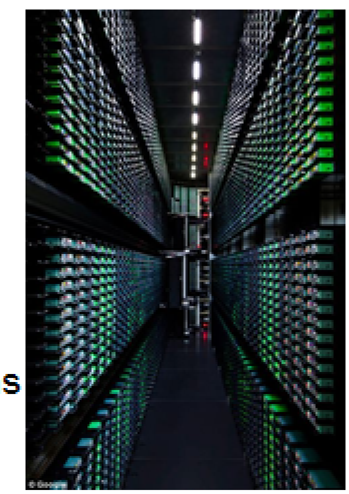
Class C Clean Agent Testing Using External Energy Augmentation from 5 To 20 kW/m^2 With And Without Air Movement

Bon F. Shaw, Brad T. Stilwell, Gene Hill P.E., Tiradej Bunyarattaphantu – Fike Corporation

Energy augmented combustion and fire extinction tests with HFC-125

Goals of Research

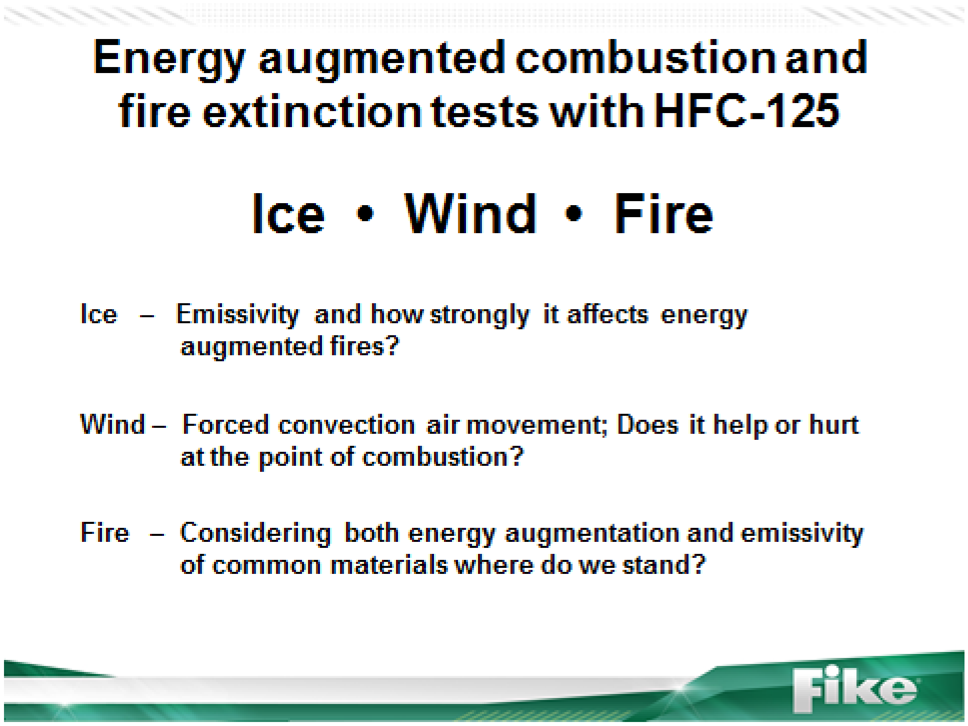
- Understand the power density trend in data centers
- Understand the augmented energy potential for various power densities
- Develop a test procedure to test clean agent concentrations required to suppress fires at different power densities.



Fike set out to develop a better understanding of the power density trends in data centers around the world.

We wanted to learn how increasing power density translates into energy augmented combustion.

And we wanted to develop test procedures that uses energy augmented combustion so we can better calibrate our clean agent concentrations required for suppression.

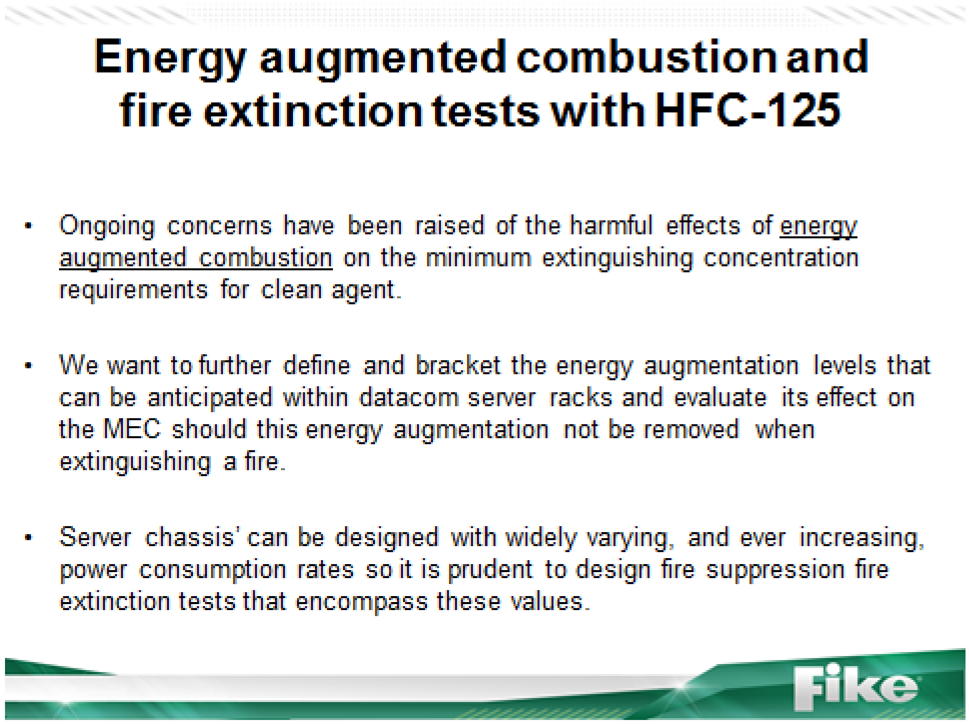


Ice Wind and Fire

Ice represents an extreme of emissivity. It is an almost ideal heat radiator and absorber. Copper, steel and aluminum on the other hand are about the worst. We'll look at why copper is the most common heat sink material in computer rooms.

Wind represents the ever present air movement in datacom facilities. We explored its effects on fire suppression extinguishment at minimal air velocities.

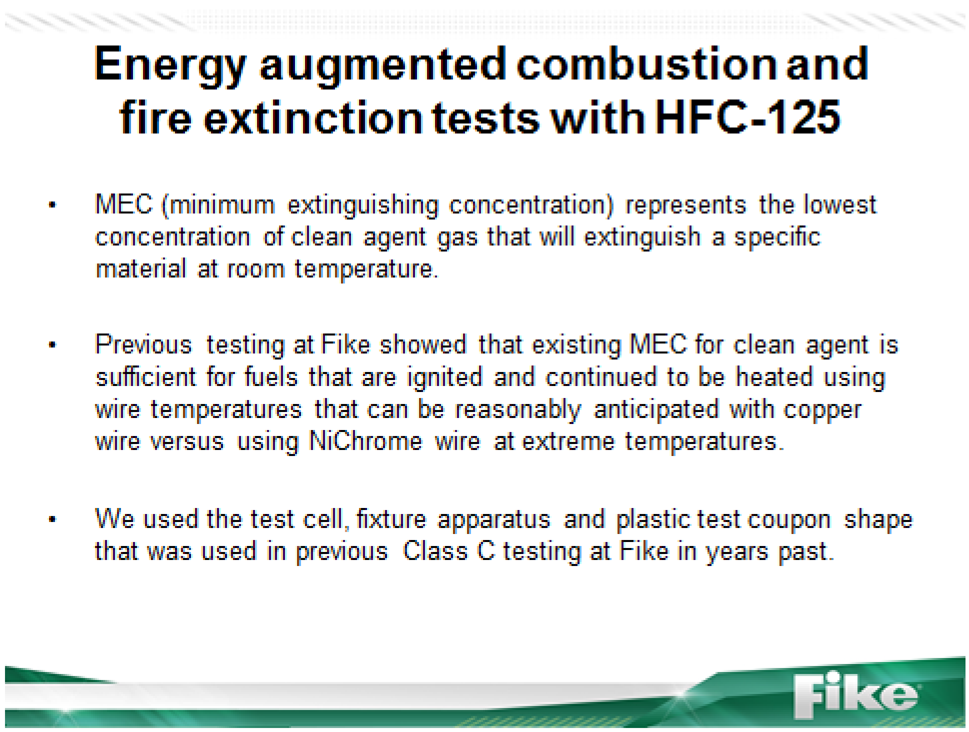
Fire – Well, we know what that represents. We know that electrical power dissipation produces heat and as the temperature of fuels increases it makes them more difficult to extinguish. We need to account for this in present and future suppression requirements in datacom facilities.



Recently, concerns of energy augmented combustion have been voiced, and reports delivered, that highlight this hazard.

We set out to put energy augmentation of fuels into the context of datacom facilities, at the rack level and how this threat can affect minimum extinguishing concentration of clean agents.

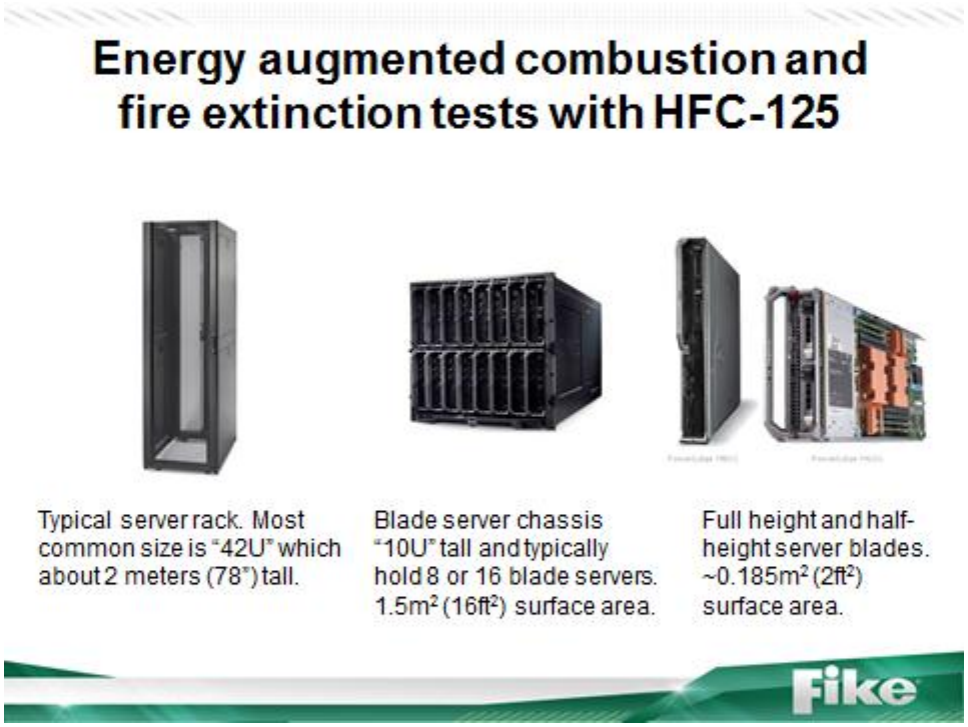
And server chassis' consume ever-increasing levels of power so we set out to assimilate future growth forecasts into our evaluation.



MEC will be often used in this presentation. MEC is short for minimum extinguishing concentration and represents the lowest concentration of clean agent gas that will extinguish a specific material at room temperature.

Previous testing at Fike showed that existing minimum extinguishing concentration (MEC) for clean agent is sufficient for fuels that are ignited and continued to be heated using wire temperatures that can be reasonably anticipated with copper wire versus using NiChrome wire at extreme temperatures.

We used the test cell, fixture apparatus and plastic coupon shape that was used in previous Class C testing at Fike in years past.



For those that may not be very familiar with typical datacom equipment we have a few examples:

On the left we have the most common server rack in use. A size "42U" rack is about 2 meters or 78" tall.

The rack is populated with equipment chassis'. The center picture is a blade server chassis. A maximum of four of these 10U tall chassis' will physically fit in a 42U rack.

And on the right we have examples of full and half-height blade servers. Each blade server is, in essence, equivalent to a desktop computer's motherboard – but on steroids @ ~$3-5,000 each. Up to 8 full height blades will fit in the blade server chassis or up to 16 half-height blade servers.

A server rack may contain $200,000 in equipment alone.

Energy augmented combustion and fire extinction tests with HFC-125

- Single phase 208-volt 30-amp supplies up to 5 kW
- 5 kW in a server chassis of 1.5m² = <u>3.33 kW/m²</u>

- 3-phase 208-volt 20-amp power supplies up to 5.76 kW
- 5.76 kW in a server chassis of 1.5m² = <u>3.84 kW/m²</u>

- 3-phase 208-volt 30-amp power supplies up to 8.65 kW
- 8.65 kW in a server chassis of 1.5m² = <u>5.76 kW/m²</u>

In a blade server configuration this is 625 W, 720 W and 1080 W maximum power dissipation respectively for <u>each</u> blade in an 8 blade server chassis.

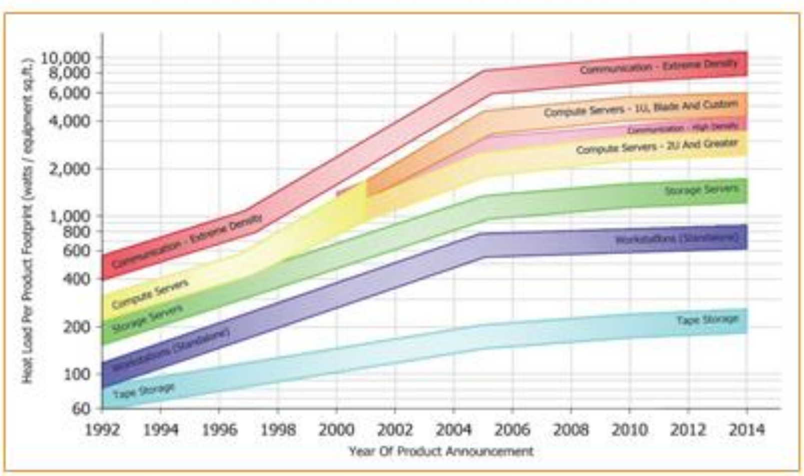
Here we have three examples of common power drops to server chassis' in use today:

A 208-volt 30-amp <u>single phase</u> supply derated with a UL 0.8 safety factor, the maximum power consumption <u>per server chassis</u> is 5 kW. If this supply feeds a single blade server chassis, and the chassis blade servers have a typical surface area of 1.5 m^2 then the power density is 3.33 kW/m^2.

With <u>3-phase</u> 208-volt <u>20</u>-amp power 3.84 kW/m^2 is possible, and likewise 3-phase 208-volt 30-amp supply provides up to 5.76 kW/m^2 of power density, per server chassis.

Specific to blade servers this provides 625 Watts, 720 Watts and 1080 Watts, maximum power dissipation respectively for each blade in an 8 blade server chassis.

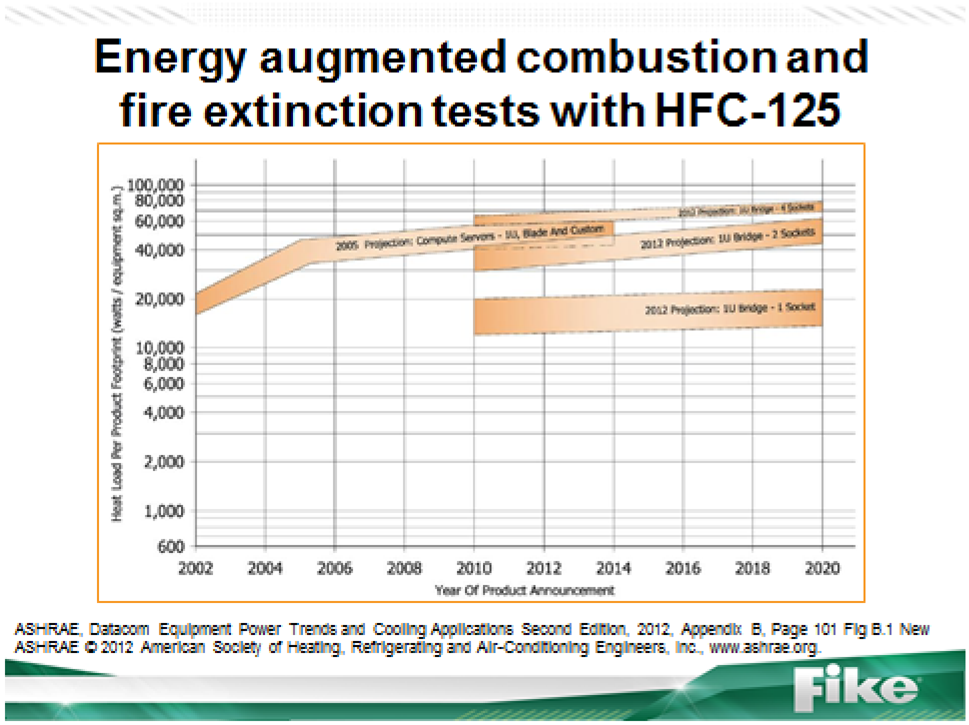
Energy augmented combustion and fire extinction tests with HFC-125



ASHRAE, Datacom Equipment Power Trends and Cooling Applications Second Edition, 2012, Chapter 4, Page 38, Fig 4.2 New ASHRAE © 2012 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org.

ASHRAE is the American Society of Heating, Refrigerating and Air Conditioning Engineers and this is a graph from ASHRAE's Datacom Equipment Power Trends and Cooling Applications First Edition.

As can be seen from the graph, the power density of computer room equipment is increasing. The data in this graph is expressed in units of watts per square foot of floor space of an equipment rack. This is the convention for computer room air conditioning and air handlers (CRAC/CRAH) engineering design decisions.



This is a graph from ASHRAE's Datacom Equipment Power Trends and Cooling Applications Second Edition published in 2012.

The power density of datacom equipment is expected to continue increasing through the year 2020. The actual power density is dependent upon the type of computing technology employed in data center and so the data from 2010 through 2020 is broken into several clusters.

ASHRAE anticipates that server power density in a **fully populated**, **maximum load**, 42U server rack will reach approximately 65,000 watts by 2020.

Energy augmented combustion and fire extinction tests with HFC-125

Power Source	Derated Chassis Power (W)	(ASHRAE) Footprint Power (W/m^2)	42U Rack Total (W)	(Surface Area) Chassis Total Heat Output (W/m^2)	(Fike Testing) Chassis Total Heat Output (W/m^2)
120V, 20A	1,920	17,723	11,520	1,280	
208V, 30A	4,992	46,080	29,952	3,328	
208V, 20A, 3ϕ	5,764	53,206	34,584	3,843	5,000
208V, 30A, 3ϕ	8,650	79,846	51,900	5,767	(ASHRAE 2020 est.)
208V, 40A, 3ϕ	11,528	106,412	69,174	7,686	
208V, 50A, 3ϕ	14,410	133,015	86,460	9,607	10,000
208V, 60A, 3ϕ	17,292	159,618	103,752	11,528	
208V, 80A, 3ϕ	23,056	212,825	138,338	15,370	15,000
208V, 100A,3ϕ	28,820	266,031	172,922	19,213	20,000

Table 1 – Computer Room Power Levels

So these predictions need to be put into context with the power sources, power densities and server chassis' total heat output.

The left most column lists the many power source options available. The next column is the wattage that is available from the power sources. Next are the ASHRAE *floor space footprint power* estimates; then the maximum wattage that a fully populated 42U rack will consume under full load. Next is the total heat output, that has been converted to w/m2 based upon the surface area of a server; and the last column, with numerals in red, are placed in their approximate levels of power for the total heat output levels tested by Fike.

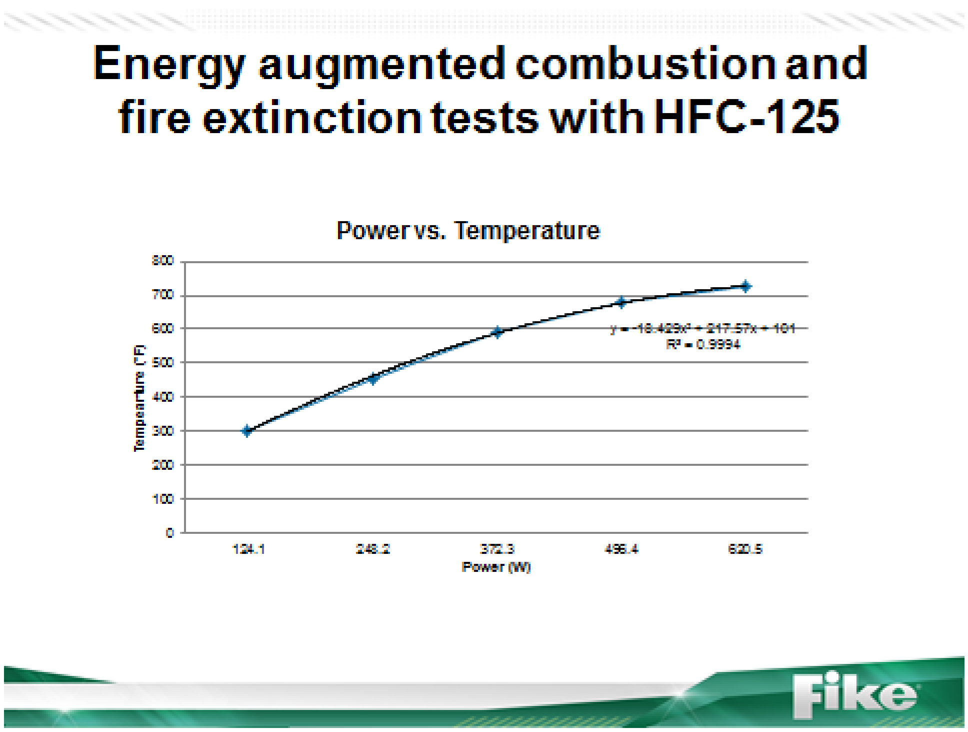
The power levels shown in blue line is the ASHRAE 2020 estimate. It's important to note that ASHRAE calculates this level of power consumption by anticipating that the entire 42U rack is filled with the same equipment from top to bottom and it is **all** running at the maximum rated power consumption. ASHRAE also points out that rack power levels above 15-20 kW (the circled levels) would be a major cooling issue for most datacom centers around the world. This puts most present installations well below the 2nd row on the table.

A Datacenter Dynamics 2011 survey shows that today's world average total power to rack is around 4.05 kW. 6 in 10 are under 5kW/rack; 3 in 10 are 5kW-10kW/rack and about 1 in 10 racks exceed 10 kW/rack.

In consideration of ASHRAE estimates and looking forward to future higher power density servers, testing at Fike was extended to power levels of 282 kW/m^2 of floor space or 20 kW/m^2 chassis total heat output.

Now on to the testing methodology and equipment:

In our tests, energy augmentation of the plastic is achieved from heat that is radiated from modified solid single-burner cook tops and coil elements. The hot plates are energized using a variable AC transformer. The thermostats of the cook top elements were bypassed giving us full control.



Initial tests were conducted to determine the correct voltage and current settings that are equivalent to specific energy augmentation levels. The area of the hot plate was used in calculations that are based upon desired power consumption from 5 kW/m^2 to 20 kW/m^2.

The initial tests were set up and carried out in a manner that closely resembles experimental Class C tests that were performed by Fike when validating MEC levels for burning plastics that are ignited by hot wire failures.

A sample of plastic is set into an aluminum test frame that holds it in a vertical, upright orientation. Two slots are cut through the sample allowing a NiChrome wire to pass through it. This test frame is set directly upon the hot plate that has been pre-warmed to the desired temperature for the test.

Three baffles are put in place to avoid blowing the fire out during discharge.

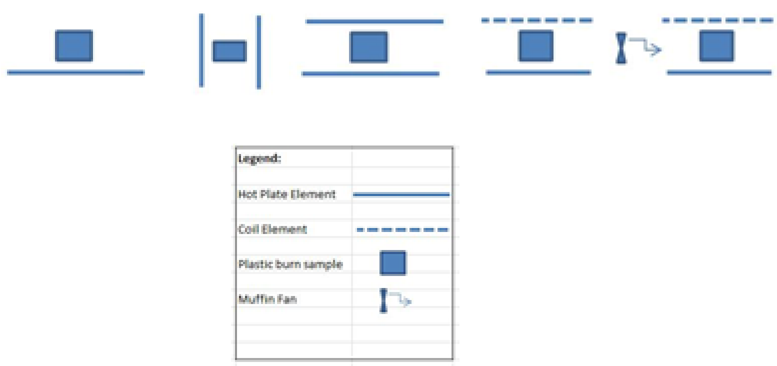
This test setup is then placed in a sealed test cell with a viewing port. This is the Fike 200 ft^3 test cell.

Various geometries for the heat radiating surfaces were utilized. They were used singly and in pairs. Solid and open coil elements were utilized.

Energy augmented combustion and fire extinction tests with HFC-125

The hot surface radiators were place in various vertical and horizontal orientations.

Energy augmented combustion and fire extinction tests with HFC-125



Pictograms used to represent test configurations

These pictograms are used to represent the various test configurations in our test results.

A solid line represents a solid surface hot plate

A dashed line in a coil type heater element

The square represents our plastic test sample

And the bowtie represents a muffin fan for air movement

So, from left to right we have:

A single, solid surface, hot plate radiator beneath the fuel

Dual, solid surface, hot plate radiators on either side of the fuel

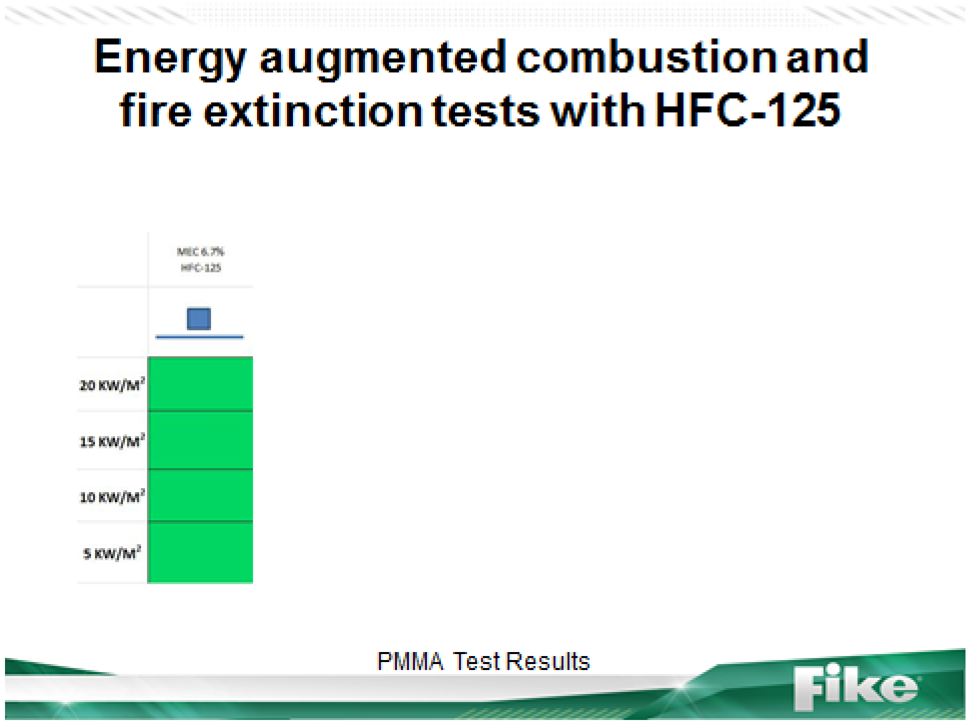
Dual, solid surface, hot plate radiators above and below the fuel

Dual hot plate radiators with a solid element below and an open coil element above the fuel

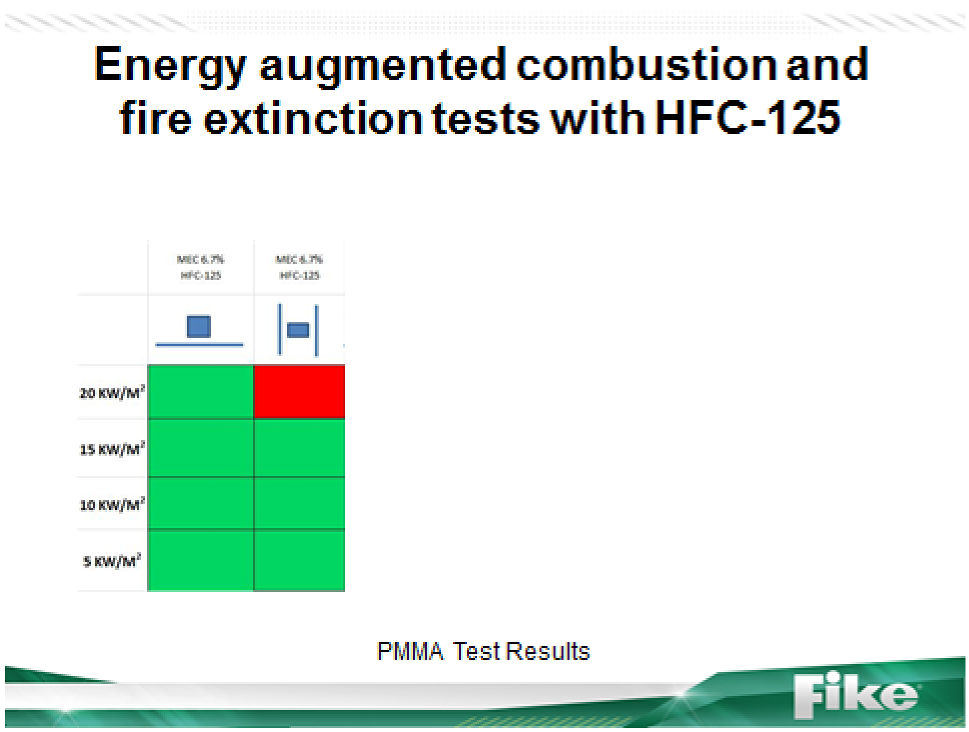
Dual hot plate radiators with solid element below and open coil element above the fuel with air movement

For all tests the hot plate surfaces were pre-heated to the test temperature and remained energized during the entire test. A NiChrome wire was used to initiate the burning of the plastic test specimen and remained energized for 30 seconds following the eruption of flaming combustion of the specimen. The test specimen was allowed a pre-burn time of 60 seconds total. HFC-125 was discharged and the end of the 60 second pre-burn period. The discharge lasts approximately 8-10 seconds.

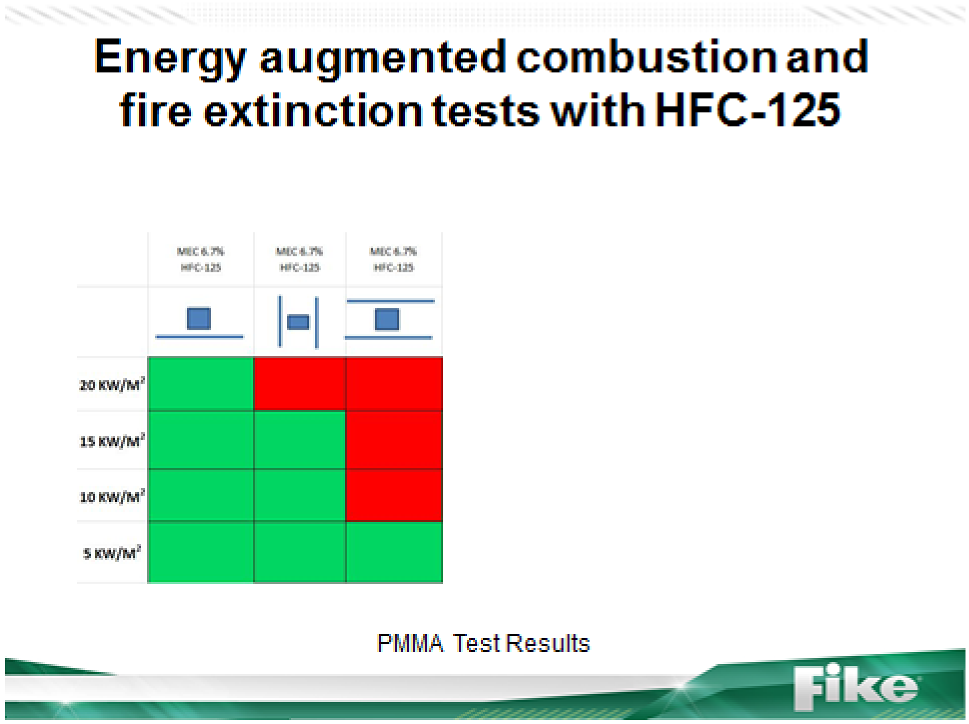
PMMA was used for the majority of tests. Some samples of Polypropylene, ABS and HDPE were spot-checked and found to extinguish at the same 15 kW/m2 as PMMA under the same conditions of twin vertical hot plate surfaces without air flow.



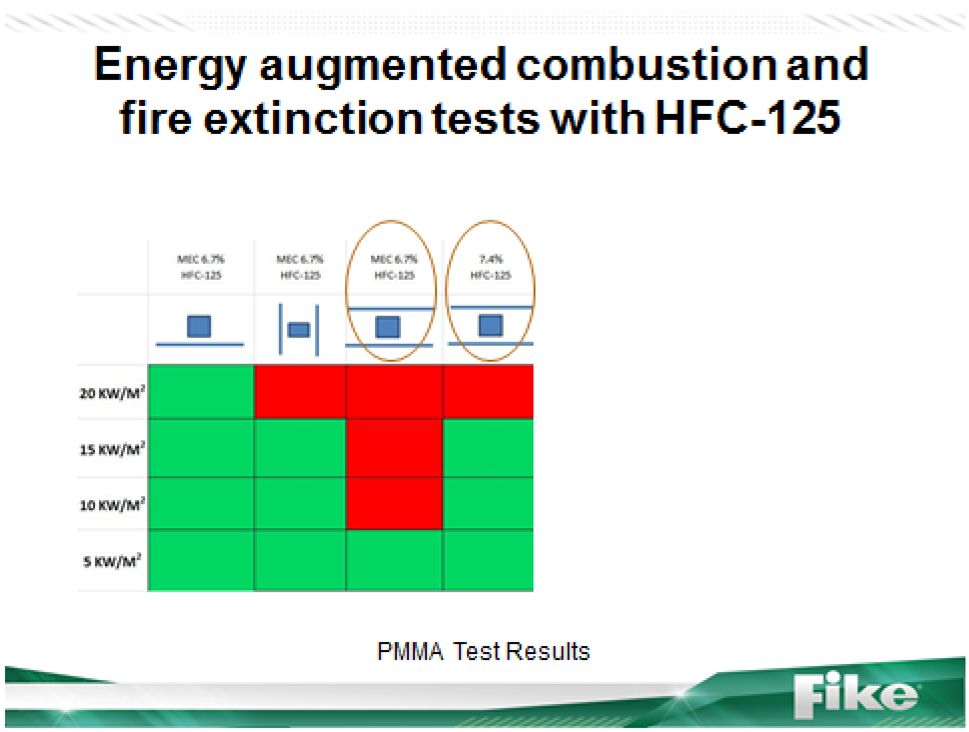
Initial tests were with a single hot plate radiator at standard MEC of 6.7% agent and we had no issues from 5 to 20 kw/m2.



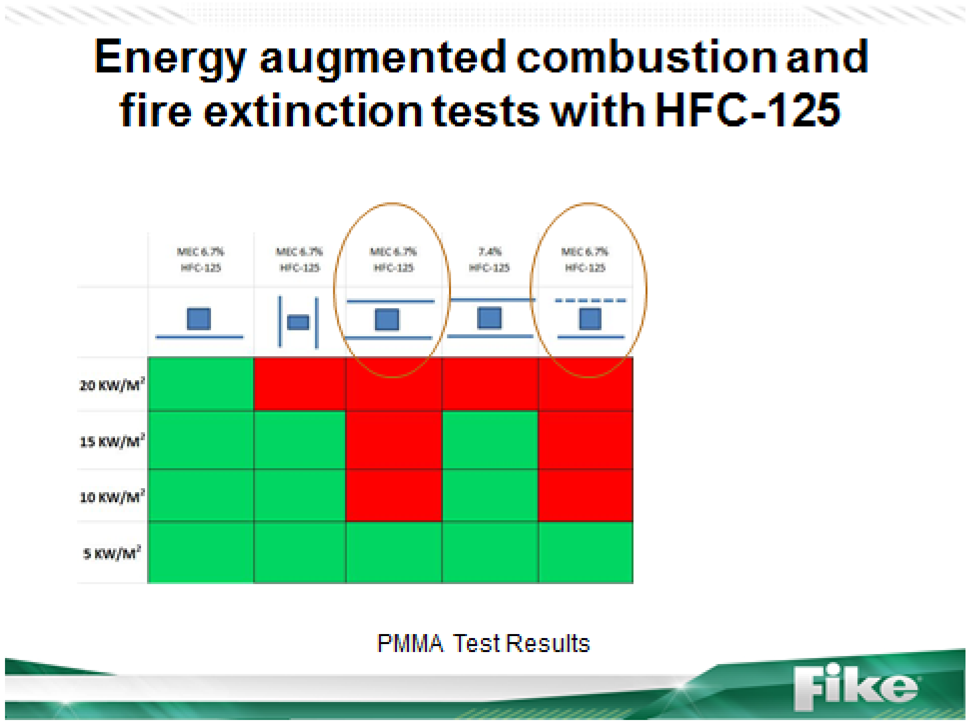
A second hot plate radiator was used and the configuration changed to vertical hot surfaces. All tests passed except for the 20kw/m2 test.



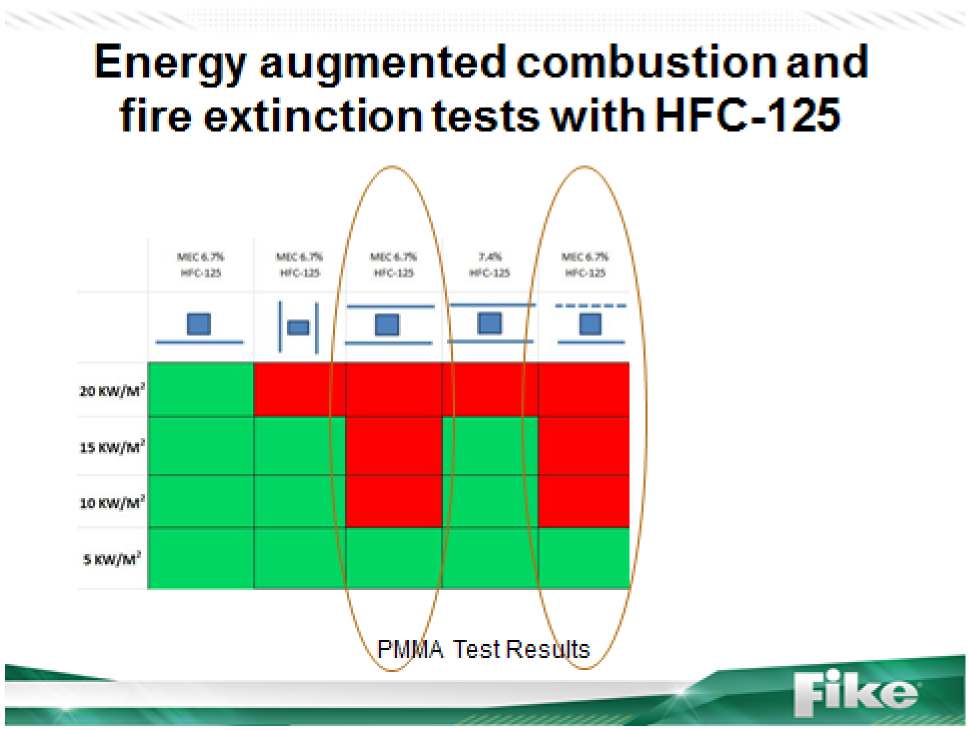
Thinking about a chimney effect, and that it might be influencing the outcomes; we changed the orientation of the hot plate radiators and repeated the previous tests.



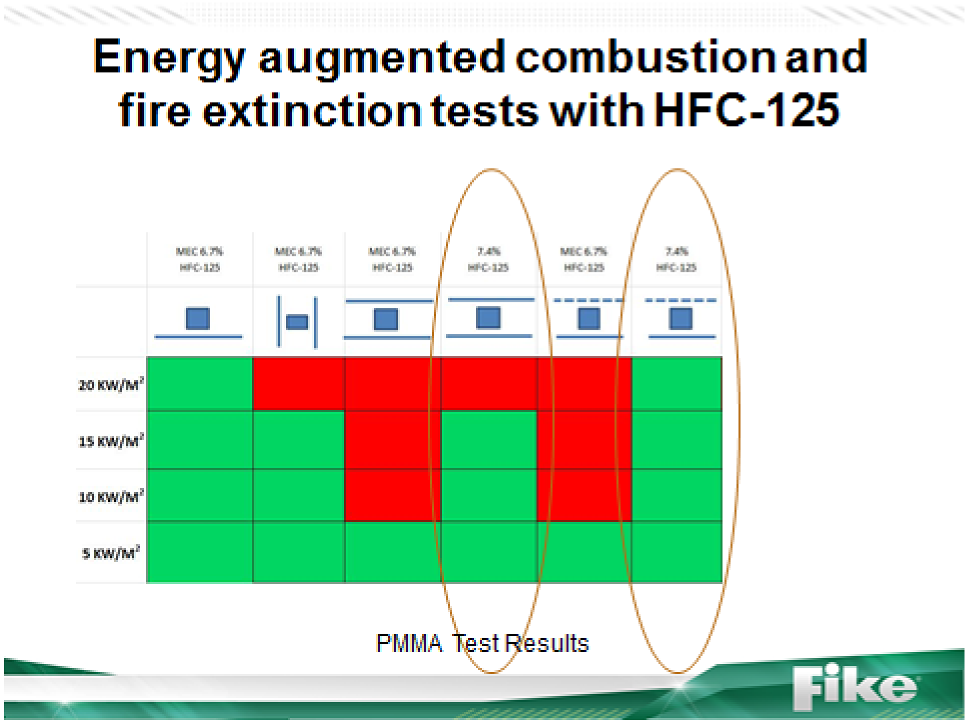
Now that we had some pass/fail reference points we added 10% additional agent and repeated the previous tests. We now had extinguishments up to 15 kW/m^2.



Exploring the idea of the chimney effect the top hot surface radiator was replaced with an open-air coil. The outcome is the same.

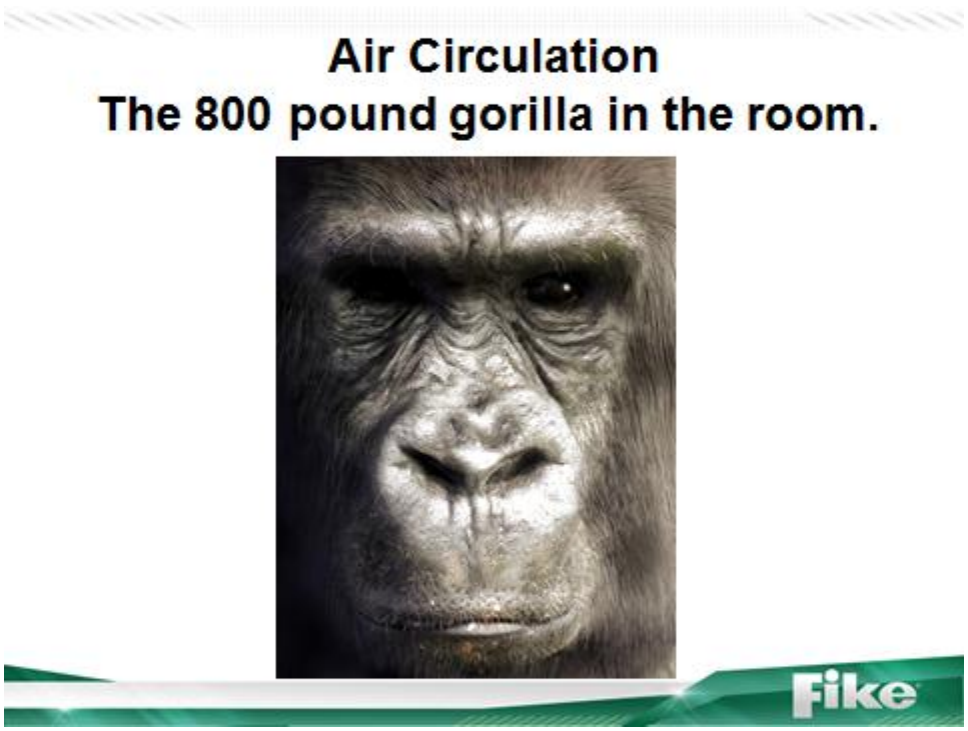


No difference in extinguishment performance was observed when exchanging the solid surface hot plate radiator with the “open air” coil heater.

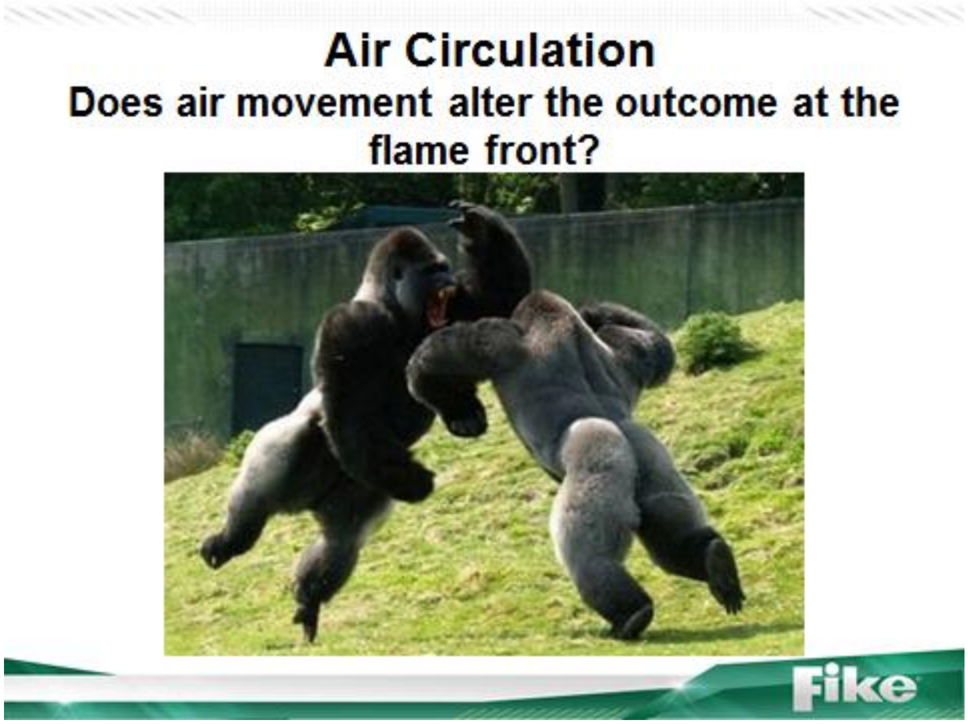


We again raised our agent concentration from MEC by 10% to 7.4% and repeated our tests. This small difference in outcome raised the question of air movement at high temperatures.

This led us to the question . . .

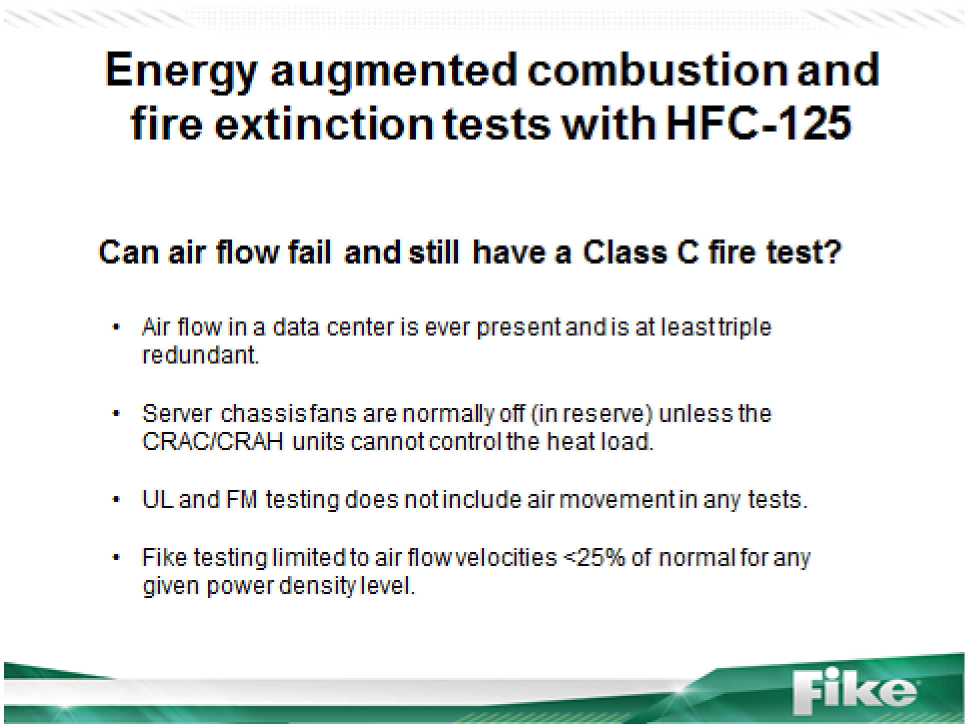


of air circulation.



Does it help or hurt when considering the effectiveness of clean agent suppression alone, but not leakage, make up air dilution or descending interface.

Opinions differ, but why argue about it?

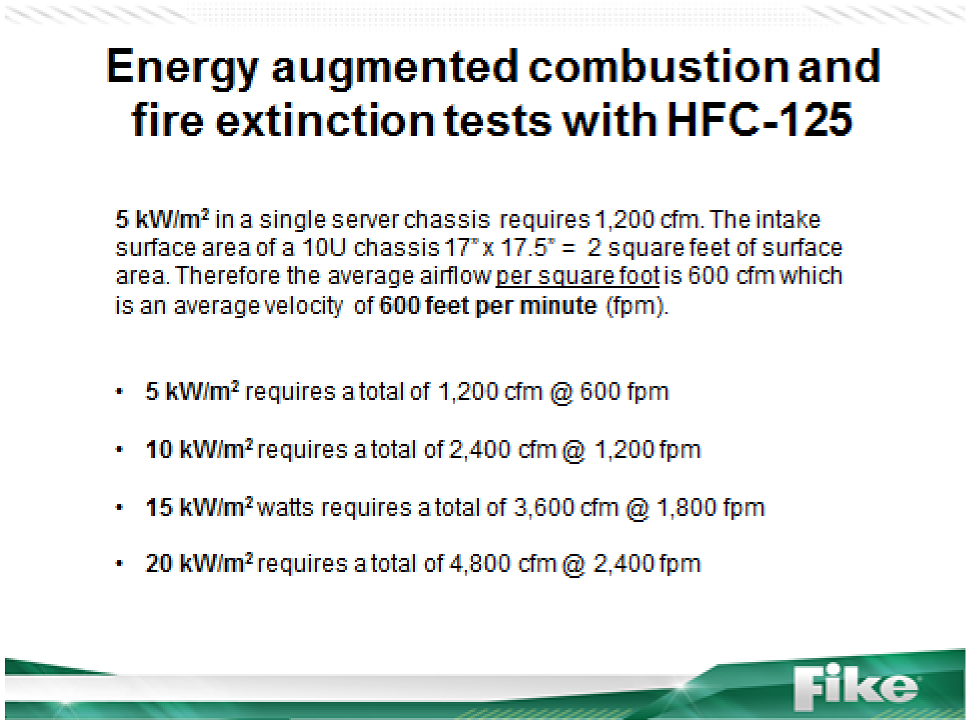


Air flow in a computer room is a given. Typical server chassis' provide internal redundant fans. In addition to these fans the computer CRAC/CRAH units provide all the necessary air flow for the equipment. Since the air flow needs are completely satisfied by the CRAC/CRAH units the fans that are internal to the server chassis remain idle unless there is an overheat condition. This design methodology provides a triple redundant air movement system.

Given that air movement is ever present it becomes necessary to quantify its effect on fire suppression designs.

It should be pointed out that, for better or worse, Underwriters Laboratories and Factory Mutual testing does not include air movement in any tests.

For our air-flow tests, and for additional safety factor against restricted or reduced air flow conditions, it was decided to limit air velocities to less than 25% of the minimum average air velocities for a given power density level.



This slide builds some context regarding air flow speeds in fpm and cfm equivalents.

A load component requires approximately 160 cubic feet per minute (cfm) per 1 kW of electrical load for an air temperature rise of 20°F or 11C. A typical 5 kW/m^2 10U server blade chassis consumes 7,500 watts to achieve this watt density. Thus 1,200 cfm is necessary to hold operational temperatures. Given the air intake area of 2 ft^2 there is an average air velocity of 600 feet per minute through the electronics.

10 kW/m^2 requires 1,200 fpm

15 kW/m^2 requires 1,800 fpm

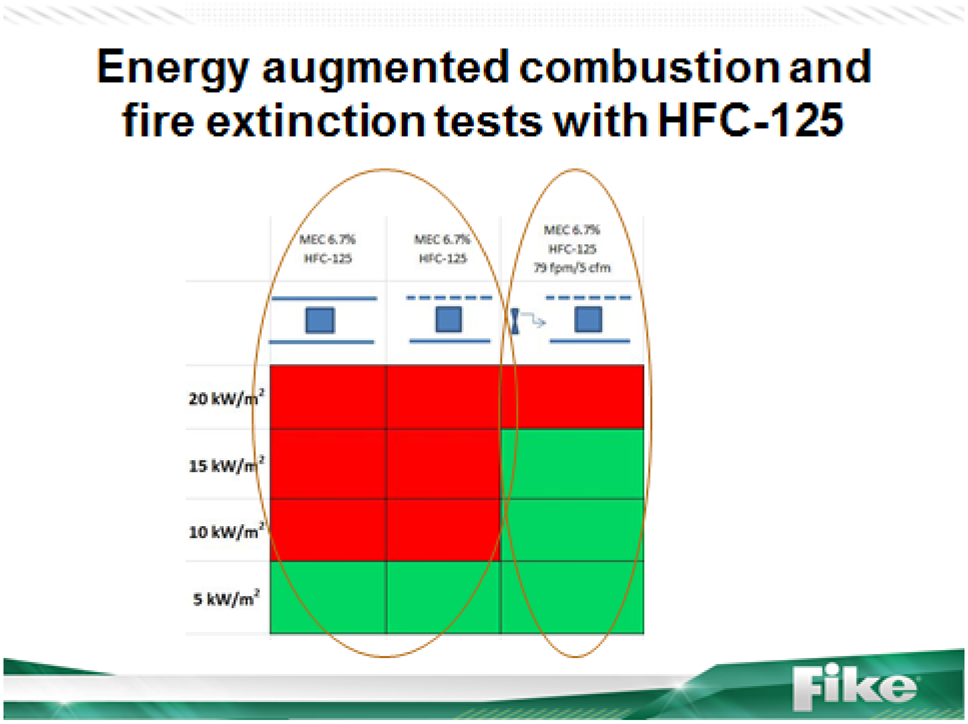
20 kW/m^2 requires 2,400 fpm

Energy augmented combustion and fire extinction tests with HFC-125

Hot Plate Radiator Power Density	Air flow rate fpm	Percentage of normal air flow
5 kW/m²	0 fpm	0%
10 kW/m²	79 fpm	6.5%
15 kW/m²	79 fpm	4.4%
20 kW/m²	120 fpm	5.0%

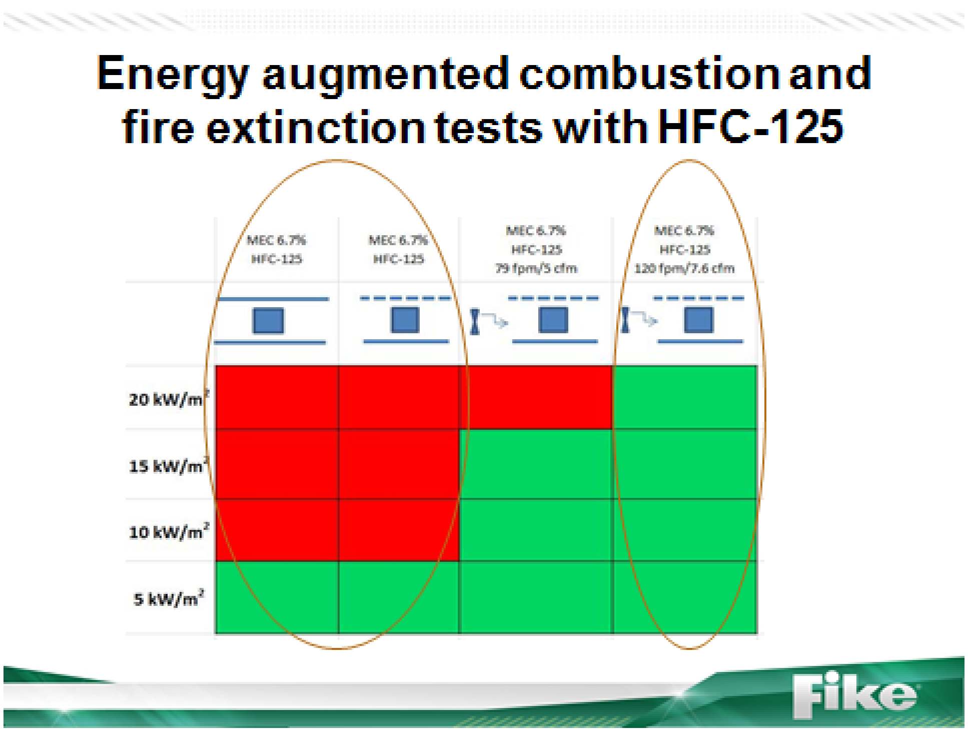
Tests were conducted at both 79 fpm and 120 fpm air velocity. The right hand column is the percentage of normal air flow that would be used for the power density specified in the left hand column. The minimum air velocity required at each power density level was not established by our testing.

Energy augmented combustion and fire extinction tests with HFC-125

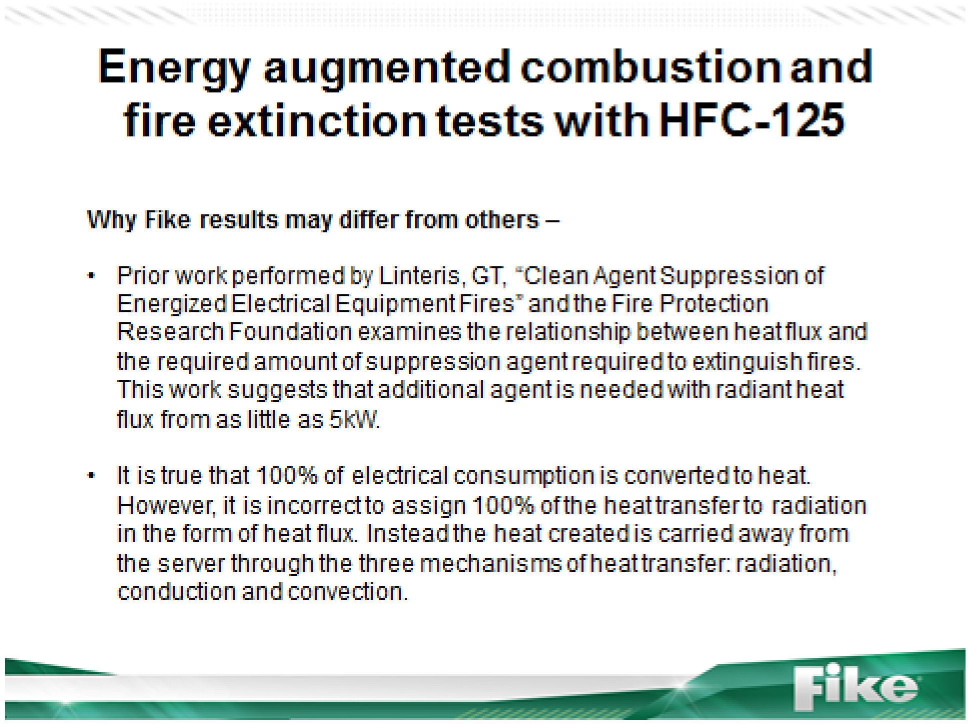


This is our fan-test results presented in the same format as our still air tests.

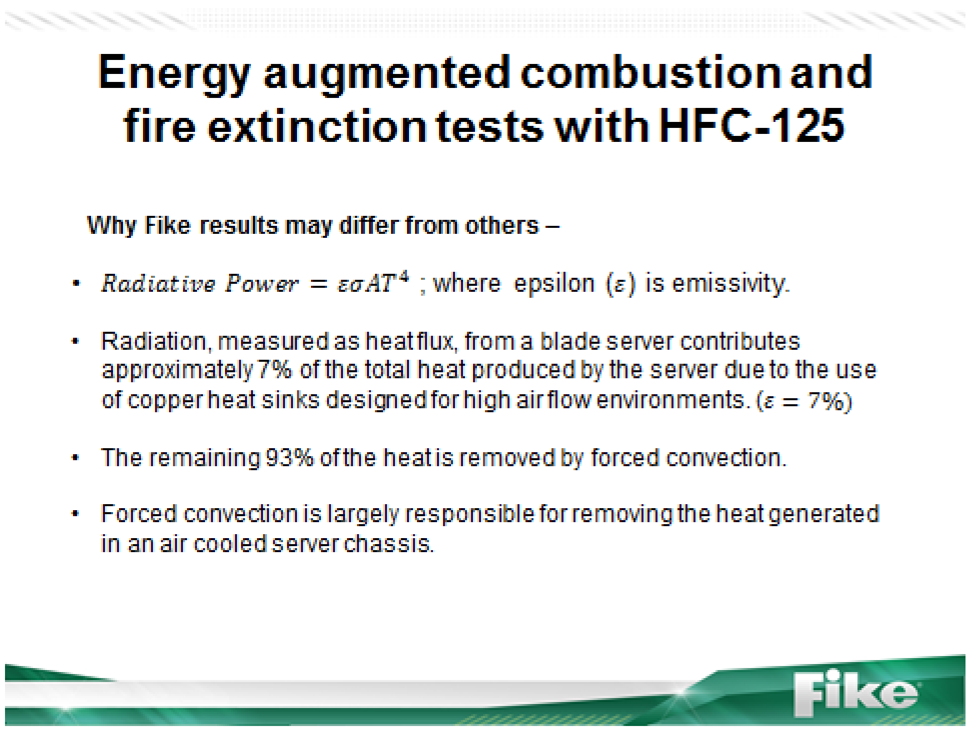
The 79 fpm tests definitely improved our results. A 200% increase in radiant heat load was extinguished with this air velocity when compared to still air. The 79 FPM air flow increased the maximum extinguishment level from 5 to 15 kW/m^2.



An increase in air flow from 79 to 120 fpm resulted in a 300% increase in radiant heat load extinguishment when compared to still air. The 120 fpm air flow increased the maximum extinguishment level from 5 to 20 kW/m^2. In no case did we need more than 6.5% of normal air flow required for extinguishment at MEC up to 20 kW/m^2.



Earlier work that was carried out a couple of years ago and presented at SUPDET 2012 suggests that additional agent is needed with radiant heat flux from power dissipation as low as 5 kW. However, it seemed that all power consumed was attributed to radiant heat flux on nearby combustibles rather than analyzing the three mechanisms of heat transfer: radiation, conduction and convection.



Radiative power is a function of emissivity; and heat sinks that are optimized for high air flow environments have relatively low emissivity. Good server design practices minimize radiated heat to avoid interaction between servers. It's simply not desirable to have a server radiating heat onto another server. Thin walled finned and convoluted copper heat sinks are used for their optimal heat conductivity, large surface area and low emissivity.

Radiation, measured as heat flux, from a blade server contributes approximately 7% of the total heat produced by the server. The remaining 93% is transferred by forced convection.

Thus, it is forced convection that is largely responsible for carrying away the heat generated in a server and this is accomplished with forced air flow through the cabinet. Because space in a server chassis is at a premium, and air flow is abundant, thin folded copper heat sinks are the norm. These have poor emissivity, are great conductors of heat, and a large surface area for heat transfer to the forced air stream.

Energy augmented combustion and fire extinction tests with HFC-125

		(ASHRAE)		(Surface Area)	(Calrod)
Power Source	Derated Chassis Pwr (W)	Footprint Power (W/m²)	Chassis Total Heat Output (W/m²)	Chassis Total Heat Output Tested (W/m²)	Radiated Heat Flux ε = .56 (W/m²)
120V, 20A	1,920	17,723	1,280		
208V, 30A	4,992	46,080	3,328		1,864
208V, 20A, 3ϕ	5,764	53,206	3,843	5,000	2,152
208V, 30A, 3ϕ	8,650	79,846	5,767	(ASHRAE 2020 est.)	3,230
208V, 40A, 3ϕ	11,528	106,412	7,686		
208V, 50A, 3ϕ	14,410	133,015	9,607	10,000	5,380
208V, 60A, 3ϕ	17,292	159,618	11,528		
208V, 80A, 3ϕ	23,056	212,825	15,370	15,000	8,607
208V, 100A, 3ϕ	28,820	266,031	19,213	20,000	10,759

Table 3 – Computer Room Power Levels

Here is a table to help put this into context with the power sources, power densities and server chassis' total heat output.

The left most column again lists the many power source options available.

The next column is the wattage that is available from the power sources.

Next is the ASHRAE *floor space footprint power* estimates;

next is the total heat output, that has been converted to W/m2 based upon the surface area of a server.

The next to last column are the Fike tested levels of ***total heat input***. The right most column is the ***total heat radiated output*** adjusted for emissivity of the Calrod heating elements used in our tests. The emissivity is estimated to be .56 or 56%. Our testing demonstrated extinguishment with standard minimum extinguishing concentrations at power levels exceeding the ASHRAE 2020 estimates

Energy augmented combustion and fire extinction tests with HFC-125

Power Source	Derated Chassis Pwr (W)	(ASHRAE) Footprint Power (W/m^2)	Chassis Total Heat Output (W/m^2)	(Surface Area) Chassis Total Heat Output Tested (W/m^2)	(Copper) Radiated Heat Flux ε =.07 (W/m^2)
120V, 20A	1,920	17,723	1,280		
208V, 30A	4,992	46,080	3,328		
208V, 20A, 3ϕ	5,764	53,206	3,843	5,000	269
208V, 30A, 3ϕ	8,650	79,846	5,767	(ASHRAE 2020 est.)	404
208V, 40A, 3ϕ	11,528	106,412	7,686		
208V, 50A, 3ϕ	14,410	133,015	9,607	10,000	673
208V, 60A, 3ϕ	17,292	159,618	11,528		
208V, 80A, 3ϕ	23,056	212,825	15,370	15,000	1,076
208V, 100A,3ϕ	28,820	266,031	19,213	20,000	1,345

Table 2 – Computer Room Power Levels

Fike

When considering bright copper as the radiating surface the radiated heat flux is well under 2,000 W/m^2 even at the highest power levels on this chart.

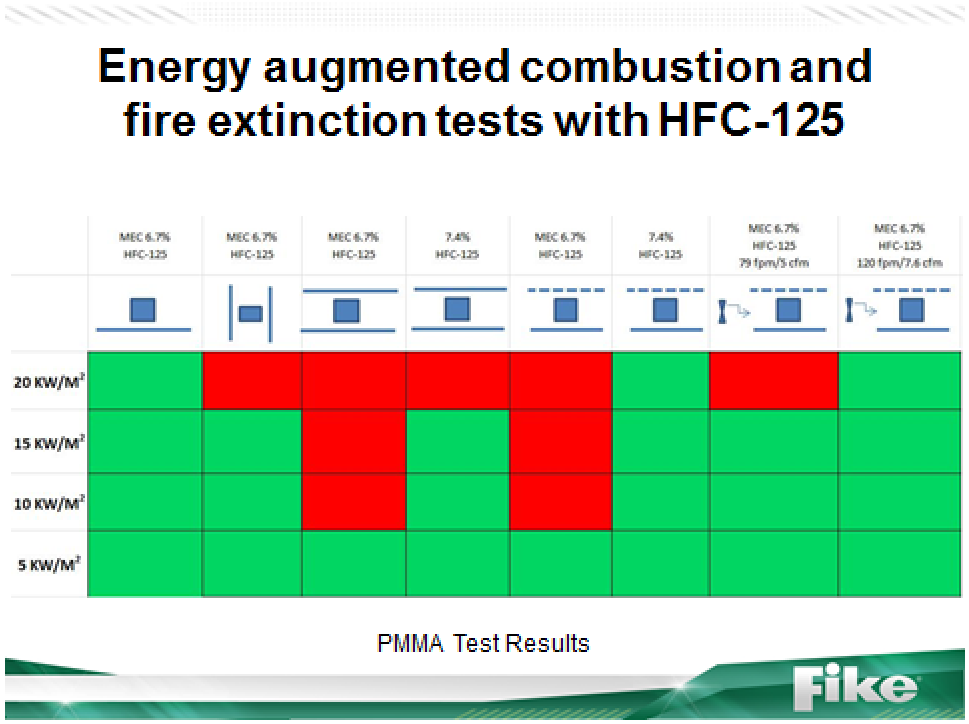
Energy augmented combustion and fire extinction tests with HFC-125

Power Source	Derated Chassis Pwr (W)	(ASHRAE) Footprint Power (W/m^2)	Chassis Total Heat Output (W/m^2)	(Surface Area) Chassis Total Heat Output Tested (W/m^2)	(Al, Steel) Radiated Heat Flux ε =.20 (W/m^2)
120V, 20A	1,920	17,723	1,280		
208V, 30A	4,992	46,080	3,328		665
208V, 20A, 3ϕ	5,764	53,206	3,843	5,000	769
208V, 30A, 3ϕ	8,650	79,846	5,767	(ASHRAE 2020 est.)	1,153
208V, 40A, 3ϕ	11,528	106,412	7,686		
208V, 50A, 3ϕ	14,410	133,015	9,607	10,000	1,921
208V, 60A, 3ϕ	17,292	159,618	11,528		
208V, 80A, 3ϕ	23,056	212,825	15,370	15,000	3,074
208V, 100A,3ϕ	28,820	266,031	19,213	20,000	3,843

Table 3 – Computer Room Power Levels

Fike

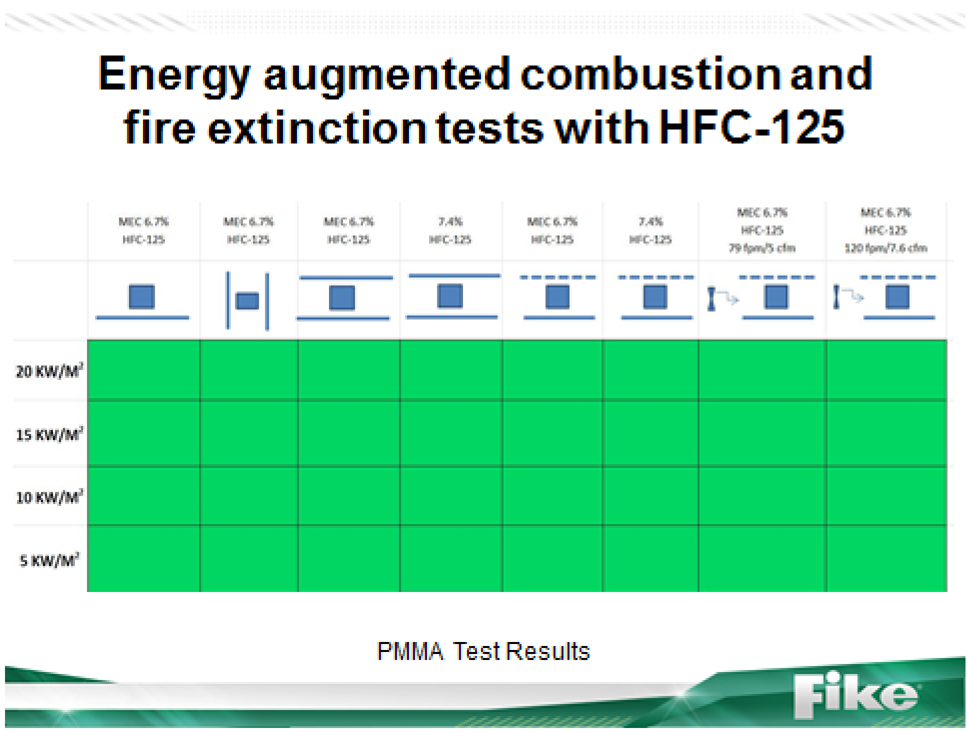
This Table shows the radiated heat based upon the worst case of aluminum or steel with emissivity which is around .20 or 20%. The real world radiated heat flux is well under 5,000 W/m^2 even at the highest power levels.



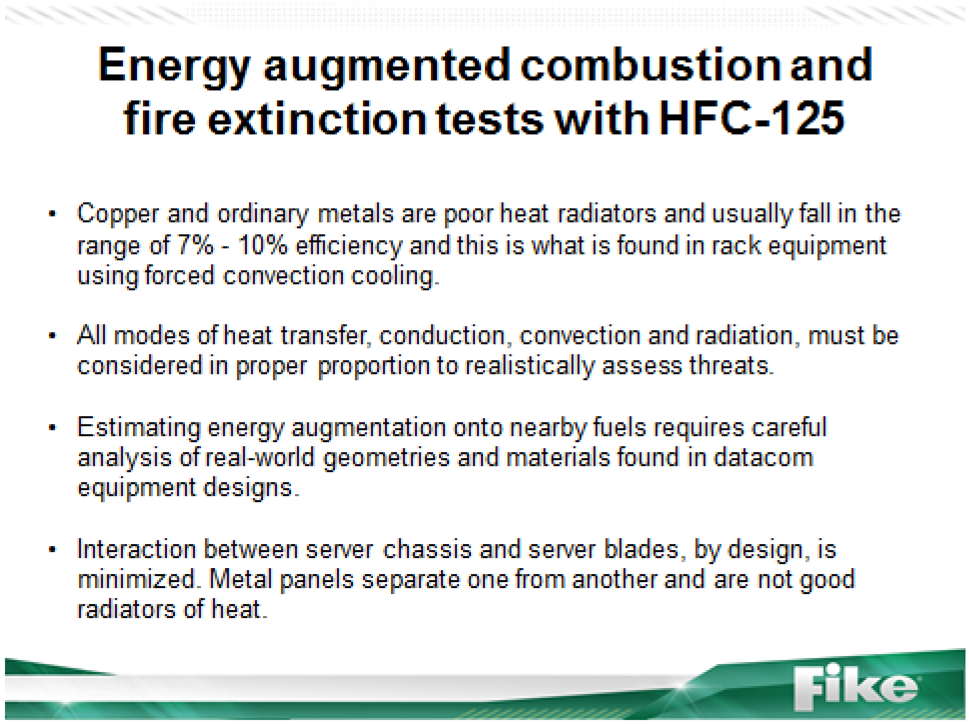
This is a quick refresher of our test results using Calrod style heating elements with emissivity of 56% over a total power range from 5 to 20 kW/m^2 both with and without air movement.

And since these tests use Calrod style heating elements with an emissivity of 56% versus copper with an emissivity of around 7%, the test outcome should be substantially different when using copper as the surface radiator.

So, we reran many of our tests using our Calrod style heating elements with a thin copper skin as the surface radiator.



And here are the test results after skinning the Calrod style heating elements with copper to more closely match emissivity of materials found in servers. All tests passed, at all power density levels from 5 to 20 kW/m^2 , in all hot plate orientations, with and without air movement.



In summary –

Copper and ordinary metals are poor heat radiators and usually fall in the range of 7% - 10% efficiency and this is what is found in rack equipment using forced convection cooling.

All modes of heat transfer: conduction, convection and radiation, must be considered in proper proportion to realistically assess threats.

Estimating energy augmentation onto nearby fuels requires careful analysis of real-world geometries, power densities, ***and materials*** found in datacom equipment designs.

Interaction between server chassis and server blades, <u>by design</u>, is minimized. Metal panels separate one from another and are not good radiators of heat.

Energy augmented combustion and fire extinction tests with HFC-125

- Air movement within datacom equipment facilities is highly reliable and is an asset to fire extinction of flame.
- As little as 5% of normal air movement is sufficient for fire extinction of PMMA fires at 200% – 300% higher energy augmentation than in still air.
- When while using copper as a radiator, all PMMA fires were extinguished with power densities ranging from 5 to 20 kW/m^2 with a minimum extinguishing concentration of HFC-125 of 6.7%.

Fike

Air movement within datacom equipment facilities is highly reliable and has been seen as an asset to extinguishment of flame when the air not being exchanged with external make-up air and room leakage is minimized.

Even slight air movements have demonstrated a profound effect on extinguishments with HFC-125 and are likely to be the same with other clean agents. Two to three times the energy augmentation levels were extinguished as compared to equivalent still-air scenarios.

Using worse case power scenarios, while using copper as a radiator, all PMMA fire tests concluded with an ordinary extinguishment with power densities ranging from 5 to 20 kW/m^2 with a minimum extinguishing concentration with HFC-125 of 6.7%.

Class C Clean Agent Testing Using External Energy Augmentation from 5 To 20 kW/m^2 With And Without Air Movement

A special Thanks to additional contributors:

Allen Clem, Heather Andersen, Eric Banks and Scott Bauer

Fike