to fire plume and sprinkler operation
  - Fan blades /Airflow interference with sprinkler water distribution
  - Sprinklers – are they capable or do we risk building loss
  - Is more water is needed with HVLS?

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HVLS Fans – Identifying the Problem

- High Volume/Low Speed (HVLS) fans are routinely used in industrial buildings protected with automatic sprinkler systems:
  - Highly energy efficient (highest CFM per watt)
  - Quiet
  - Green design (LEED credits)
- Effect on automatic sprinkler operation?
- Initial research initiated by XL Gaps in 2007
  - Group A plastics in cartons, 6 " flues
  - 15' high palletized storage test, 25' ceiling
  - ELO K=11.2, standard 286° F sprinkler
  - 0.60 gpm/ft²
  - Fan @ 50%, off at 1st sprinkler
  - 73 sprinklers operated
- This concern resulted in the Fire Protection Research Foundation initiating the research program *"High Volume / Low Speed Fan and Sprinkler Operation"* in 2008.

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HVLS Testing Focus and Key Parameters

- Storage Scenarios
  - Rack Storage of Group A Plastics
  - Palletized storage arrays of Group A Plastics
- Storage Height / Ceiling Height / Clearance above storage
  - Rack storage of 30 ft. maximium under 40 ft. ceiling
  - Palletized storage of 15 ft. under 25 ft. ceiling
- Sprinklers
  - Early Suppression Fast Response, ESFR
  - Control Mode Density Area, CMDA
- Fan Location
  - Hub approximately over ignition
  - Fan tip over ignition

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High Volume Low Speed Fan Description

- Definition: *A ceiling fan which is approximately 6 - 24 feet in diameter with a rotational speed of approximately 30 - 70 revolutions per minute* (NFPA 13 language).
- Fan configuration varies for 4 -10 blades which can produce up to approximately 300,000 – 400,000 cfm.
- Performance characteristics are elusive and not well understood. Air driven by the fans moves in many different directions and air speeds are also inconsistent and vary greatly by location and elevation.

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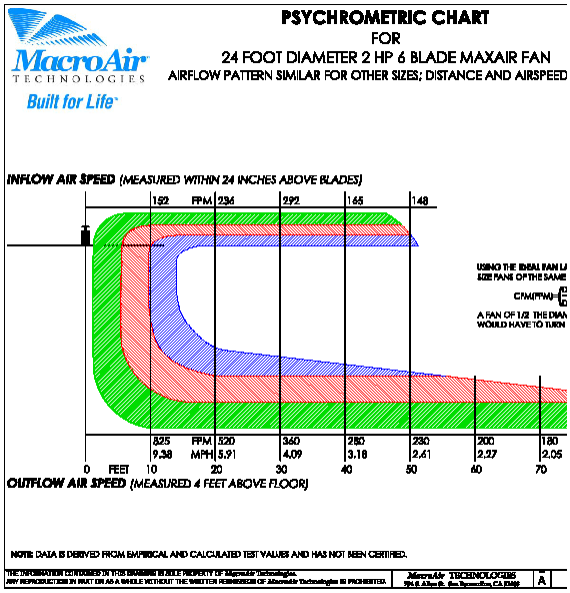
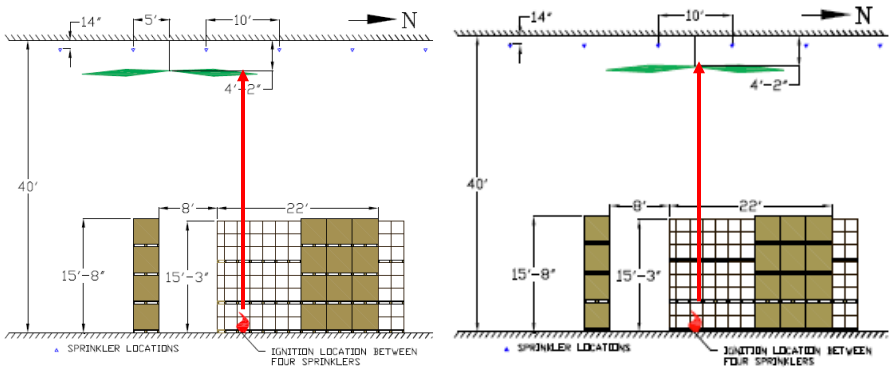
Example HVLS Fan Airflow Distribution

- Highest air speeds occur at approximately ½ -⅔ of the blade length from the center of the fan
- For testing, two ignition locations were selected – near the tip of the fan blade and under the fan hub. The former was selected based upon fan performance data, the latter based upon observations of Phase I testing.
- Again, Phase I testing showed vertical force of the fan appeared to have a greater effect than horizontal force.



Fan Locations Relative to Fire Ignition



Fan Orientation Details (Courtesy of UL)

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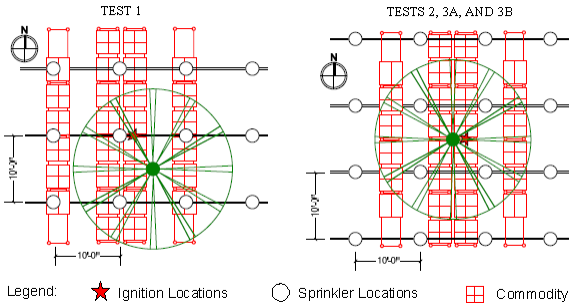
Fan Product Selection

Fan Product Selected for Testing:

- MaxAir Whisperfoil XL (Model MA24XL2006) manufactured by MacroAir.
- Largest model manufactured - six blade and 24 feet in diameter (same size as the fan from Phase I).
- Largest fan capacity manufactured - approximately 330,000 cfm at 63 rpm (same capacity as the fan used in Phase I).

Full Scale ESFR Rack Storage Fire Testing (continued)

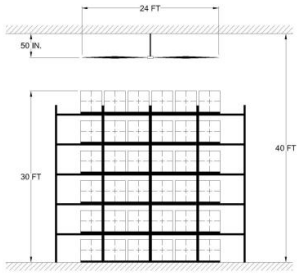


Orientation of Fan, Ignition Location, and Sprinklers for Tests 1-3B
(Courtesy of FM Global)

FIRE TESTS	FPRF Test 1 (FM-1) 8/5/2010	FPRF Test 2 (FM-2) 8/20/2010
PARAMETERS		
Location of Test	FM Global	FM Global
Storage Type	Double-Row Rack	Double-Row Rack
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	30	30
Nominal Ceiling Height (ft)	40	40
Nominal Clearance (ft)	10	10
Aisle Width (in.)	48	48
Longitudinal/Transverse Flue (in.)	6/6	6/6
Ignition Location	Under 1 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)
Igniter Details	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165
Sprinkler Orientation	Pendent	Pendent
Sprinkler Sensitivity	Fast Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1
Deflector to Ceiling (in.)	14	14
Nominal Sprinkler Discharge Coefficient K (gpm/psi$^{1/2}$)	14	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10
Fan Size (ft)	24	24
Fan Location	Fan Tip 4.9 ft Beyond Ignition	Hub Above Ignition (no offset)
Fan Distance Below Ceiling (in.)	50	50
HVLS Fan Speed (rpm)	66	66
HVLS Fan Operation	On (no shutdown)	On (no shutdown)
HVLS Fan Manufacturer	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2006
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6
RESULTS		
Length of Test (hr:min:s)	0:35:00	0:25:00
First Ceiling Sprinkler Operation (min:s)	1:28	1:42
Last Ceiling Sprinkler Operation (min:s)	7:53	3:57
Number of Operated Ceiling Sprinklers	12	12
Peak Steel Temperature at Ceiling Above Ignition (°F)	169	117
Max. 1 Min. Average Steel Temperature Above Ignition (°F)	559	266
Fire Spread Across Aisle	YES	YES
Fire spread to the Ends of the Array	NO	NO
Fuel Consumed (number of pallets)	12.5	5
Test Outcome (Pass/Fail)	FAIL	FAIL
Comments	Test failed due to 12 sprinklers activating	Test failed due to 12 sprinklers activating

Table E-1. Results for Tests 1-3B

Both Tests - Fans are Operating & No Shutdown Occurs



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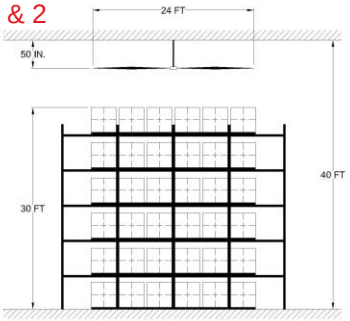
ESFR Rack Tests, Group A Plastics, Tests 1 & 2

- Ignition between 4 sprinklers (offset 2 ft.)
- Hub directly above ignition , no offset
- Both Tests - Fans are Operating & No Shutdown Occurs



	RESULTS	
Length of Test (hr:min:s)	0:35:00	0:25:00
First Ceiling Sprinkler Operation (min:s)	1:28	1:42
Last Ceiling Sprinkler Operation (min:s)	7:53	3:57
Number of Operated Ceiling Sprinklers	12	12
Peak Steel Temperature at Ceiling Above Ignition (°F)	169	117
Max. 1 Min. Average Steel Temperature Above Ignition (°F)	559	266
Fire Spread Across Aisle	YES	YES
Fire spread to the Ends of the Array	NO	NO
Fuel Consumed (number of pallets)	12.5	5
Test Outcome (Pass/Fail)	FAIL	FAIL
Comments	Test failed due to 12 sprinklers activating	Test failed due to 12 sprinklers activating

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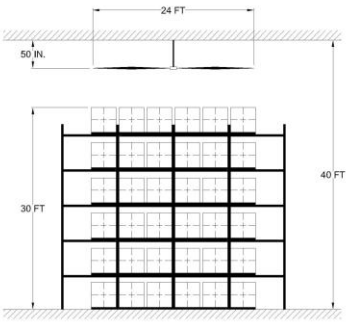
ESFR Rack Tests, Group A Plastics Test 3

- Ignition between 4 sprinklers (offset 2 ft.)
- Hub directly above ignition , no offset
- Test 3 - Fans are Depowered 90 s after waterflow



	RESULTS		
Length of Test (hr:min:s)	0:35:00	0:25:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:28	1:42	1:54
Last Ceiling Sprinkler Operation (min:s)	7:53	3:57	2:03
Number of Operated Ceiling Sprinklers	12	12	4
Peak Steel Temperature at Ceiling Above Ignition (°F)	169	117	113
Max. 1 Min. Average Steel Temperature Above Ignition (°F)	559	266	291
Fire Spread Across Aisle	YES	YES	NO
Fire spread to the Ends of the Array	NO	NO	NO
Fuel Consumed (number of pallets)	12.5	5	2.5
Test Outcome (Pass/Fail)	FAIL	FAIL	PASS
Comments	Test failed due to 12 sprinklers activating	Test failed due to 12 sprinklers activating	Repeat of Test 2 with fan shutdown at waterflow

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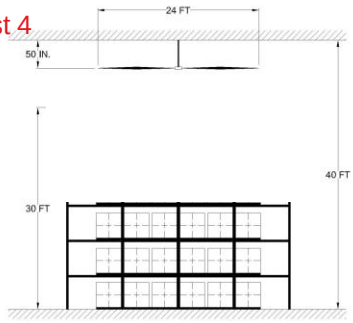
ESFR Rack Tests, Group A Plastics Test 4

- Storage height reduced to 15 ft.
- Ignition between 4 sprinklers (offset 2 ft.)
- Hub directly above ignition , no offset
- Test 3 - Fans are Depowered 90 s after waterflow



	RESULTS			
Length of Test (hr:min:s)	0:35:00	0:25:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:28	1:42	1:54	1:39
Last Ceiling Sprinkler Operation (min:s)	7:53	3:57	2:03	1:42
Number of Operated Ceiling Sprinklers	12	12	4	4
Peak Steel Temperature at Ceiling Above Ignition (°F)	169	117	113	113
Max. 1 Min. Average Steel Temperature Above Ignition (°F)	559	266	291	112
Fire Spread Across Aisle	YES	YES	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO	NO
Fuel Consumed (number of pallets)	12.5	5	2.5	0.5
Test Outcome (Pass/Fail)	FAIL	FAIL	PASS	PASS
Comments	Test failed due to 12 sprinklers activating	Test failed due to 12 sprinklers activating	Repeat of Test 2 with fan shutdown at waterflow	Repeat of Test 3A with 15 feet storage height

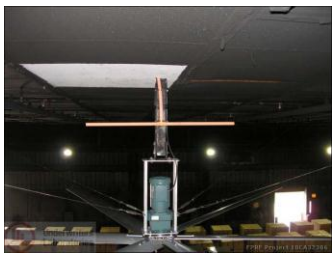
AON

ESFR Sprinklers Performance in Solid Pile Storage Scenarios

- Storage height 15 ft. under 40 ft. ceiling
- Ignition between 4 sprinklers (centered.)
- Fan tip 2 ft. beyond ignition
- Fan running continuously

Control Mode Density Area (CMDA) Sprinkler Testing

- Cartoned, unexpanded Group A plastic used for all tests
- Palletized array (previous GAPS testing was successful for rack storage array)
- Fan operates at full speed entire test until activation of air sampling detection, spot ionization smoke detector, or sprinkler water flow plus 90 second delay (one test of each shutdown method)
  - Air Sampling – Type Detection (Tests 6-8)
    - Sampling tubes located 18 inches above the fan motor
    - Sensitivity settings:
      - Alert: 0.08% / ft
      - Action: 0.14% / ft
      - Fire 1: 0.20% / ft
      - Fire 2: 2.0% / ft

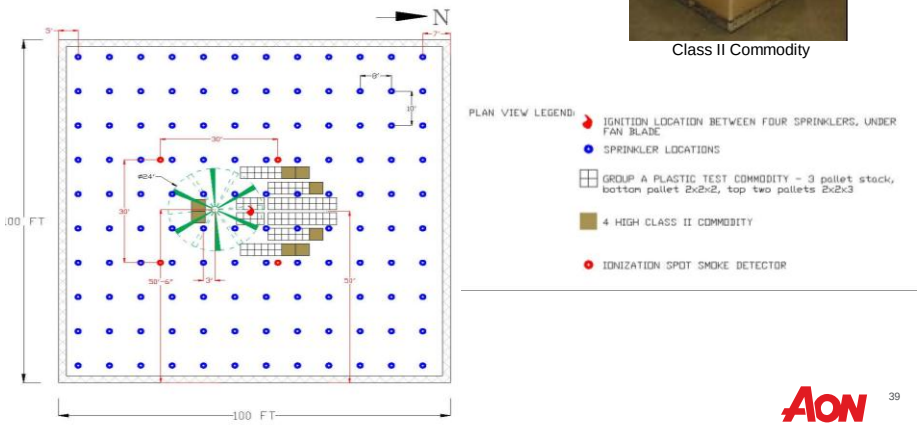


Air sampling type detection sample tube assembly (Courtesy of UL)

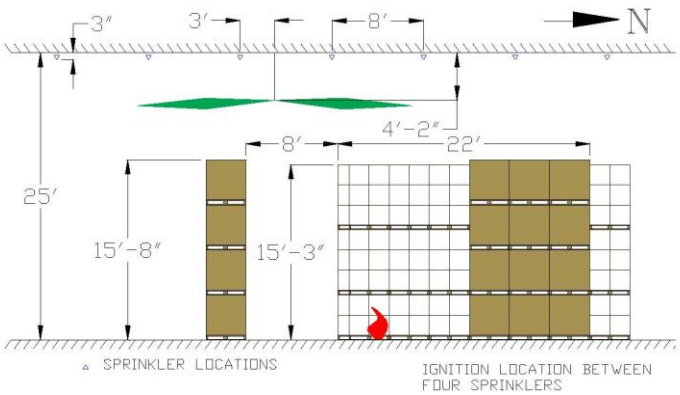
Control Mode Density Area (CMDA) Sprinkler Testing

- Ionization Smoke Detection (Tests 7 and 8)
  - One detector above the fan
  - Four detectors installed around the fan at 30ft spacing
  - Sensitivity 0.59-1.46% / ft

Class II Commodity



CMDA Tests

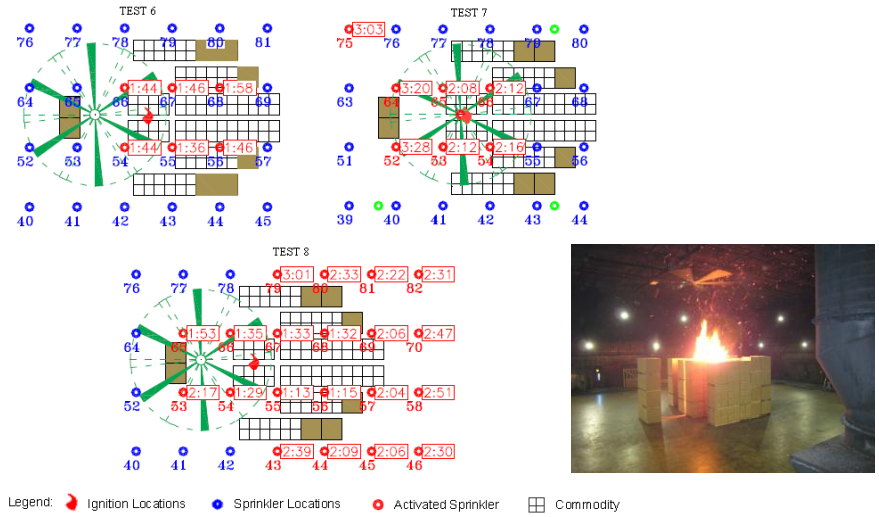


Test Section View (Courtesy of UL)

Table 3. Results for Tests 6-8

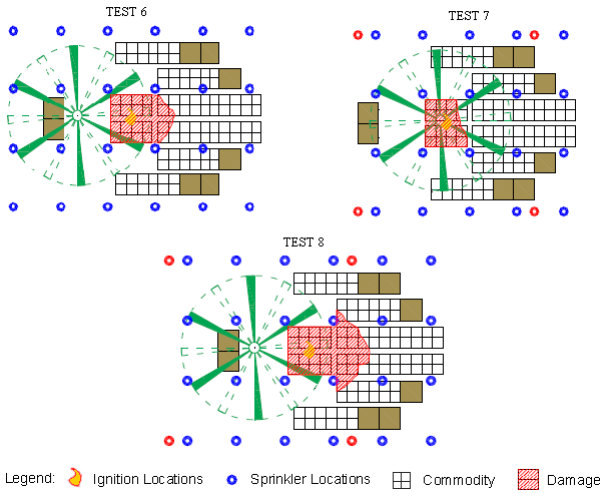
FIRE TESTS	FPRF Test 6 (UL-3) 9/21/2010	FPRF Test 7 (UL-4) 9/23/2010	FPRF Test 8 (UL-5) 9/28/2010
PARAMETERS			
Location of Test	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15
Nominal Ceiling Height (ft)	25	25	25
Nominal Clearance (ft)	10	10	10
Aisle Width (in.)	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	CMDA/286	CMDA/286	CMDA/286
Sprinkler Orientation	Upright	Upright	Upright
Sprinkler Sensitivity	Std. Response	Std. Response	Std. Response
Sprinkler Make/Model Number	Tyco/ELO-231-B	Tyco/ELO-231-B	Tyco/ELO-231-B
Deflector to Ceiling (in.)	3	3	3
Nominal Sprinkler Discharge Coefficient K (gpm/psi½)	11.2	11.2	11.2
Density/Nominal Sprinkler Discharge Pressure (psi)	0.60 gpm/sq ft	0.60 gpm/sq ft	0.60 gpm/sq ft
Sprinkler Spacing (ft x ft)	8 x 10	8 x 10	8 x 10
Fan Size (ft)	24	24	24
Fan Location	Fan Tip 3 ft Beyond Ignition	Hub 1 ft West of Ignition	Fan Tip 3 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	54.5
HVLS Fan Speed (rpm)	83	83	83
HVLS Fan Operation	Off at Air Sampling-Type Detection (1:36) (no delay)	Off at Ion Smoke Detector Operation (1:43) (no delay)	Off at Waterflow (90 sec delay)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2006	MA24XL2006
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6
RESULTS			
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:36	2:08	1:13
Last Ceiling Sprinkler Operation (min:s)	1:58	3:28	3:01
Number of Operated Ceiling Sprinklers	6	7	20
Peak Gas Temperature at Ceiling Above Ignition (°F)	1468	504	1506
Max. 1 Min. Average Gas Temp. at Ceiling Above Ignition (°F)	1042	360	1287
Peak Steel Temperature at Ceiling Above Ignition (°F)	244	122	415
Max. 1 Min. Average Steel Temp. Above Ignition (°F)	219	122	410
Fire Spread Across Aisle	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO
Fuel Consumed (number of pallets)	26	15	32
Test Outcome (Pass/Fail)	PASS	PASS	PASS
Comments		Fan blades failed (bent) after shutdown	

CMDA Tests



Tests 6-8 Sprinkler Operation (Courtesy of UL)

CMDA Tests



Tests 6-8 Damage Diagrams (Courtesy of UL)

Summary – HVLS Fans

- NFPA 13 Revised
  - The maximum fan diameter shall be 24 feet.
  - HVLS fan shall be centered approximately between four adjacent sprinklers.
  - The vertical clearance from the HVLS fans to sprinkler deflectors shall be a minimum of 3 feet
  - All HVLS fans shall be interlocked to shutdown immediately upon receiving a waterflow signal from the alarm system in accordance with the requirements of NFPA 72.
  - NOTE: Effectively, power shut down must occur within 90 seconds of water flow from the first operating sprinkler

- Sustainability Outcome
  - HVLS fan technology will continue as a green ventilation solution
  - Conflicts between HVLS technology and sprinklers are resolved
  - A technical solution is recognized to allow HVLS fans and sprinklers coexist

Conclusions

- Only three examples of how fire research is supporting the needs for sustainable / green design are reviewed.
- There is, however, many other examples and research projects underway that are addressing similar issues.

- Key Points to consider:
  - Existing and new sustainable design solutions should be evaluated with regard to their impact or unintended consequences on fire safety features and methods
  - Often, codes and standards committees may rush to judgment to ban new green technologies or imposed overly restrictive rules for use. Fire research must be key to validating such decisions.
  - Much work needs to be done in the area of understanding how to optimize fire protection systems. This applies to individual product applications and the myriad of fire systems applied in the building designs.