Use of Gaseous Suppression Systems in High Air Flow Environments – Phase 1

FINAL REPORT

PREPARED BY:
Eric Forssell
Jensen Hughes
Baltimore, MD, USA

RESEARCH FOUNDATION
RESEARCH FOR THE NFPA MISSION

FIRE PROTECTION RESEARCH FOUNDATION
ONE BATTERMARCH PARK | QUINCY, MASSACHUSETTS, USA 02169-7471
E-MAIL: FOUNDATION@NFPA.ORG | WEB: WWW.NFPA.ORG/FOUNDATION

FOREWORD

Information-technology and telecommunications (IT/telecom) facilities provide critical services in today's world. From a risk standpoint, the indirect impact of fire loss due to business interruption and loss of critical operations, sometimes geographically very distant from the IT/telecom facility itself, can far outweigh the direct property loss.

In the past few years, there have been dramatic changes in the equipment housed in these facilities, which have placed increased demands on HVAC systems. As a result, engineered-airflow containment solutions are being introduced to enhance heat extraction and increase energy efficiency. From the perspective of fire-suppression system design, the use of airflow containment systems creates areas of high-air velocities within an increasingly obstructed equipment space, which could affect the effectiveness of transport of suppression agents throughout the protected volume.

Requirements related to use of gaseous-agent fire extinguishing systems in IT/telecom facilities are directly addressed by NFPA 75, *Standard for the Fire Protection of Information Technology Equipment*, and NFPA 76, *Standard for the Fire Protection of Telecommunications Facilities*. NFPA 75, 2013 edition, addresses these issues related to gaseous agent systems in several places.

> *5.6.7 Where aisle containment systems are installed, the existing suppression and detection systems shall be evaluated, modified, and tested as necessary to maintain compliance with the applicable codes and standards.*
>
> *5.6.8 Where automatic sprinklers are present and the application of aisle containment systems or hot air collars creates obstructions to proper operation of sprinkler systems, the sprinkler system shall be modified as necessary to comply with NFPA 13, Standard for the Installation of Sprinkler Systems.*
>
> *5.6.10 If the aisle containment prevents the gaseous suppression system, where present, from producing the required design concentrations throughout the entire volume served, the gaseous suppression system shall be modified to produce the required concentration throughout the volume served.*
>
> *5.6.10.1* Gaseous suppression system modifications shall not be required where all the following conditions are met:*
>
> > *(1)*An automatic means of smoke detection initiates the removal of the obstruction prior to the suppression system operation.*
> > *(2) Removing the obstruction or portion thereof does not compromise means of egress per NFPA 101, Life Safety Code.*
> > *(3) The design and installation of removable obstruction elements does not diminish the level of protection below that which existed prior to the installation of the aisle containment or hot air collar.*
> > *(4)*The releasing devices are listed for the application.*
> > *(5) All removable obstructions are removed for the entire suppression zone.*
>
> *8.4.3 Hot aisle or cold aisle containment systems shall not obstruct the free flow of gaseous clean agent suppression systems to the IT equipment or cooling system serving the contained aisle within an information technology equipment room or zone.*

Still, there are questions about the impact of the high airflows on dispersion of agent from nozzles and the impact of containment on gaseous suppression agents. The Fire Protection Research Foundation undertook a project with the goals to (a) develop an understanding of the operational features of datacenters, especially those employing "engineered-aisle-designs," and associated elevated air flow velocities, that may pose challenges to effective transport of gaseous fire extinguishing agents in accordance with current minimum design requirements, and current field design and installation practices, (b) perform a gap analysis on the topic, and (c) develop a research plan including a recommended test plan for future work.

The Fire Protection Research Foundation expresses gratitude to the report author Eric Forssell, who is with Jensen Hughes located in Baltimore, MD, USA. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsors, and all others that contributed to this research effort.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

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Keywords: gaseous suppression, gaseous agents, inert agents, high air flow environment, air flow containment, data center, aisle containment, IT, telecom, NFPA 75, NFPA 76, NFPA 2001

PROJECT TECHNICAL PANEL

Steve Dryden, AMEC

Jeff Harrington, Harrington Group, Inc.

Richard Kluge, Telcordia Technologies (Ericsson)

Karl Meredith, FM Global

Keith Polasko, NSA

Jack Poole, Poole Fire Protection Inc.

Dave Quirk, DLB Associates

Blake Shugarman, UL

Ralph Transue, Jensen Hughes

Randy Willard, CIA

Barry Chase, NFPA Staff Liaison

Jon Hart, NFPA Staff Liaison

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1. BACKGROUND

Information-technology (IT) and telecommunications (telecom) facilities provide critical services that warrant early detection of fires to minimize loss of capability due to a fire. Between cost of equipment and the potential cost of interrupted business operations, these facilities have a high value. These facilities contain a high-density of electronics equipment that must be kept cool to prevent thermal failure and to improve longevity of semiconductor devices and magnetic storage devices. High airflow rate cooling, using a variety of airflow arrangements, is commonly used.

In an effort to increase the cooling efficiency, a hot aisle – cold aisle configuration is becoming increasingly common. In this configuration, the cooling air is introduced between alternating rows of equipment racks referred to as the cold aisle. The air then passes through the equipment and is withdrawn from the opposite hot aisle. This configuration limits the mixing between supplied cooling air and the heated exhaust increasing the cooling efficiency. The use of containment systems to prevent bypass airflow from the cold aisle to the hot aisle, further increase the cooling efficiency.

NFPA 75, Fire Protection of Information Technology Equipment, and NFPA 76, Fire Protection of Telecommunications Facilities, along with NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems, address the use and application of gaseous fire protection systems in these facilities. Only NFPA 75 has a section that specifically addresses hot aisle cold aisle configurations and the use of containment systems. Section 5.6.10 of NFPA 75 states that “if the aisle containment prevents the gaseous suppression system from producing the required design concentrations throughout the entire volume served, the gaseous suppression system shall be modified to produce the required concentration throughout the volume served.” Section 8.4.3 of NFPA 75 states that “hot aisle or cold aisle containment systems shall not obstruct the free flow of the gaseous clean agent to the IT equipment or cooling system serving the contained aisle within an information technology equipment room or zone.” In Appendix A of NFPA 75, Section A.8.4.3, it is stated that the flow of agent from a gaseous agent system applied to the entire enclosure should be able to penetrate the IT equipment and create a uniform mixture in most cases. This implies that special handling or treatment of the aisle containment zone as a separate enclosure may not be necessary.

The FM Global Loss Prevention Data Sheet on Data Centers and Related Facilities (FM Data Sheet 5-32) states that the gaseous clean agent fire protection system must be designed to provide proper clearance from the containment system boundaries and the proper agent design concentration both within the containment zone and outside of it. This implies the treatment of the space within the containment zone (cold aisle or hot aisle) as a separate enclosure is required.

The FM Data Sheet 5-32, NFPA 75, nor NFPA 76, address whether modifications, or compensation should be applied to the design of gaseous clean agent fire suppression systems when applied to data centers with high air flow rates, or hot aisle: cold aisle configurations without aisle containment systems. The airflow rate involved in these configurations and the obstructions to the flow of the agent within the protected enclosure may prevent or delay the achievement of the required agent concentration in order for the gaseous clean agent fire suppression system to be effective. The impact of this or the modifications required in the suppression system design to prevent this impact has not been fully assessed and is currently left to the system designer to evaluate.

2. DISCUSSION OF GASEOUS CLEAN AGENT FIRE SUPPRESSION SYSTEM DESIGN

The interaction of a number of design and operation features have the potential to have an impact on the ability of a total flooding fire suppression system to achieve its design concentration uniformly throughout the protected space. The high air flow-rate associated with datacenters has the potential to both aid in the development of the uniform concentration by increasing the amount of the turbulent mixing within the enclosure and to hinder the achievement of the design concentration by increasing the amount of agent lost through leaks in the compartment boundaries and ventilation systems. The presence of an economizer, which utilizes cooler outdoor air when available to provide datacenter cooling, would be another potential agent loss site.

Interactions between the nozzle flows and obstructions within the protected space have the potential to prevent the achievement of a uniform concentration throughout the protected enclosure. The obstructions absorb and deflect the kinetic energy of the nozzle flow leaving less energy available to mix the agent with the air in the enclosure. The obstructions have the potential to create low concentration zones within the enclosure on the downstream side of the obstruction particularly if elevated within the protected space. With the resultant reduced turbulence from the agent discharge, an increased reliance on the cooling system flow to distribute the agent would result.

A research program involving both CFD modeling and full scale validation testing would be needed to address the concerns related to the application of gaseous clean agent fire suppression systems in this application.

3. APPROACH

Ultimately, the goal of the larger project is twofold. The first goal is to develop an understanding of the operational features of datacenters and associated high air flow velocities, and the impact of these features on the ability to achieve a homogeneous design concentration throughout the datacenter. The second goal is to determine whether the current design practices and limited guidance currently provided, adequately address the challenges represented by these configurations. If these applications are not addressed adequately, revised guidelines will need to be developed for these applications

This initial project will define operational features of these datacenters, and develop a full-scale test plan to assess the impact of these features on the performance of applied gaseous clean agent fire suppression systems.

4. DATA CENTER CHARACTERIZATION AND DESIGN GUIDANCE

4.1. Design and Operational Features of Modern Datacenters that may Influence the Transport and Concentration of Gaseous Fire Extinguishing Agents (Task 1)

Datacenter parameters that can affect the performance of a gaseous clean agent fire suppression system would include: air flow rate and velocities; degree of containment of either cold or hot aisle, airflow rate to enclosure volume, aisle spacing, separation from compartment boundaries, plenum volume.

The FPRF program on validation testing of CFD modeling tools for detection system design in high airflow environments provides a typical layout for a modern data center that is reproduced as Figure 1 [1]. This layout was used for their CFD modeling efforts and as the basis for the design of the enclosure used for the validation testing performed. The modeling efforts utilized two ceiling heights, 3 m (10 ft) and 6.1 m (20 ft) as measured from the top of the sub-floor to suspended ceiling.

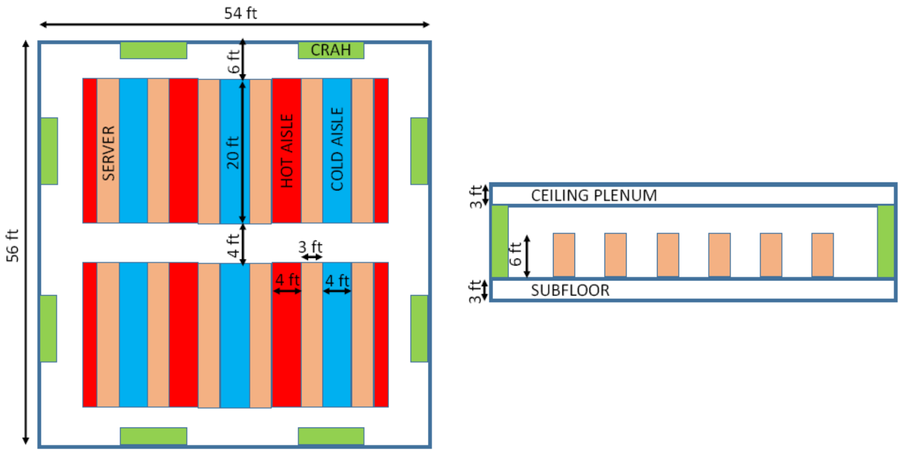


Figure 1 – Data Center Layout [1].

The previous FPRF project estimated the cooling airflow requirements for a data center based on the heat load of the servers as reproduced in Table 1 [1]. The power density is the heat load of the servers divided by the floor area actually occupied by the servers (not by the total floor area). The cooling airflow rate requirement was estimated based on a 10 °C (18 °F) rise in air temperature across the servers which corresponds to a flow rate of 4.9 m^3/min/kW (173 CFM/kW or 3 ft^3/Btu). The estimated air change rate did include the volume of the sub-floor and the ceiling plenum. The CRAH (computer room air handler), also referred to as a CRAC (computer room air chiller), was estimated to have a maximum air flow rate of 708,000 LPM (25,000 CFM), which nominally corresponds to a 140 kW (40 ton) unit corresponding to 6 operating units for the highest heat load and 1 operating unit at the lowest heat load.

Table 1 – Estimated Data Center Flow Rates [1]

Power Density (Heat Load per Server Cabinet Occupied Floor Area)			Total Heat Load			Air Flow Rate Requirement {10 °C [18ºF] Temperature Differential}		
[kW/m^2]	[W/ft^2]	[Btu/hr ft^2]	[kW]	[Btu/hr]	[ton]	[m^3/min]	[CFM]	[ACH]
0.54	50	171	36	122,844	10	176	6,216	7.7
1.08	100	341	72	245,687	20	352	12,432	15.4
2.15	200	682	144	491,374	41	704	24,864	30.8
6.46	600	2,047	432	1,474,123	123	2,112	74,591	92.5
10.76	1,000	3,412	720	2,456,872	205	3,520	124,319	154.2

Two data centers at the University of Maryland were surveyed in order to verify the estimated parameters. Both of these data centers did not use the space above the suspended ceiling as the return air plenum. The CRAC units drew their return air from the main space of the data center. This configuration allows the heated exhaust from the servers to mix with the main space and would be less efficient than if the return air was drawn directly from the hot aisle.

The hot aisle was wider in the surveyed data centers than in the layout utilized in the previous study. The 0.6 m (2 ft) wide server cabinets were lined up in rows with up to 20 cabinets per row. The front face of the cabinet was aligned with the front edge of the 0.6 x 0.6 m (2 x 2 ft) floor tile it sat on. The rear face of 0.9 m (3 ft) deep cabinets extended half–way across a second row of tiles. In order to keep the alignment of the server rows with the raised floor tile grid, and to provide two rows of removable floor tiles for maintenance between the rows, the hot aisles were 1.8 m (6 ft) wide while the cold aisles were 1.2 m (4 ft) wide. The configuration difference results in a nominal 15% reduction in capacity for the data center relative to the layout from the previous FPRF study.

The first data center surveyed was the primary data center for the computer science department of the university and located in the A.V. Williams Building. It was originally designed for use as a data center and has been in use for more than thirty years. It has undergone several remodeling and reconfigurations reflecting the advances in computer equipment over that time period. It is currently operating with approximately half the potential server space occupied. It has a 0.6 m (2 ft) raised floor and suspended ceiling that is 3 m (10 ft) above the raised floor. The ceiling slab is 1.2 m (4 ft) above the suspended ceiling. It has five 40 ton (140 kW) CRAC units, although only three are operating at one time. The return air vents on the units that are not operating are covered to prevent back flow through the unit. The temperature differential across the servers (hot aisle – cold aisle) was measured to be approximately 14 °C (25 °F). This increased temperature difference would correspond to a reduction in air flow rate requirements by 40% to 3.5 m^3/min/kW (123 CFM/kW or 2.2 ft^3/Btu). The velocity of the air flow from the perforated tiles was measured as 0.7 m/s (138 ft/min) corresponding to a flow rate of 2300 LPM (80 CFM) from each of the vented tiles in the cold aisles of the data center.

The second data center surveyed was an auxiliary data center in the CSS Building, which is operated by the computer science department on behalf of the other departments and colleges of the university. It was not originally designed as a data center, which is reflected in some of the parameters for this space. It has a reduced ceiling height with 2.1 m (7 ft) between the raised sub-floor and the suspended ceiling. It is currently operating much closer to the data center capacity which is reflected in the much higher cooling air flow-rates. This data center has five 20 ton (70 kW) CRAC units along the walls, all of which are operating. The CSS had the power distribution units within the server array rather than along the perimeter walls, due to space requirements. The CSS also had a multi-rack UPS within the server array. In the A.V. Williams data center, the UPS devices were located outside of the data center. The CSS also had access ramps within the data center to facilitate the 0.6 m (2 ft) elevation difference between the hallway outside the data center and the raised floor within the data center. This attribute tended to reduce the capacity of the data center and suppress the cooling air flow rate relative to the data center volume.

The parameters of the two surveyed data centers are given in Table 2. The A.V. Williams data center had a much lower flow rate compared to the parameters in the previous FPRF study, primarily reflecting the data center not being at full operating capacity. The CSS data center is nominally mid-range in the parameter range of the previous FPRF study.

The dead air zone note in Table 2 represents an area within the data center where the cooling air flow is not needed and the floor has solid tiles rather than vented or perforated tiles installed. For the A.V. Williams data center, this area was available for future expansion and represented the increased capacity per floor area requirement changes over the lifetime that this data center has been in use. For the CSS data center, the small space availability led to PDU and UPS equipment to be within the server array rather than in an auxiliary space or along the perimeter of the data center.

Table 2 – Surveyed Data Center Parameters

Parameter	Units	A.V. Williams	CSS
Floor Area	[m^2]	548.1	231.9
	[ft^2]	5900	2496
Ceiling Height	[m]	3.0	2.1
	[ft]	10.0	7.0
Subfloor Height	[m]	0.6	0.6
	[ft]	2.0	2.0
Main Space Volume	[m^3]	1,671	495
	[ft^3]	59,000	17,472
Sub-Floor Volume	[m^3]	334	141
	[ft^3]	11,800	4,992
Total Volume	[m^3]	2,005	636
	[ft^3]	70,800	22,464
Dead Air Zone (Excluding Access Aisles)	[m^2]	145	16
	[ft^2]	1,564	176
	[% Total]	26.5%	7.1%
CRAC Units	[installed]	5	5
	[Operating]	3	5
CRAC Capacity	[kW]	141	70
	[ton]	40	20
Cold Aisle Temperature	[^{o}C]	10.7	14.0
	[^{o}F]	51.3	57.1
Hot Aisle Temperature	[^{o}C]	25	29.0
	[^{o}F]	77.0	84.3
Cold Aisle Tile Air Flow Velocity	[m/s]	0.70	2.31
	[FPM]	138.4	455.4
Cold Aisle Flow Rate per Vented Tile	[LPM]	2,259	5,191
	[CFM]	79.8	183.3
Total Cooling Air Flow Rate	[LPM]	140,048	316,659
	[CFM]	4,946	11,183
	[ACH]	4.2	29.9

4.2. Current Minimum Design Standards for Use of Gaseous Clean Agent Fire Suppression System in Applications Where Air Circulation at High Flow Rates Continue during and after Agent Discharge, such as Datacenters (Task 2)

The current applicable NFPA standards were reviewed for requirement relative to gaseous clean agent fire suppression system design as applied to high air flow environments like data centers. The standards reviewed included the NFPA standards on gaseous clean agent fire suppression systems (NFPA 2001) [2], on fire protection of IT and data processing facilities (NFPA 75) [3] and on fire protection of telecommunications facilities (NFPA 76) [4]. Few specific requirements or guidance on the application of gaseous clean agent fire suppression systems in these applications are included in these standards. NFPA 2001 in Section 5.3.6 states that, “Other than the ventilation systems identified in 5.3.6.2, forced-air ventilation systems, including self-contained recirculation systems, shall be shut down or closed automatically where there continued operation would adversely affect the performance of the fire extinguishing system or result in propagation of the fire,” [2]. Section 5.3.6.2 states that “Ventilation systems necessary to ensure safety shall not be required to be shut down upon activation of the fire suppression system,” [2]. Section A.5.3.6 in the Annex A states that “Examples of ventilation systems necessary to ensure safety include cooling of vital equipment required for process safety and ventilation systems required for containment of hazardous materials. Where recirculating ventilation is not shut off, additional agent could be needed to compensate for room leakage during the hold time,” [2].

NFPA 75 states in section 8.4.5 that “Where the operation of the air handling system would exhaust the agent supply, it shall be interlocked to shut-down when the extinguishing system is actuated,” [3]. NFPA 76 does not contain a specific statement regarding the shut-down or continuous operation of the cooling air ventilation system. Both NFPA 75 and NFPA 76 have some provisions applicable to aisle containment systems.

While these provisions recommend that the ventilation system be shut-down, it is left up to the designer to determine if the continued operation of the ventilation system would adversely affect the performance of the suppression system. Unless the data processing equipment is shut-down as well, shutting down the cooling air ventilation would result in equipment over-heat, and potential equipment damage.

The Factory Mutual Property Loss Prevention Data Sheet on data processing facilities (5-32) [5] states in section 2.4.6.3.14 that a cooling air ventilation system is not required to be shut-down provided that:

- It does not introduce make-up/outside air,
- The volume of the plenum ducts, and equipment are accounted for in the agent requirement, and
- Agent is provided to compensate for any losses during the hold time.

Gaseous clean agent fire suppression systems are designed and installed in accordance with the provisions of NFPA 2001 [2] and the system supplier’s UL Listing [6,7] and/or FM Approval [8]. The UL Listing and FM Approval process involves the determination of the system parameters under which a gaseous agent system would be expected to perform as intended. Key system parameters of the minimum nozzle pressure and the nozzle spacing requirements that are embodied in the maximum area coverage and maximum nozzle height provisions of the UL Listing [6,7] and FM Approval [8]. These system parameters are established through experimental tests in still air environments.

4.3. Current System Design Practices Differ from Minimum Standards (Task 3)

The current system design practices are based on compliance with the standards listed in the previous section. When applied to modern data centers, the recommendation that the equipment be shut-down, power secured and the ventilation system be shut-down prior to the gaseous clean agent fire suppression system activation is meeting increased resistance. This resistance is due to the complexity of the power down procedures and subsequent restart procedures, and the cost of the service interruption of the data center. As described in the previous section, the decision as to whether the ventilation is shut-down or not, is left to the designer in conjunction with the authority having jurisdiction and is to be based on whether the continued operation of the ventilation system would adversely affect the performance of the gaseous clean agent fire suppression system. There currently is no guidance provided to the system designer or to the authority having jurisdiction as to the circumstances as to when the system performance would be adversely be affected other than when the continued ventilation system operation would exhaust the agent supply as noted in the appendix of NFPA 75 [3] or would introduce make-up air to the enclosure as noted in the FM Data Sheet 5-32 [5].

4.4. Gap Analysis of Current System Design Practices and Minimum Standards Relative to Effective Gaseous Suppression System Performance (Task 4)

As discussed in the previous sections, there is a clear gap between the requirements in the current standards to shutdown the recycling air cooling system where the continued operation would adversely affect the performance of the fire suppression system and the current knowledge of the effects of the continued air flow on the performance of the fire suppression system. The effects of the continued air flow on the ability of the gaseous agent system to achieve a uniform concentration throughout the protected space are unknown.

The effects of increased use of aisle containment systems, which prevent the mixing of the cold air upstream of the server cabinets and the hot air downstream of the server cabinets, on the applied gaseous fire suppression system performance is unknown as well. While the contained aisle, hot or cold, would be treated as separate enclosure in accordance with NFPA 75 [3] and the FM Loss Prevention Data Sheet [5], the effects of the presence of these containment systems in conjunction with the continued air flow is unknown.

5. RESEARCH PLAN

A two tiered research program is recommended to address the knowledge gap identified. The first tier of the research program would address the effects of the continued air flow on the gaseous agent fire suppression systems without the presence of an aisle containment system. The second tier of the research program would address the effects of the continued air flow on the gaseous fire suppression system with an aisle containment system.

Both tiers of the research program will utilize CFD modeling to evaluate the effects of the continued air flow on the ability of the gaseous agent fire suppression system to develop a uniform agent concentration throughout the enclosure. A limited experimental program will be utilized to assess the accuracy and validity of the CFD modeling performed

5.1. First Tier Research Plan: High Air Flow Environment without Aisle Containment

5.1.1. Approach

Evaluate the effects high air flow environments on the performance of a total flooding fire suppression agent utilizing a combination of computational fluid dynamics (CFD) and experimental investigations. The evaluation will be conducted for three primary agents: HFC-227ea (FM-200), FK-5-1-12 (Novec 1230) and IG-541 (Inergen). These agents represent the primary agents currently in use with HFC-227ea and FK-5-1-12 representing halocarbon type agents and IG-541 representing inert gas type agents. Other agents could be utilized in addition to or instead of these agents based on cost and availability. Variables to be investigated include: air flow rate in the enclosure, and dead air zone. Variables held constant include: enclosure geometry (volume, contents, and dimensions), system parameters (concentration (NFPA 2001 Class C minimum design), discharge time, nozzle pressure and nozzle spacing).

Research will start with modeling the extreme cases (Still air, Maximum air flow rate, and Maximum air flow rate with maximum dead air zone). If evaluated cases warrant further investigation, then intermediate cases would be modeled. Two enclosure volumes will be utilized during this program. The smaller volume will allow for validation testing at reduced cost.

Verification testing will be conducted for a couple of selected cases that are included in the CFD modeling utilizing the smaller of the two enclosures. The results of the CFD modeling will be utilized to aid in selecting the locations for the instrumentation to be utilized during these tests.

The experimental validation tests will ignore the heat load from the servers and the cooling from the CRAH units. The CFD model runs for comparison will also ignore the effects of the heat addition from the servers and the cooling from the CRAH units. The remaining CFD model runs will incorporate the heat addition from the servers and the cooling from the CRAH units.

The CFD model will be refined based on the results of the experimental validation tests in the smaller enclosure prior to commencing with the modeling of the larger enclosure. If sufficient agreement is not achieved between the CFD model and the experimental results, then additional experimental testing will be conducted.

5.1.2. Variables Held Constant

5.1.2.1. Enclosure Geometry

Two enclosure geometries are proposed for this evaluation. The smaller of the two has a main space volume of 255 m^3 (9,000 ft^3). This volume nominally represents the largest volume that can be protected by a single nozzle system employing any one of the three proposed agents (HFC-227ea, FK-5-1-12, and IG-541). This volume is smaller than that utilized during the previous investigation of the effects of high air flow rate environments on the performance of smoke detection systems and either of the data centers visited. The reduced volume would simplify the analysis, especially with respect to nozzle location. Basic enclosure geometry to be used is illustrated in Figure 2.

The second enclosure geometry is similar to that utilized in the previous investigation and would require a four nozzle system to cover the main space volume of 856 m^3 (30,240 ft^3). The larger volume allows for a more symmetrical geometry with respect to the hot aisle-cold aisle configuration and captures more of the geometry of a typical data center. This geometry is illustrated in Figure 3.

The enclosure parameters relative to the parameters of the enclosure used in the previous investigation and the visited data centers are given in Table 3.

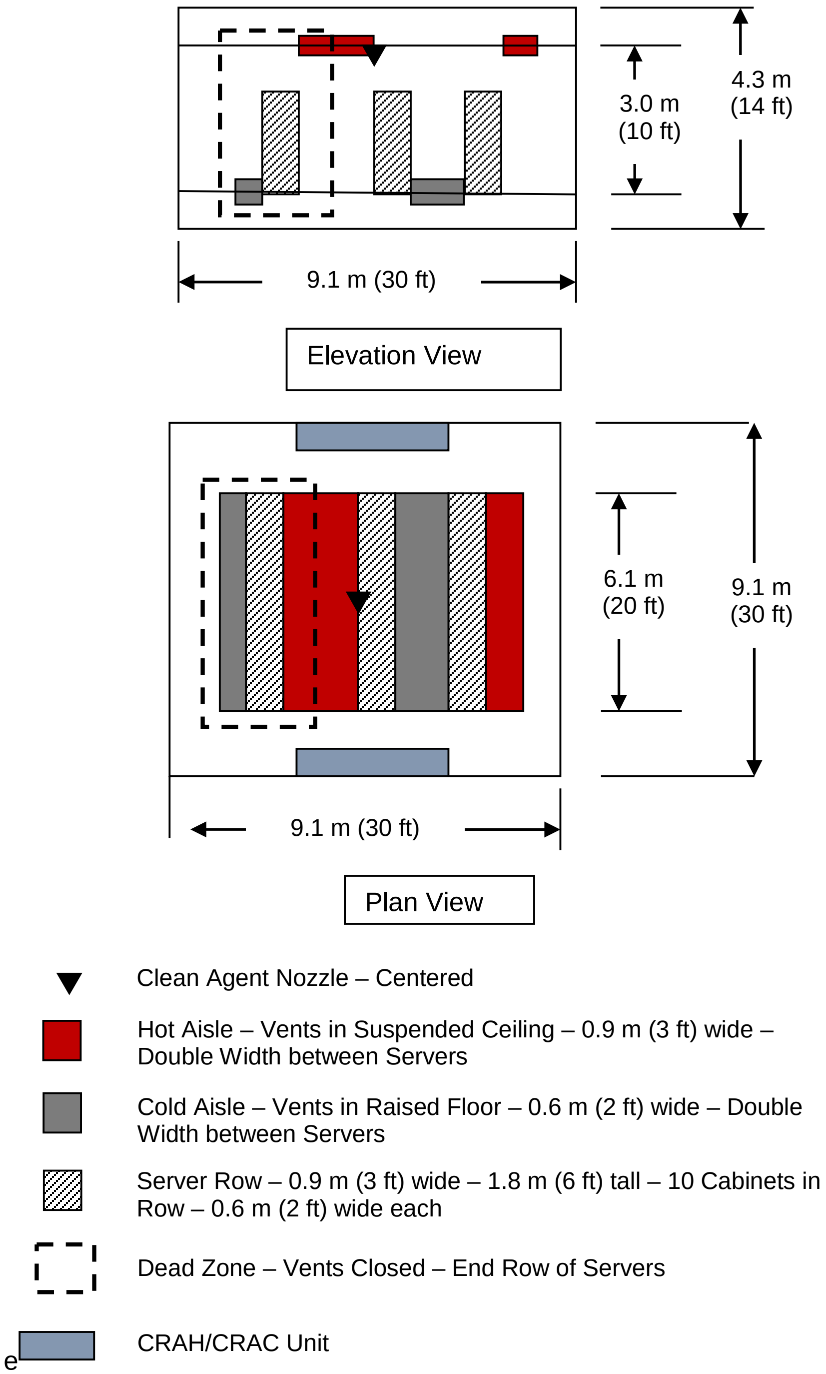
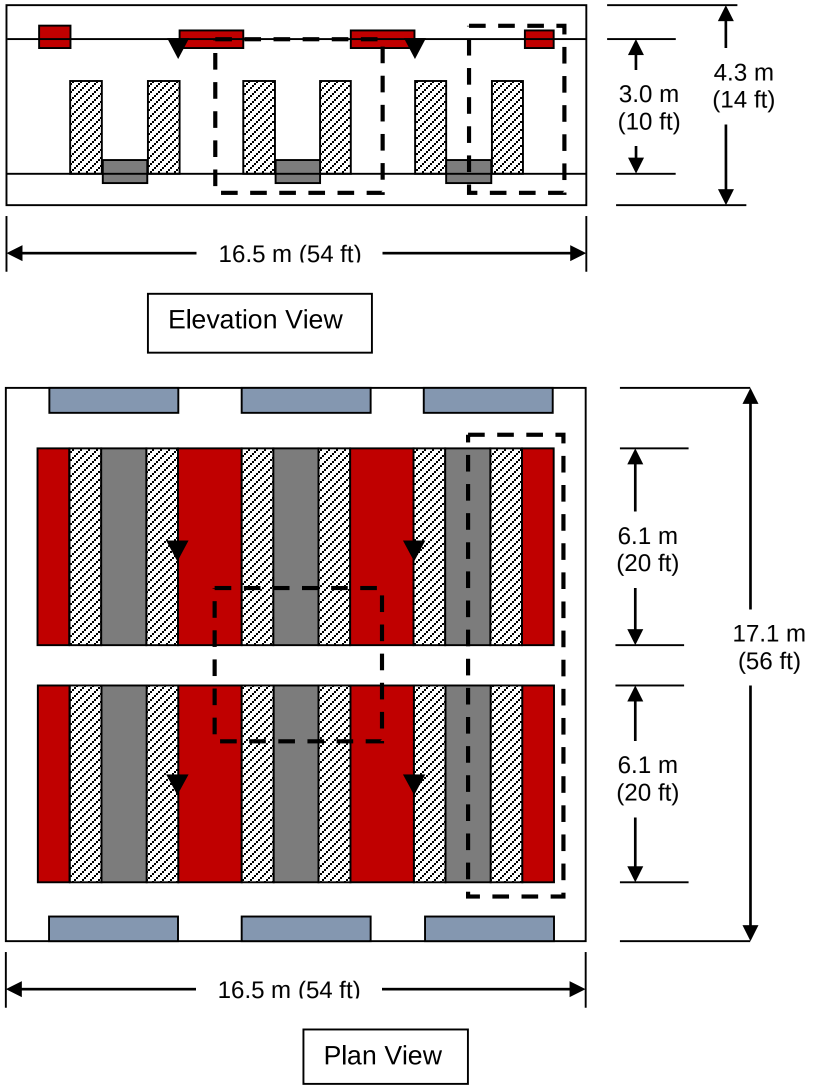


Figure 2 – 255 m^3 (9,000 ft^3) Enclosure Geometry



▼ Clean Agent Nozzle – 4 Nozzles – Centered in each

🟥 Hot Aisle – Vents in Suspended Ceiling – 0.9 m (3 ft) wide – Double Width between Servers

⬛ Cold Aisle – Vents in Raised Floor – 0.6 m (2 ft) wide – Double Width between Servers

▨ Server Row – 0.9 m (3 ft) wide – 1.8 m (6 ft) tall – 10 Cabinets in Row – 0.6 m (2 ft) wide each

⬚ Dead Zone – Vents Closed – 4.3 x 4.9 m (14 x 16 ft) in Center – End Row of Servers

🟦

Figure 3 – 856 m^3 (30,240 ft^3) Enclosure Geometry – Four Nozzle Coverage

Table 3 – Enclosure Parameters

Parameter	Units	Proposed Enclosures		Visited Data Centers		Previous Investigation Enclosure
		Single Nozzle	Four Nozzles	A.V. Williams	CSS	
Floor Area	[m²]	83.6	280.9	548.1	231.9	280.9
	[ft²]	900	3024	5900	2496	3024
Ceiling Height	[m]	3.0	3.0	3.0	2.1	3.0
	[ft]	10.0	10.0	10.0	7.0	10.0
Subfloor Height	[m]	0.6	0.6	0.6	0.6	0.9
	[ft]	2.0	2.0	2.0	2.0	3.0
Suspended Ceiling Height	[m]	0.6	0.6			0.9
	[ft]	2.0	2.0			3.0
Main Space Volume	[m³]	255	856	1,671	495	856
	[ft³]	9,000	30,240	59,000	17,472	30,240
Sub-Floor Volume	[m³]	51	171	334	141	257
	[ft³]	1,800	6,048	11,800	4,992	9,072
Suspended Ceiling Volume	[m³]	51	171			257
	[ft³]	1,800	6,048			9,072
Total Volume	[m³]	357	1,199	2,005	636	1,370
	[ft³]	12,600	42,336	70,800	22,464	48,384
Floor Area Occupied by Server Cabinets	[m²]	16.7	66.9	49.1	30.7	66.9
	[ft²]	180	720	528	330	720
	[% Total]	20.0%	23.8%	8.9%	13.2%	23.8%

5.1.2.2. System Parameters

Each of the three agents will be employed at their minimum Class C (energized electrical hazard) design concentration as specified in NFPA 2001. The Class C design concentration incorporates a 35% safety factor over the Class A (solid material hazard) minimum extinguishing concentration. A Class A design concentration would incorporate a 20% safety factor with a minimum concentration equal to the n-heptane extinguishing concentration. With the power to the data center secured, the lower Class A design concentration would apply. NFPA 75 [3] requires that the power to a data center be secured in 8.4.2.1 .This requirement is based on the concerns that the energized electrical equipment could provide energy to a fire, causing an increase in the agent concentration requirements and that the electrical equipment could also be a persistent ignition source that could re-ignite the fire after the agent has dispersed. However there are cases where the power is permitted to be on after system actuation. The use of the higher Class C agent concentration is not expected to influence the results of this research program.

A single nozzle located in the center of the enclosure, or four nozzles located in the center of the four quadrants of the enclosure would be utilized to discharge the agent into the main space of the enclosure. Additional nozzles will be utilized to discharge the agent into the sub-floor and into the space above the suspended ceiling. These additional nozzles would be located similarly to those in the main space of the enclosure. The nozzle locations are illustrated in Figures 2 and 3.

The systems will be designed to deliver the agent at the maximum discharge time: 10 seconds for HFC-227ea and FK-5-1-12, and 120 seconds for IG-541. The systems will also be designed to be near their minimum average nozzle pressure, approximately 5.5 bar (80 psig) for halocarbon type agents and approximately 13.8 bar (200 psig). An over-pressure relief vent will be installed and operational for the inert gas tests. It will be held closed during the tests with the halocarbon agents.

The gaseous clean agent fire suppression system hardware used in the CFD model effort will be as generic as possible to not reflect any particular manufacturer or distributer. The exception to this will be for the validation test cases which will be compared to the experimental tests. In those cases, the actual hardware used will be modeled.

The agent quantity would be increased over the minimum quantity based on the size of the agent cylinders to be utilized.

Although inert gas cylinders equipped with regulating valves are increasingly available, this research program will utilize the more traditional system hardware that utilizes an orifice plate to limit the system pressure downstream of the cylinder manifold. The effects of the use of the regulated cylinder valves which discharges the agent at a lower, more uniform pressure, on the results of this investigation is not clear. The higher initial flow rates of the traditional inert gas system may be more resistant to the effects of the high air flow environment than the inert gas system utilizing the regulating valves.

The system parameters are outlined in Table 4.

Table 4 – System Parameters

			255 m³ (9,000 ft³) Single Nozzle (Main Space)				856 m³ (30,240 ft³) Four Nozzle (Main Space)			
			Main	Sub-Floor	Suspended Ceiling	Total	Main	Sub-Floor	Suspended Ceiling	Total
Volume		[m^3]	255	51	51	357	856	171	171	1,199
		[ft^3]	9,000	1,800	1,800	12,600	30,240	6,048	6,048	42,336
HFC-227ea	Class A MEC	[%]	5.2							
	Class C Design	[%]	7.0							
	Agent Mass	[kg]	139	28	28	195	468	94	94	655
		[lb]	307	61	61	430	1031	206	206	1444
FK-5-1-12	Class A MEC	[%]	3.5							
	Class C Design	[%]	4.7							
	Agent Mass	[kg]	174	35	35	244	585	117	117	819
		[lb]	384	77	77	537	1290	258	258	1805
IG-541	Class A MEC	[%]	28.5							
	Class C Design	[%]	38.5							
	Agent Volume*	[m^3]	124	25	25	173	416	83	83	583
		[ft^3]	4,375	875	875	6,125	14,701	2,940	2,940	20,581

* Agent volume will be rounded up to the next whole cylinder

5.1.3. Investigation Variables

5.1.3.1. Air Flow Rate

The range of the air flow rate to be investigated corresponds to a cooling demand range between 0.54 to 26.9 kW/m^2 (50 to 2,500 W/ft^2 (171 to 8,530 Btu/hr ft^2)) of occupied floor area. The corresponding flow rate was based on a 15 °C (27 °F) air temperature differential between the cold air supply plenum (sub-floor) and the hot air return plenum (above the suspended ceiling). The air flow rate range and corresponding cooling demand is outlined in Tables 5 and 6 for the two enclosures. The presented air changes per hour, ACH, is calculated based on the total volume including the sub-floor and plenum above the suspended ceiling.

Air velocities and differential pressures presented in Tables 5 and 6, are based on a floor tile open area ratio of 25% (open area/total tile area) with these tiles covering the entire floor area of the cold aisle. The increased density of the colder air is neglected. The air velocity and the differential pressure across the suspended ceiling would be the same if the extra width of the hot aisles is not utilized. The velocity would be reduced by 33% and the pressure difference by 56% if the full width of the hot aisle is used for the return vents. The 25% open area ratio floor tiles are commonly encountered in data centers and were present in the data centers surveyed. Floor tiles with open area ratios of up to 70% are commercially available. The higher open area would reduce the pressure drop across the flow tiles and the velocity for the same volumetric flow rate. Neglecting the temperature difference from ambient represents an approximate 2% error in the estimated pressure difference.

5.1.3.2. Dead Air Space

Dead air space arises from either the data center not being at full capacity or due to the inclusion within the rack array space of non-cooled equipment, such as power distribution units. This was observed in both of the data centers visited. The dead air area may represent a low concentration zone as the agent directed toward this area may be diverted into the recycling air flow.

The dead air zones proposed for the two enclosures are shown in Figures 2 and 3. The total areas of these zones and portion of the total floor area represented by these zones are given in Table 7. The walkway around the boundary of the enclosures, other than that occupied by the CRAC units, and the center aisle in the larger enclosure would represent a dead zone in any case.

Table 5 – Air Flow Rate Range – 255 m^3 (9,000 ft^3) Single Main Space Nozzle Enclosure with 16.7 m^2 (180 ft^2) Server Rack Occupied Floor Area

Heat Load per Occupied Floor Area			Total Heat Load			Air Flow Rate Requirement {15 °C [27°F] Temperature Differential}			Cold Aisle Air Velocity through Perforated Floor Tiles		Pressure Difference Across Floor Tiles	
[kW/m^2]	[W/ft^2]	[Btu/hr ft^2]	[kW]	[Btu/hr]	[ton]	[m^3/min]	[CFM]	[ACH]	[m/s]	[ft/s]	[Pa]	[psf]
0.54	50	171	9	30,711	3	29.3	1,036	4.9	0.29	0.94	0.050	0.001
1.08	100	341	18	61,422	5	58.7	2,072	9.9	0.58	1.89	0.202	0.004
2.15	200	682	36	122,844	10	117	4,144	19.7	1.15	3.77	0.807	0.017
6.46	600	2,047	108	368,531	31	352	12,432	59.2	3.45	11.3	7.26	0.153
10.76	1,000	3,412	180	614,218	51	587	20,720	98.7	5.75	18.9	20.2	0.424
26.91	2,500	8,531	450	1,535,545	128	1467	51,800	246.7	14.4	47.2	126	2.65

Table 6 – Air Flow Rate Range – 856 m^3 (30,240 ft^3) Four Main Space Nozzle Enclosure with 66.9 m^2 (720 ft^2) Server Rack Occupied Floor Area

Heat Load per Occupied Floor Area			Total Heat Load			Air Flow Rate Requirement {15 °C [27°F] Temperature Differential}			Cold Aisle Air Velocity through Perforated Floor Tiles		Pressure Difference Across Floor Tiles	
[kW/m^2]	[W/ft^2]	[Btu/hr ft^2]	[kW]	[Btu/hr]	[ton]	[m^3/min]	[CFM]	[ACH]	[m/s]	[ft/s]	[Pa]	[psf]
0.54	50	171	36	122,844	10	117	4,144	5.9	0.29	0.94	0.050	0.001
1.08	100	341	72	245,687	20	235	8,288	11.7	0.58	1.89	0.202	0.004
2.15	200	682	144	491,374	41	469	16,576	23.5	1.15	3.77	0.807	0.017
6.46	600	2,047	432	1,474,123	123	1408	49,728	70.5	3.45	11.3	7.26	0.153
10.76	1,000	3,412	720	2,456,872	205	2347	82,879	117.5	5.75	18.9	20.2	0.424
26.91	2,500	8,531	1,800	6,142,180	512	5867	207,198	293.6	14.4	47.2	126	2.65

Table 7 – Dead Air Zones in the Proposed Enclosures

	Dead Air Zone						
	Length		Width		Area		
	[m]	[ft]	[m]	[ft]	[m^2]	[ft^2]	[% total]
Single Nozzle Enclosure							
End Server Row	6.1	20	2.4	8	14.9	160.0	17.8%
Four Nozzle Enclosure							
End Server Row (Includes portion of Center Aisle)	13.4	44	2.4	8	32.7	352.0	11.6%
Center Area (Includes portion of Center Aisle)	4.3	14	4.9	16	20.8	224.0	7.4%
Total					53.5	576.0	19.0%

5.1.4. Model Case Matrix

The initial investigation of the extreme cases consists of 24 cases as outlined in Table 8. The case matrix consists of twelve cases in the larger enclosure and six cases in the smaller enclosure. The six cases in the smaller enclosure will be repeated without the heat addition from the servers and the cooling from the CRAH units for comparison with the validation tests. A more detailed evaluation would follow on based on the results obtained. The follow-on evaluation would concentrate on the parameters that evidence the greatest effects on the system performance.

The modeling efforts would initially be conducted for the smaller enclosure to allow for an assessment of the accuracy and validity of the model prior to proceeding to the larger enclosure. The modeling efforts in the smaller enclosure would be compared to the results of the experimental testing outlined in the next section for this assessment. The model would refined as necessary to align with the experimental results.

Table 8 – Initial CFD Model Case Matrix

Case Number	Test Enclosure	Agent	Air Flow Rate			Dead Volume Area			Comments
			[m^3/min]	[CFM]	[ACH]	[m^2]	[ft^2]	[% total]	
1	255 m^3 (9,000 ft^3) - Single Main Space Nozzle	HFC-227ea	0	0	0	0	0	0	Base Case – Still Air
2		FK-5-1-12	0	0	0	0	0	0	
3		IG-541	0	0	0	0	0	0	
4		HFC-227ea	587	20,720	98.7	14.9	160	17.8%	High Air Flow – Dead Zone
5		FK-5-1-12	587	20,720	98.7	14.9	160	17.8%	
6		IG-541	587	20,720	98.7	14.9	160	17.8%	
7	255 m^3 (9,000 ft^3) - Single Main Space Nozzle – Repeat Cases without Heat from Servers and Cooling from CRAH Units for Comparison to Validation Tests	HFC-227ea	0	0	0	0	0	0	Base Case – Still Air
8		FK-5-1-12	0	0	0	0	0	0	
9		IG-541	0	0	0	0	0	0	
10		HFC-227ea	587	20,720	98.7	14.9	160	17.8%	High Air Flow – Dead Zone
11		FK-5-1-12	587	20,720	98.7	14.9	160	17.8%	
12		IG-541	587	20,720	98.7	14.9	160	17.8%	
13	856 m^3 (30,240 ft^3) – Four Main Space Nozzles	HFC-227ea	0	0	0	0	0	0	Base Case – Still Air
14		FK-5-1-12	0	0	0	0	0	0	
15		IG-541	0	0	0	0	0	0	
16		HFC-227ea	469	16,576	23.5	0	0	0	Medium Air Flow – No Dead Zone
17		FK-5-1-12	469	16,576	23.5	0	0	0	
18		IG-541	469	16,576	23.5	0	0	0	
19		HFC-227ea	469	16,576	23.5	53.5	576	19.0%	Medium Air Flow
20		FK-5-1-12	469	16,576	23.5	53.5	576	19.0%	
21		IG-541	469	16,576	23.5	53.5	576	19.0%	
22		HFC-227ea	2,347	82,879	117.5	53.5	576	19.0%	High Air Flow
23		FK-5-1-12	2,347	82,879	117.5	53.5	576	19.0%	
24		IG-541	2,347	82,879	117.5	53.5	576	19.0%	

5.2. Model Validation Testing

In order to validate the CFD model results, a set of experiments would be conducted. These tests would be performed in the smaller of the two enclosures used in the Tier 1 CFD modeling described in Section 5.1. Any differences in the exact geometry of the enclosure and that modeled would be reconciled to ensure that the comparison of the experimental and model results is valid.

These tests would be performed for all three agents involved in the modeling effort: HFC-227ea (FM-200), FK-5-1-12 (Novec 1230) and IG-541 (Inergen). Substitutions and or additions of differing agents is acceptable provided:

- At least one is a halocarbon type agent that is super-pressurized with nitrogen,
- At least one is an inert gas type agent, and
- All agents used are included in the modeling effort to provide a direct comparison of the obtained results.

5.2.1. Enclosure Geometry

The smaller of the two enclosures will be used for the experimental validation tests. It has a main space volume of 255 m^3 (9,000 ft^3). This volume nominally represents the largest volume that can be protected by a single nozzle system employing any one of the three proposed agents (HFC-227ea, FK-5-1-12, and IG-541). This volume is smaller than that utilized during the previous investigation of the effects of high air flow rate environments on the performance of smoke detection systems and either of the data centers visited. The reduced volume would simplify the analysis, especially with respect to nozzle location. Basic enclosure geometry to be used is illustrated in Figure 4.

The CRAH units will be simulated utilizing blowers connected to ducts running from the suspended ceiling to the sub-floor. Four to eight blowers and ducts will be used depending on blower capacity: 71 to 142 m^3/min (2,500 to 5,000 CFM). Blowers and ducts will be arranged symmetrically along the enclosure walls to produce as uniform as possible flow profile through the enclosure.

The effects of the heat input from the operating servers and the cooling from the CRAH units will not be incorporated into the experimental tests.

The leakage area present in the test enclosure will be evaluated prior to the start of the tests with a door fan apparatus. All of the enclosure configurations to be used during the test program will be evaluated.

5.2.2. System Parameters

Each of the three agents will be employed at their minimum Class C design concentration as specified in NFPA 2001. A single nozzle located in the center of the enclosure would be utilized to discharge the agent into the main space of the enclosure. Additional nozzles will be utilized to discharge the agent into the sub-floor and into the space above the suspended ceiling. These additional nozzles would be located similarly to those in the main space of the enclosure. Separate cylinders will be used for the sub-floor and suspended ceiling systems to avoid the error associated with the two flow splits that would otherwise be involved.

The systems will be designed to deliver the agent at the maximum discharge time: 10 seconds for HFC-227ea and FK-5-1-12, and 120 seconds for IG-541. The systems will also be designed to be near their minimum average nozzle pressure, approximately 5.5 bar (80 psig) for halocarbon type agents and approximately 13.8 bar (200 psig). An over-pressure relief vent will be installed and operational for the insert gas tests. It will be held closed during the tests with the halocarbon agents. The size of the pressure relief vent for the inert gas system tests will be based on the final system design. A pressure relief vent for the halocarbon agent tests is not anticipated to be necessary. The need for pressure relief will be reviewed prior to the start of the actual tests.

The agent quantity would be increased over the minimum quantity based on the size of the agent cylinders to be utilized.

The system parameters are outlined in Table 9.

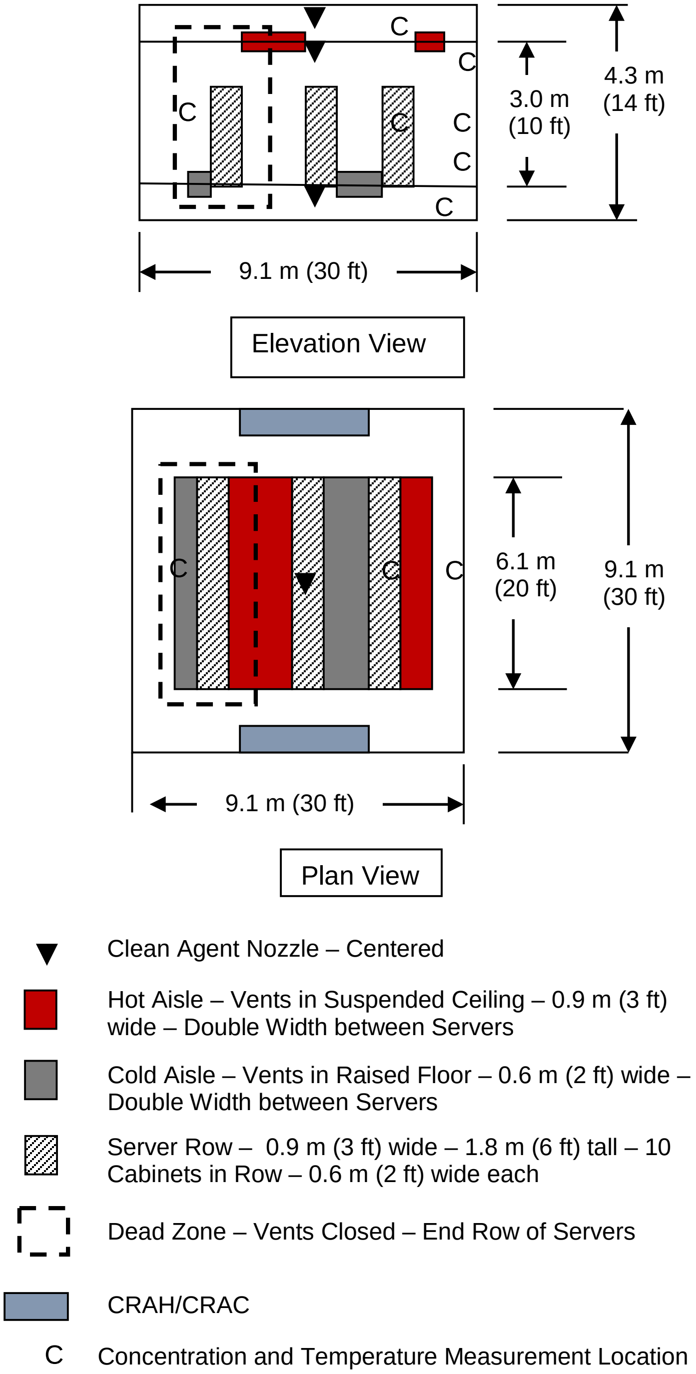


Figure 4 – 255 m^3 (9,000 ft^3) Enclosure Geometry

Table 9 – System Parameters

			255 m^3 (9,000 ft^3) Single Nozzle (Main Space)			
			Main	Sub-Floor	Suspended Ceiling	Total
Volume		[m^3]	255	51	51	357
		[ft^3]	9,000	1,800	1,800	12,600
HFC-227ea	Class A MEC	[%]	5.2			
	Class C Design	[%]	7.0			
	Agent Mass	[kg]	139	28	28	195
		[lb]	307	61	61	430
FK-5-1-12	Class A MEC	[%]	3.5			
	Class C Design	[%]	4.7			
	Agent Mass	[kg]	174	35	35	244
		[lb]	384	77	77	537
IG-541	Class A MEC	[%]	28.5			
	Class C Design	[%]	38.5			
	Agent Volume*	[m^3]	124	25	25	173
		[ft^3]	4,375	875	875	6,125

* Agent volume will be rounded up to the next whole cylinder

5.2.3. Instrumentation

The agent concentration within the enclosure will be monitored at a minimum of 7 locations. These locations are shown in Figure 4. Additional locations maybe added if available and would be located at area shown by the CFD modeling to be interesting by having a delay in reaching the design concentration or an offset from the design concentration. Thermal conductivity analyzers, similar to those used previously for Halon 1301 discharge tests, are available for use with the halocarbon agents and some of the inert gas agents (Tripoint Instrument Inc of Cincinnati OH). Inert gas agent concentrations would be monitored utilizing oxygen concentration analyzers with the agent concentration being derived from the reduction in oxygen concentration. The thermal conductivity meters and oxygen analyzers will be calibrated prior to each test.

Pressure transducers and thermocouples would be utilized to monitor the discharge of the agent through the system piping and into the test enclosure.

Low range pressure transducers will be utilized to monitor the differential pressures across the compartment boundaries (interior and exterior), across the sub-floor (above and below) and across the suspended ceiling (above and below).

A door fan apparatus will be utilized to measure the leakage area present prior to the start of these tests. The leakage area will be measured with the over-pressure relief vent configured for a halocarbon agent test (closed) and for an inert gas agent test (operational).

The air flow field throughout the enclosure will be mapped with the blowers operating to aid in the CFD modeling prior to the start of the tests. A hand held anemometer will be used to measure the air flow velocity through the perforated floor tiles, through the ceiling plenum vents, and through the cabinet racks.

5.2.4. Test Matrix

In order to validate the CFD model results, a set of nine experiments would be conducted with the geometry of the smaller enclosure. These tests would consist of both the base case, still air case and the case with flow rate and dead air space that evidences the greatest effect on the system performance. The tests at the high air flow rate would be repeated in order to establish repeatability and to ensure a valid comparison with the CFD Model. These tests are nominally outlined in Table 10.

The procedure to be used for these tests would be to initially configure the enclosure for the test conditions to be used. The analyzers would be calibrated for the agent to be used in the test. The blowers would be set for the desired air flow condition. The cylinders would be filled and attached to the gaseous clean agent fire suppression system piping.

The data acquisition system would be started. After two minutes of background data have been acquired, the clean agent would be discharged into the test enclosure. The test would last until the concentration profile is no longer changing with a minimum duration of thirty minutes after the end of the agent discharge into the enclosure.

At the conclusion of the test, the chamber would be thoroughly purged.

Table 10 – Validation Test Matrix

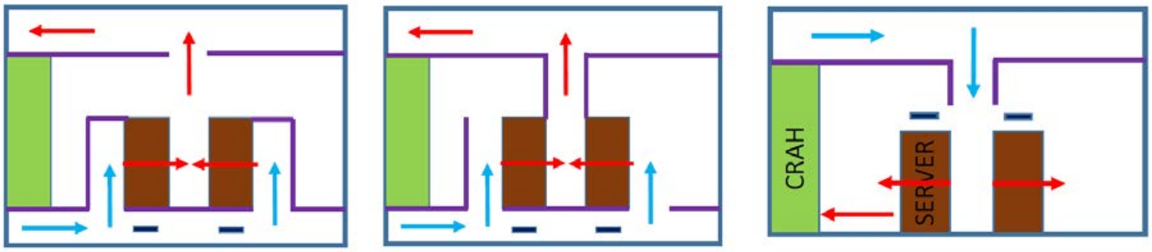
Case Number	Enclosure	Agent	Air Flow Rate			Dead Volume Area			Comments
			[m^3/min]	[CFM]	[ACH]	[m^2]	[ft^2]	[% total]	
1	255 m^3 (9,000 ft^3) Single Main Space Nozzle	HFC-227ea	0.0	0	0.0	0.0	0	0.0%	Base Case – Still Air – Small Enclosure
2		FK-5-1-12	0.0	0	0.0	0.0	0	0.0%	
3		IG-541	0.0	0	0.0	0.0	0	0.0%	
4		HFC-227ea	586.7	20,720	98.7	14.9	160	17.8%	High Air Flow – Small Enclosure
5		FK-5-1-12	586.7	20,720	98.7	14.9	160	17.8%	
6		IG-541	586.7	20,720	98.7	14.9	160	17.8%	
7		HFC-227ea	586.7	20,720	98.7	14.9	160	17.8%	High Air Flow – Small Enclosure Repeat Tests
8		FK-5-1-12	586.7	20,720	98.7	14.9	160	17.8%	
9		IG-541	586.7	20,720	98.7	14.9	160	17.8%	

5.3. Second Tier Research Plan: High Air Flow Environment with Aisle Containment

5.3.1. Approach

Evaluate the effects high air flow environments with aisle containment systems on the performance of a total flooding fire suppression agent utilizing a computational fluid dynamics (CFD). The evaluation will be conducted for three primary agents: HFC-227ea (FM-200), FK-5-1-12 (Novec 1230) and IG-541 (Inergen). These agents represent the primary agents currently in use with HFC-227ea and FK-5-1-12 representing halocarbon type agents and IG-541 representing inert gas type agents. Variables to be investigated include: enclosure configuration, air flow rate in the enclosure, and dead air zone. Variables held constant include: enclosure geometry (volume, contents, and dimensions), system parameters (concentration (NFPA Class A minimum design), discharge time, nozzle pressure and nozzle spacing).

Three primary aisle containment configurations will be evaluated: Cold Aisle Containment, Hot Aisle Containment, and Cold Aisle Containment with Ceiling Plenum Only. These configurations are illustrated in Figure 5. Other configurations could be considered as well.



Cold Aisle Containment

Hot Aisle Containment

Cold Aisle Containment with Ceiling Plenum Only

Figure 5 – Aisle Containment Configurations

While gaseous clean agent fire suppression system configuration would be considered a constant with respect to varying air flow rates, the gaseous clean agent fire suppression system configuration cannot stay the same for all of the aisle containment configurations. While the nozzles locations in the plenum above the suspended ceiling and below the raised floor may remain the same, the nozzle locations in the main space will be vastly different. The nozzles outside of the contained aisle would be relocated to the compartment boundaries in a 180º pattern location with additional nozzles located within the contained aisle. This treats the contained aisle as a separate enclosure as suggested by NFPA 75 [3], NFPA 76 [4], and the FM Data Sheet [5].

Research will start with modeling the extreme cases (Still air, Maximum air flow rate, and Maximum air flow rate with maximum dead air zone). If evaluated cases warrant further investigation, then intermediate cases would be modeled.

The CFD models utilized during the first tier of this research program will be considered valid for this tier and no experimental testing is anticipated as part of this tier of the program.

5.3.2. Enclosure Geometry

The enclosure geometry is the same as the large of the two enclosures used without aisle containment with a main space volume of 856 m^3 (30,240 ft^3). The enclosure configured for the three aisle containment configurations are shown in Figures 6 through 8.

For the cold containment configuration (Figure 6), the six cold aisles between the server racks are encased up to the height of the racks. Cooling air flowing from the sub-flow has to pass through the server racks to enter the main space of the enclosure. The heated air is withdrawn through the vents in the suspended ceiling and returned to the CRAH. The area above the height of the racks remains free of obstructions and the main space clean agent nozzles could remain in their more centralized locations rather than pulled back to the 180º pattern location as drawn in Figure 6.

For the hot aisle containment configuration (Figure 7), the eight hot aisles are contained from floor to ceiling obstructing the area above the cabinet height. As the cool air enters the main space from the floor and allowed to mix with the main space air prior to being drawn through the cabinets, the main space would be kept cooler with this configuration relative to the cold aisle configuration.

The cold aisle containment with ceiling only plenum (Figure 8), has the six cold aisle encased from floor to ceiling. The cooling air flows from the ceiling plenum and through the racks prior to mixing with the main space air and returned to the CRAH.

Other configurations could be considered.

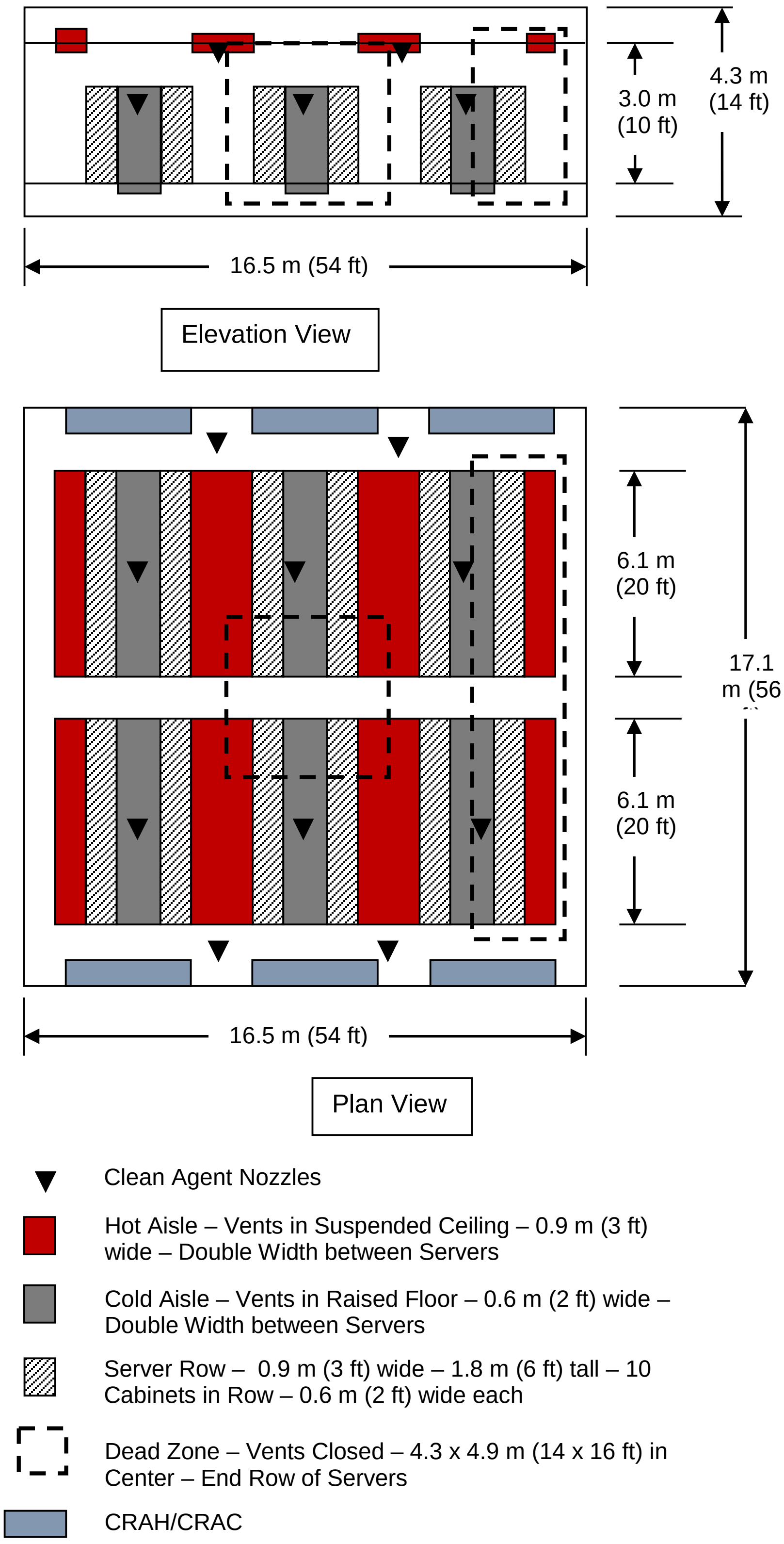


Figure 6 – 856 m^3 (30,240 ft^3) Enclosure Geometry – Cold Aisle Containment Configuration

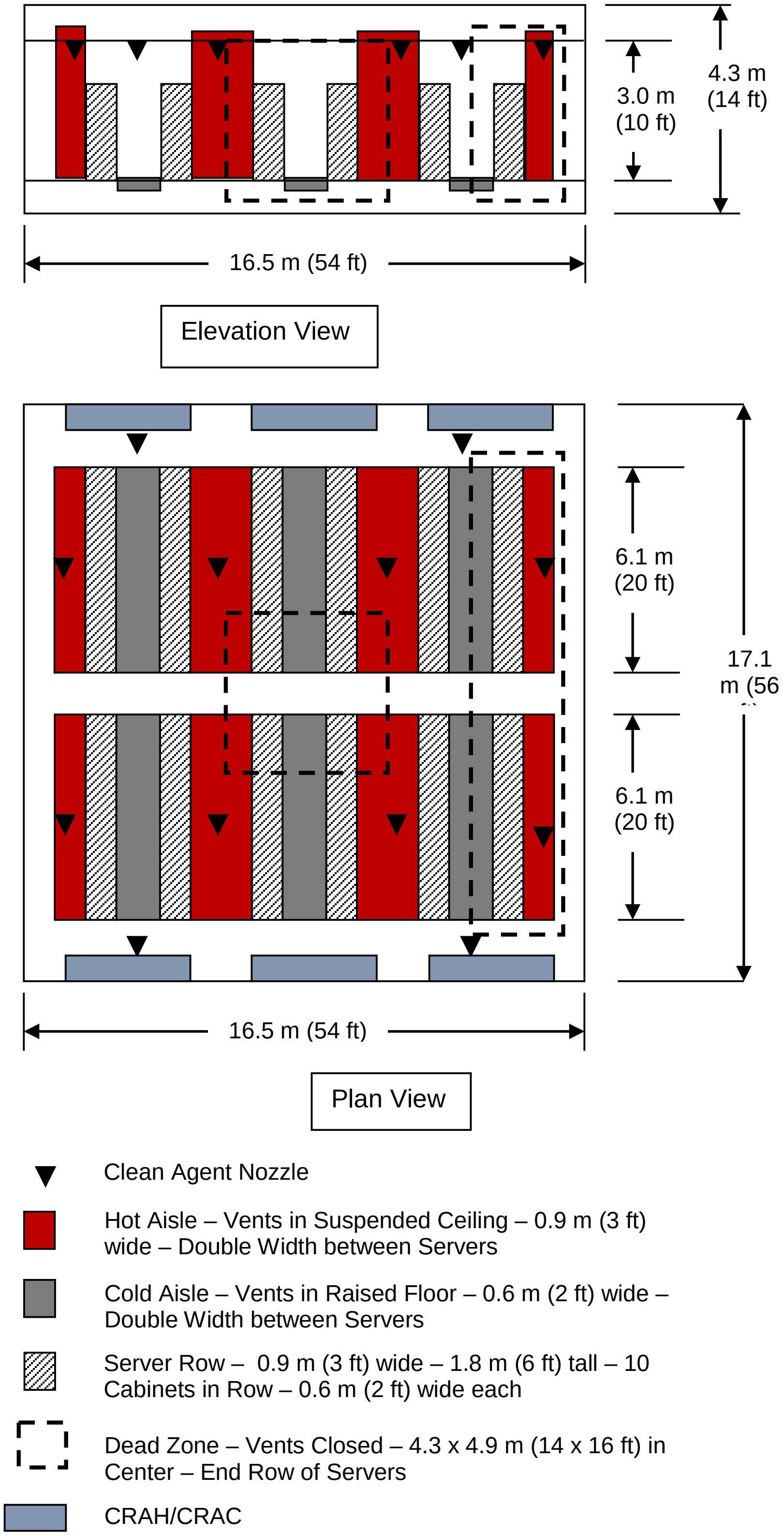


Figure 7 – 856 m^3 (30,240 ft^3) Enclosure Geometry – Hot Aisle Containment Configuration

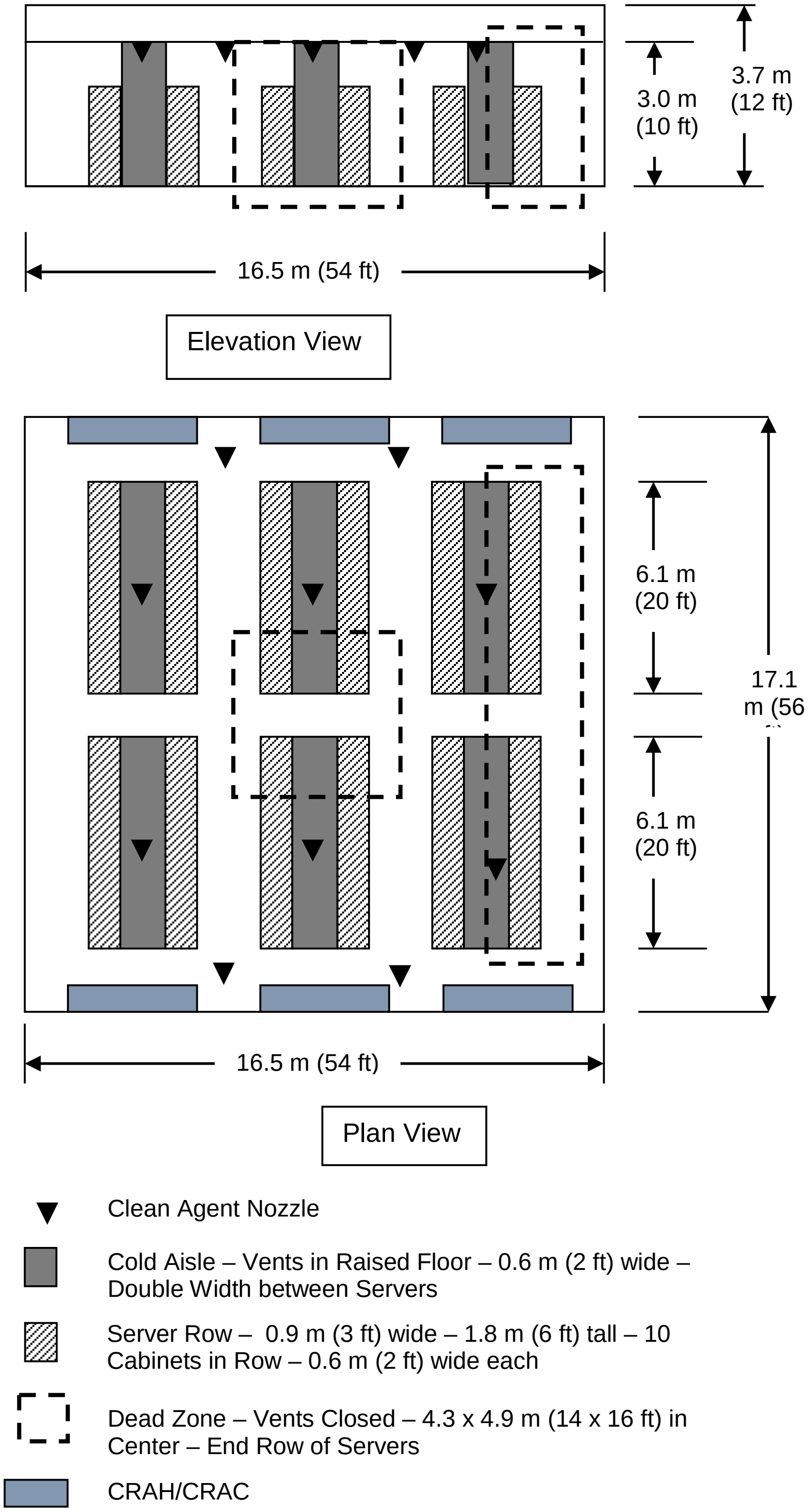


Figure 8 – 856 m^3 (30,240 ft^3) Enclosure Geometry – Cold Aisle Containment with Ceiling Plenum Only

The enclosure parameters relative to the parameters of the enclosure used in the previous investigation and the visited data centers are given in Table 11.

Table 11 – Enclosure Parameters

Parameter	Units	Enclosure to be Modeled	Visited Data Centers		Previous Investigation Enclosure
			A.V. Williams	CSS	
Floor Area	[m^2]	280.9	548.1	231.9	280.9
	[ft^2]	3024	5900	2496	3024
Ceiling Height	[m]	3.0	3.0	2.1	3.0
	[ft]	10.0	10.0	7.0	10.0
Subfloor Height	[m]	0.6	0.6	0.6	0.9
	[ft]	2.0	2.0	2.0	3.0
Suspended Ceiling Height	[m]	0.6			0.9
	[ft]	2.0			3.0
Main Space Volume	[m^3]	856	1,671	495	856
	[ft^3]	30,240	59,000	17,472	30,240
Sub-Floor Volume	[m^3]	171	334	141	257
	[ft^3]	6,048	11,800	4,992	9,072
Suspended Ceiling Volume	[m^3]	171			257
	[ft^3]	6,048			9,072
Total Volume	[m^3]	1,199	2,005	636	1,370
	[ft^3]	42,336	70,800	22,464	48,384
Floor Area Occupied by Server Cabinets	[m^2]	66.9	49.1	30.7	66.9
	[ft^2]	720	528	330	720
	[% Total]	23.8%	8.9%	13.2%	23.8%

5.3.3. System Parameters

Each of the three agents will be employed at their minimum Class C design concentration as specified in NFPA 2001. The nozzles discharging into the main space will be located in 180º pattern locations to avoid the obstructions caused by the aisle containment systems. Additional nozzles will be added to discharge the agent into the contained aisles. This is consistent with the recommendations of NFPA 75 [3], NFPA 76 [4] and the FM Data Sheet 5-32 [5]. The nozzles discharging into the sub-floor and the plenum above the suspended ceiling will be locating in center of each quadrant with four nozzles in each space.

A less conservative system approach will optionally be modeled as well. This approach would eliminate the nozzles within the contained aisle, shifting the agent mass to the sub-floor plenum (cold aisle containment), the main space (hot aisle containment) or the above the suspended ceiling plenum (cold aisle containment without sub-floor). This approach would only be effective if the recycling cooling air flow remains operating and would only be modeled in that case.

The systems will be designed to deliver the agent at the maximum discharge time: 10 seconds for HFC-227ea and FK-5-1-12, and 120 seconds for IG-541. The systems will also be designed to be near their minimum average nozzle pressure, approximately 5.5 bar (80 psig) for halocarbon type agents and approximatetly 13.8 bar (200 psig). An over-pressure relief vent will be installed and operational for the insert gas tests. It will be held closed during the tests with the halocarbon agents.

The gaseous clean agent fire suppression system hardware used in the CFD model effort will be as generic as possible to not reflect any particular manufacturer or distributer.

The agent quantity would be increased over the minimum quantity based on the size of the agent cylinders to be utilized.

The system parameters are outlined in Table 12 through 14.

Table 12 – System Parameters – Cold Aisle Containment

			Cold Aisle Containment						
			Main Space Excluding Contained Aisles	Contained Aisles (each)	Number of Contained Aisles	Contained Aisles (total)	Sub-Floor	Suspended Ceiling	Total
Volume		[m^3]	652	34	6	204	171	171	1,199
		[ft^3]	23,040	1,200	6	7,200	6,048	6,048	42,336
HFC-227ea	Class A MEC	[%]	5.2						
	Class C Design	[%]	7.0						
	Agent Mass	[kg]	356	19		111	94	94	655
		[lb]	786	41		245	206	206	1444
FK-5-1-12	Class A MEC	[%]	3.5						
	Class C Design	[%]	4.7						
	Agent Mass	[kg]	446	23		139	117	117	819
		[lb]	983	51		307	258	258	1805
IG-541	Class A MEC	[%]	28.5						
	Class C Design	[%]	38.5						
	Agent Volume*	[m^3]	317	17		99	83	83	583
		[ft^3]	11,201	583		3,500	2,940	2,940	20,581

* Agent volume will be rounded up to the next whole cylinder

Table 13 – System Parameters – Hot Aisle Containment

			Hot Aisle Containment							
			Main Space Excluding Contained Aisles	Contained Aisles* (each)		Number of Contained Aisles**	Contained Aisles (total)	Sub-Floor	Suspended Ceiling	Total
				Double Width	Single Width					
Volume		[m^3]	449	68	34	4 Double 4 Single	408	171	171	1,199
		[ft^3]	15,840	2,400	1,200		14,400	6,048	6,048	42,336
HFC-227ea	Class A MEC	[%]	5.2							
	Class C Design	[%]	7.0							
	Agent Mass	[kg]	245	37	19		223	94	94	655
		[lb]	540	82	41		491	206	206	1444
FK-5-1-12	Class A MEC	[%]	3.5							
	Class C Design	[%]	4.7							
	Agent Mass	[kg]	306	46	23		279	117	117	819
		[lb]	676	102	51		614	258	258	1805
IG-541	Class A MEC	[%]	28.5							
	Class C Design	[%]	38.5							
	Agent Volume**	[m^3]	218	33	17		198	83	83	583
		[ft^3]	7,700	1,167	583		7,000	2,940	2,940	20,581

*Double width aisles between rows of cabinets – Single width row before first row and after last row on either side of center aisle

* *Agent volume will be rounded up to the next whole cylinder

Table 14 – System Parameters – Cold Aisle Containment with Ceiling Plenum Only

			Cold Aisle Containment with Ceiling Plenum Only					
			Main Space Excluding Contained Aisles	Contained Aisles (each)	Number of Contained Aisles	Contained Aisles (total)	Suspended Ceiling	Total
Volume		[m³]	516	57	6	340	171	1,028
		[ft³]	18,240	2,000	6	12,000	6,048	36,288
HFC-227ea	Class A MEC	[%]	5.2					
	Class C Design	[%]	7.0					
	Agent Mass	[kg]	282	31		186	94	561
		[lb]	622	68		409	206	1237
FK-5-1-12	Class A MEC	[%]	3.5					
	Class C Design	[%]	4.7					
	Agent Mass	[kg]	353	39		232	117	702
		[lb]	778	85		512	258	1548
IG-541	Class A MEC	[%]	28.5					
	Class C Design	[%]	38.5					
	Agent Volume*	[m³]	251	28		165	83	500
		[ft³]	8,867	972		5,834	2,940	17,641

* Agent volume will be rounded up to the next whole cylinder

5.3.4. Air Flow Rate

The range of the air flow rate to be investigated corresponds to a cooling demand range between 0.54 to 26.9 kW/m^2 (50 to 2,500 W/ft^2 (171 to 8,530 Btu/hr ft^2)) of occupied floor area. The corresponding flow rate was based on a 15 °C (27 °F) air temperature differential between the cold air supply plenum (sub-floor) and the hot air return plenum (above the suspended ceiling). The air flow rate range and corresponding cooling demand is outlined in Table 15. The presented air changes per hour, ACH, is calculated based on the total volume including the sub-floor and plenum above the suspended ceiling. The air change rate would be higher for the ceiling plenum only case due to the elimination of the sub-floor volume

Table 15 – Air Flow Rate Range

Enclosure {856 m^3 (30,240 ft^3) Volume and 66.9 m^2 (720 ft^2) Occupied Floor Area}							
Heat Load per Occupied Floor Area			**Total Heat Load**		**Air Flow Rate Requirement {15°C [27°F] Temperature Differential}**		
[kW/m^2]	**[W/ft^2]**	**[Btu/hr ft^2]**	**[kW]**	**[Btu/hr]**	**[m3/min]**	**[CFM]**	**[ACH]**
0.54	50	171	36	122,844	117.3	4,144	6.3
1.08	100	341	72	245,687	234.7	8,288	12.6
2.15	200	682	144	491,374	469.4	16,576	25.2
6.46	600	2,047	432	1,474,123	1408.1	49,728	75.5
10.76	1,000	3,412	720	2,456,872	2346.9	82,879	125.8
26.91	2,500	8,531	1,800	6,142,180	5867.2	207,198	314.6

5.3.5. Dead Air Space

Dead air space arises from either the data center not being at full capacity or due to the inclusion within the rack array space of non-cooled equipment, such as power distribution units. This was observed in both of the data centers visited. The dead air area may represent a low concentration zone as the agent directed toward this area may be diverted into the recycling air flow.

The dead air zones proposed for the enclosure are shown in Figures 6 through 8. The total areas of these zones and portion of the total floor area represented by these zones are given in Table 16. The walkway around the boundary of the enclosures, other than that occupied by the CRAC units, and the center aisle in the larger enclosure would represent a dead zone in any case.

Table 16 – Dead Air Zones in the Proposed Enclosures

	Dead Air Zone						
	Length		**Width**		**Area**		
	[m]	**[ft]**	**[m]**	**[ft]**	**[m^2]**	**[ft^2]**	**[% total]**
End Server Row (Includes portion of Center Aisle)	13.4	44	2.4	8	32.7	352.0	11.6%
Center Area (Includes portion of Center Aisle)	4.3	14	4.9	16	20.8	224.0	7.4%
Total					53.5	576.0	19.0%

5.3.6. Model Case Matrix

The initial investigation of the extreme cases consists of 18 cases with each of the three aisle containment configurations as outlined in Tables 17 through 19. The case matrix consists of twelve cases in the with the conservative system configuration and nine cases with the less conservative configuration with the nozzles in the contained aisles removed and the agent discharged from the upstream nozzles (sub-floor plenum, main space, or above ceiling plenum for the cold aisle containment, hot aisle containment or cold aisle containment with ceiling plenum only, respectively). The less conservative case will be modeled with lower air flow rates to investigate the effects of an impaired recycling ventilation system. A more detailed evaluation would follow on based on the results obtained. The follow-on evaluation would concentrate on the parameters that evidence the greatest effects on the system performance.

Table 17 – CFD Model Case Matrix with Cold Aisle Containment Configuration

Case Number	Clean Agent System Configuration	Agent	Air Flow Rate			Dead Volume Area			Comments
			[m^3/min]	[CFM]	[ACH]	[m^2]	[ft^2]	[% total]	
1	Conservative	HFC-227ea	0	0	0	0	0	0	Base Case – Still Air
2		FK-5-1-12	0	0	0	0	0	0	
3		IG-541	0	0	0	0	0	0	
4		HFC-227ea	469	16,576	23.5	0	0	0	Medium Air Flow – No Dead Zone
5		FK-5-1-12	469	16,576	23.5	0	0	0	
6		IG-541	469	16,576	23.5	0	0	0	
7		HFC-227ea	469	16,576	23.5	53.5	576	19.0%	Medium Air Flow
8		FK-5-1-12	469	16,576	23.5	53.5	576	19.0%	
9		IG-541	469	16,576	23.5	53.5	576	19.0%	
10		HFC-227ea	2347	82,879	117	53.5	576	19.0%	High Air Flow
11		FK-5-1-12	2347	82,879	117.5	53.5	576	19.0%	
12		IG-541	2347	82,879	117.5	53.5	576	19.0%	
13	Nozzles Removed from Aisle Containment – Agent Added to Sub-Floor Plenum Nozzles	HFC-227ea	0	0	0	0	0	0	Still Air
14		FK-5-1-12	0	0	0	0	0	0	
15		IG-541	0	0	0	0	0	0	
16		HFC-227ea	117	4,144	23.5	53.5	576	19.0%	Low Air Flow
17		FK-5-1-12	117	4,144	23.5	53.5	576	19.0%	
18		IG-541	117	4,144	23.5	53.5	576	19.0%	
19		HFC-227ea	2347	82,879	117	53.5	576	19.0%	High Air Flow
20		FK-5-1-12	2347	82,879	117.5	53.5	576	19.0%	
21		IG-541	2347	82,879	117.5	53.5	576	19.0%	

Table 18 – CFD Model Case Matrix with Hot Aisle Containment Configuration

Case Number	Clean Agent System Configuration	Agent	Air Flow Rate			Dead Volume Area			Comments
			[m^3/min]	[CFM]	[ACH]	[m^2]	[ft^2]	[% total]	
1	Conservative	HFC-227ea	0	0	0	0	0	0	Base Case – Still Air
2		FK-5-1-12	0	0	0	0	0	0	
3		IG-541	0	0	0	0	0	0	
4		HFC-227ea	469	16,576	23.5	0	0	0	Medium Air Flow – No Dead Zone
5		FK-5-1-12	469	16,576	23.5	0	0	0	
6		IG-541	469	16,576	23.5	0	0	0	
7		HFC-227ea	469	16,576	23.5	53.5	576	19.0%	Medium Air Flow
8		FK-5-1-12	469	16,576	23.5	53.5	576	19.0%	
9		IG-541	469	16,576	23.5	53.5	576	19.0%	
10		HFC-227ea	2347	82,879	117	53.5	576	19.0%	High Air Flow
11		FK-5-1-12	2347	82,879	117.5	53.5	576	19.0%	
12		IG-541	2347	82,879	117.5	53.5	576	19.0%	
13	Nozzles Removed from Aisle Containment – Agent Added to Main Space Nozzles	HFC-227ea	0	0	0	0	0	0	Still Air
14		FK-5-1-12	0	0	0	0	0	0	
15		IG-541	0	0	0	0	0	0	
16		HFC-227ea	117	4,144	23.5	53.5	576	19.0%	Low Air Flow
17		FK-5-1-12	117	4,144	23.5	53.5	576	19.0%	
18		IG-541	117	4,144	23.5	53.5	576	19.0%	
19		HFC-227ea	2347	82,879	117	53.5	576	19.0%	High Air Flow
20		FK-5-1-12	2347	82,879	117.5	53.5	576	19.0%	
21		IG-541	2347	82,879	117.5	53.5	576	19.0%	

Table 19 – CFD Model Case Matrix with Cold Aisle Containment with Ceiling Plenum Only

Case Number	Configuration	Agent	Air Flow Rate			Dead Volume Area			Comments
			[m^3/min]	[CFM]	[ACH]	[m^2]	[ft^2]	[% total]	
1	Conservative	HFC-227ea	0	0	0	0	0	0	Base Case – Still Air
2		FK-5-1-12	0	0	0	0	0	0	
3		IG-541	0	0	0	0	0	0	
4		HFC-227ea	469	16,576	27.4	0	0	0	Medium Air Flow – No Dead Zone
5		FK-5-1-12	469	16,576	27.4	0	0	0	
6		IG-541	469	16,576	27.4	0	0	0	
7		HFC-227ea	469	16,576	27.4	53.5	576	19.0%	Medium Air Flow
8		FK-5-1-12	469	16,576	27.4	53.5	576	19.0%	
9		IG-541	469	16,576	27.4	53.5	576	19.0%	
10		HFC-227ea	2347	82879	137.0	53.5	576	19.0%	High Air Flow
11		FK-5-1-12	2347	82,879	137.0	53.5	576	19.0%	
12		IG-541	2347	82,879	137.0	53.5	576	19.0%	
13	Nozzles Removed from Aisle Containment – Added to Ceiling Plenum Nozzles	HFC-227ea	0	0	0	0	0	0	Still Air
14		FK-5-1-12	0	0	0	0	0	0	
15		IG-541	0	0	0	0	0	0	
16		HFC-227ea	117	4,144	27.4	53.5	576	19.0%	Low Air Flow
17		FK-5-1-12	117	4,144	27.4	53.5	576	19.0%	
18		IG-541	117	4,144	27.4	53.5	576	19.0%	
19		HFC-227ea	2347	82,879	137.0	53.5	576	19.0%	High Air Flow
20		FK-5-1-12	2347	82,879	137.0	53.5	576	19.0%	
21		IG-541	2347	82,879	137.0	53.5	576	19.0%	

6. REFERENCES

1. Floyd, J. and Gottuk, D.T., “Validation of Modeling Tools for Detection Design in High Air Flow Environments, Phase II Report: Part 3,” The Fire Protection Research Foundation, Quincy, MA, August 2014.

2. “Standard on Clean Agent Fire Extinguishing Systems,” NFPA 2001, 2015 Edition, National Fire Protection Association, Quincy, MA, 2015.

3. “Standard for the Fire Protection of Information Technology Equipment,” NFPA 75, 2013 Edition, National Fire Protection Association, Quincy, MA, 2013.

4. “Standard for the Fire Protection of Telecommunications Facilities,” NFPA 76, 2012 Edition, National Fire Protection Association, Quincy, MA, 2012.

5. “FM Global Property Loss Prevention Data Sheet 5-32, Data Centers and Related Facilities,” FM Global, Johnston, RI, July 2012.

6. ANSI/UL 2127, “Standard for Inert Gas Clean Agent Extinguishing System Units,” Underwriters Laboratories Inc., Northbrook, IL, 2012.

7. ANSI/UL 2166, “Standard for Halocarbon Clean Agent Extinguishing System Units,” Underwriters Laboratories Inc., Northbrook, IL, 2012.

8. FM Approvals, “Approval Standard for Clean Agent Extinguishing Systems: Class Number 5600,” FM Approvals, Johnston, RI, February 2009.