Data Center Airflow Management Basics: Economics of Containment Systems

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Introduction

Based on data extrapolated in the June 2016 United States Data Center Energy Usage Report[1], average individual rack density for a rack full of servers will range between 4 kW and 11 kW by 2020. It is important to recognize that as rack densities exceed 4 kW, traditional hot aisle/cold aisle configurations become less effective. Hot air recirculates over and through the cabinet, causing hot spots, which is typically met with the costly oversupply of cold air.

You can reliably dissipate the heat in these racks by utilizing a containment system that effectively isolates hot air from cold air and directs hot exhaust airflow away from equipment and back to air handlers. More importantly, careful airflow management through the use of containment systems allows several cooling system adjustments that can reduce overall cooling energy costs at any rack density.

This white paper by Chatsworth Products (CPI) examines how implementing a complete containment system contributes to overall reduced cooling system energy costs in the data center and prepares your site for an anticipated increase in rack density.

Fast Fact

For more details on the three basic types of containment systems, including a comparison of the architectural and design considerations for each system, please read the companion paper, *Data Center Airflow Management Basics: Comparing Containment Systems*.

Energy Efficiency through Airflow Containment

Containment systems that effectively isolate hot and cold air enable strict control of inlet temperatures, optimal adjustment of airflow volume and increased return air temperatures, allowing room temperatures to be reliably raised. In turn, the efficiency of cooling systems is improved and the number of days that economizers can be used for “free cooling” is increased. Optimal airflow volume means fewer air handlers need to be operated, the chilled water temperatures can be increased, which leads to further chiller efficiencies, and power usage effectiveness (PUE) will be lowered because the overall energy used for cooling equipment will be reduced.

All of this begins with strict separation of hot and cold air within the data center with a complete containment system – both inside the rack and within the room.

A complete containment system allows you to:

- Maintain strict control over inlet temperature
- Reduce the volume of supply air
- Increase the temperature of supply air
- Increase the temperature of chilled water

These adjustments result in:

- Improved cooling unit efficiency
- Improved chiller efficiency
- Access to more free cooling hours when using economizers
- Lower PUE

Fast Fact

"Free cooling" refers to the number of hours that the economizer can be used instead of the chiller. "Free cooling" is not free, but economizers generally cost less to operate than chillers. The economizer rejects heat outdoors when the outdoor temperature is lower than the temperature of the chilled water loop. So when the chilled water loop temperature increases, there are typically more hours that the economizer can be operated instead of the chiller. As an added bonus, higher chilled water temperature also typically improves chiller efficiency.

Maintain Strict Control Over Inlet Temperature

The first noticeable effect when implementing a complete containment system is the change in room temperature. Containing hot exhaust air reduces or eliminates hot spots by blocking the recirculation and preventing the mixing of supply and exhaust air. As a result, the temperature variation across the front of racks is reduced, as shown in [Figure 1] below.

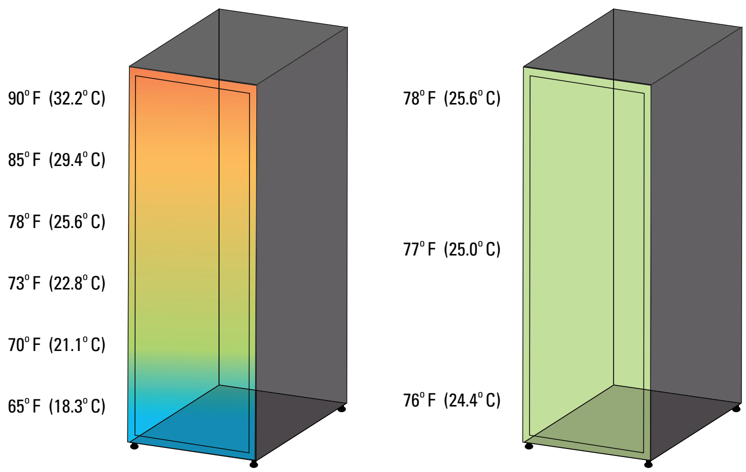

FIGURE 1: Inlet air temperature variations in traditional hot aisle/cold aisle application (left side) and typical containment system (right side). Note: The much larger temperature variation is in the hot aisle/cold aisle application.

Reduce the Volume of Supply Air

Complete containment also typically allows the volume of air delivered to equipment to be reduced. Traditional hot aisle/cold aisle systems are often oversupplied in an attempt to overcome bypass airflow over and around cabinets. The volume of airflow can typically be reduced once containment is in place.

In existing sites with air handlers that do not have variable speed fans, this means turning some units off, resulting in some savings from reduced energy consumption. In sites with units that have variable speed fans, the fan speeds can be reduced to take advantage of fan affinity laws. Fans use less overall energy when running at reduced speed (partial capacity) because they are moving less air. Essentially, all units are run at low partial capacity instead of several units at full capacity. This configuration still provides capacity for N+1 redundancy or better, if needed, while maintaining reduced energy costs.

It is important to have a sufficient pressure difference between the open and contained space to cause air to exhaust toward the air handlers. With automation, this difference can be fine-tuned to a minimal amount to further reduce energy cost.

Increase the Temperature of Supply Air

Because containment results in less temperature variation in supply air, operators can reliably increase room temperatures closer to required inlet temperatures on equipment. The *ASHRAE Datacom Series 1, Thermal Guidelines for Data Processing Environments, Fourth Edition (RP-1499)* [2] defines recommended and allowable equipment environment specifications for air cooling in data center computer rooms, see [Table 1] below.

Equipment Environmental Specifications For Air Cooling, Operating Conditions, 2015				
Class	**Low °F (°C)**	**High °F (°C)**	**Humidity Range**	**Max Dew Point °F (°C)**
Recommended (A1-A4)	64.4 (18)	80.6 (27)	15.8°F (-9°C) DP to 59°F (15°C) DP and 60% RH	
Allowable A1	59 (15)	89.6 (32)	15.8°F (-9°C) DP and 8% RH to 80.6°F (27°C) DP and 80% RH	62.6 (17)
Allowable A2	50 (10)	95 (35)	10.4°F (-12°C) DP and 8% RH to 80.6°F (27°C) DP and 80% RH	69.8 (21)
Allowable A3	41 (5)	104 (40)	10.4°F (-12°C) DP and 8% RH to 80.6°F (27°C) DP and 85% RH	75.2 (24)
Allowable A4	41 (5)	113 (45)	10.4°F (-12°C) DP and 8% RH to 80.6°F (27°C) DP and 90% RH	75.2 (24)

Note: Maximum elevation is 10,000 feet (3050 meters) above sea level, and maximum rate of change is 9°F over 36 hours (5°C over 20 hours).

TABLE 1: Summary of 2015 Thermal Guidelines from ASHRAE Datacom Series 1, Thermal Guidelines for Data Processing Environments, Fourth Edition (RP-1499)[2]. Refer to the guideline for the complete environmental recommendation.

The current guideline recommends that chilled supply air should be delivered to the data center environment in the 64.4°F to 80.6°F (18°C to 27°C) recommended range with a 15.8°F to 59°F (-9°C to 15°C) dew point and 60 percent relative humidity to ensure proper cooling.

In traditional open hot aisle/cold aisle configurations, chilled air may be delivered at a much lower temperature, for example 55°F (12.8°C), to overcome the mixing of supply and return air. However, when complete isolation between hot and cold aisles is achieved, recirculation of hot return air is eliminated. Much lower temperature air is no longer necessary to overcome air mixing, and it is possible to safely raise the temperature of the supply air up to the recommended 64.4°F to 80.6°F (18°C to 27°C) range.

In general, server equipment can now also operate efficiently at higher temperatures. Typical server specifications[3] now list continuous operating temperatures from 50°F to 95°F (10°C to 35°C), above the recommended range in the ASHRAE guideline. Some server manufacturers even include performance information for operation above the standard server specification range, >95°F (>35°C). Likewise, the guideline also defines four allowable ranges and classes of equipment that span high temperature thresholds from 80.6°F (27°C) to 113°F (45°C). When equipment is specified to operate in the allowable ranges (Class A1, A2, A3, A4), some operators are choosing to set environments in the allowable range, at least part of the year, to realize additional energy savings.

The advantage of increasing the temperature of supply air is improved cooling unit efficiency as a result of the corresponding higher return air temperatures and access to more “free cooling” hours when using economizers.

Increase the Temperature of Chilled Water

In chilled water systems, fluid is used to transfer heat between air handlers and chillers and/or economizers. Depending on required conditions and system design, it may also be beneficial to raise the temperature of the chilled water (fluid).

The advantage of increasing the temperature of chilled water is improved chiller efficiency when using mechanical cooling and access to more “free cooling” hours when using economizers.

Improved Cooling Unit Efficiency

With chilled water cooling units, increasing return air temperature generally results in increased sensible cooling. See [Table 2] below. Containment systems isolate, and guide hot exhaust air back to the cooling units, which typically increases the return air temperature.

		Net Sensible Cooling in MBH for Various Return Air Temperatures *for down flow unit, includes motor heat @ rated CFM and ESP, At 50°F EWT, 0% Glycol Solution, 14°F ΔTw*		
Capacity kW	**Stulz Model Number**	**75°FDB/62.5°FWB 50%RH, 55°FDP**	**80°FDB/64.2°FWB 42%RH, 55°FDP**	**85°FDB/65.9°FWB 36%RH, 55°FDP**
60	CFD-060-C1	124	185	242
90	CFD-090-C1	141	208	270
120	CFD-120-C1	167	254	332
150	CFD-150-C1	171	251	327
180	CFD-180-C1	223	324	416

Note: Values are in MBH (thousand BTU/hr), so 124 MBH is 124,000 BTU/hr. For conversion: 12 MBH (or 12,000 BTU/hr) = 3.5 kW (or 3516 W) = 1 ton (refrigeration).

TABLE 2: Table comparing the cooling capacity of chilled water cooling units as the return air temperature increases (left-to-right). Source: STULZ CyberAir CW Engineering Manual[4].

In existing facilities, this relationship typically allows higher densities in the data center once containment allows reliable airflow separation and temperature control. In new construction, this relationship can be used to optimize the sizing of units for anticipated heat loads, reducing first cost and project capital expenditure.

Improved Chiller Efficiency

As the temperature of supply air is raised resulting in an increase in return air temperature, the temperature of the chilled water in the corresponding chilled water loop can also be raised. Higher chilled water loop temperature results in better chiller efficiency when using mechanical cooling. The result is a lower relative energy cost for cooling the chilled water, see [Figure 2] below.

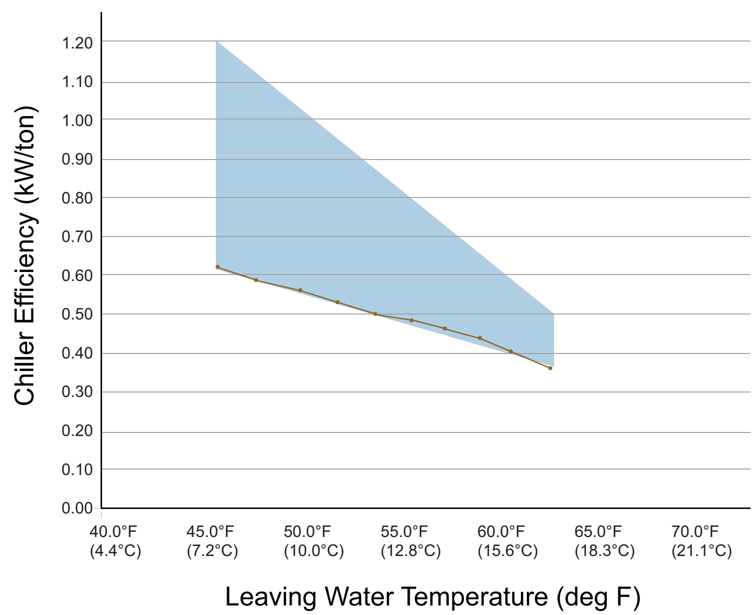

FIGURE 2: Range of chiller efficiency (kW/ton) as a function of leaving water temperature with all other parameters held essentially constant. Based on ASHRAE Datacom Series 6, Best Practices for Datacom Facility Energy Efficiency, Second Edition (2009).[5]

Access to More Free Cooling Hours When Using Economizers

Likewise, if using an economizer to reject heat outdoors, higher room temperatures and the corresponding higher chilled water loop temperatures typically equate to more hours of "free cooling."

The table [Table 3] below compares operating conditions for traditional hot aisle/cold aisle configurations and containment when combined with various types of economizers. This scenario is based on a CPI ducted exhaust cabinet: the F-Series TeraFrame® Cabinet with Vertical Exhaust Duct System. Note that supply air temperatures (second row) are 20°F (11.1°C) higher for the ducted exhaust cabinet but are still within the ASHRAE guideline's recommended temperature range of 64.4°F to 80.6°F (18°C to 27°C). Additionally, there is a significant difference in outdoor air temperatures (the last row) for scenarios with and without containment. (Outdoor air temperature is the temperature threshold below which economizers can be used.) As a result, in most locations, combining containment and economizers translates into many more hours of "free cooling" a year, reducing the number of hours that require more expensive mechanical cooling.

	Typical Operating Temperature Differences for Various Systems				
	Hot Aisle/Cold Aisle Configuration With Open Air Return		Ducted Exhaust Cabinet Configuration F-Series TeraFrame Cabinet with Vertical Exhaust Duct		
	Most Data Centers	TIA-942 Best Prac-tices	CRAC with Economizer	Kyoto Cooling	Evaporative Air Economizer
Room Air	60°F to 85°F (16°C to 29°C)	68°F to 77°F (20°C to 25°C)	77°F (25°C)	77°F (25°C)	77°F (25°C)
Supply Air	52°F to 55°F (11°C to 13°C)	52°F to 55°F (11°C to 13°C)	77°F (25°C)	77°F (25°C)	77°F (25°C)
Chilled Water	42°F (6°C)	42°F (6°C)	65°F (18°C)	N/A	65°F (18°C)
Outdoor Air	37°F (3°C)	37°F (3°C)	60°F (16°C)	72°F (22°C)	77°F (25°C)

Note: Room air temperature is the temperature at equipment air intakes. Supply air temperature is the temperature at the CRAC/CRAH supply outlet. Chilled water temperature is the water temperature required to produce the required supply air temperature. Outdoor air temperature is the outdoor air temperature required to use economizers to chill water for "free cooling" hours. The evaporative air economizer temperature is wet bulb temperature; all other temperatures are dry bulb temperatures.

TABLE 3: Estimated operating conditions for traditional hot aisle/cold aisle configurations and containment when combined with various types of economizers.

The number of hours of "free-cooling" available to your site will vary depending on the location (typical weather conditions), the type of economizer and your operating parameters. Regardless, using economizers with a containment system will increase the number of "free cooling" hours and the corresponding savings. Additionally, implementing a containment system makes the use of an economizer as an alternative to mechanical cooling practical in more locations.

Fast Fact

To estimate energy savings from "free-cooling" for your site, use the online Free-Cooling Estimated Savings tool[6] developed by The Green Grid (TGG) (http://cooling.thegreengrid.org/).

Lower PUE

PUE, a metric published by TGG for measuring infrastructure energy efficiency in data centers, is a ratio that compares total site energy to the energy used to power IT equipment. The combined effects of the cooling system adjustments described in this paper and made possible by implementing a complete containment system, result in a lower overall site energy value, which lowers PUE.

Many organizations, including governments, now have specific PUE goals. For example, in March 2016, the U.S. government[7] announced that tiered federal data centers must now perform at a PUE lower than 1.5 for existing facilities and 1.4 or even lower in new builds. Beijing[8], a robust manufacturing hub in China, recently banned any data center in the city to operate with a PUE above 1.5.

Fast Fact

A detailed explanation of PUE is available in TGG white paper #49, *PUE: A Comprehensive Examination of the Metric*[9] or in the ASHRAE TC9.9 guideline booklet *ASHRAE Datacom Series 11, PUE™: A Comprehensive Examination of the Metric. (2013)*[10].

Reduced Expenses, Increased Capacity and more Energy Efficiency

For existing data center installs, effective airflow management with a containment system offers two overall benefits:

1. It lowers operational expenses (OpEx) by reducing the power consumption necessary to provide cooling to the data center environment. In turn, PUE rates are favorably affected.
2. It allows data center operators to increase server capacity in the data center. As long as there is complete isolation between hot and cold air, and the necessary power, cooling and airflow, it is possible to run high-density server loads at higher temperatures, while providing the servers with adequate cooling to prevent overheating and shutdowns.

For new installs, there is an additional savings in capital expenses (CapEx) required to build the data center. Designing a proper airflow containment strategy eliminates the need to for extra cooling units and raised floors.

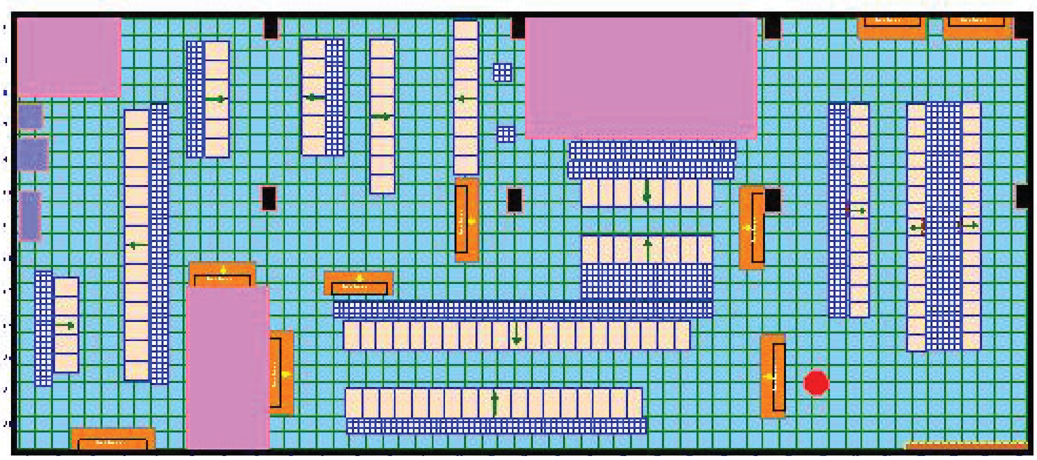

FIGURE 3: Converting the high-density cabinets in the four horizontal rows of this data center into ducted exhaust cabinets with Vertical Exhaust Ducts resulted in the elimination of over half of the chilled water cooling units. Source: CPI created CFD model using TileFlow.

The figure [Figure 3] above shows a data center layout that has been modeled with ducted exhaust return air containment. The two short horizontal rows of cabinets hold an average load of 8 kW, and the two longer horizontal rows hold higher loads, averaging around 16 kW. The vertical rows are either low-density cabinets (2 kW to 2.5 kW each) or connectivity racks. The 8 kW and 16 kW cabinets are ducted into the suspended ceiling return air plenum, with added ceiling grates above the hot aisles for the low-density cabinets to prevent air recirculation in the room.

This layout eliminates serious hot spots in the high-density cabinets and drives up the return air temperature high enough to raise the CRAC efficiency. As a result, the data center operator is able to reduce the number of CRAC units in this environment from twelve to seven, see [Table 4] below. (There are two dormant CRAC units in the room to ensure redundancy in the cooling system.)

Reduction of Required Cooling Capacity Resulting from Implementing a Containment System				
Cooling Unit Make/Model	Open Hot Aisle/Cold Aisle		Ducted Exhaust Cabinets	
	Quantity	Total Capacity	Quantity	Total Capacity
Stulz CCD-600-CWE	2	40 tons	0	0 tons
Stulz CCD-900-CWE	7	210 tons	3	90 tons
Stulz CCD-1800-CWE	2	60 tons	3	90 tons
Stulz CCD-2300-CWE	1	40 tons	1	40 tons
Total Capacity	Before	350 tons	After	220 tons

TABLE 4: Almost half of the chilled water cooling units can be eliminated after converting the high-density cabinets in the data center shown in [Figure 3] into ducted exhaust cabinets. Source: CPI created CFD model using TileFlow.

As a result of containment, HVAC energy requirement for this space is reduced by 700,000 kW hours per year, and that's before any additional energy savings from using an economizer are accounted for. The annual electricity cost savings for this space with an actual heat load of 800 kW is more than $60,000, plus the additional capital savings for the reduced number of CRAC units needed, versus the extra costs for Vertical Exhaust Ducts on four rows of cabinets.

Conclusion

Effective airflow containment achieved through complete isolation of hot and cold aisles provides many benefits, including:

- Supply air temperatures in the room can be raised to the recommended 64.4 to 80.6°F (18°C to 27°C) range in ASHRAE guidelines.
- Energy efficiency of chilled water cooling units can be improved by returning higher temperature exhaust air to the units. This causes the units to put out additional tons of cooling capacity, without increasing power levels to provide that cooling.
- When the air temperature in the room is raised, it is possible to increase the temperature of the condenser water in the chilled water loop to cooling units to around 65°F (18.3°C).
- If the temperature of condenser water is raised to 65°F (18.3°C), the economizer can provide "free cooling" when the outside temperature drops below 60°F (15.6°C). This increases the number of "free cooling" hours for data centers in most locations.
- When the economizers are providing "free cooling" to the data center, the chillers can be shut down, saving power.
- In existing data center installs, containment systems lower operational expenses (OpEx) by reducing the power consumption necessary to provide cooling to the data center environment.
- In new data center installs, containment systems lower the capital investment (CapEx) by reducing the size of some cooling system components and eliminating the need to purchase additional cooling units including the associated energy cost to operate the units or to build a raised floor environment.
- Containment systems allow data center operators to increase server capacity in the data center, while still providing adequate cooling.
- Through improved cooling performance and power use, PUE values can be greatly reduced to meet organizational goals and the latest regulations.
- While this paper focuses mainly on chilled water solutions, refrigerant based (DX) cooling solutions could also achieve much greater cooling cost savings when deploying containment solutions. DX cooling systems can also be configured with economizers to increase cooling savings.

The exact results of containment will vary for each site. Overall performance, the initial cost of the system (CapEx), the estimated operating cost (OpEx), resulting savings and return on investment will also vary.

If you are interested in learning more about how a containment system will improve your site, please contact CPI. Our Field Application Engineers will help you determine the right solution for your site, make specific recommendations and provide some analysis on how the implementation of containment will impact your bottom line.

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Acknowledgement

This paper presents the basics of airflow management and consolidates, summarizes and updates content from previous CPI white papers authored by Ian Seaton, retired.

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