Research Report

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

A Joint Study by the Fire Suppression Systems Association
and the Fire Industry Association (UK)

Issued November 1, 2023

Purposely Left Blank

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

Acknowledgments

The project on the effect of high airflow and aisle containment on the uniformity of clean agent concentration in data centers was sponsored by the Fire Suppression Systems Association (FSSA) and the Fire Industry Association (FIA – UK). The sponsors wish to acknowledge the contributions of the following companies to this research project:

- Fike Corporation
- Johnson Controls, Inc.
- The Chemours Company
- 3M Company
- Fireline Corporation
- Phoenix Fire Systems, Inc.
- Victaulic
- American Fire (Tyler)
- American Fire Technologies
- 3S Incorporated
- Minimax
- Janus Fire Systems
- ORR Protection
- The Hiller Companies.

Cautionary Statement

Nothing in this report overrides

- Existing applicable laws, codes, and standards
- Manufacturer's design, installation, servicing, and maintenance instructions and guidance
- The need for design guidance from a fire protection professional.

Executive Summary

NFPA Standard 2001 Clean Agent Fire Extinguishing Systems, ISO 14520, and EN 15004 require that system discharge nozzles be listed for their intended use. The UL and FM standards for approval of clean agent systems require nozzles to demonstrate their ability to produce a uniform concentration of clean agent throughout a given volume. The approval tests are done in still air. That is, no air movement is present in the test enclosure.

In contrast, clean agent systems are often used in data centers where airflow is maintained during and after system discharges. A project was initiated under the Fire Protection Research Foundation's leadership to examine the effect of continuous airflow on the uniformity of the clean agent concentration (also known as "agent distribution") produced by a system discharge. The planning project was completed in 2015. In 2018, the Fire Suppression Systems Association (FSSA - USA) and the Fire Industry Association (FIA – UK) partnered to complete the project by testing clean agent systems in high airflow environments. The project scope was expanded to include an examination of the effect of aisle containments on agent distribution.

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

Background

Data processing equipment has become essential to maintaining business and commerce, emergency services, health care, research, government services, and education. Few areas of modern life do not depend on the availability of computer services. The practical and financial implications of loss of data processing availability are enormous. The average cost of data center downtime has been estimated to be on the order of $300,000 per hour.

Data center uptime is categorized by tiers based on availability. A Tier 1 center guarantees 99.671% availability, while a Tier 4 center guarantees 99.995% availability. It is essential to keep various systems, including electric power supply and cooling, continuously operating to maintain such high levels of availability. It is essential to protect the data center from fires that can permanently damage IT equipment, reducing availability to 0%.

Clean agent systems often provide fire protection in areas containing high-value electronic equipment such as data centers. The high power density ITE in today's data centers requires continuous cooling to remove the substantial heat produced and keep the electronics from overheating. Various means are used to cool the ITE, the most common means being passing cool air through the ITE enclosures.

Data center operators often require cooling airflow to continue even if a fire or clean agent system discharge is detected.

Numerous codes and standards are related to clean agent system application and cooling airflow in data centers. These include:

NFPA 75: Fire Protection of Information Technology Equipment
NFPA 2001: Clean Agent Fire Extinguishing Systems
ISO 14520: Gaseous Fire Extinguishing Systems
EN 15004: Fixed firefighting systems - Gas extinguishing systems
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

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

Table of Contents

List of Figures

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

1 HVAC Control in Standards for Clean Agent Systems

NFPA, ISO, and EN standards on clean agents indicate that air handling equipment in a protected enclosure should be shut down *if their continued operation adversely affects system performance.* The project investigates the effect on the development of uniform agent concentration in an enclosure with continued operation of air handling equipment.

> NFPA 2001 "7.1.7 * - Other than the ventilation systems identified in 7.1.7.2, forced-air ventilating systems, including self-contained air recirculation 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."
>
> ISO 14520 & EN 15004 Requirements - "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. Ventilation systems necessary to ensure safety are not required to be shut down upon system activation."

NFPA, EN, and British Standards covering the protection of ITE installations all contain cautions about the shutdown of cooling air supplies to the ITE.

> BS 6266 allows for the shutdown of ventilation but notes: "If it is important to maintain a supply of cool air, it is appropriate for ventilation to be continued…maintain recirculation…shut down fresh air makeup."
>
> European Standard EN 50600-2-5 notes: "An alarm should not automatically disrupt the function of the facilities and infrastructures of the data center (e.g.,…maintain recirculation…shut down fresh air makeup)."
>
> NFPA 75 discusses HVAC shutdown in some detail. In part, it states: "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.
>
> Fire suppression systems used in IT facilities are often designed to detect and extinguish a fire in its incipient stage while cooling airflow through the facility is maintained and servers remain running."

2 Clean Agent Discharge Study

In data center applications, clean agents typically use the "total flood" application method. These systems are intended to produce a uniform extinguishing concentration of clean agent throughout the protected space. NFPA 2001, ISO 14520, and EN 15004 require that clean agent discharge nozzles be listed for their intended use. UL 2166, 2127, and FM 5600 contain specific test requirements. The listing process includes discharging clean agent from the nozzle into a volume, demonstrating that a homogenous agent concentration is achieved throughout the volume. In all cases, the discharge tests for listing these nozzles are performed in still air (i.e., no air movement).

Because modern data centers often require that cooling airflow be maintained during a clean agent discharge, the clean agent fire protection industry initiated a project to study the effects of high airflows on the development of clean agent concentrations. In 2015, the Fire Protection Research Foundation completed a planning project to lay the groundwork for testing clean agents in high airflow environments. In 2018, the Fire Suppression Systems Association (FSSA - USA) and the Fire Industry Association (FIA – UK) partnered to test clean agent systems in high airflow environments, Phase 2 of the aforementioned project.

3 Description of Test Project

A 7,275 ft^3 (206 m^3) test chamber was configured as a mock ITE server room. Two computer room air handlers (CRAH) and two rows of server cabinets were installed. The chamber was 26 ft (7.9 m) long by 20 ft (6.1 m) wide. The chamber had a 1 ½ ft (458 mm) deep subfloor and a 2 ft (610 mm) high space above the drop ceiling. The main room was 10 ½ ft (3.2 m) high.

Two Rows of Server Cabinets

Two Computer Room Air Handlers (CRAH)

Initially, carbon dioxide was used as a surrogate test gas instead of the halocarbon agents. Preliminary tests demonstrated that the carbon dioxide mimicked the distribution performance of the halocarbon agents. Follow-up tests were conducted with actual halocarbon agents NOVEC 1230 (FK-5-1-12) and FM-200 (HFC-227ea). The halocarbon and surrogate gas tests were done with nominal 10-second discharge times, in line with the system design standards.

Inert gas tests used IG-100 with discharge times of 60 seconds and 120 seconds, in line with the system design standards.

Agent concentrations were measured at key locations within the test chamber, including within the server cabinets. (See Figures 4 and 5.)

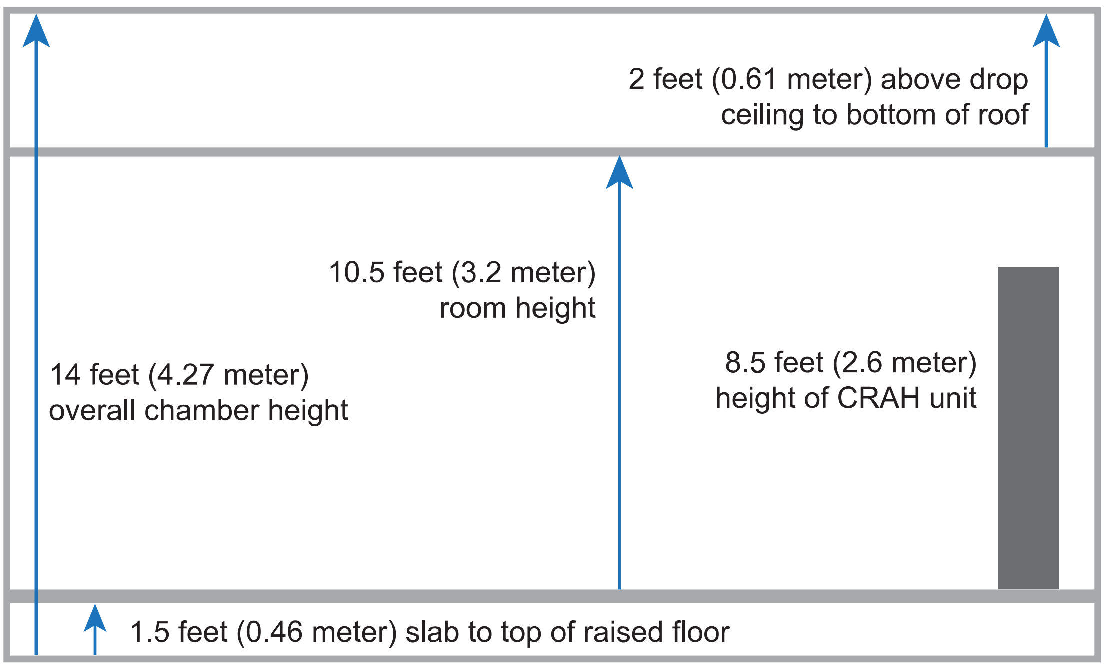

Figure 1 Dimensioned elevation cross-section of the test chamber.

Tests were conducted with airflows in the test chamber ranging from still air (no airflow) to a nominal 60 air changes per hour (60 ACH). The computer room air handlers (CRAH) were in 100% recirculating mode, with no makeup air.

Aisle containments, commonly used to separate cool air entering the ITE from the heated air returning to the CRAH, were installed for some tests.

3.1 Nozzle Locations

Room: A sidewall nozzle with a 180° discharge pattern was located in the main room approximately 6 inches (152 mm) below the drop ceiling and centered on the long wall of the chamber (See Figure 2).

Subfloor: A sidewall nozzle with a 180° discharge pattern was located below the raised floor approximately 9 inches (225 mm) below the bottom of the raised floor tiles and centered on the long wall of the chamber.

Above Ceiling: A sidewall nozzle with a 180° discharge pattern was located in the main room approximately 6 inches (152 mm) below the roof deck of the chamber and centered on the long wall of the chamber.

Aisle: A nozzle with a 360° discharge pattern was located in the center of the containment aisle (See Figure 2).

Figure 2 Photo showing the nozzle feed pipe to the containment aisle and the nozzle's location on the main room's wall. The aisle is configured as a "cold aisle."

3.2 Instrumentation

The atmosphere from the test chamber was drawn into sample hoses, as shown in Figures 4 and 5. The sample hose outlets were connected to the calibrated meters described below.

Carbon dioxide concentrations were measured using:

- CM-0010 CO_2 data loggers with a stated accuracy of ±70 ppm ± 5% of value.
- K30 10% CO_2 SENSOR SE-0118 with a stated accuracy of ± 300 ppm ± 3 % of measured value.

Nitrogen concentrations were derived from oxygen measurements. Oxygen was measured using Bacharach Fyrite™ InTech™ combustion analyzers (0 to 20.9% O_2 with 0.1% resolution and ±0.3% stated accuracy). Oxygen values were converted to nitrogen concentrations using the following equation:

$$Added\ Nitrogen\% = 100(Oxygen_1 - Oxygen_2)/Oxygen_1$$

Where $Oxygen_1$ is the pre-discharge oxygen concentration
$Oxygen_2$ is the oxygen concentration at the end of the discharge.

Halocarbon agent concentrations (FM-200™ and NOVEC 1230™) were measured using three-channel thermal conductivity meters. The accuracy of such meters is ±2% of reading at a constant temperature of 21°C (70°F) and humidity.

Meters were checked against a calibrated source before each test. The calibrations indicated the differences between channels on the various meters and could be taken into account when examining the actual test data.

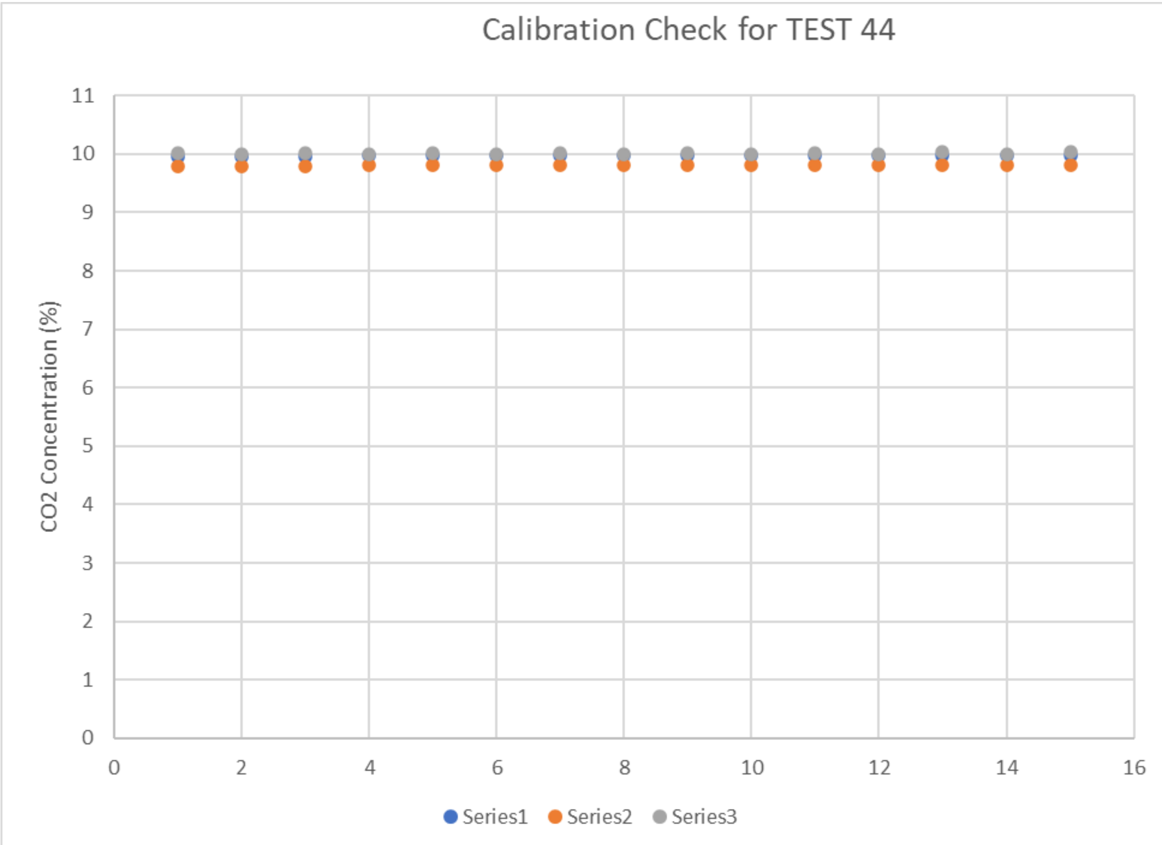

Figure 3 Example of calibration check for CO_2 meters. The check was done using a certified 10% CO_2 in air sample.

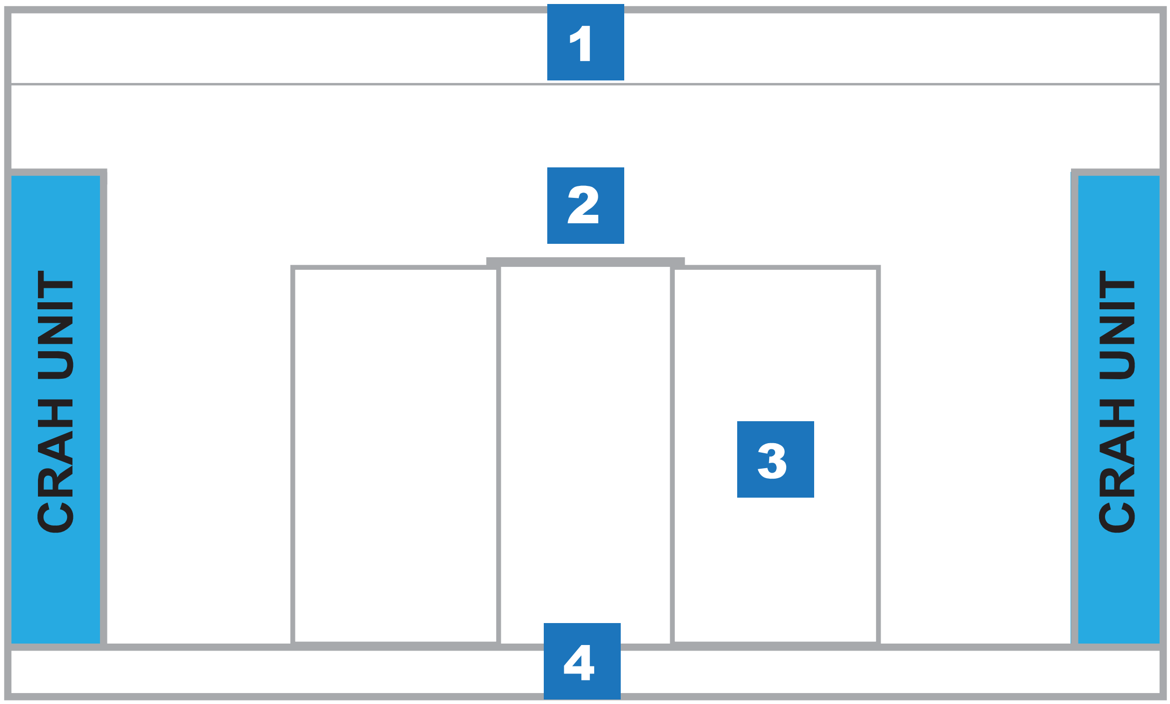

Figure 4 Locations of concentration sample hose for cold aisle configuration.

Sample point locations for the cold aisle configuration are as follows:

1. Above drop ceiling on wall opposite discharge nozzle
2. On the wall of the room near the top of the server cabinet, approximately 8 ½ ft (2.6 m) above the raised floor tile opposite the discharge nozzle
3. Inside server cabinet approximately 3 ft (915 mm) above raised floor tile
4. Under the raised floor, approximately 9 inches (225 mm) above the finished floor on the wall opposite the discharge nozzle.

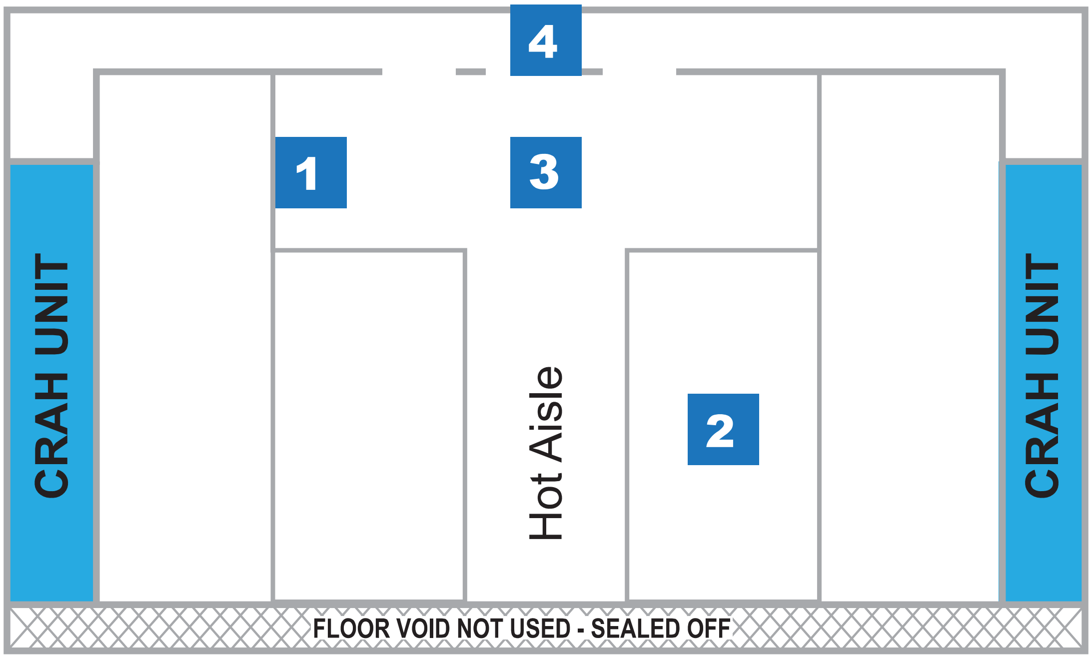

Figure 5 Elevation view showing the location of sample points for hot aisle configuration.

Sample point locations for the hot aisle configuration were as follows:

1) In the aisle above the server cabinet, approximately 8 ½ ft (2.6m) above the floor
2) Inside the server cabinet, approximately 3 ft (9015mm) above the floor
3) In the room on the wall opposite the discharge nozzle, approximately 8 ½ ft (2.6 m) above the raised floor tile
4) Above the drop ceiling on the wall opposite the nozzle.

Since the goal of the testing was to determine if a uniform concentration of agent was achieved throughout the test enclosure, the absolute values of the concentration readings were not important. Still, the relative concentrations between the sample points within the enclosure were important.

During some of the tests, the sample points were rotated between the meters with the concentrations from all sample points read on each meter. The dips in the meter readings occur each time a sample hose is disconnected from the meter, and another sample hose is connected to that meter. The dips in the meter readings are expected and should be ignored. Please see Figure 6 for an example of a test showing the effects of rotating the sample points between meters.

3.3 Pass/Fail Criteria

The discharge was considered to "PASS" if the concentration readings at all measuring points became identical within the limits of instrument error. A test was also considered to "PASS" if all measuring points reached at least 95% of the target concentration within 2 minutes after the end of the agent discharge.[1]

The discharge was considered a "FAIL" if the above requirements were unmet.

Some examples of tests considered to PASS are shown on the following pages.

[1] NFPA 2001, ISO 14520, and EN 15004 require the design concentrations to be the minimum extinguishing concentration multiplied by a safety factor for each agent/fuel combination. The minimum safety factor permitted by NFPA 2001 is 1.2 while the minimum safety factor permitted by ISO 14520 and EN 15004 is 1.3. The design concentration is the minimum extinguishing concentration times the safety factor. When the 1.2 safety factor is applied, 85% of the design concentration would extinguish flame. When the 1.3 safety factor is applied, 77% of the design concentration would extinguish flame. Thus, if a discharge produced 95% of the target concentration at all sample points, the flame extinguishing concentration would have been achieved with some margin for error.

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

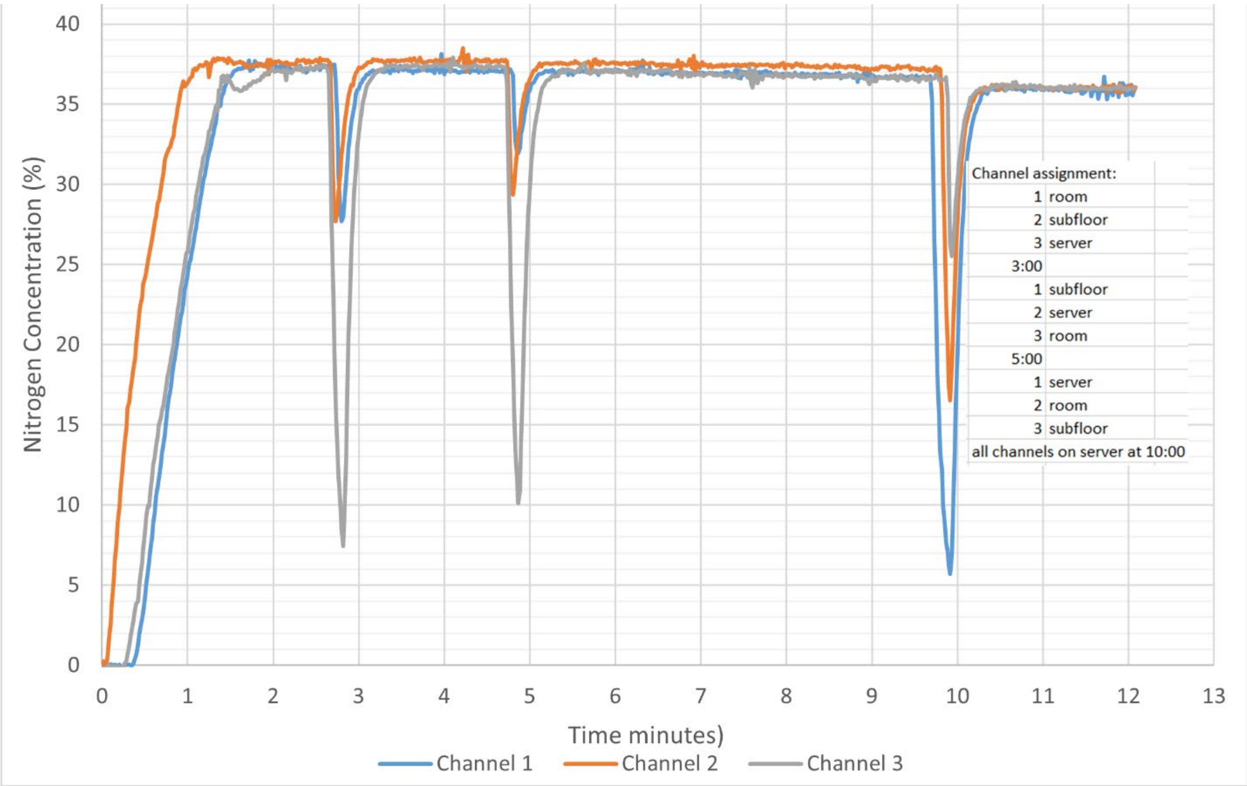

Figure 6 Example of test which PASSED

Figure 6 shows a nitrogen discharge into the chamber configured with a cold aisle. The hoses drawing atmospheric samples from the test enclosure were rotated from channel to channel, shown as dips in the concentration readings, to eliminate channel bias.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
55	Cold	FM-200	5.9	Room, Subfloor	60 ACH

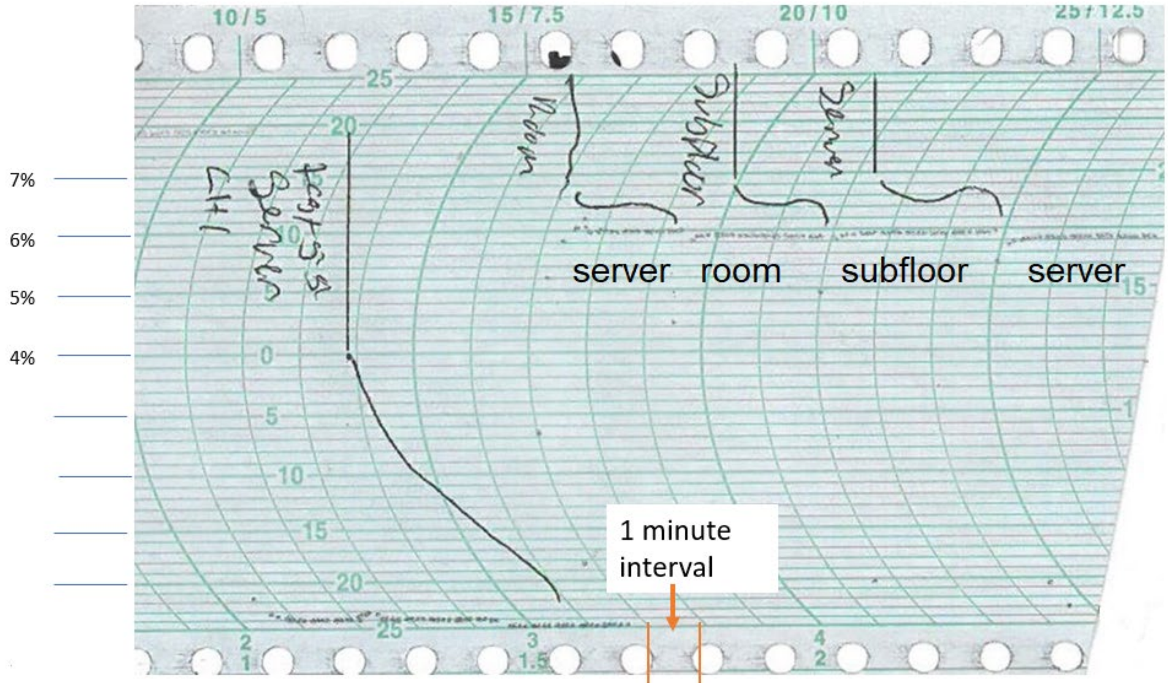

Figure 7 Halocarbon agent test PASSED

Figure 7 shows data from an FM-200™ test, which PASSED. The hoses drawing atmospheric samples from the test chamber were rotated from channel to channel to eliminate channel bias.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
62	Hot	CO_2	6	Room, Above Ceiling	18 ACH

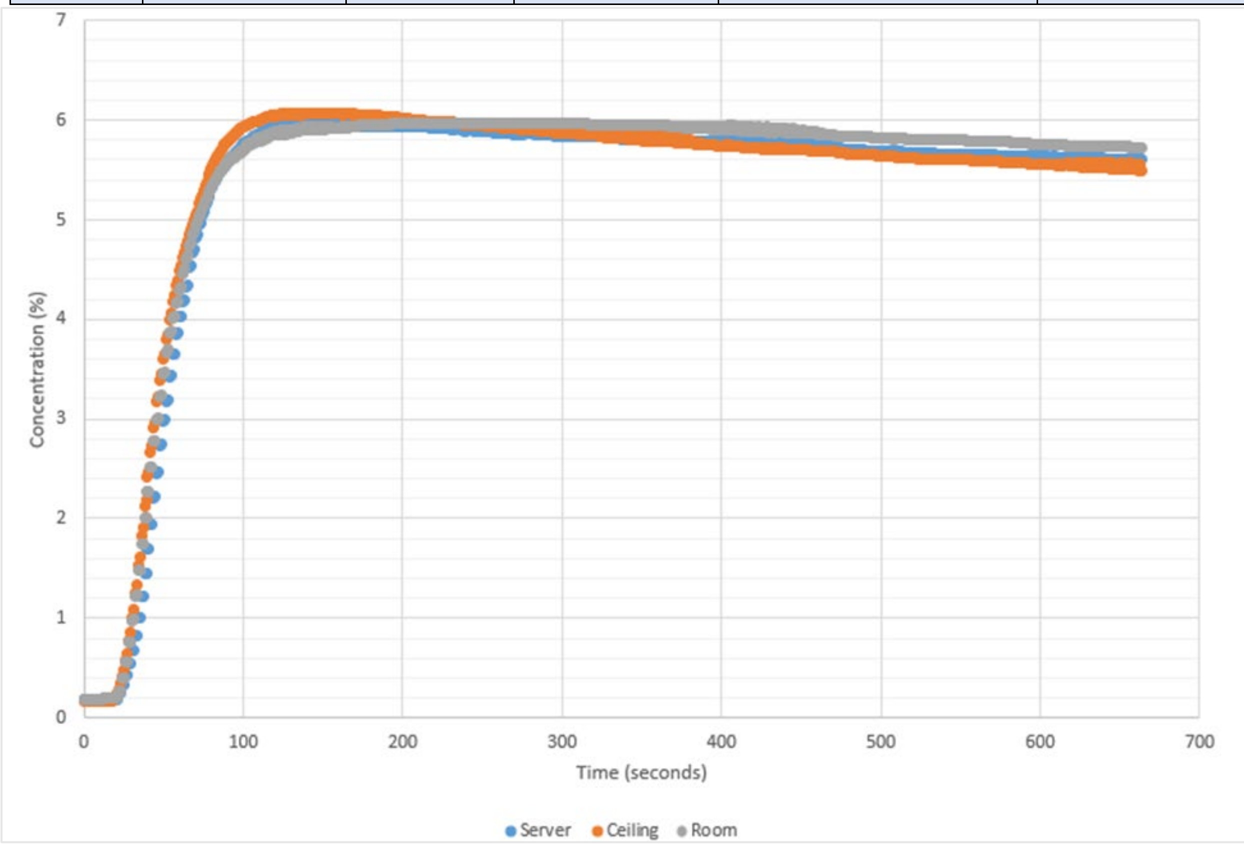

Figure 8 Test 62 using CO_2 as surrogate test gas PASSED

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
66	Hot	CO_2	6	Aisle, Above Ceiling	None

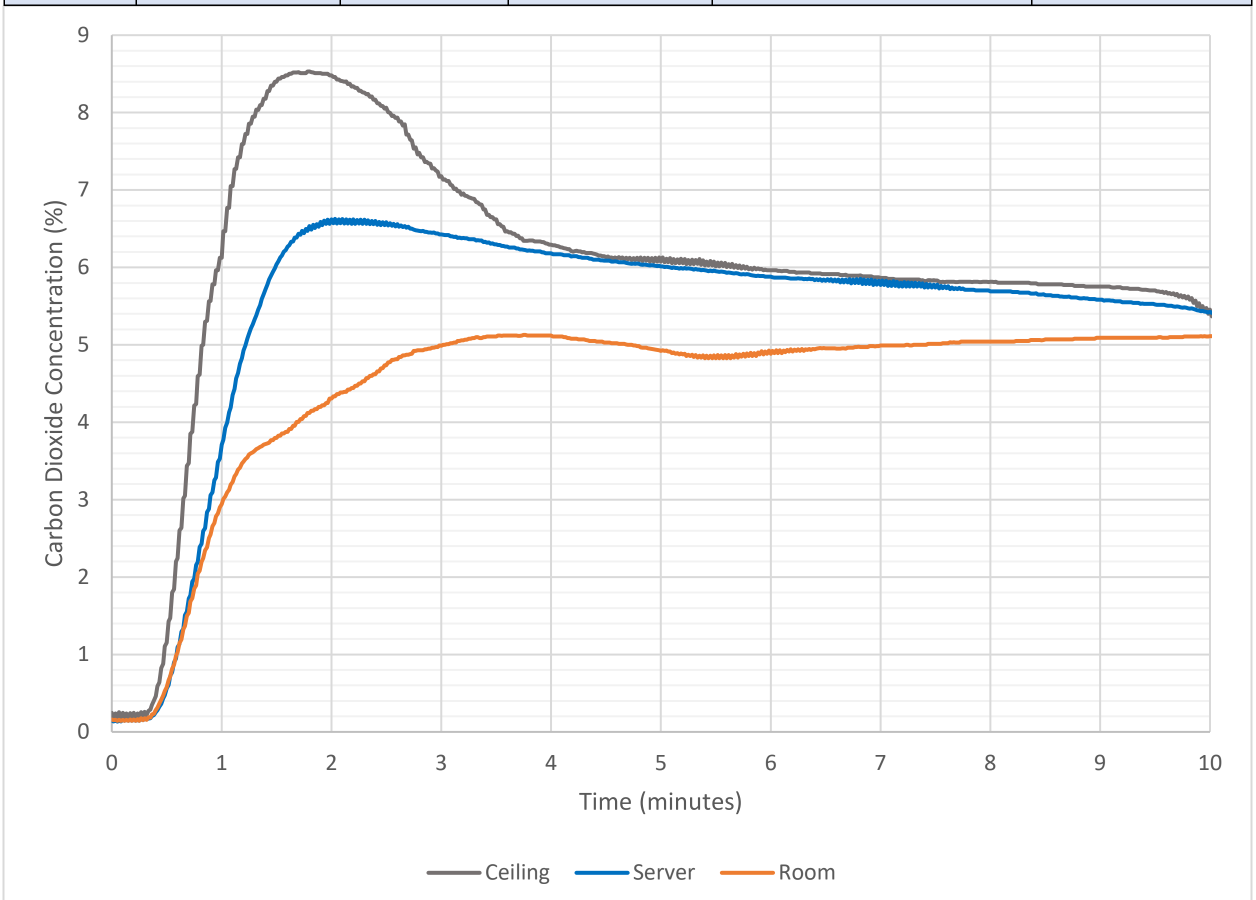

Figure 9 Test 66 shows the effect of eliminating the nozzle from the room. FAILS

Figure 9 displays data from a hot aisle test that FAILED. A nozzle was located in the center of the hot aisle, and a nozzle was located above the drop ceiling. The concentration in the room at the sample point located 8 ½ ft (2.6 m) above the floor failed to reach the target concentration.

3.4 Cold Aisle Test Results

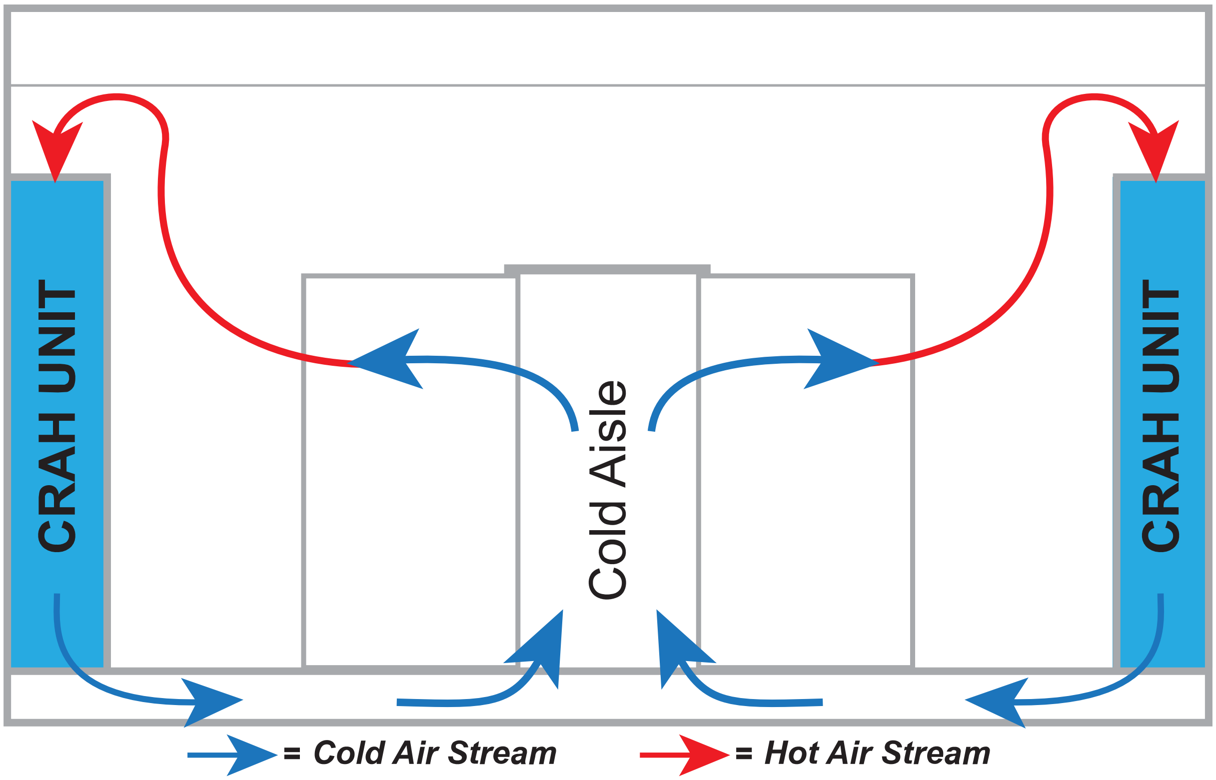

Figure 10 COLD AISLE CONFIGURATION airflow depicted.

Please see Figure 2 for a photograph of the chamber configured with a cold aisle.

Thirty-seven tests were completed in the enclosure with a cold aisle containment. Results are summarized in Table 1.

NOTE: Table 1 summarizes the test results. There are some discontinuities in the test numbers. This is due to some failures of data acquisition, which prevented concentration readings from being obtained for some tests – these tests were given numbers in the test log but are not included in the tables.

Table 1 Cold Aisle Configuration

Test	Aisle Containment Configuration	Nozzle Locations Indicated by an "X"				Agent	Airflow	Result
		Room	Subfloor	Aisle	Ceiling			
1	Cold	X	X	X	X	Nitrogen	No	Pass
3	Cold	X	X	X	X	Nitrogen	36 ACH	Pass
4	Cold	X	X	X	X	Nitrogen	62 ACH	Pass
5	Cold	X	X		X	Nitrogen	No	Pass
6	Cold		X	X	X	Nitrogen	No	Pass
7	Cold	X	X		X	Nitrogen	No	Pass
20	Cold	X	X		X	CO_2	No	Pass
23	Cold	X	X			CO_2	No	Pass
24	Cold	X	X		X	Nitrogen	36 ACH	Pass
25	Cold	X	X			CO_2	36 ACH	Pass[2]
26	Cold	X	X			CO_2	62 ACH	Pass
28	Cold	X	X			CO_2	36 ACH	Pass
29	Cold	X	X			CO_2	36 ACH	Pass
30	Cold	X	X			CO_2	62 ACH	Pass
31	Cold		X	X		CO_2	No	Fail[3]
32	Cold		X	X		CO_2	18 ACH	Pass [4]
36	Cold	X	X			CO_2	18 ACH	Pass
37	Cold		X			CO_2	No	Fail
38	Cold		X			CO_2	18 ACH	Fail
39	Cold		X			CO_2	36 ACH	Fail
41	Cold	X	X			CO_2	No	Pass
42	Cold	X	X			CO_2	59 ACH	Pass
43	Cold		X	X		CO_2	18 ACH	Pass
44	Cold		X	X		CO_2	38 ACH	Pass
45	Cold	X				CO_2	No	Fail
46	Cold	X				CO_2	18 ACH	Pass
47	Cold		X	X		CO_2	38 ACH	Pass

[2] Test 25 used the K30 sensors measuring room, subfloor and within server cabinet. Test 28 used K30 sensors to measure room, above ceiling and subfloor with the CM-0010 data loggers measuring room, subfloor and within server cabinet. Test 29 used both K30 and CM-0010 to sample room, subfloor, and within server cabinet. All tests passed.

[3] Test 31 had a nozzle in the cold aisle and in the subfloor but no nozzle within the room. The concentration in the subfloor exceeded 10%, concentration in the aisle averaged 5.4%, concentration in the room averaged 4.7%. Poor mixing was evident.

[4] Test 32 is a continuation of Test 31. 10 minutes after the start of discharge in Test 31, airflow was initiated and 40 seconds after initiation of airflow, concentrations readings in the subfloor, aisle and room converged to 5.7%.

Test	Aisle Containment Configuration	Room	Subfloor	Aisle	Ceiling	Agent	Airflow	Result
48	Cold		X	X		CO_2	No	Pass
49	Cold	X	X			NOVEC	No	Pass
51	Cold	X	X			FM-200	No	Pass
52	Cold	X	X			NOVEC	60 ACH	Pass
53	Cold	X	X			NOVEC	18 ACH	Pass
54	Cold	X	X			NOVEC	60 ACH	Pass
55	Cold	X	X			FM-200	60 ACH	Pass
86	Cold	X	X		X	Nitrogen	No	Demo test[5]
87	Cold	X	X		X	Nitrogen	9 ACH	Pass
88	Cold	X	X		X	Nitrogen	9 ACH	Pass

All tests using the cold aisle configuration "passed" except for those where nozzles were not correctly located. The following tests were considered to have failed: test 31, test 37, test 38, test 39, and test 45. Reasons for the "failures" are discussed on the following pages.

[5] Test 86 With no airflow, the agent concentration under the raised floor was 33% while the concentration in the room (above the raised floor) was 38%. The test was repeated with airflow (tests 87 and 88). With airflow present, a uniform concentration of 37% was measured in the subfloor, aisle, and room. For test 87, the discharge time was 60 seconds. For test 88, the discharge time was 120 seconds.

3.4.1 Discussion of Cold Aisle Tests

In test 31, nozzles were located in the subfloor and within the cold aisle. There was no airflow. The concentration results for this test are shown below. Ten minutes after the end of the system discharge, an airflow of 18 ACH was initiated. Within 40 seconds of the initiation of airflow, concentrations in the subfloor, room, and server cabinet converged to 5.7% (the continuation of test 31 with airflow is labeled test 32). Please see Figures 11 and 12 for data.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
31	Cold	CO_2	6	Subfloor, Cold Aisle	None

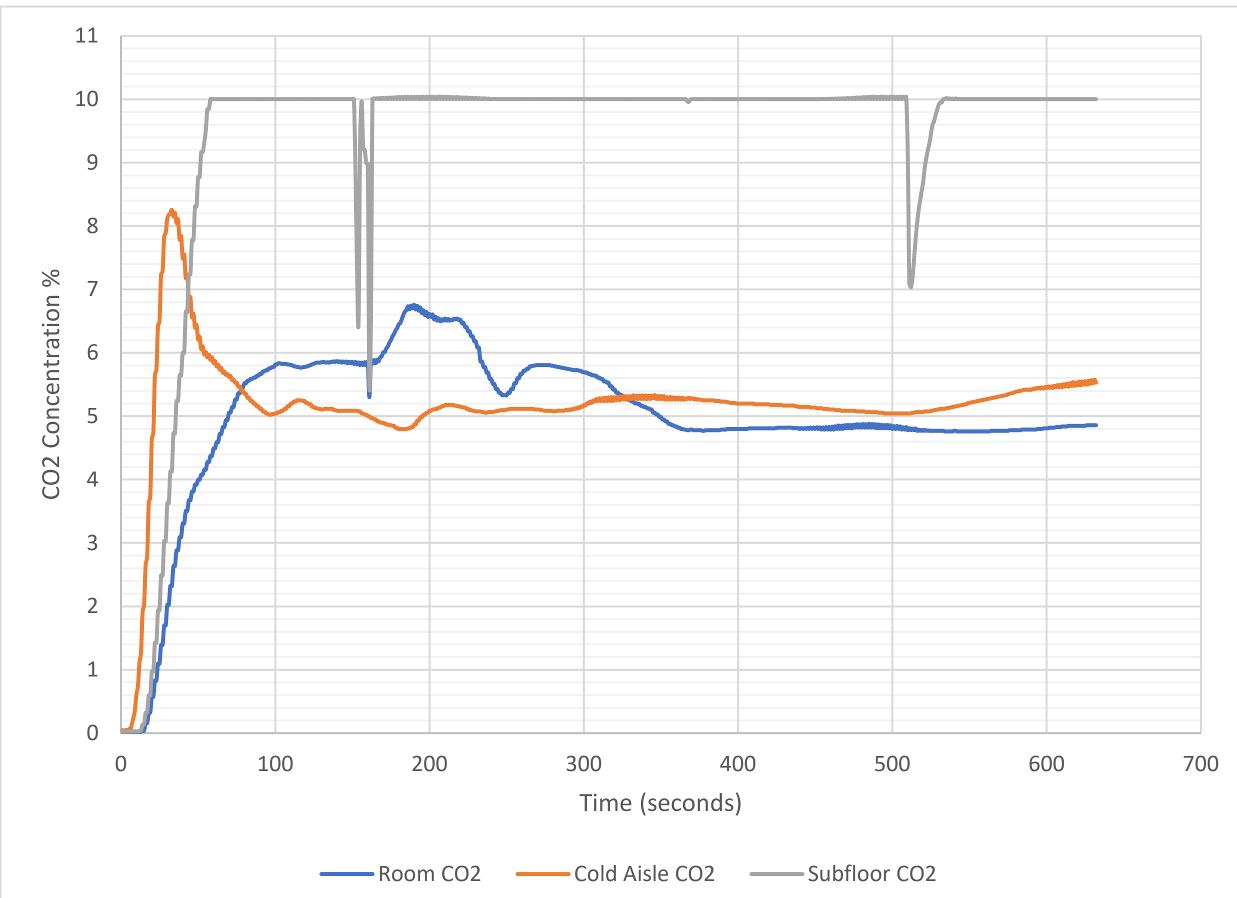

Figure 11 Concentration reading taken during test 31, cold aisle configuration. FAILS

Test data continued on the next page.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
32	Cold	CO_2	6	Subfloor, Cold Aisle	18 ACH
Continuation of Test 31 (see description in text)					

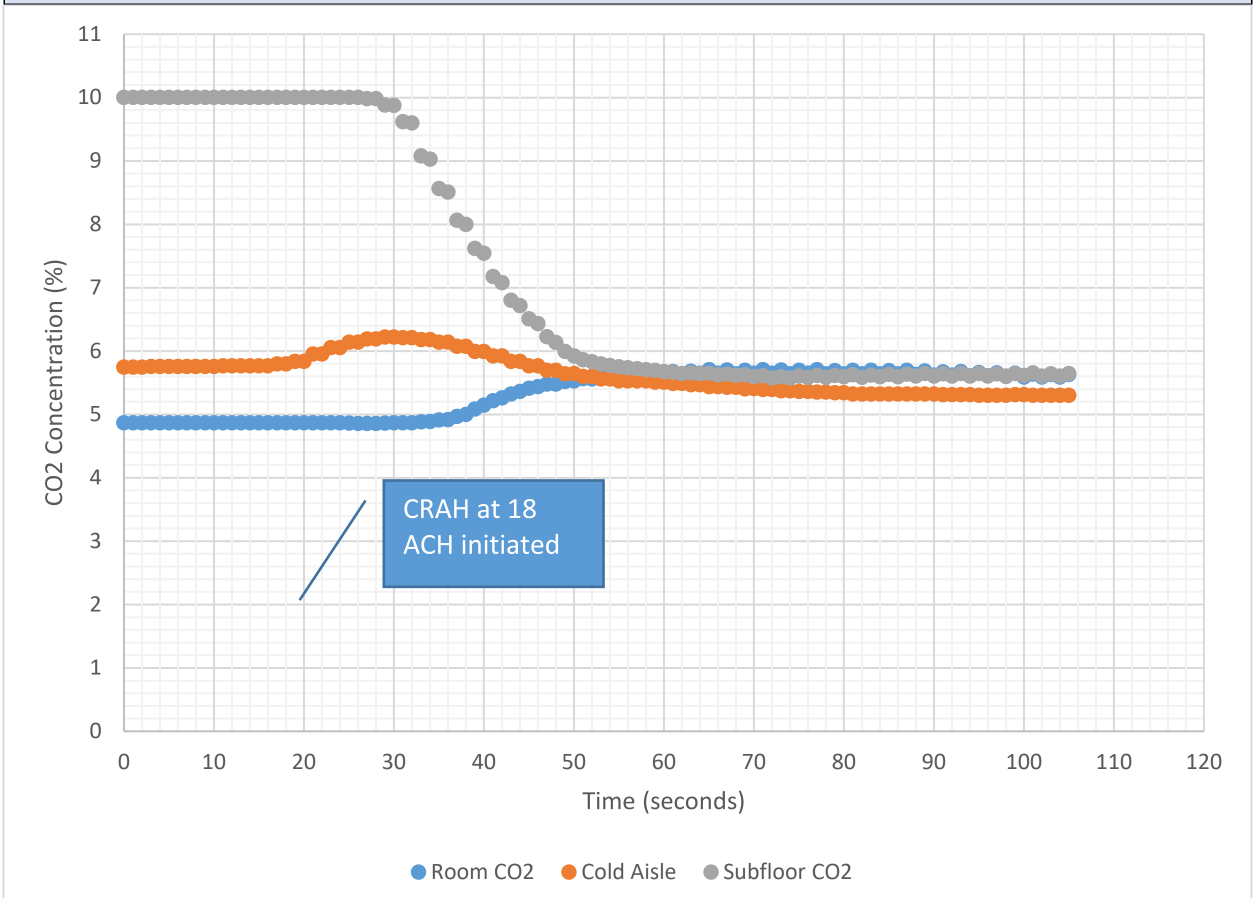

Figure 12 Test 32 is the continuation of Test 31 with airflow initiated. PASS

Tests 37, 38, 39 Cold Aisle Subfloor nozzle only

Tests 37, 38, and 39 were done with a nozzle in the subfloor—no nozzle in the room nor the cold aisle. The entire agent required to produce the target concentration in the enclosure was discharged into the subfloor. All of these tests are considered to fail.

During test 37, there was no airflow. The concentration in the subfloor exceeded the meter's entire span (10%), while no agent was measured in the room at 2.44 m (8 feet) above the floor, and no agent measured above the drop ceiling.

During test 38, an airflow of 18 ACH was used. The concentration in the room at 2.6 m (8 1/2 ft) above the floor) peaked at 6.5%, while the concentration in the subfloor peaked at 5.4%. No agent was detected at the sample point above the drop ceiling. Concentration readings are shown in Figure 13.

During test 39, an airflow of 36 ACH was used. Concentration readings for this test are shown in Figure 14.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
38	Cold	CO_2	5.5	Subfloor (2 noz)	18 ACH

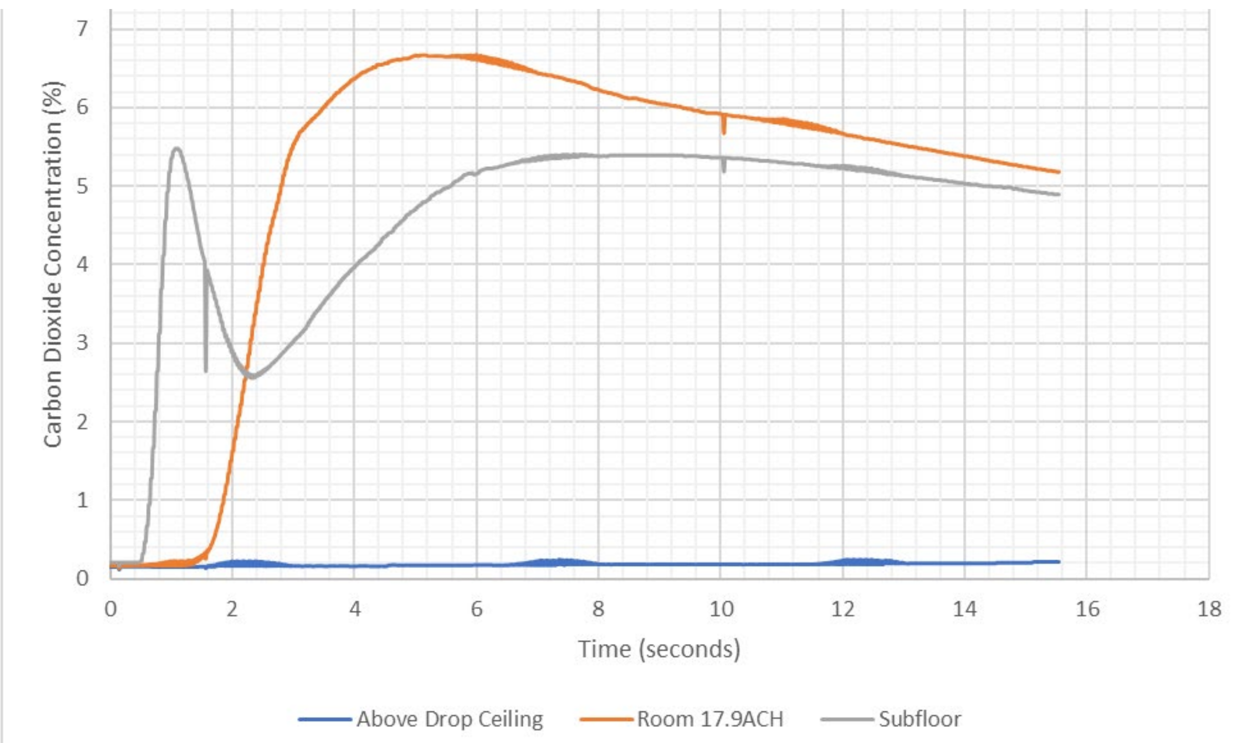

Figure 13 Test 38 concentrations FAILS

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
39	Cold	CO_2	5.5	Subfloor (2 noz)	36 ACH

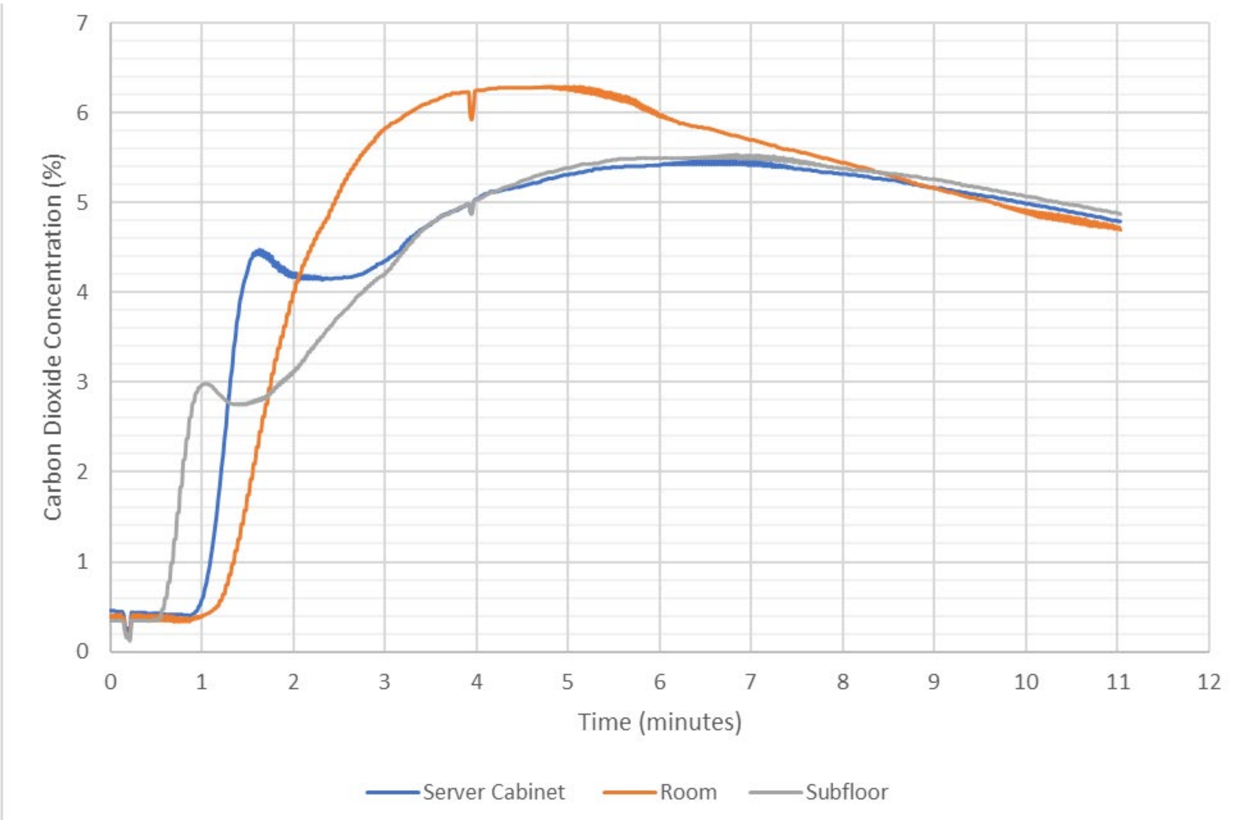

Figure 14 Concentration readings taken during test 39, cold aisle configuration. FAILS

Tests 45 and 46 Cold Aisle Room nozzle only

Test 45 (Figure 15) had a nozzle in the room, no nozzle in the subfloor, and no airflow. The subfloor did not reach the target concentration until 12 minutes after the end of the system discharge. (Test 46 was a repeat of test 45, except that airflow was 18 ACH. Test 46 passed.)

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
45	Cold	CO_2	5.5	Room	None

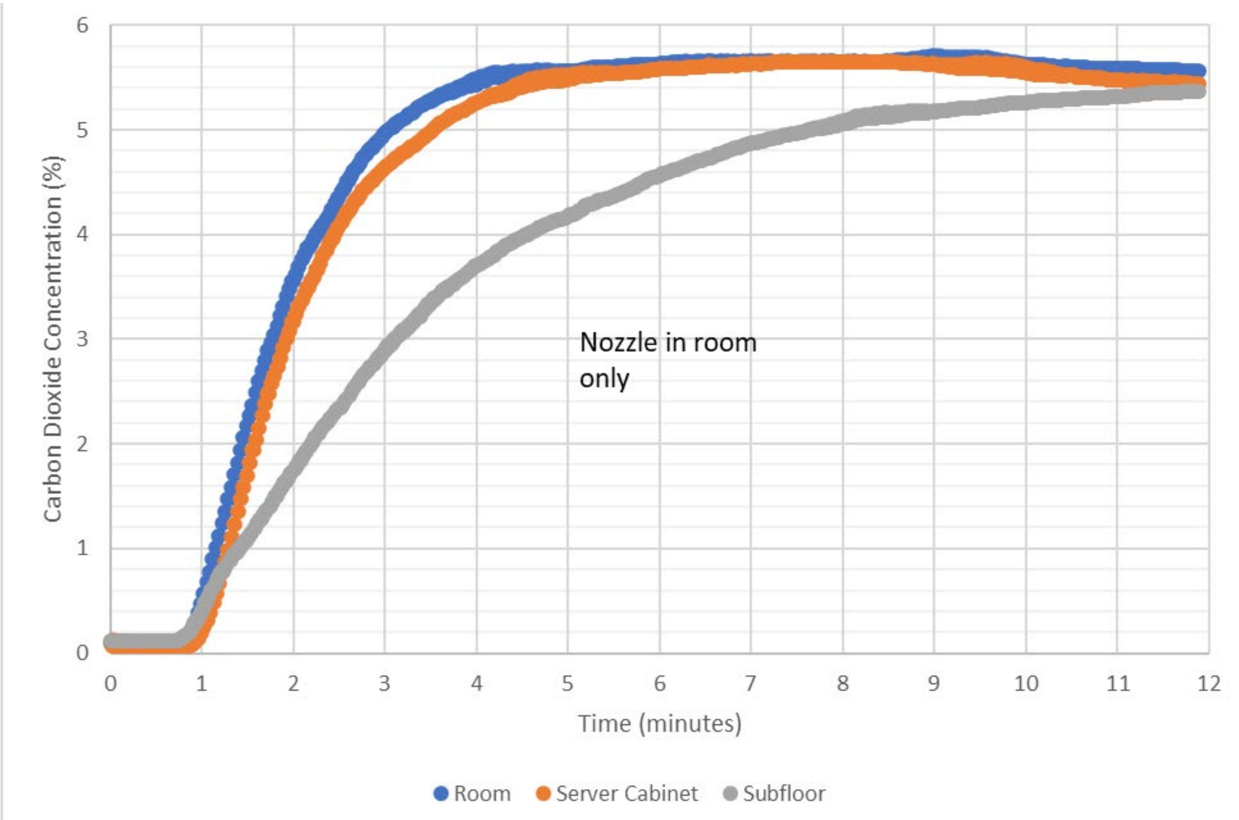

Figure 15 Test 45 with no airflow, a single nozzle in the room. FAIL

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

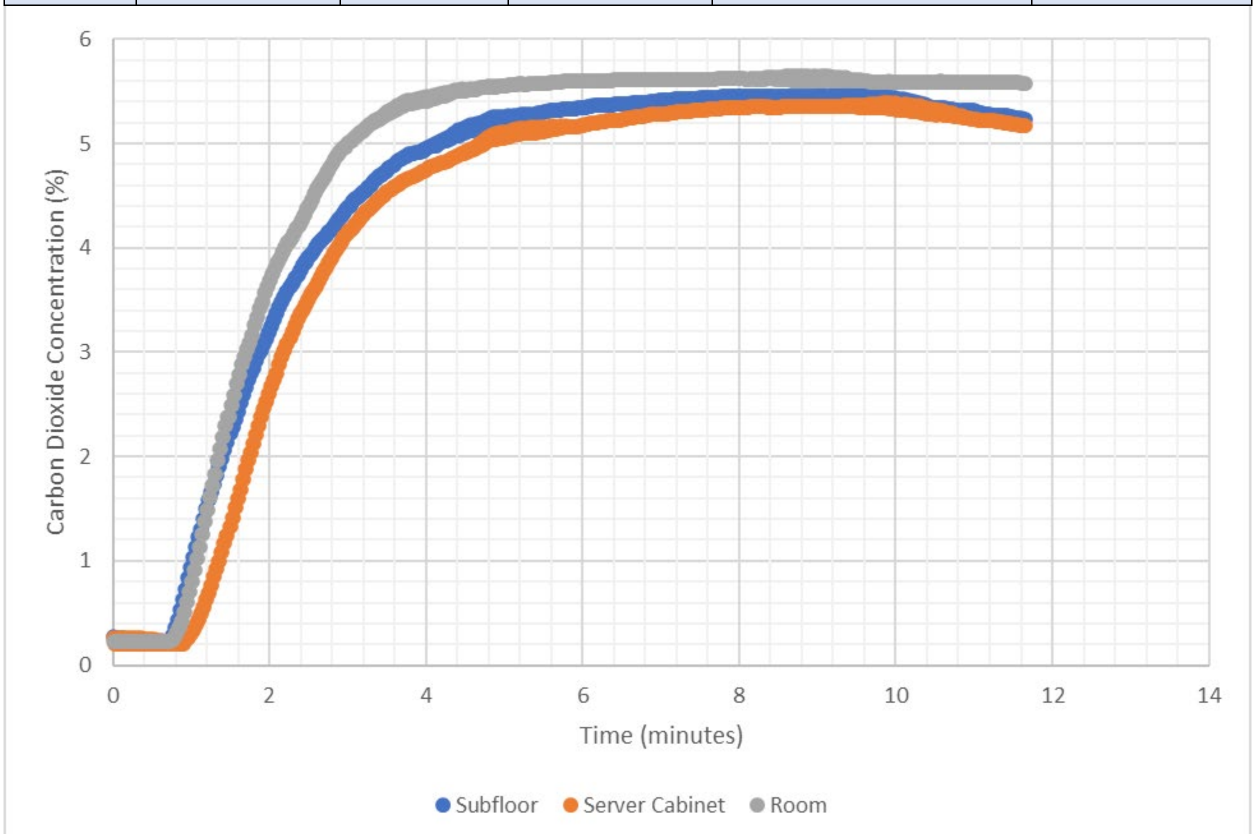

Figure 16 Test 46 is a repeat of Test 45 with airflow of 18 ACH. PASS

3.5 Hot Aisle Test Results (Twenty-Six Tests)

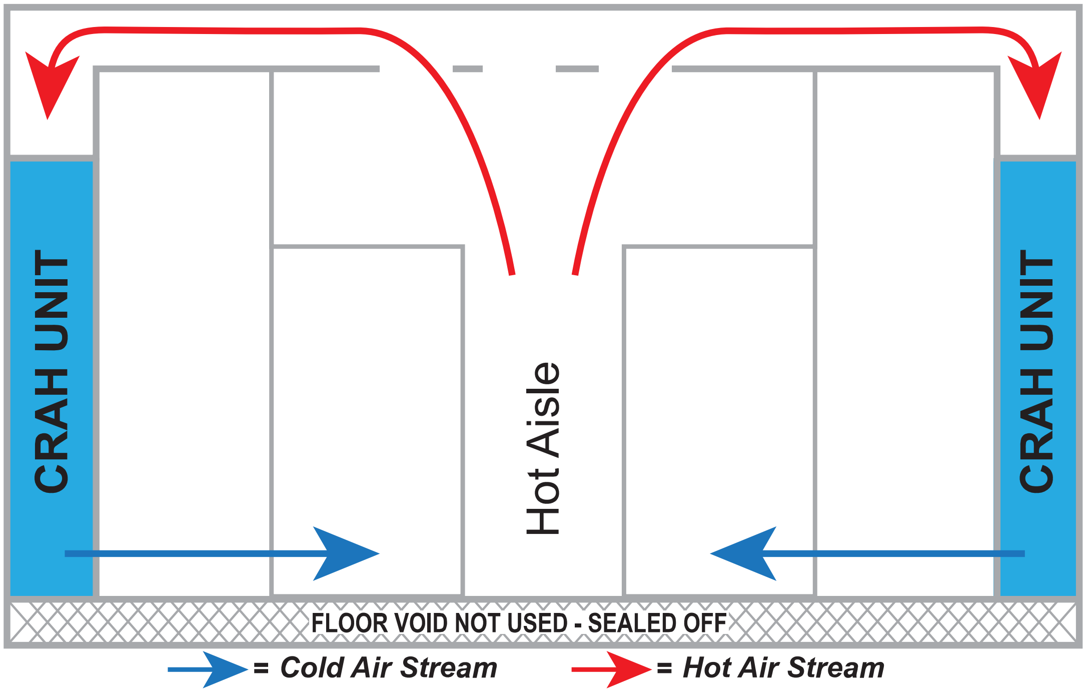

Figure 17 HOT AISLE CONFIGURATION depicted with airflow pattern.

Figure 18 Photo of test enclosure configured with a hot aisle.

Figure 19 Nozzle inside hot aisle for tests 9, 66, 67, and 68. Concentration sample hose can be seen entering the hot aisle.

Table 2 Hot Aisle Configuration

Test	Aisle Containment Configuration	Nozzle Locations Indicated by an "X"			Agent	Airflow	Result
		Room	Aisle	Ceiling			
8	Hot	X		X	Nitrogen	36.6 ACH	Pass
9	Hot	X	X	X	Nitrogen	No	Pass
10	Hot	X			Nitrogen	No	Pass
21	Hot	X		X	CO_2	36.6 ACH	Pass
59	Hot	X		X	CO_2	No	Pass
60	Hot	X		X	CO_2	No	Pass
61	Hot	X		X	CO_2	61 ACH	Pass
62	Hot	X		X	CO_2	18 ACH	Pass
63	Hot	X		X	CO_2	No	Pass[6]
64	Hot	X		X	CO_2	60 ACH	Pass[7]
65	Hot	X		X	CO_2	No	Pass[8]
66	Hot		X	X	CO_2	No	Fail[9]
67	Hot		X	X	CO_2	18 ACH	Pass[10]
68	Hot	X	X	X	CO_2	60 ACH	Pass
69	Hot	X			CO_2	18 ACH	Pass/Fail?[11]
73	Hot	X		X	NOVEC	No	Pass
74	Hot	X		X	NOVEC	18 ACH	Pass
75	Hot	X		X	NOVEC	18 ACH	Pass
77	Hot	X		X	FM-200	No	Fail[12]
78	Hot	X		X	FM-200	18 ACH	Pass
79	Hot	X		X	CO_2	18 ACH	Pass
81	Hot	X		X	Nitrogen	No	Pass
82	Hot	X		X	Nitrogen	Various	Pass
83	Hot	X		X	Nitrogen	18 ACH	Pass
84	Hot	X		X	CO_2	No	Pass
85	Hot	X		X	FM-200	No	Fail[11]

[6] Test 63 Ceiling tile near CRAH blew off during discharge. Initial concentration above ceiling 6.8%; 6.0% at room and at server sample points. CO_2 from room nozzle went into space above drop ceiling through open ceiling tile.

[7] Test 64 Room and Server concentrations 6.4%; Concentration above drop ceiling 5.8%. Airflow shut down at end of discharge.

[8] Test 65 Room and Server concentrations 6%; concentration above drop ceiling 5.7%.

[9] Test 66 Room concentration peaked at 85% of target concentration. Server and above ceiling exceeded 6%.

[10] Test 67 Server and above ceiling concentrations initially exceeded 6% target; room initially reached 5.75% (96% of target concentration).

[11] Test 69 Room and server concentrations reached 6.5% initially; concentration above drop ceiling reached target concentration 3 minutes after end of discharge.

[12,11] Tests 77 and 85 Discharge nozzle located too close to aisle containment partition. Liquid agent impinged on partition and ran down the partition to floor of the chamber resulting in higher concentration near floor at 0.9m (3 ft) above floor and a lower concentration at top of server cabinet 2.6m (8 ½ ft) above floor.

3.5.1 Discussion of Hot Aisle Tests

When the test chamber was configured with a hot aisle, the space above the drop ceiling served as a return air plenum. The number and location of discharge nozzles varied among the tests:

- Nozzle in the room and above the ceiling.
- Nozzle in the room
- Nozzle in the aisle and above the ceiling (no nozzle in the room).

Discharges of inert gas (nitrogen) in the hot aisle produced consistently uniform concentrations in the room, hot aisle, and above the connected drop ceiling.

In the 15 hot aisle tests using CO_2 as a surrogate test gas, uniform concentrations were measured in nine of the tests at all sample points. In six tests, uniform concentrations were not measured at all sample points. The following considers the six tests in which uniform concentrations were not measured at all sample points.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
63	Hot	CO_2	6.2	Room, Above Ceiling	None

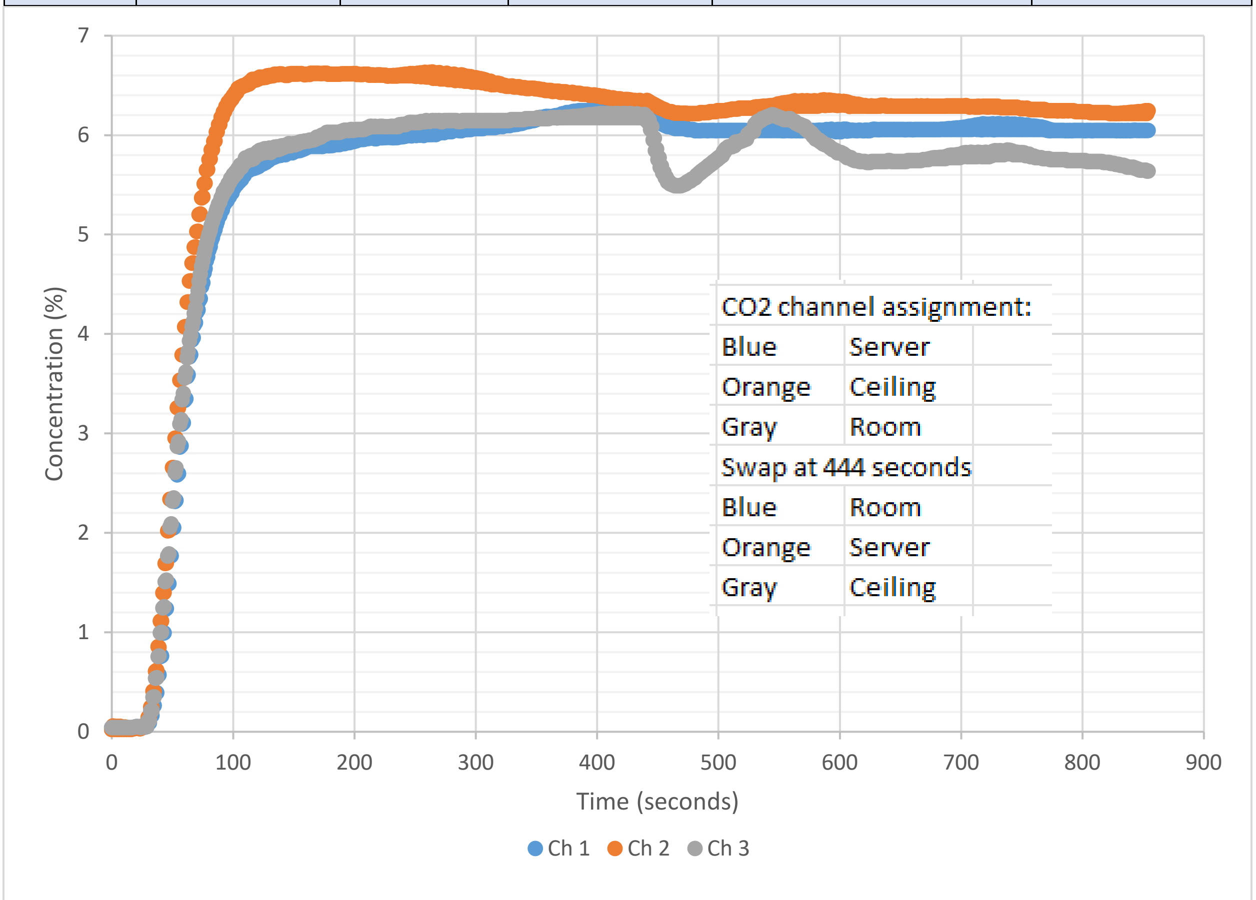

Figure 20 Test 63, hot aisle configuration PASS

Test 63 was performed with no airflow and nozzles in the room and above the drop ceiling. A ceiling tile was dislodged at the start of the discharge, allowing test gas from one of the discharge nozzle ports to go into the ceiling void. The concentration above the drop ceiling initially measured 6.6%, while the concentration in the room and within the server cabinet initially measured 5.8%. Within approximately 7 minutes, the concentrations throughout the test chamber equalized to 6.2%, the target concentration. Given that the concentrations throughout the enclosure and above the ceiling initially exceeded 95% of the target concentration, the test was considered a passing test.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
65	Hot	CO_2	6	Room, Above Ceiling	None

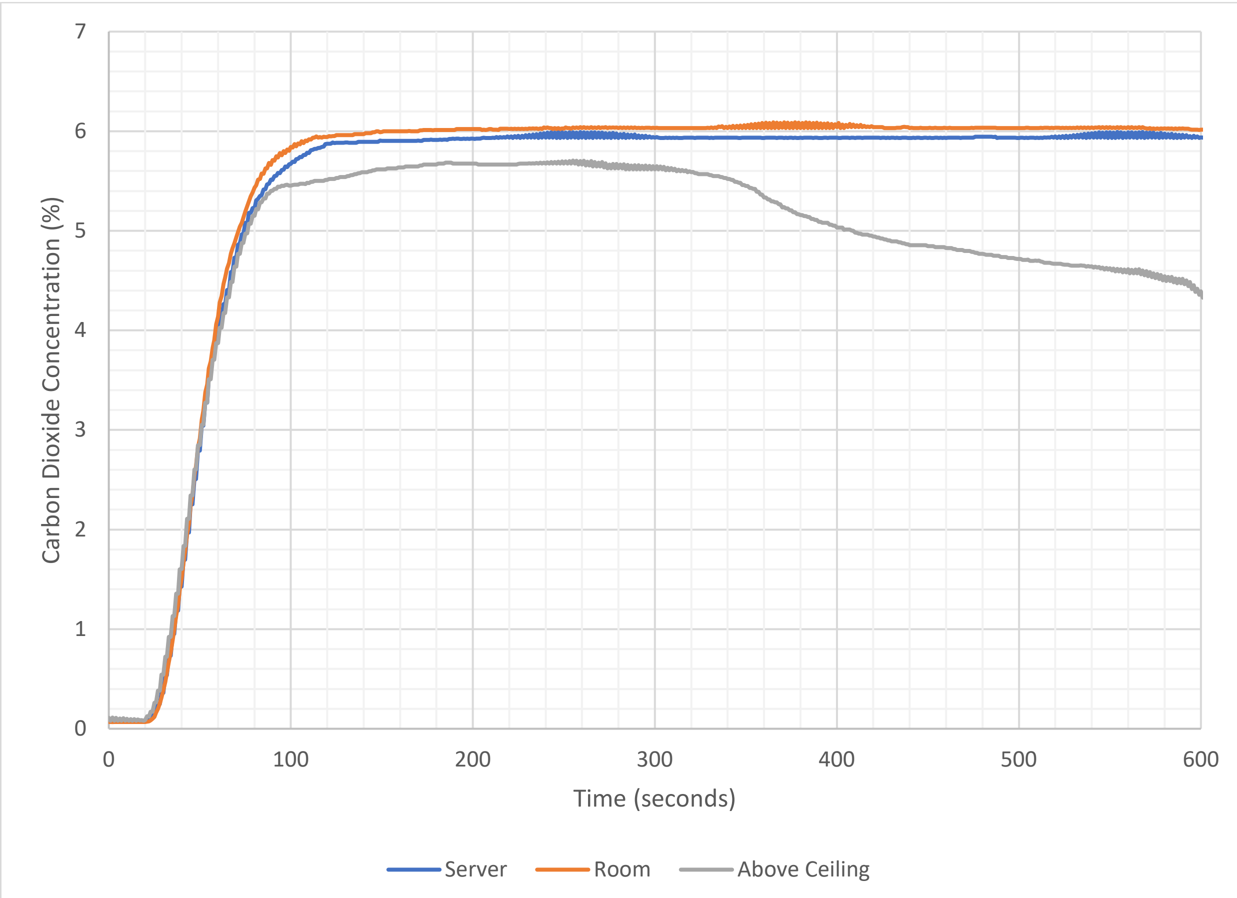

Figure 21 Hot Aisle; no airflow; nozzles in the room and above the ceiling. PASS

Test 65 was a repeat of Test 63, except that the ceiling tile dislodged in Test 63 was secured to keep it in place during the discharge. The concentration above the drop ceiling peaked at 5.7%, 95% of the target concentration (PASS). This slight shortfall resulted from how the system pipework and nozzles were configured during the tests and were not considered important. The slight shortfall was offset in test 63 due to ceiling tiles lifting during the discharge, allowing some of the agent discharged from the room nozzle to directly enter the space above the ceiling through the opening at the displaced tile.

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
64	Hot	CO_2	6.2	Room, Above-ceiling	60 ACH
Airflow was shut down at the end of the discharge.					

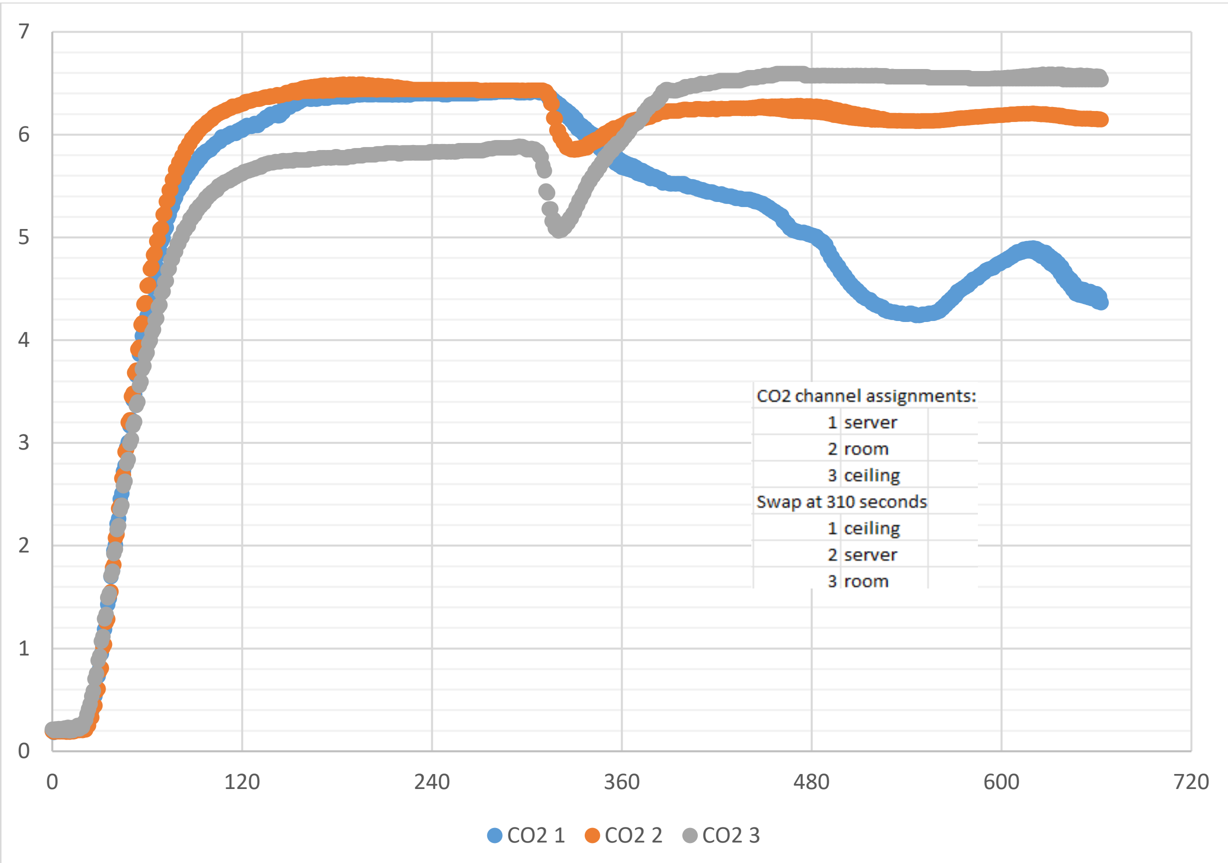

Figure 22 Hot aisle configuration; 60 ACH during discharge, airflow shut down at end of discharge. FAIL

Test 64 was a variation of test 63. The test configuration was identical to test 63, except that steps were taken to prevent the ceiling tiles from being displaced during the discharge. An airflow providing 60 ACH was maintained during the 10-second discharge, and the airflow was shut down at the end of the discharge. The concentration above the drop ceiling leveled at about 5.8% (94% of the 6.2% target concentration, hence counted as a FAIL), while concentrations in the room and server cabinet reached 6.4%. The shortfall in agent discharged above the ceiling is similar to that observed with no airflow (Test 65 discussed above). It is not a result of airflow but rather due to the system pipework and nozzle configuration for these tests. As observed in other tests, airflow during the discharge did not affect the agent distribution within the enclosure.

Tests 66 and 67 (Hot Aisle)

Tests 66 and 67 had nozzles located within the hot aisle and above the drop ceiling, and no nozzle in the room. These tests illustrated the need to locate a nozzle within the room. The tests also demonstrate that the presence of airflow in the range tested up to 60 ACH does not have a negative effect on agent distribution.

In test 66, with no airflow, the concentration measured in the room outside the hot aisle reached 5%, while the concentration measured in the aisle and above the drop ceiling equalized at 6.2%. This was considered a "fail."

Test #	Aisle	Agent	Target %	Nozzle Location	Airflow
66	Hot	CO_2	6	Hot Aisle, Above Ceiling	None

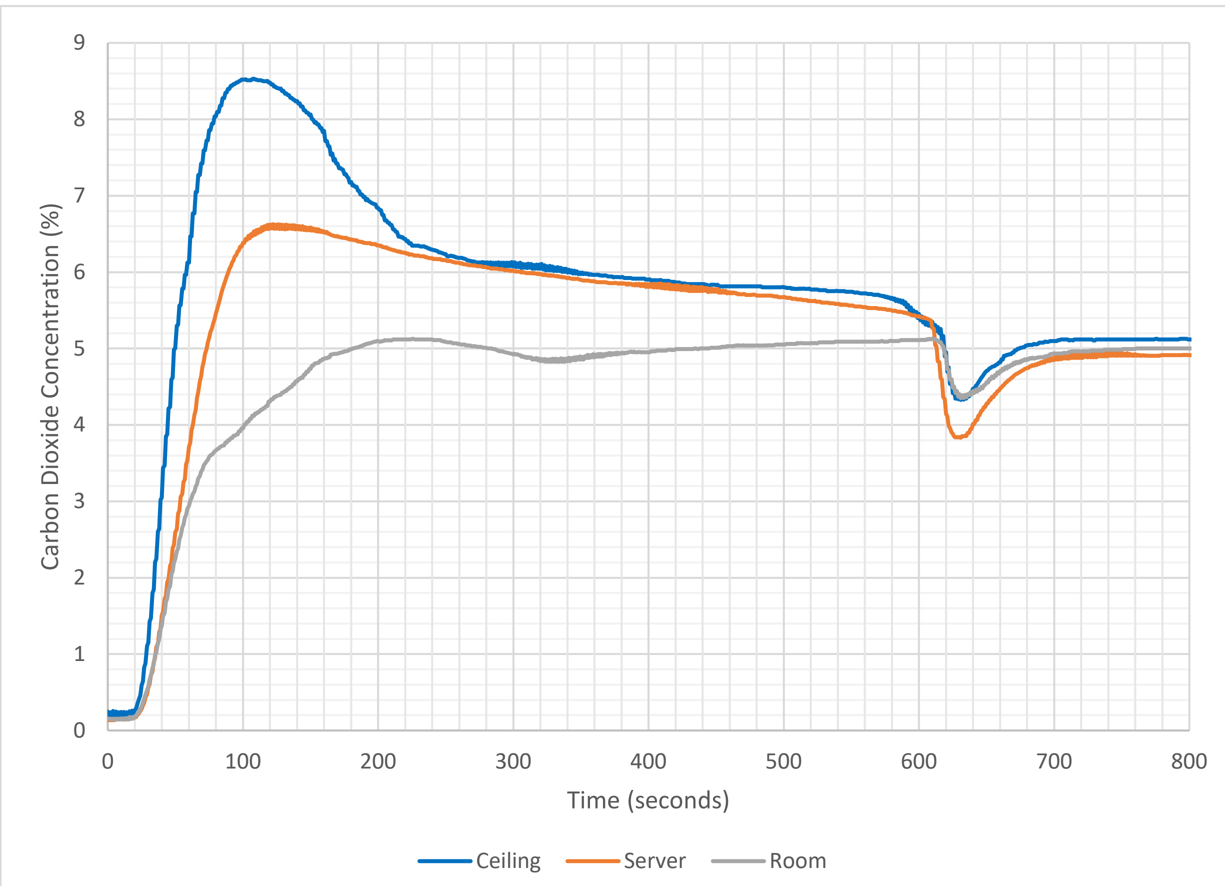

Figure 23 Test 66 illustrates the effect of improper nozzle placement, i.e., no nozzle in the room. FAILS

In test 67, with an airflow of 18 ACH, the concentrations reached 5.8%. In contrast, concentration readings above the drop ceiling and in the aisle momentarily reached 6.8% and 6.2%, respectively, before converging to 5.7% at all sample points, room, aisle, and above the drop ceiling. Given that all concentrations converged to 95% of the 6% target concentration, this test was considered a passing test.

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

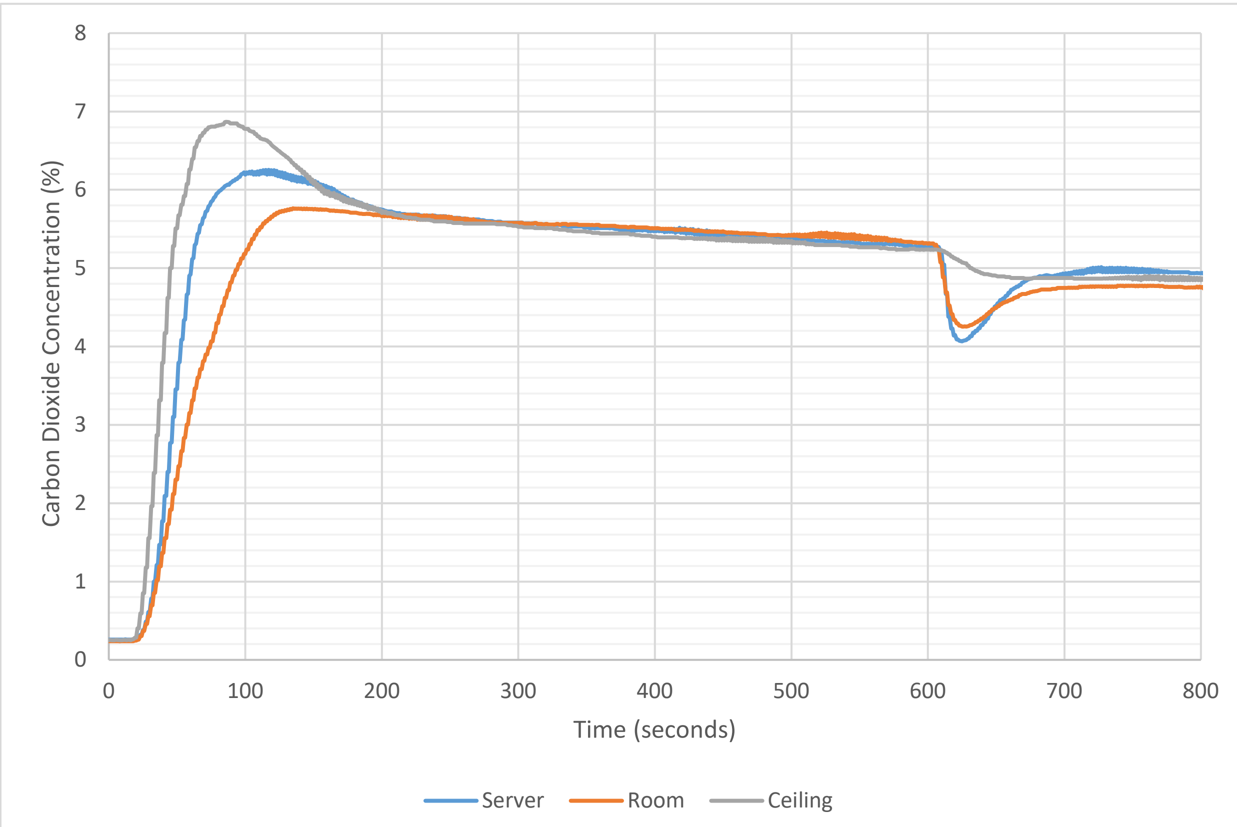

Figure 24 Test 67 shows the effect of airflow on a system that lacks the recommended nozzle in the room. PASS

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

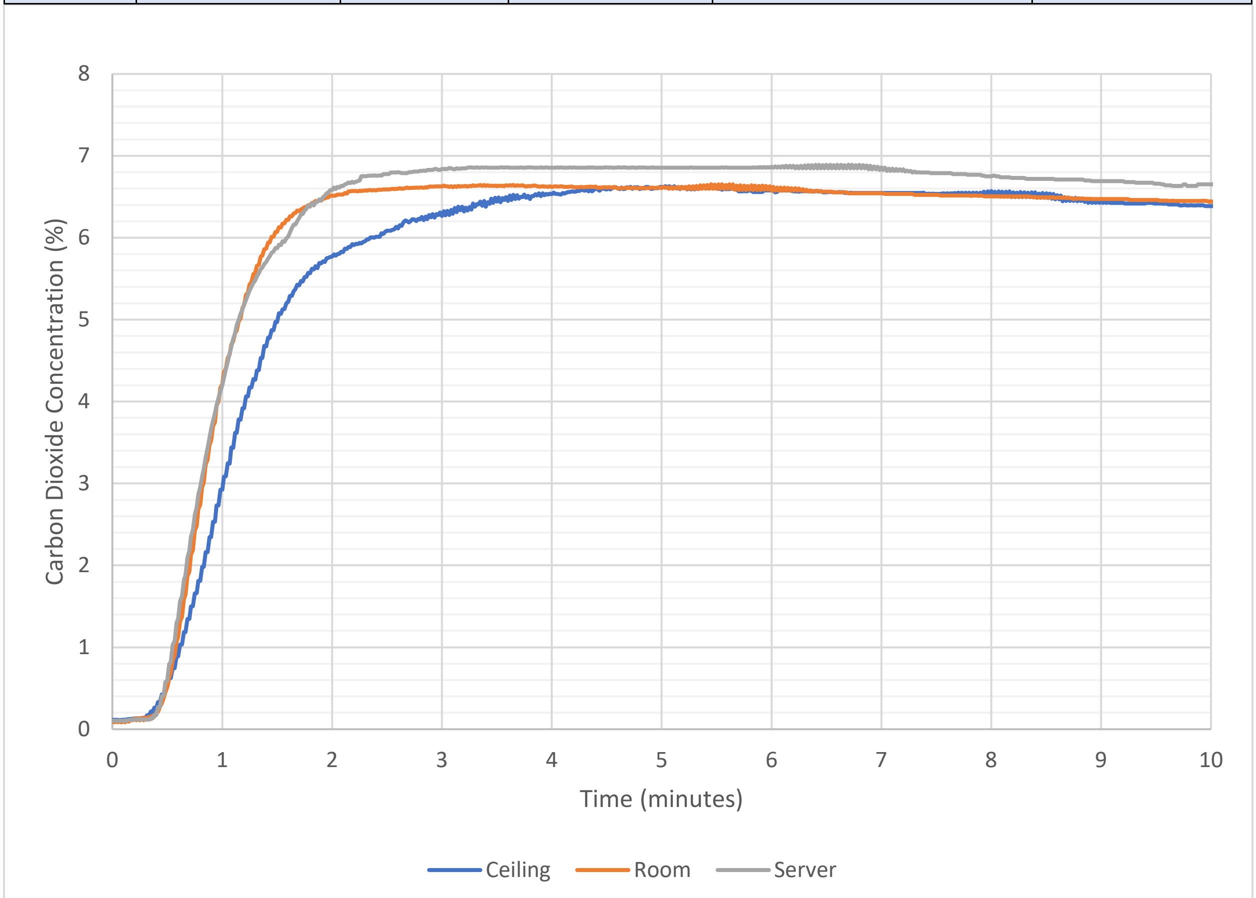

Figure 25 Test 69 data. See the discussion below.

Test 69 had a single nozzle on the room's wall outside the hot aisle. The concentrations in the room and within the hot aisle reached 6.6% and 6.8%, respectively, within 2 minutes after the end of the discharge. The concentration above the drop ceiling reached 6% (92 % of the target concentration of 6.5%) 2 minutes after the end of discharge. The concentration above the ceiling peaked at 6.6% approximately 4 minutes after the end of the discharge. Using the convention that all concentration readings must reach 95% of the design concentration within 2 minutes after the end of discharge, this test failed. If this test had been conducted in an actual hazard with no combustibles above the drop ceiling, a "pass" could be justified.

Even if combustibles were present above the drop ceiling, it could be argued that the system provided adequate protection based on the following considerations:

1. If a 1.3 safety factor had been used, the extinguishing concentration for flame would be 5%. 5% was reached above the drop ceiling approximately 1 minute after the end of discharge.
2. If a 1.2 safety factor had been used, the extinguishing concentration for flame would be 5.4%. 5.4% was reached above the drop ceiling approximately 1½ minutes after the end of discharge.

Nonetheless, the conservative recommendation in this report is that a nozzle should be located above drop ceilings containing combustibles. This is further discussed in this report's "Nozzle Location" section.

3.6 Tests with no Aisle Containment

Three tests were conducted with no aisle containment. CRAH discharged air directly into the room with return air through the space above the drop ceiling. The tests used the surrogate test gas, CO_2.

Table 3 No Aisle Containment

Test	Aisle Containment Configuration	Nozzle Locations Indicated by an "X"			Agent	Airflow	Result
		Room	Aisle	Ceiling			
70	None	X		X	CO_2	18 ACH	Pass
71	None	X		X	CO^2	60 ACH	Pass
72	None	X		X	CO_2	60 ACH	Pass [13]

3.7 CONCLUSION: Effect of Airflow

Airflow either improved the homogeneity of agent concentration throughout the test chamber, including within the server cabinets, or in cases where the agent concentration was uniform with no airflow, it did not affect the homogeneity of concentration.

[13] The concentration measured in the server cabinet was 6.5% versus 6.2% measured in the room and above the ceiling during Test 71. The test was repeated (Test 72) with the sample points swapped between the server cabinet and above ceiling. The concentration measured above the ceiling was 7.1% versus 6.8% measured in the server cabinet. This verified that the 5% difference in measured concentrations observed in Test 71 and the similar difference in Test 72 were due to channel variation in the instrument used for these tests.

4 Nozzle Location Study

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

Some have questioned whether the provision of discharge nozzles in each volume is necessary, mainly when there is airflow to help distribute the agent.

Another question related to the location of nozzles is whether a nozzle needs to be located within each aisle partition. NFPA 75 states the following:

> "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."
>
> "A.9.4.3 Various methods of isolating the aisles between rows of equipment racks, known as hot aisle or cold aisle containment, are employed to prevent the mixing of hot exhaust air or cold intake air through the ITE. In the event that a fire triggers the release of a clean agent gaseous suppression system, the gas suppressant should be able to penetrate all of the ITE. In most cases of whole room total flooding systems, the airflow through the ITE normally would be sufficient to satisfy this requirement, but the method should be evaluated on a case-by-case basis."

Several tests were done to examine the above NFPA requirements. The tests are considered in some detail in the sections of this report dealing with the cold and hot aisle configurations. A summary of the results is shown in the following tables.

Table 4 One or more nozzles omitted – cold aisle configuration

Cold Aisle Configuration with Subfloor				
Test	**Nozzle Locations**	**Airflow**	**Result**	**Comment**
37	Subfloor only (no room nozzle)	None	Fail	No agent in server cabinets[14]
38	Subfloor only (no room nozzle)	18 ACH	Fail	Subfloor fails to reach design concentration[15]
39	Subfloor only (no room nozzle)	36 ACH	Fail	Subfloor and server cabinet fail to reach design concentration
45	Room only (no subfloor nozzle)	None	Fail	Subfloor takes 10 minutes to reach design concentration
46	Room only (no subfloor nozzle)	18 ACH	Pass	Subfloor, server, and room concentration readings within 5% of each other
41	Room and subfloor	None	Pass	Target concentration [16]achieved in room and subfloor.
42	Room and subfloor	59 ACH	Pass	Target concentration achieved in room and subfloor.

Table 5 One or more nozzles omitted - hot aisle configuration

Hot Aisle Configuration				
Test	**Nozzle locations**	**Airflow**	**Result**	**Comment**
66	Aisle and above drop ceiling (no room nozzle)	None	Fail	Room fails to reach design concentration
67	Aisle and above drop ceiling (no room nozzle)	18 ACH	Pass	See the discussion on page 33.
69	Room (no nozzle in aisle; no nozzle above drop ceiling)	18 ACH	Depends	See the discussion on page 34.

[14] The total agent required for the entire enclosure was discharged into the subfloor. The concentration under the raised floor exceeded the range of the meter (10%). See page 21 for further discussion.
[15] Test 38 No measurement was taken in the server cabinet during this test. Test 39 was the same system configuration with an increased airflow.
[16] Test 41 and test 42 concentration was not measured within the cold aisle. Since the aisle was open to the room, the concentration within the aisle would be the same as that measured in the room. Thus, the test passed.

4.1 Conclusions – Nozzle Location Study

Based on the above-described tests:

1. Nozzles are required in the room and under the raised floor.
2. A nozzle above a drop ceiling is required if the space above the drop ceiling contains combustibles.
3. A nozzle above a drop ceiling is not required if the space above the drop ceiling does not contain combustibles. However, the volume of the space used for return air must be added to the room volume to calculate the quantity of agent to be discharged from the nozzles in the room.

Regarding nozzles in containment aisles, nozzles are not required within the containment aisles so long as all the following are true:

1. ITE permits air from the room to flow through the ITE cabinets.
2. Nozzles are located 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 mandated by the manufacturer, insurer, or code requirement.
5. The volume of the containment aisles and ITE cabinets is included in the volume to calculate the quantity of agent to be discharged from the nozzles in the room.

5 Summary Conclusions

- Airflow either improved homogeneity or for configurations where mixing was ideal in still air, mixing remained ideal with airflow.
- Nozzles are required in each protected volume, e.g., room, subfloor, ceiling void.
- Nozzles are generally not required in containment aisles if ITE cabinets permit the flow of air from the room through the cabinets.
- The net room volume calculations must include the volume of the containment aisles and the ITE cabinets, with the agent quantity calculations based on the total volume of the protected enclosure, including the volume of the air handlers and any ventilation system ductwork. The volume of permanent impermeable building elements within the enclosure may be deducted from the total volume of the enclosure.
- Nozzles must be located per listed limits.
- Manufacturer-recommended clearances between nozzles and structural components, including aisle containment partitions, must be maintained.
- Results may support future code developments.

NOTE: The conclusions apply to situations where the air handlers are in 100% recirculating mode, with no makeup air. Results could be different if makeup air is introduced.

Nothing in this report overrides existing applicable laws, codes, and standards, manufacturer's design, installation, servicing, and maintenance instructions and guidance, and the need for design guidance from a fire protection professional.

The original test data files are archived by the Fire Suppression Systems Association and the Fire Industry Association.

CONTACT INFORMATION

Fire Suppression Systems Association | 3601 E. Joppa Road | Baltimore, MD 21234 | Phone: 410-931-8100 | www.fssa.net

Fire Industry Association | Tudor House | Kingsway Business Park | Oldfield Road |Hampton, Middlesex, TW12 2HD | Phone: 020 3166 5002 | www.fia.uk.com

