Effect of High Airflow and Aisle Containment on Clean Agent System Performance in Data Centers

November 2, 2022

Fire Industry Association

Fire Suppression Systems Association

Effect of High Airflow on Clean Agent Concentrations

01

Background Info Codes and Standards

02

Latest Research

03

Design Considerations

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Legacy Computer Rooms

- Lower power density computer equipment (solid state electronics)
- Air conditioning for operator comfort and equipment cooling
- Computers and Air Handlers typically **shut down in case of fire alarm**

Today's Data Centers

- High power density Information Technology Equipment (ITE)
- **Continuous operation (99+% uptime)**
- **Continuous cooling required to prevent damage to equipment**
- Multiple air changes per hour
- Aisle containments separate hot air and cold air within space
- **Computer operations and airflow often continue even in case of fire alarm**

Data centers typically seeking 99%+ uptime.

Best Fire Suppressants for ITE

Clean

Dry

Electrically non-conductive

5

Gaseous Agent Fire Protection

Legacy

- Carbon dioxide
- Halon 1301

Today

- Clean Agent

Pertinent Standards

NFPA 75 Fire Protection of Information Technology Equipment

NFPA 2001 Clean Agent Fire Extinguishing Systems

ISO Standard 14520 Gaseous Media Fire Extinguishing Systems

EN Standard 15004 Fixed firefighting systems - Gas extinguishing systems

Australian Standard AS 4214 Gaseous Fire Extinguishing Systems

UL 2166 Halocarbon Clean Agent Extinguishing System Units

UL 2127 Inert Gas Clean Agent Extinguishing System Units

FM 5600 Approval Standard for Clean Agent Extinguishing Systems

BS 6266 Fire Protection for Electronic Equipment Installations - Code of Practice

EN 50600-2-5 Information technology - Data centre facilities and infrastructures - Part 2-5: Security systems

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Nozzles must be “listed”

NFPA, ISO, EN Standards

NFPA 2001 requirement

- *5.2.5.1 Discharge nozzles **shall be listed for the intended use.** Listing criteria shall include flow characteristics, **area coverage**, height limits, and minimum pressures.*

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ISO 14520 & EN 15004 Requirements

Nozzles, including nozzles directly attached to containers, shall be approved . . .

The type, number and placement of nozzles shall be such that the design concentration is achieved in all parts of the enclosure.

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ISO and EN agent standards likewise require approval of nozzles.

Performance testing for nozzle listing

- UL, FM, ISO and EN Standards require a nozzle to produce homogenous agent concentration
  - Throughout a *volume*
  - Within 30 seconds after end of discharge.
- The *volume* represents the maximum area and the maximum and minimum height covered by the nozzle.
- Tests are performed in **still air – no air movement.**

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11

For nozzles to be listed, agencies such as UL and FM require performance tests. The performance testing is done in still air – no air movement. How does this test correlate with conditions of use in the field?

Shutdown Air flow???

Codes, Standards, Common Practice

12

Can we expect airflow to be shut down in case of a fire alarm?

NFPA 2001, ISO 14520, EN 15004 Requirements

<u>If HVAC adversely affects system performance, shut it down.</u>

"Forced-air ventilating systems shall be shut down or closed automatically where their continued operation would adversely affect the performance of the fire-extinguishing system or result in propagation of the fire. . ."

<u>"Ventilation systems necessary to ensure safety are not required to be shut down upon system activation."</u>

13

Agent standards such as NFPA 2001 and ISO 14520 require HVAC to be shut down upon activation of the fire system if the HVAC adversely affects system performance. The standards make an exception if the ventilation system is necessary the ensure safety.

BS 6266
Fire Protection for Electronic Equipment Installations

Allows for shut-down of ventilation, but notes:

✓ **"If it is important to maintain a supply of cool air . . .**
1. **Maintain recirculation**
2. **Shut down fresh air makeup . . .**

14

Occupancy standards such as BS 6266, EN 50600-2-5 and NFPA 75 recognize the need to maintain cooling airflow while equipment is running.

European Standard EN 50600-2-5

Information technology - Data centre facilities and infrastructures

- ✓"An alarm **should not automatically disrupt the function of the facilities and infrastructures** of the data centre (e.g. . . ."
  1. **Maintain recirculation**
  2. **Shut down fresh air makeup**

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The British Standard and the European standard caution that if airflow is continued, the airflow must be fully recirculating with no fresh air makeup.

NFPA 75

Fire Protection of Information Technology Equipment

"**A.11.4.5.2** Cooling of ITE is critical to its operation. Information technology (IT) servers run applications that are crucial to business continuity and frequently have life safety implications.

An unplanned shutdown of ITE can cause loss of control over life support systems, emergency response systems, and security systems, as well as loss of essential data.

Therefore, **it can be undesirable, even dangerous, to automatically shut down equipment that is not directly involved in a fire."**

(Emphasis added)

NFPA 75 cautions against automatic equipment shutdown and recognizes the need for continuous cooling of Information Technology Equipment.

Common Practice in Data Centers

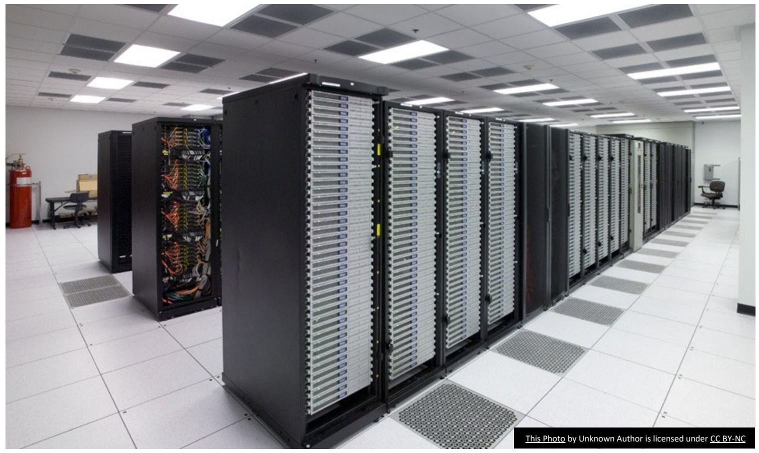
- Continuous airflow to cool equipment
- Multiple air changes per hour
- Airflow does not shut down while equipment is operating

Note: Operating ITE could be damaged in minutes without cooling.

17

So, in practice we expect airflow to continue so long as IT equipment is operating, and we expect IT equipment to operate nearly 100% of the time. These facts lead to the question . . . Does airflow affect the development of clean agent concentrations?

Does airflow affect development of clean agent concentrations?



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High Airflow Project – Two Phases

Phase 1: “Planning Project” by the Fire Protection Research Foundation completed in 2015

Phase 2: “Testing Project” initiated in 2018 by

- Fire Suppression Systems Association (FSSA)
- Fire Industry Association (FIA).
- Test work completed in 2021.
- Results presented in 2022.

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Project Testing Overview

- Discharge gaseous agents into a mock server room
- Measure agent concentration at key locations in the room

Variables

Range of Airflows

- 0 Air Changes Per Hour (ACH)
- 9 ACH low airflow
- 18 to 36 ACH moderate to high
- 60 ACH very high airflow

Aisle Containment

- No containment
- Cold Aisle
- Hot Aisle

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The tests were done with various airflows – from still air to over 60 Air Changes Per Hour – and various aisle containment configurations.

Number of Tests	Test Agent
42	Carbon Dioxide
7	NOVEC 1230™ (FK-5-1-12)
6	FM-200™ (HFC-227ea)
16	Nitrogen (IG-100)

71 tests

Over 70 discharge tests done with various agents. Carbon dioxide was used as a surrogate test gas for the liquefied agents to reduce cost and establish some baseline data. In preliminary testing we found that carbon dioxide mimicked the distribution of the halocarbon agents quite well. Carbon dioxide had the advantage of relatively low cost compared to the halocarbon agents – and by using a bulk storage tank of CO_2 we saved considerable time and labor . The CO_2 as well as the halocarbon systems were designed to discharge in 10 seconds, and the design concentrations were in the range of 4 ½ to 6 percent. For the inert gas tests, we used a listed system with nitrogen as the agent. Discharge times for the inert gas systems were one minute and two minutes per standard design parameters.

Test Chamber

- 7,275 ft^3 (206 m^3)
  - 26 ft (7.9 m) by 20 ft (6.1 m) interior dimensions
  - 14 ft (4.3 m) overall height
  - 1 ½ ft (46 cm) deep subfloor
  - 2 ft (61 cm) high space above drop ceiling
  - 10.5 ft (3.2 m) main room height
- Within a warehouse to minimize wind effects

Inside the Chamber

- Two rows of server cabinets

- Two computer room air handlers (CRAH)

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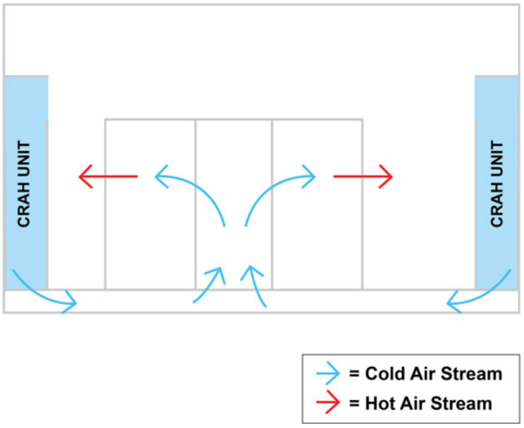
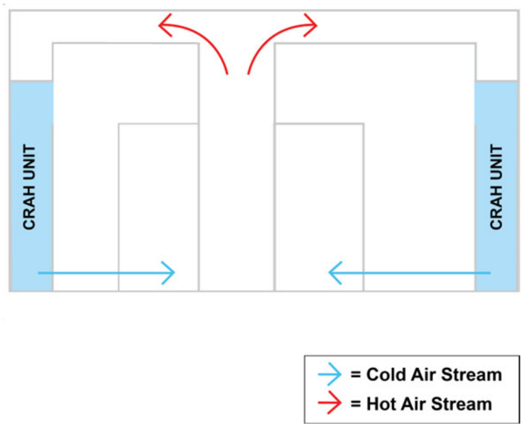
Cold Aisle Configuration



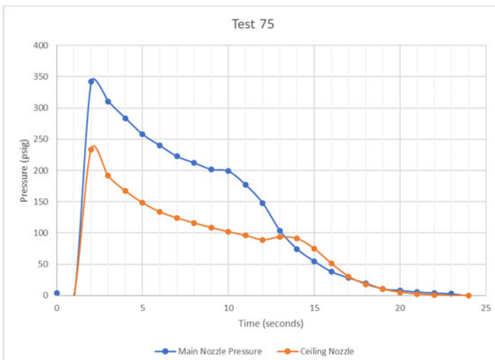
Cold air from subfloor flows into "cold aisle," through ITE; hot air flows into room, back to CRAH.

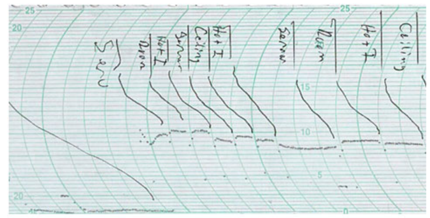
Hot Aisle Configuration

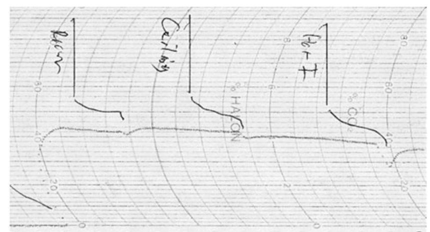


Cold air flows from room into ITE with heated air from ITE flowing into a central aisle return to CRAH.

Some data







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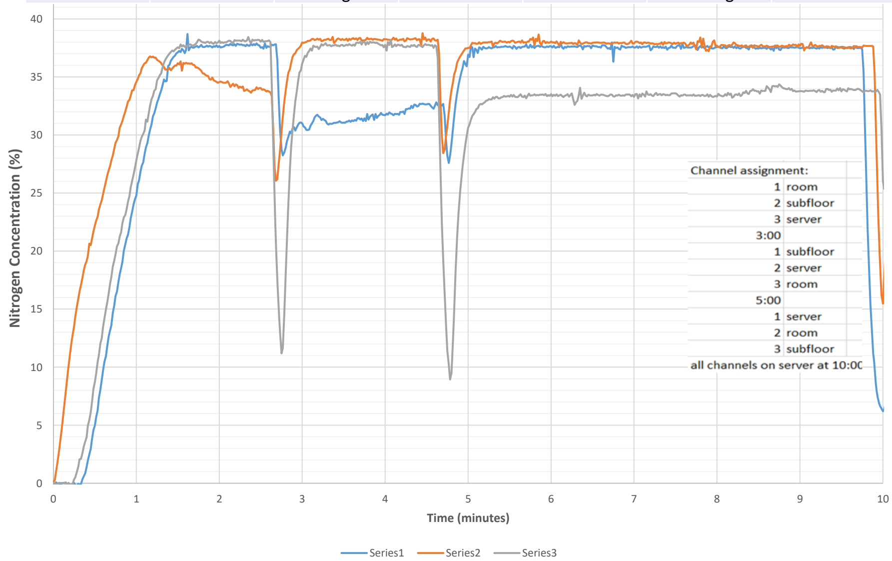
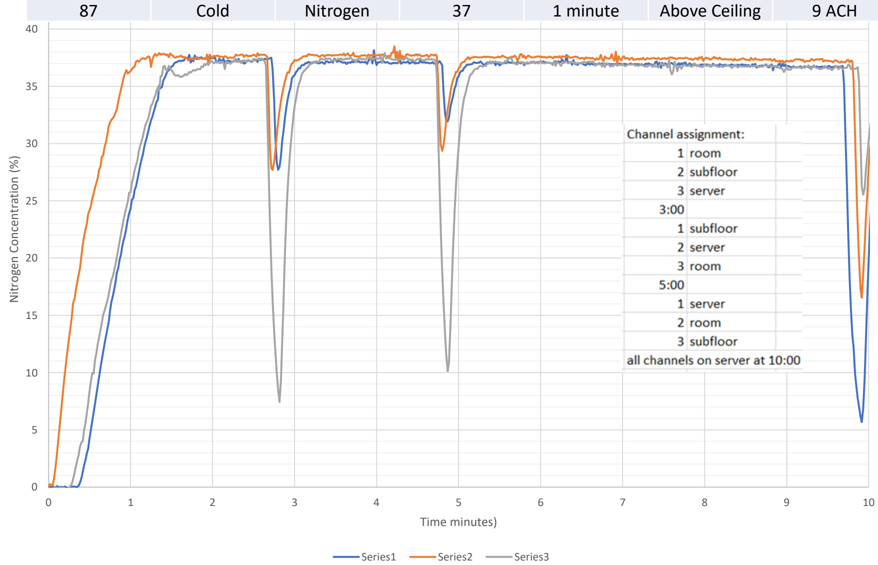
Test #	Aisle	Agent	Target %	Discharge Time	Nozzle Locations	Airflow
86	Cold	Nitrogen	37	1 minute	Room, Subfloor, Ceiling	No



28

Inert gas discharge. Designed system to purposely discharge less nitrogen under raised floor than required to reach 37% design concentration. One nozzle each in room, under raised floor, and above drop ceiling. The nitrogen concentration is plotted on the y axis against time, shown on the x axis. These dips in the concentration curves are when we switched the sampling hoses between the meter channels – we wanted to get all three sample points on each meter channel to eliminate any channel bias. The result of this test is the subfloor concentration only reached about 33% while the concentrations measured in the room and within the server cabinets reached 37%. This indicates that the nozzle used under the raised floor was a bit too small.

Test #	Aisle	Agent	Target %	Discharge Time	Nozzle Locations	Airflow
87	Cold	Nitrogen	37	1 minute	Room, Subfloor, Above Ceiling	9 ACH



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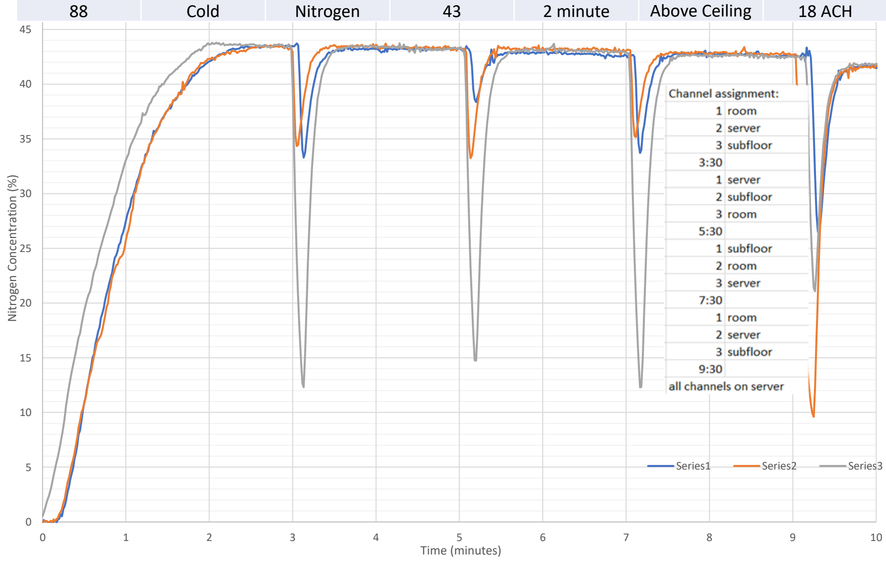
We repeated the previous test with one air handler operating at low airflow. As shown, the concentrations at all three sample points quickly leveled to the target concentration of 37%. The presence of airflow improved the uniformity of agent concentration.

Test #	Aisle	Agent	Target %	Discharge Time	Nozzle Locations	Airflow
88	Cold	Nitrogen	43	2 minute	Room, Subfloor, Above Ceiling	18 ACH



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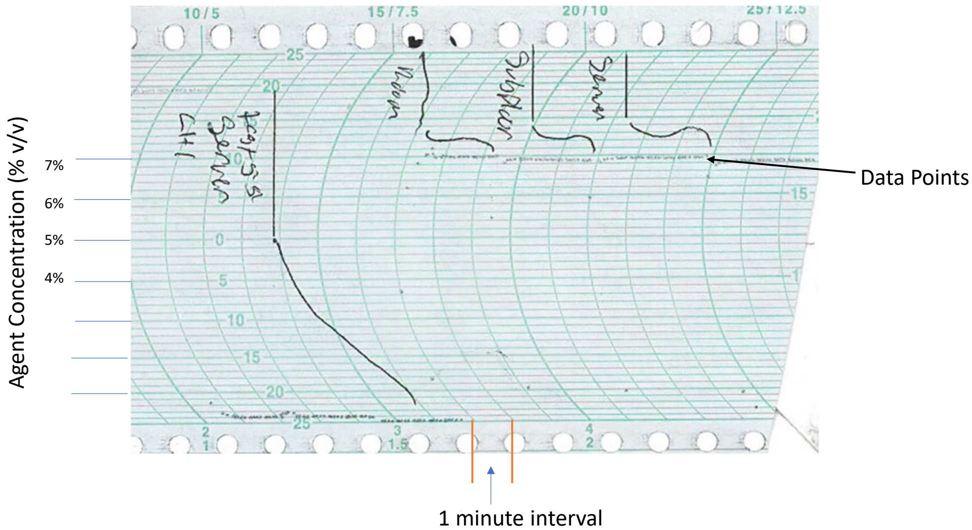
The test was repeated with a two minute discharge and airflow at 18 ACH – again all sample points quickly converged to the target concentration.

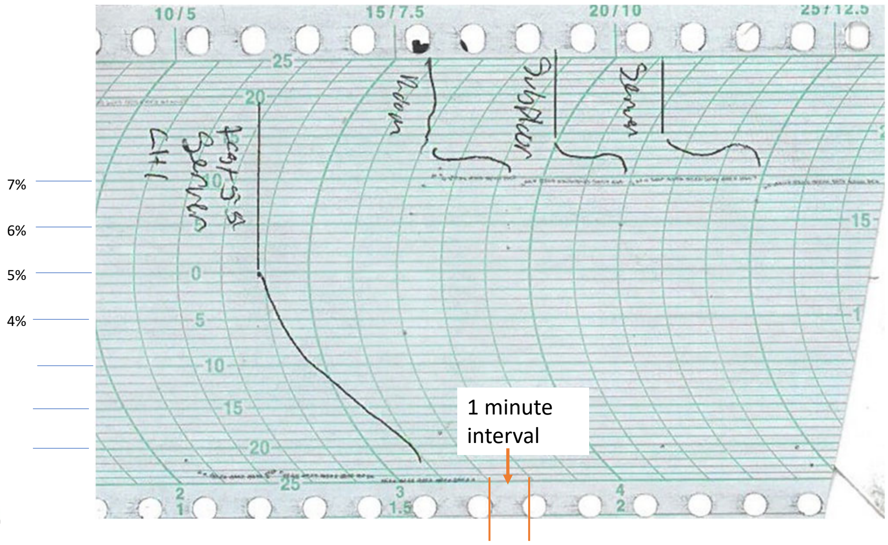
Halocarbon Concentration vs Time Chart

Halocarbon Concentration vs Time Chart



Now we'll look at some halocarbon test data. Before we do, let's quickly look at the recording chart used for the halocarbon testing. The halocarbon concentration is plotted on the Y axis against time plotted on the X axis. The distance between the curved lines on the x axis represents 1 minute.

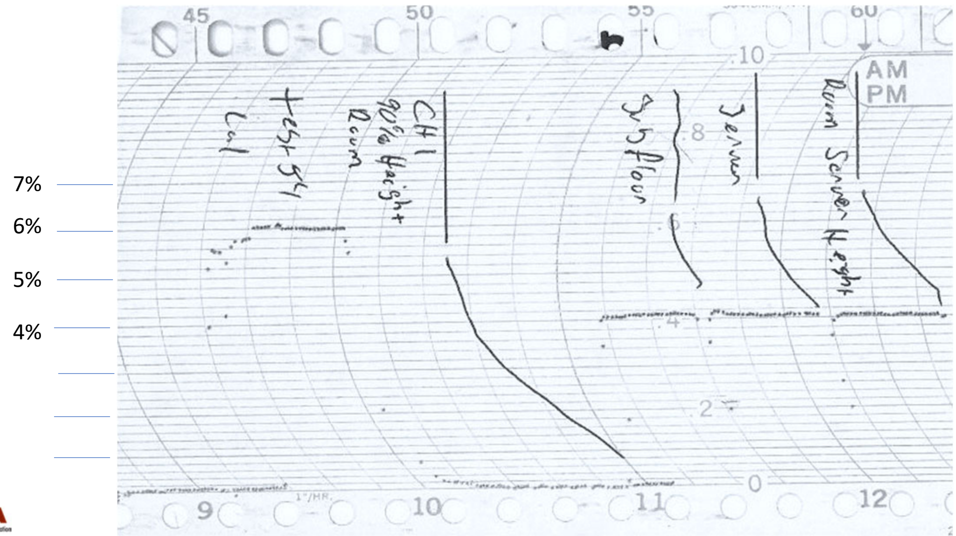
Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
55	Cold	FM-200	7	Room, Subfloor	60



33

This test used actual FM-200 discharged into the chamber with the cold aisle configuration. A nozzle was located in the room and under the raised floor. The airflow was quite high – 60 air changes per hour and the agent concentration measured under the raised floor, within the server about 3 feet above the raised floor, and in the room about 10 feet above the raised floor was uniform. Airflow shut off after discharge was completed to eliminate enhanced leakage due to air movement and allow accurate measurement of concentrations from various sample points.

Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
54	Cold	NOVEC	4.1	Room, Subfloor	60



34

Here we see a repeat of the previous test, this test using NOVEC 1230, FK-5-1-12. Again, the measured agent concentrations under the raised floor, in the server cabinet, and in the room are the same.

Test 54 Airflow shut off after discharge was completed to eliminate enhanced leakage due to air movement and allow accurate measurement of concentrations from various sample points.

Results

- In all configurations with all agents, airflow either
  - IMPROVED uniformity of concentration
  - Or, for configurations where mixing was ideal in still air, mixing remained ideal with airflow.

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In summary, the data indicated that the presence of airflow during a clean agent discharge has no bad effect on the uniformity of agent concentration – if anything, airflow improves the homogeneity of concentration in the protected space.

NFPA 2001

- 7.1.6.2 Each volume, room, and raised or sunken floor to be protected shall be provided with detectors, piping network, and nozzles.

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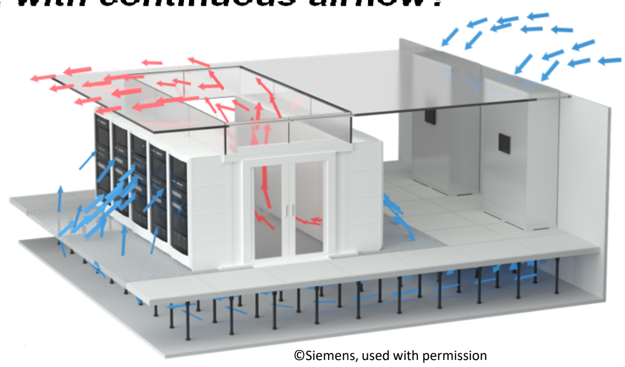
NFPA 2001 requires a nozzle in each protected volume. This requirement has been questioned by some.

QUESTION

- **Is it necessary to conform to NFPA 2001 7.1.6.2, i.e., a nozzle in each volume, with continuous airflow?**



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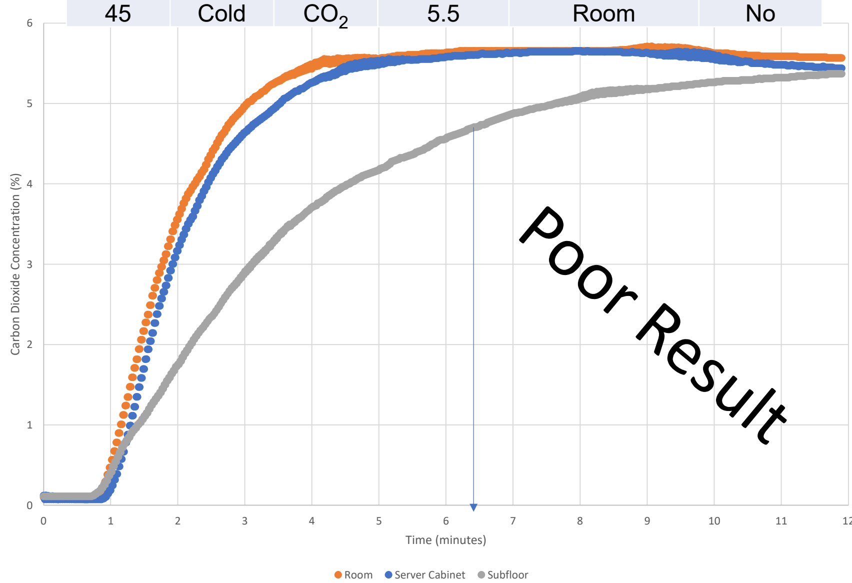
Some have suggested that nozzles might be omitted under raised floors allowing gravity to carry the agent into the subfloor.

We ran several tests to investigate the need for a nozzle in each volume. Here a nozzle is provided in the room, but none under the raised floor. The test results look like this.

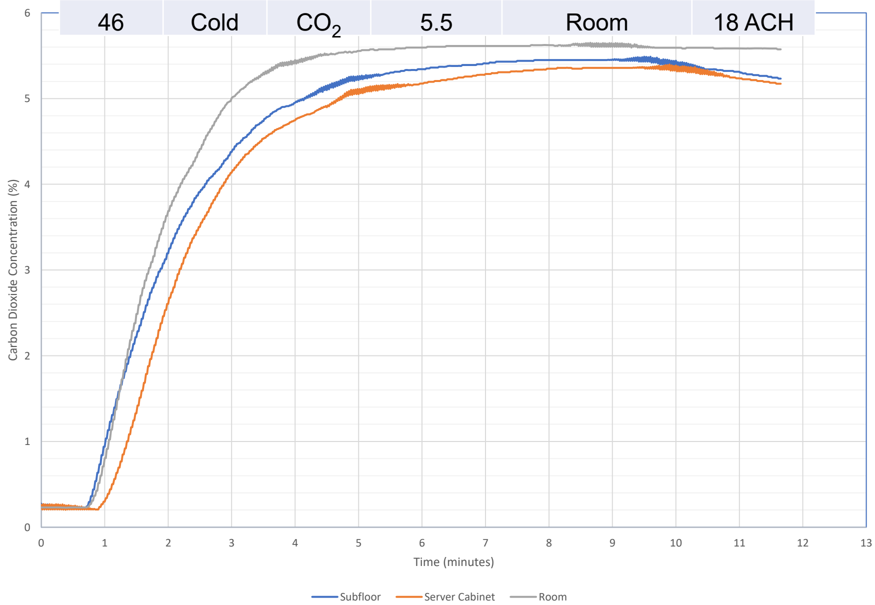
Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
45	Cold	CO_2	5.5	Room	No



39

TARGET CONCENTRATION 5.5%. It took 12 MINUTES FOR CONCENTRATION IN THE SUBFLOOR TO REACH THE DESIGN VALUE WITH NO AIRFLOW.

Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
46	Cold	CO_2	5.5	Room	18 ACH



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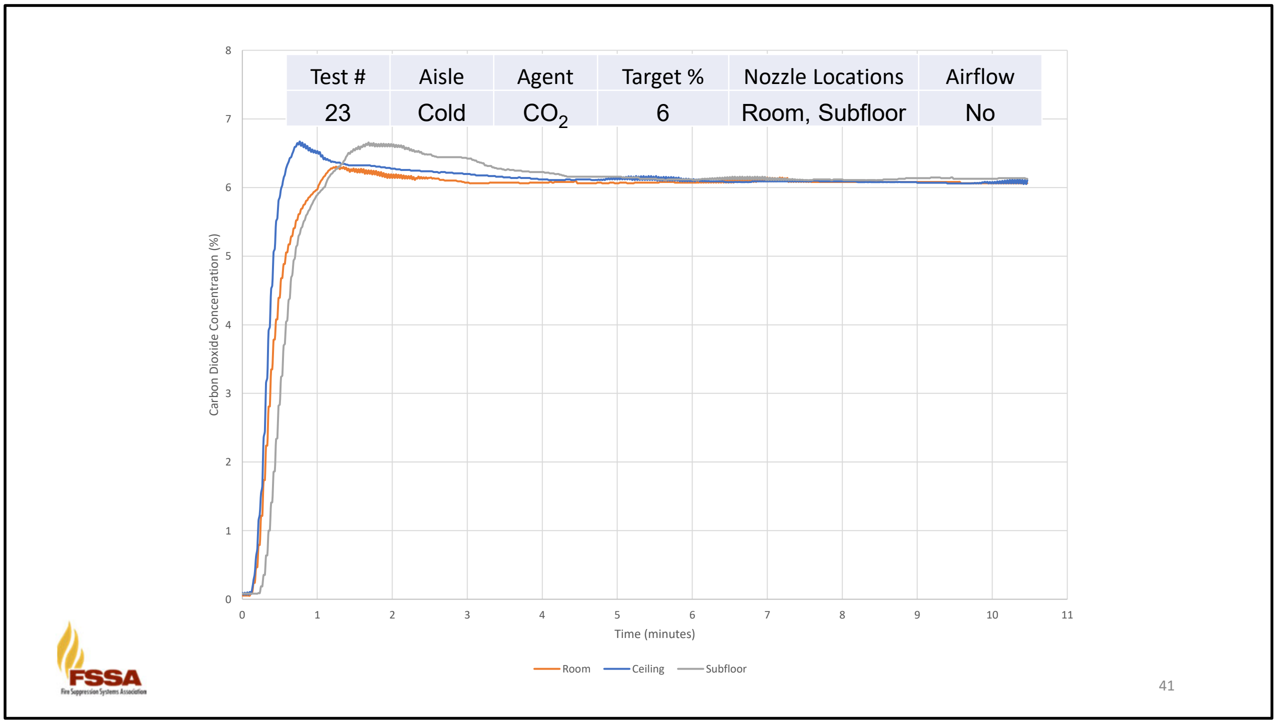
We repeated the test with moderate airflow. The concentration within the cold aisle and under the raised floor lagged the concentration measured in the room. Although this is an improvement over the no airflow situation, it is hardly ideal. (Likely had air with little agent around the periphery of the subfloor which continued to dilute the air/agent mix in the subfloor.)



Here we see the results when nozzles are located as required by NFPA 2001.

Cold Aisle with 2 nozzles under raised floor
No Room Nozzle

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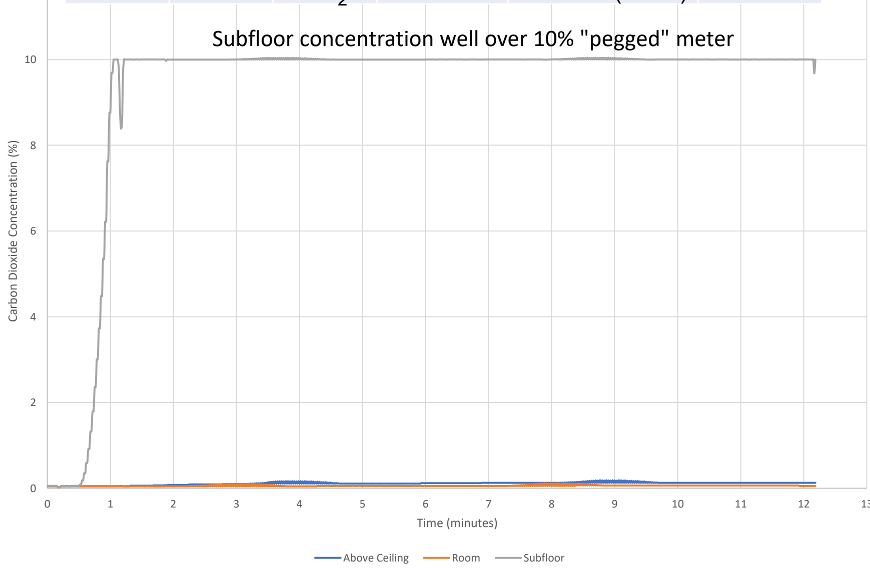
Here are some tests which were requested . . . Discharge enough agent into the subfloor to protect the entire volume of the chamber – with nozzles located under the raised floor – no room nozzle.

Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
37	Cold	CO_2	5.5	Subfloor (2 noz)	No



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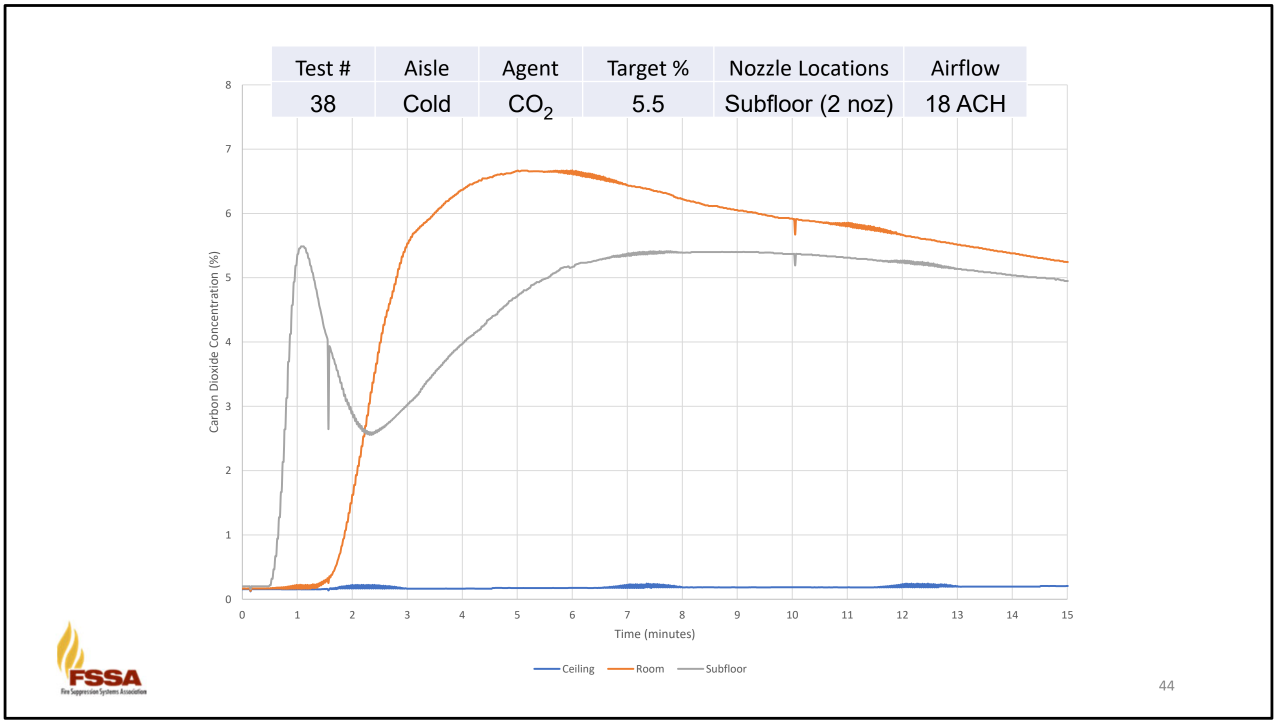
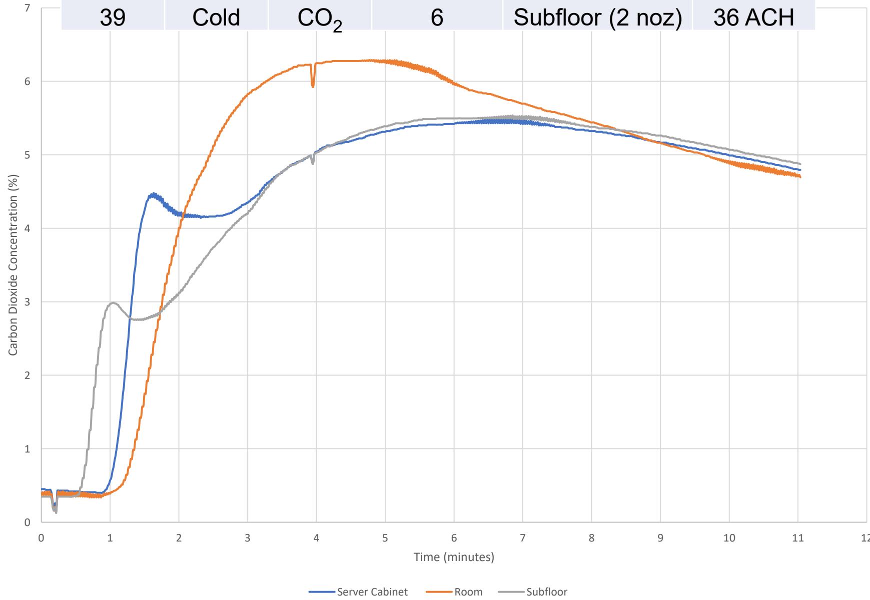
5.5% target concentration 10 second discharge. NO SURPRISE with no airflow that the concentration under the raised floor exceeded the span of the measuring instrument – and virtually no agent reached the sample point 8 feet above the raised floor in the room.



The same configuration with moderate airflow yielded this rather curious data – not an acceptable system.

Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
39	Cold	CO_2	6	Subfloor (2 noz)	36 ACH



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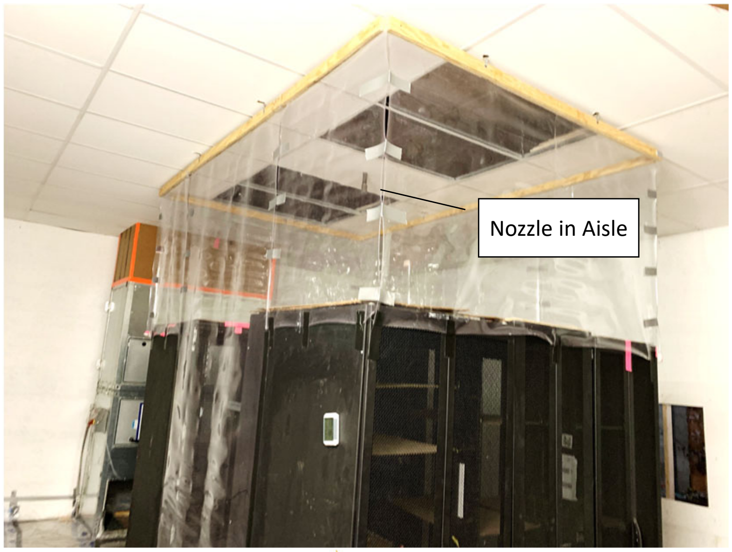
45

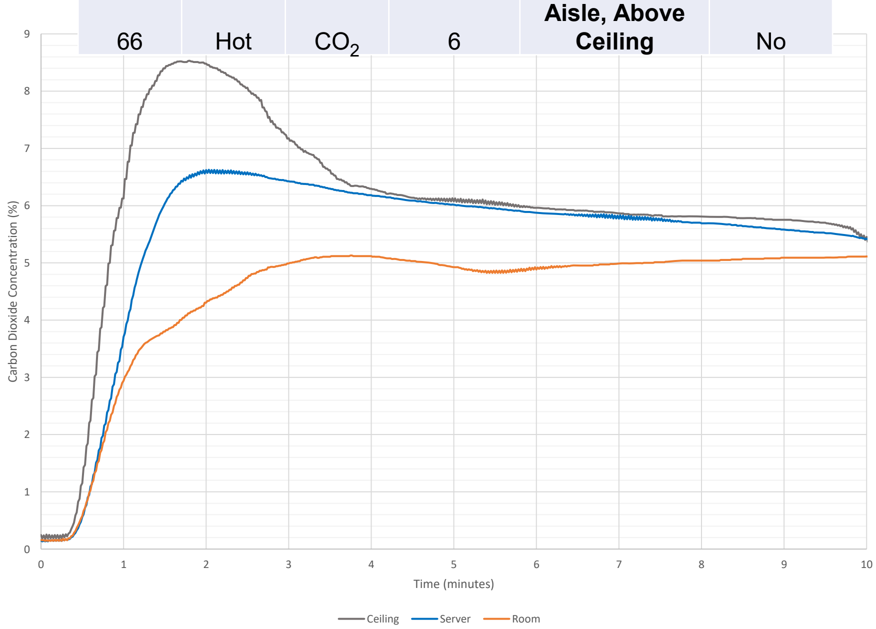
A third test with increased airflow, 36 ACH yielded another curious set of data – again, not an acceptable system.

Hot Aisle – Nozzle in Aisle



At times, a clean agent system will be installed in a space which is wide open, no aisle containments, and aisle containments are added later. Here we simulated such an arrangement. The nozzle intended to protect the entire room is “trapped” in a hot aisle.

Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
66	Hot	CO_2	6	**Aisle, Above Ceiling**	No



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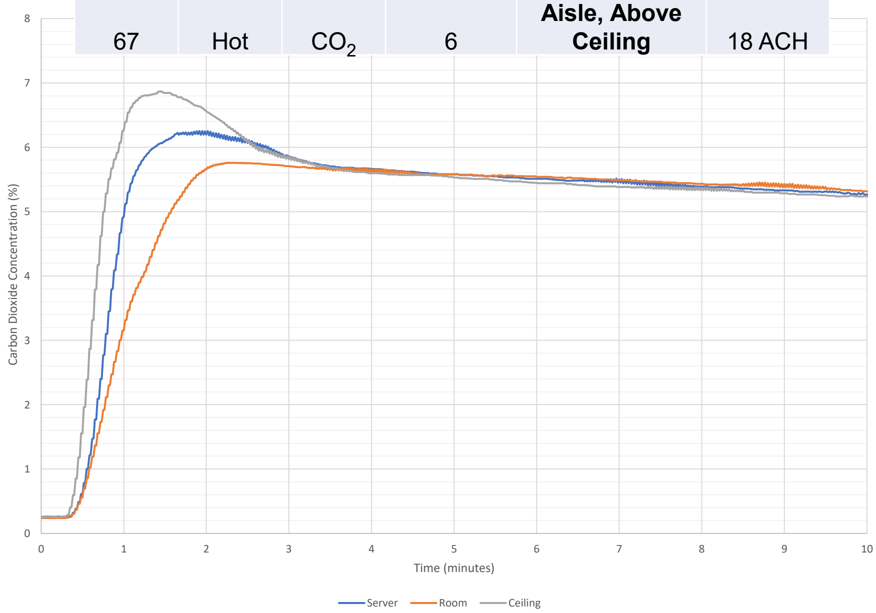
47

Nozzles are located in the hot aisle and above the drop ceiling. There is no nozzle in the room outside the aisle. With no airflow the room never reaches the target concentration.

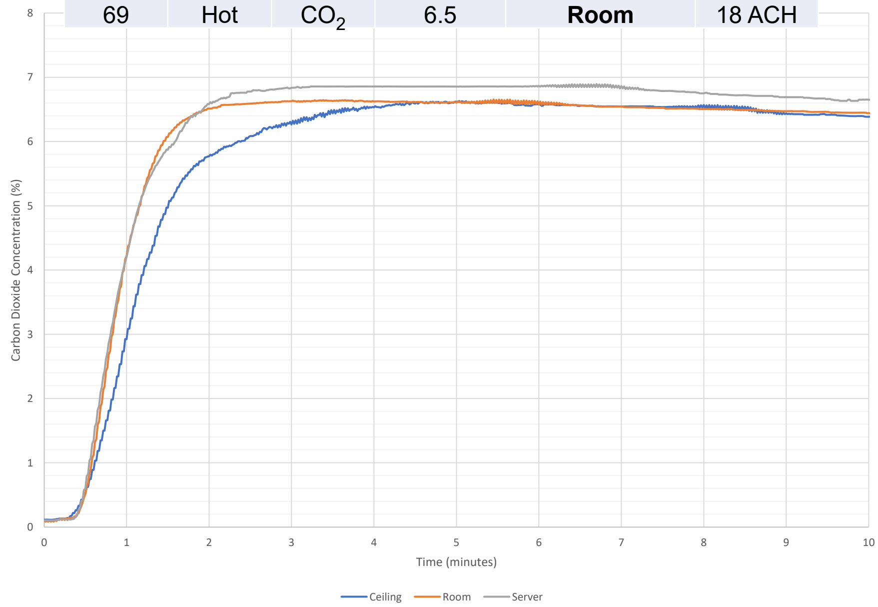
Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
67	Hot	CO_2	6	**Aisle, Above Ceiling**	18 ACH



48

Nozzles are located in the hot aisle and above the drop ceiling. There is no nozzle in the room outside the aisle. This is an improvement over the no airflow situation but not ideal.

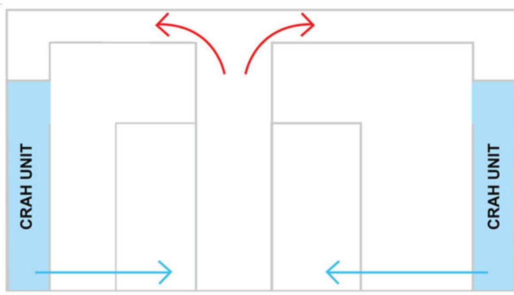
Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
69	Hot	CO_2	6.5	**Room**	18 ACH



49

Finally, a test with a single nozzle located in the room outside the hot aisle containment. The concentration measured above the drop ceiling takes about 4 minutes to reach the target, even with airflow. But the room and server concentrations quickly reached the design level. This results indicates that if there are combustibles being protected above the drop ceiling it is necessary to install a nozzle above the ceiling. It is likewise important regardless of whether or not protection above the drop ceiling is required to supply enough agent for both the entire room and the volume above the drop ceiling.

Connected ducts/plenums



- Supply sufficient agent to develop design concentration in the room AND in connected air ducts/plenums and ventilation system components.

QUESTION

- **Is it necessary to conform to NFPA 2001 7.1.6.2, i.e., a nozzle in each volume, with continuous airflow?**
- **YES, NFPA 2001 7.1.6.2 applies regardless of airflow.**

NFPA 2001 7.1.6.2 Each volume, room, and raised or sunken floor to be protected shall be provided with detectors, piping network, and nozzles.

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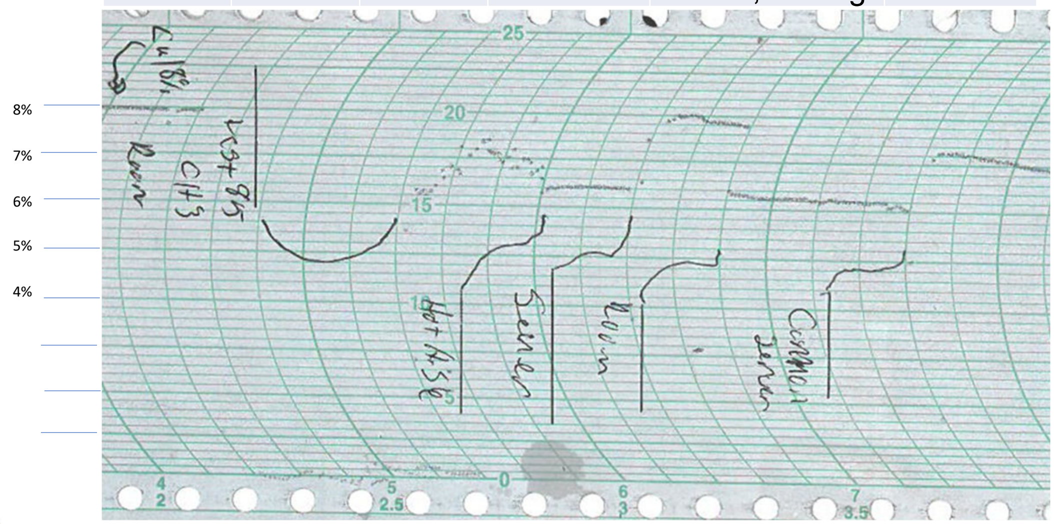
Based on these tests, we conclude that the requirements for nozzle locations in NFPA 2001 are suitable – even when continuous airflow is present.

Inadvertently, the recommended distance between the discharge nozzle and a containment curtain was not followed in one of the tests. Liquid FM-200 discharging from the nozzle was observed to impinge on the curtain and flow down the curtain toward the floor of the room. The measured concentrations looked like this.

Test #	Aisle	Agent	Target %	Nozzle Locations	Airflow
85	Hot	FM-200	7	Room, Ceiling	No



53

The concentration in the server cabinet 3 feet above the floor reached 8 percent. Concentration in the room at 8 feet above the floor reached 7 percent momentarily and leveled at about 6.2%. The stratification in concentration was no doubt due to the impingement of liquid agent on the containment curtain – preventing the agent from quickly vaporizing and mixing with the air in the room.

- Manufacturer recommended clearance between nozzles and structural components (including aisle containment partitions) must be maintained

Maintain clearance recommended by system manufacturer

Nozzles within Containment Aisle?

56

Related to the preceding data is the question DO WE NEED A NOZZLE IN EACH AISLE CONTAINMENT?

NFPA 75 requirement

- 9.4.3 * Hot aisle or cold aisle containment systems shall not obstruct the free flow of gaseous clean agent suppression systems to the ITE or cooling system serving the contained aisle within an ITE room or zone.

NFPA 75 considers this question in 9.4.3 and further in the Annex material to 9.4.3.

NFPA 75 annex

- A.9.4.3 . . . **the gas suppressant should be able to penetrate all of the ITE.**

  In most cases of whole room total flooding systems, the flow of air through the ITE normally would be sufficient to satisfy this requirement, but the method should be evaluated on a case-by-case basis.

Demonstrated by test

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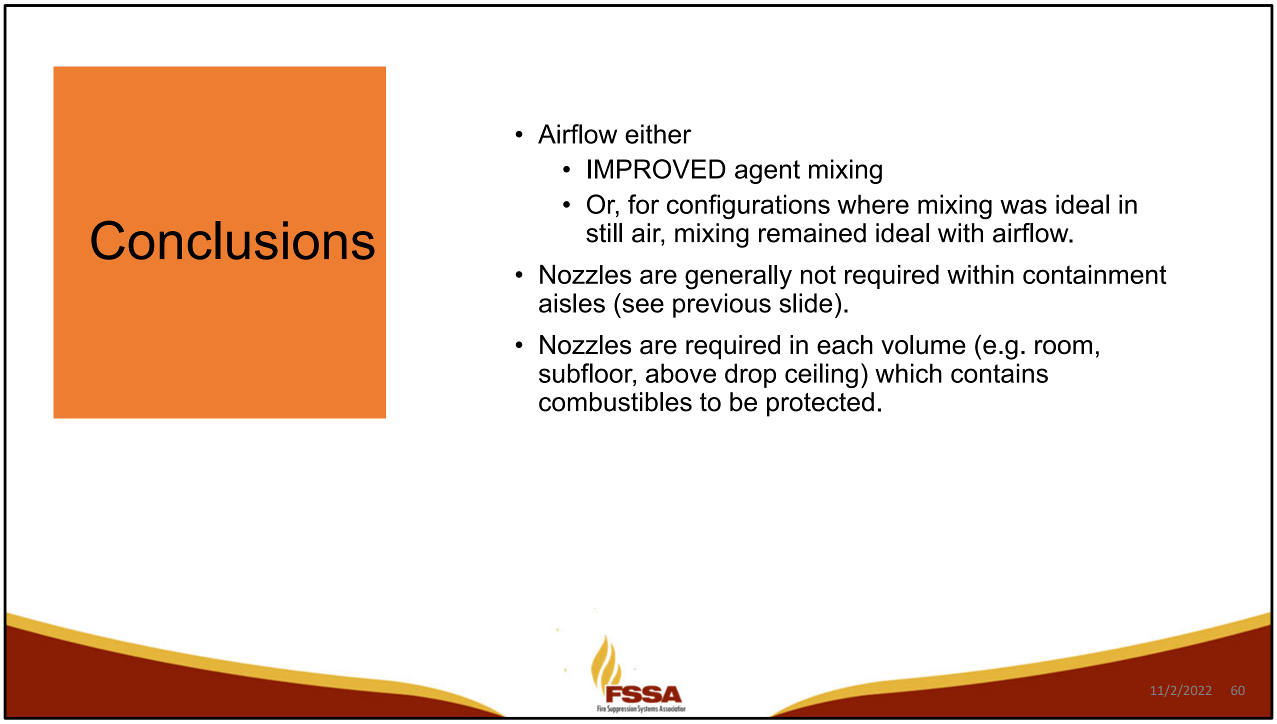
75 notes that when an entire room is flooded with gaseous agent, the gaseous agent will penetrate the equipment. The tests in this research project confirmed this.

Is a nozzle required within each containment aisle?

NO . . . . IF ALL OF THE FOLLOWING ARE TRUE.

1. ITE permits air from room to flow through cabinets;
2. Nozzles are located in the room per listed limits (area of coverage, height limits);
3. Manufacturer recommended clearance between nozzles and structural components (including aisle containment partitions) is maintained; and
4. Nozzles within an aisle are not otherwise mandated by manufacturer, insurer, or code requirement.

So our answer to the question is "no" so long as these four criteria are met. Item 3 is particularly important for liquified compressed gases, halocarbons.



To summarize the conclusions from this study – airflow basically improves homogeneity of agent concentration; nozzles are required in each protected volume including under raised floors; nozzles generally not required in containment aisles when room is totally flooded. We will share the information gathered in this study with the various standards development agencies for consideration in future standards.

Relevant Design Considerations

- If airflow is to be continued during a discharge, it must be
  - in FULL RECIRCULATING mode
  - with NO MAKEUP AIR.
- Nozzles are required in each protected volume, e.g., room, subfloor, ceiling void.
- Nozzles must be located per listed limits.
- Manufacturer recommended clearances between nozzles and structural components INCLUDING aisle containment partitions must be maintained.

Caution

Nothing in this presentation overrides

- ✓Existing applicable codes and standards
- ✓Manufacturer's installation guidance
- ✓The need for design guidance from a fire protection professional.

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Thank you

Major corporate contributors

Johnson Controls
Chemours
3M Company
Fike Corporation
Janus Fire Systems

Special thanks to Fike Corporation

- Facility to house test chamber
- Manpower to perform tests
- Inert gas agent and carbon dioxide.

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Questions?

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