Hot-Aisle vs. Cold-Aisle Containment for Data Centers

White Paper 135

Revision 1

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> Executive summary

Both hot-air and cold-air containment can improve the predictability and efficiency of traditional data center cooling systems. While both approaches minimize the mixing of hot and cold air, there are practical differences in implementation and operation that have significant consequences on work environment conditions, PUE, and economizer hours. The choice of hot-aisle containment over cold-aisle containment can save 40% in annual cooling system energy cost, corresponding to a 13% reduction in annualized PUE. This paper examines both methodologies and highlights the reasons why hot-aisle containment emerges as the preferred best practice.

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Introduction

High energy costs and accelerated energy consumption rates have forced data center professionals to consider hot-air and cold-air containment strategies. According to Bruce Myatt of EYP Mission Critical, the separation of hot and cold air "is one of the most promising energy-efficiency measures available to new and legacy data centers today" (*Mission Critical*, Fall 2007). In addition to energy efficiency, containment allows uniform IT inlet temperatures and eliminates hot spots typically found in traditional uncontained data centers.

While hot-aisle containment is the preferred solution in all new installations and many retrofit installations, it may be difficult or expensive to implement in retrofit applications that have a raised floor, but low headroom or no accessible dropped ceiling plenum. Cold-aisle containment, although not optimal, may be the best feasible option in these cases.

Both hot-aisle and cold-aisle containment provide significant energy savings over traditional uncontained configurations. This paper analyzes and quantifies the energy consumption of both containment methods. While both hot-aisle and cold-aisle containment strategies offer energy savings, this paper concludes that hot-aisle containment can provide 40% cooling system energy savings over cold-aisle containment due mainly to increased economizer hours. It also concludes that hot-aisle containment should always be used for new data centers.

Efficiency benefits of containment

The containment of hot or cold aisles in a data center results in the following efficiency benefits. It is important to note that a hot-aisle / cold-aisle row layout[1] is a prerequisite for either type of containment.

- **Cooling systems can be set to a higher supply temperature (thereby saving energy and increasing cooling capacity) and still supply the load with safe operating temperatures.** The temperature of room-oriented uncontained cooling systems is set much lower (i.e. approx 55°F/13°C) than required by IT equipment, in order to prevent hot spots. Hot spots occur when heat is picked up by the cold air as it makes its way from the cooling unit to the front of the racks. Containment allows for increased cold air supply temperatures and the warmest possible return air back to the cooling unit. The benefit of higher return temperature to the cooling unit is better heat exchange across the cooling coil, increased cooling capacity, and overall higher efficiency. This effect holds true for virtually all air conditioning equipment. Some equipment may have limits on the maximum return temperature it can handle, but, in general, all cooling systems yield higher capacities with warmer return air.
- **Elimination of hot spots.** Containment allows cooling unit supply air to reach the front of IT equipment without mixing with hot air. This means that the temperature of the supply air at the cooling unit is the same as the IT inlet air temperature – i.e., uniform IT inlet air temperatures. When no mixing occurs, the supply air temperature can be increased without risk of hot spots while still gaining economizer hours.
- **Economizer hours are increased.** When outdoor temperature is lower than indoor temperature, the cooling system compressors don't need to work to reject heat to the outdoors[2]. Increasing the set point temperature on cooling systems results in a larger number of hours that the cooling system can turn off its compressors and save energy.[3]
- **Humidification / dehumidification costs are reduced.** By eliminating mixing between hot and cold air, the cooling system's supply air temperatures can be increased, allow-

> What allows more economizer hours?

The basic function of a chiller is to remove heat energy from a data center by compressing and expanding a refrigerant to keep chilled water at a set supply temperature, typically 45°F/7°C. When the outdoor temperature is about 19°F/11°C colder than the chilled water temperature, the chiller can be turned off. The cooling tower now bypasses the chiller and removes the heat directly from the data center.

By increasing the chilled water supply temperature, the number of hours that the chiller can be turned off (economizer hours) increases. For example, there may be 1000 hours per year when the outdoor temperature is at least 19°F/11°C below the 45°F/7°C chilled water temperature. But if the chilled water is increased to 55°F/13°C, the economizer hours increase to 3,700.

[1] A rack layout where a row of racks is positioned with the rack fronts facing the rack fronts of the adjacent row. This layout forms alternating hot and cold aisles.

[2] The difference between outdoor and indoor temperature must be large enough to account for inefficiencies in heat exchangers, imperfect insulation, and other losses.

[3] Set points may be constrained in building-wide cooling systems shared by the data center

ing the cooling system to operate above the dewpoint temperature. When supplying air above the dewpoint, no humidity is removed from the air. If no humidity is removed, adding humidity is not required, saving energy and water.

- **Better overall physical infrastructure utilization, which enables right-sizing – which, in turn, results in equipment running at higher efficiencies.** Larger over-sized equipment experiences larger fixed losses[4] than right-sized equipment. However, oversizing is necessary for traditional cooling because extra fan power is required both to overcome underfloor obstructions and to pressurize the raised-floor plenum.

Cold-aisle containment

A cold-aisle containment system (CACS) encloses the cold aisle, allowing the rest of the data center to become a large hot-air return plenum. By containing the cold aisle, the hot and cold air streams are separated. Note that this containment method requires that the rows of racks be set up in a consistent hot-aisle / cold-aisle arrangement.

Figure 1 shows the basic principle of cold-air containment in a data center with room-oriented cooling and a raised floor. Some homegrown solutions are being deployed where data center operators are taking various types of plastic curtain material suspended from the ceiling to enclose the cold aisle (**Figure 2**). Some vendors are beginning to offer ceiling panels and end doors that mount to adjoining racks to help separate cold aisles from the warm air circulating in the room.

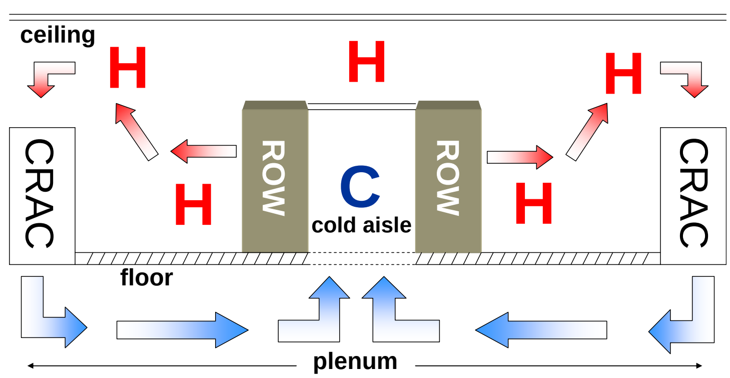


Figure 1

Cold-aisle containment system (CACS) deployed with a room-based cooling approach

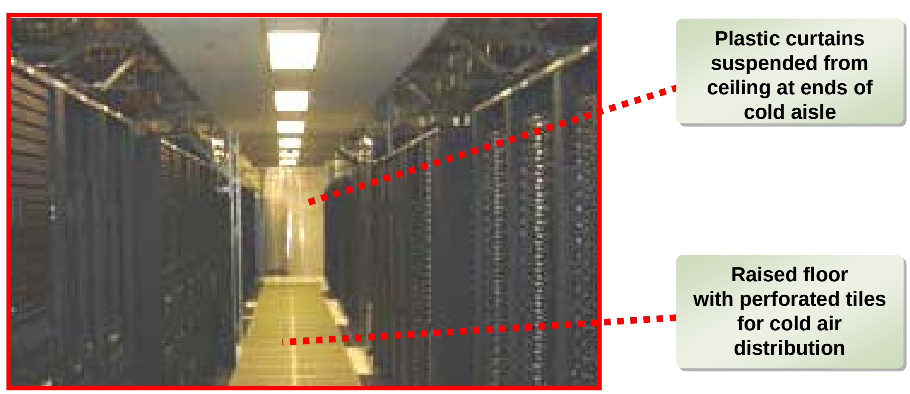


Figure 2

Example of a "homegrown" cold-aisle containment system

[4] Fixed loss – also called no-load, fixed, shunt, or tare loss – is a constant loss that is independent of load. A constant speed air conditioner fan is an example of fixed loss because it runs at the same speed all the time, regardless of load.

Hot-aisle containment

A hot-aisle containment system (HACS) encloses the hot aisle to collect the IT equipment's hot exhaust air, allowing the rest of the data center to become a large cold-air return plenum. By containing the hot aisle, the hot and cold air streams are separated. Note that this containment method requires that the rows of racks be set up in a consistent hot-aisle / cold-aisle arrangement. **Figure 3** shows the basic principle of HACS operation in a row-oriented air distribution architecture. An example of HACS operating as an independent zone is shown in **Figure 4**.

Alternatively, the HACS may be ducted to a computer room air handler (CRAH) or large remote air conditioning unit using a large chimney located over the entire hot aisle (**Figure 5**). A major advantage of this HACS option is the potential to use available existing water-side and/or air-side economizers. This type of HACS design is preferred in large purpose-built data centers because of the efficiency gains through air-side economizers. With the exception of increased fan power when using room-oriented cooling, such a system will exhibit the same benefits of a row-oriented approach as shown in **Figure 3**, and may require large fabricated air plenums and/or a custom-built building to efficiently handle the large air volume. Therefore this variation of HACS is best suited for new designs or very large data centers. For existing buildings, retrofits, smaller data centers, or high-density zones, the row-oriented design is more practical. Note that the HACS options mentioned here are also possible with CACS, however, this paper will show that the energy savings with HACS are significantly higher.

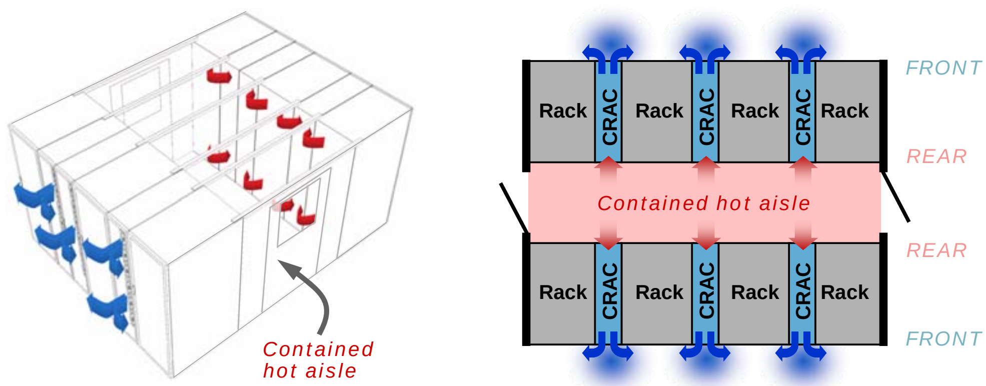


Figure 3

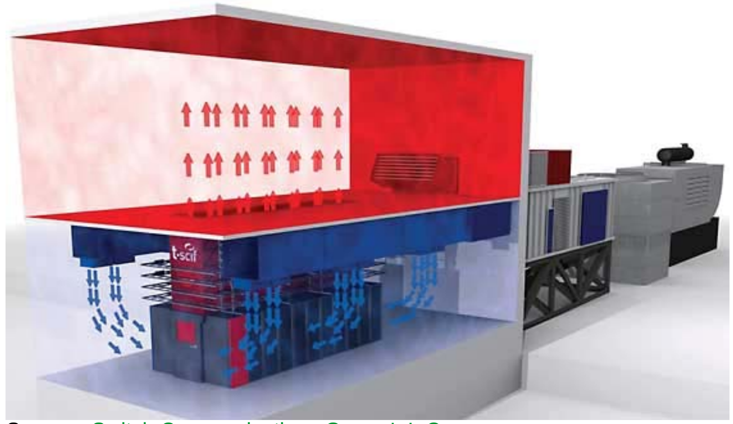
Hot-aisle containment system (HACS) deployed with row-oriented cooling

Figure 4

Example of a hot-aisle containment system (HACS) operating as an independent zone

Figure 5

Hot-aisle containment system (HACS) ducted to a remote air conditioner



Source: Switch Communications Group L.L.C.

Effect of containment on the work environment

Link to resource
APC White Paper 123
Impact of High Density Hot Aisles on IT Personnel Work Conditions

Regardless of the type of containment system, people still need to work inside a data center. The work environment must be kept at a reasonable temperature so as not to violate OSHA regulations or ISO 7243 guidelines for exceeding wet-bulb globe temperature (WBGT)[5]. With cold-aisle containment, the general working area (walkways, workstations, etc.) becomes the hot aisle as shown in **Figure 6**. With hot-aisle containment, the general working area of the data center becomes the cold aisle. For more information on environmental work conditions see APC White Paper 123, *Impact of High Density Hot Aisles on IT Personnel Work Conditions*.

Letting the hot-aisle temperature get too high with CACS can be problematic for IT personnel who are permanently stationed at a desk in the data center. With HACS, high temperatures in the hot aisle (at the back of IT racks) are mitigated by temporarily opening the aisle to let in cooler air. Even if the hot aisle remains closed, work environment regulations are still met for two reasons: 1) workers are not permanently stationed in the hot aisle, as is the case with CACS, and 2) most routine work takes place at the *front* of IT racks. This allows for a work / rest regimen of 25% work / 75% rest which allows for a maximum WBGT[6] of 90°F/32.2°C. This means that the HACS hot-aisle temperature can get as high 117°F/47°C. **The higher hot-aisle temperature allowed with HACS is the key difference between HACS and CACS since it allows the CRAH units to operate more efficiently.**

The 2008 version of ASHRAE Standard TC9.9 recommends server inlet temperatures in the range 64.4-80.6°F / 18-27°C. With CACS, the air in the rest of the room (the work environment) becomes hotter – well above 80°F/27°C, and in cases with high-density IT equipment, above 100°F/38°C. Therefore, anyone entering the data center is typically surprised when entering such hot conditions, and tours become impractical. With CACS, people's expectations need to be adjusted so they understand that the higher temperatures are "normal" and not a sign of impending system breakdown. This cultural change can be challenging for workers not accustomed to entering a data center operating at higher temperatures.

Furthermore, when operating a data center at elevated temperatures, special provisions must be made for non-racked IT equipment. With a CACS system, the room is a reservoir for hot air, and miscellaneous devices (such as tape libraries and standalone servers) will need to have custom ducting in order to enable them to pull cold air from the contained cold aisles.

> WBGT

The "wet-bulb globe temperature" (WBGT) is an index that measures heat stress in human work environments.

WBGT = 0.7*NWB + 0.3*GT

NWB is the natural wet-bulb temperature and GT is the globe temperature

NWB is measured by placing a water-soaked wick over the bulb of a mercury thermometer. Evaporation reduces the temperature relative to dry-bulb temperature and is a direct representation of the ease with which a worker can dissipate heat by sweating. For a data center, the dry-bulb temperature can be used in place of GT without compromising accuracy. "Dry-bulb" refers to temperature measured using a typical analog or digital thermometer.

Maximum OSHA WBGT:

Continuous work**: 86°F / 30°C**
25% work 75% rest: **90°F / 32°C**

[5] OSHA (Occupational Safety & Health Administration) Technical Manual section III, Chapter 4 ISO (International Organization for Standardization) 7243, "Hot environments – Estimation of the heat stress on working man based on WBGT index"

[6] The web-bulb globe temperature (WBGT) is a measure of heat stress. The maximum hot-aisle temperature of 117°F/47°C assumes a cold-aisle relative humidity of 45%.

Adding perforated tiles in the hot aisle will help cool this equipment but defeats purpose of containment. In addition, electric outlets, lighting, fire suppression, and other systems in the room will need to be evaluated for suitability of operations at elevated temperatures.

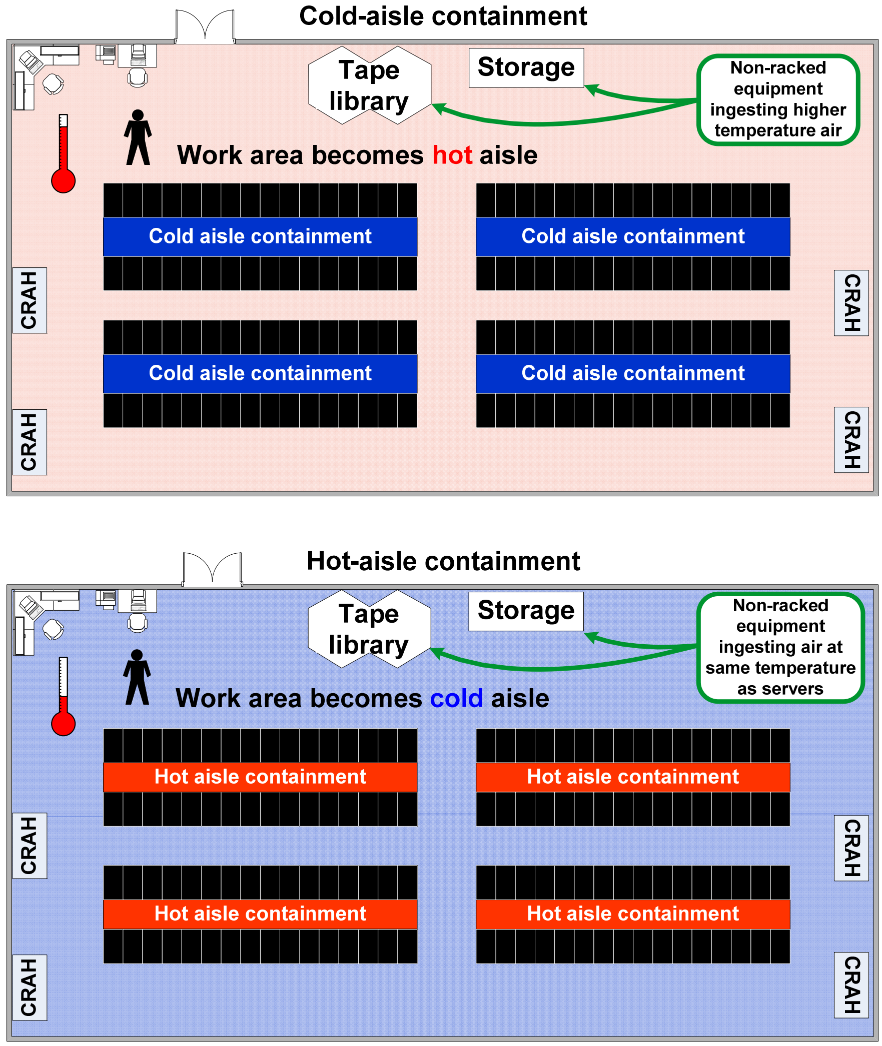


Figure 6

Work environments with cold-aisle and hot-aisle containment

Analysis of CACS and HACS

We did a theoretical analysis to compare CACS and HACS with no hot or cold air leakage so as to represent the very best performance of each. Raised floor leakage is typically 25-50%, while containment system leakage is typically 3-10%. The assumptions used for this analysis are included in the **Appendix**. The number of economizer hours and resulting PUE were estimated for each scenario using an economizer hour model and a data center PUE model. A traditional uncontained data center was also analyzed and serves as a baseline to compare CACS and HACS, which are analyzed under two conditions:

1. IT inlet air temperature held constant at 80.6°F/27°C – the maximum ASHARE recommended inlet air temperature (no limit on work environment temperature)
2. Work environment temperature held constant at 75°F/24°C – a standard indoor design temperature[7]

[7]American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2001 ASHRAE Fundamentals Handbook, page 28.5

Table 1 summarizes the results of the analysis, using these parameters:

- IT inlet air temperature
- Work environment temperature, as defined in this paper
- Economizer hours – the number of hours the chiller was off during the year
- Cubic feet per minute (CFM) – the total airflow supplied by the CRAH units as a percent of total IT equipment airflow
- PUE – the data center industry's standard efficiency metric
- Wet-bulb globe temperature (WBGT) for the data center work environment

Table 1

Results for uncontained HACS and CACS

Containment type	IT inlet air	Work env.	Econ hours	CFM[8]	PUE	WBGT work env.	Comments
Traditional uncontained	56-81°F 13-27°C	75°F 24°C	0	149%	1.93	62°F	Baseline with 40% cold and 20% hot-air leakage[9]
CACS Max ASHRAE IT inlet air temp and no limit on work environment temp	81°F 27°C	106°F 41°C	4,267	0%	1.60	83°F	WBGT only 3°F/2°C below OSHA max regulations. Includes 34% reduction in chiller power consumption with increased CW supply.
CACS 75°F/24°C max work environment temp	50°F 10°C	75°F 24°C	0	0%	1.87	68°F	Acceptable work environment but worse efficiency than typical data center, and violates ASHRAE minimum IT inlet air temp of 64.4°F/18°C. Includes 18% increase in chiller power consumption with decreased CW supply
HACS Max ASHRAE IT inlet air temp and no limit on work environment temp	81°F 27°C	81°F 27°C	4,267	0%	1.60	70°F	WBGT 13°F/7°C below OSHA max regulations. Includes 34% reduction in chiller power consumption with increased CW supply
HACS 75°F/24°C max work environment temp	75°F 24°C	75°F 24°C	3,428	0%	1.64	65°F	Highest efficiency, complies with OSHA, and complies with ASHRAE. Includes 25% reduction in chiller power consumption with increased CW supply. Note the hot-aisle temperature is 100°F/38°C.

This best case scenario for CACS provides 5,277 hours of economizer, but with an unrealistic work environment dry-bulb temperature of 106°F/41°C. This is equivalent to a WBGT of 83°F/28°C, nearly at the WBGT maximum OSHA limit of 86°F/30°C. Lowering the CACS work environment to 75°F/24°C results in zero annual economizer hours and a 17% increase in PUE. The resulting IT inlet air temperature falls 14°F/8°C below the minimum ASHRAE recommended temperature, but presents little risk to IT equipment.

This best case HACS scenario provides the same annual economizer hours and PUE as the best case CACS scenario. The only difference between these two cases is that the HACS work environment dry-bulb temperature is 80.6°F/27°C compared to 106°F/41°C for CACS. This lower HACS work environment temperature results in a lower WBGT of 70°F/21°C.

[8] Total airflow (% of IT airflow)

[9] Hot-air leakage occurs when hot exhaust air from servers mixes with the raised floor supply air, which increases server inlet temperature. Cold-air leakage occurs when cold air from gaps/voids in the raised floor mixes with return air, lowering return temperature and decreasing the cooling unit's efficiency.

However, a temperature of 80.6°F/27°C in the work environment is still perceived as high and is uncomfortable for workers.

Lowering the HACS work environment to 75°F/24°C results in a decrease in annual economizer hours of 20% and a 2% increase in PUE. This allows for an acceptable work environment temperature and an IT inlet air temperature within the ASHRAE recommended range.

The only two containment cases in **Table 1** that allow for an acceptable work environment temperature while providing acceptable IT inlet air temperatures are CACS (3rd row) and HACS (5th row), highlighted in green shading. **In comparing these two cases, the HACS case provides 3,428 more economizer hours and provides 13% improvement in PUE.** **Table 2** breaks down and quantifies the energy consumption between these two cases. The energy costs are broken down by IT, power, cooling, and total data center energy consumption.

- The IT energy includes all IT equipment, which is held constant in this analysis at 700kW
- The "power energy" includes losses from switchgear, generator, UPS, primary and critical auxiliary devices, UPS, lighting, and critical power distribution
- The "cooling energy" includes losses from chiller, cooling tower, chilled water pumps, condenser water pumps, and perimeter CRAH units
- Total energy is the sum of IT, power, and cooling energy and is directly related to PUE

Table 2

Cost breakdown between CACS and HACS at maximum 75°F / 24°C work environment temperature

	IT energy	Power energy	Cooling energy	Total energy	PUE
CACS	$735,840	$213,084	$429,883	$1,378,806	1.87
HACS	$735,840	$211,564	$255,968	$1,203,372	1.64
% Savings	0%	1%	40%	13%	13%

In a typical data center, 50% loaded, the IT energy is the largest portion of the energy cost, followed by the cooling system energy cost. **In comparison to CACS, at the same 75°F/24°C work environment, the HACS consumes 40% less cooling system energy.** The majority of these savings are attributed to the economizer hours when the chiller is off, as shown in **Figure 7**. At this work environment temperature, the CACS is unable to benefit from any economizer hours due to the low chilled water supply temperature. The small difference in the power system energy is due to an increase in losses across the switchgear which is caused by the extra hours of chiller operation in the CACS case.

In comparison to the traditional uncontained baseline case, the CACS consumes 9% less cooling system energy and 3% less total data center energy. In comparison to the traditional uncontained baseline case, the HACS consumes 46% less cooling system energy and 15% less total data center energy.

From this analysis it is clear that under practical work environment temperature constraints and temperate climates, hot-aisle containment provides significantly more economizer hours and lower PUE compared to cold-aisle containment. This is true regardless of the cooling architecture or heat rejection method used (i.e., perimeter vs. row oriented, chilled water vs. direct expansion).

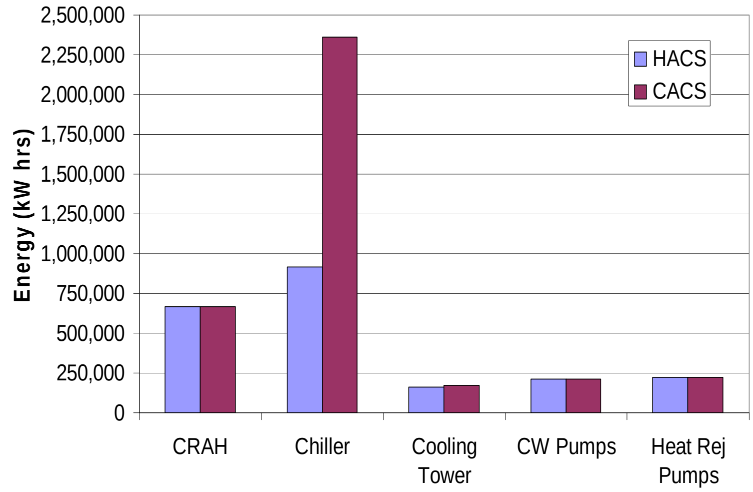
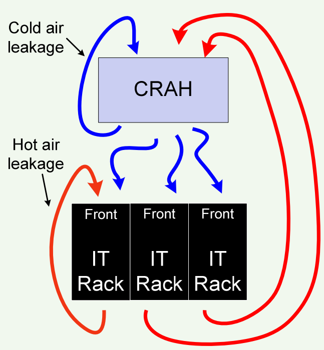


Figure 7

Breakdown of annual cooling system energy consumption

> **Hot and cold air leakage**
>
> Most hot exhaust air from IT equipment goes back to the CRAH where it is cooled. Hot-air leakage occurs when the IT exhaust air makes its way back to the IT equipment inlets and mixes with the cold inlet air.
>
> Cold-air leakage occurs when the cold supply air from the CRAH mixes with the CRAH's hot return air without ever getting to the IT equipment inlets.



Effect of air leakage on theoretical analysis

The analysis above considered the CACS and HACS to be completely sealed. This unlikely assumption allows us to calculate the maximum efficiency of the CRAH units and allows for a fair comparison between CACS and HACS. In reality, there is always cold air leakage with CACS or HACS requiring the CRAH fan airflow to be greater than the IT equipment airflow – this is true even with CRAH units with variable speed fans. The balance of airflow must equal the IT equipment airflow plus the percentage of leakage from the containment system or air delivery system such as a raised floor. For example, if the CRAH units supply 1,000 cubic feet per minute (CFM) of air and the IT equipment takes 800 CFM of air, the remaining 200 CFM must make its way back to the CRAH units.

Any air not used to cool IT equipment represents wasted energy. This wasted energy comes in two forms: 1) The fan energy used to move the air and 2) the pump energy used to move chilled water through the CRAH coil. Furthermore, hot/cold air mixing decreases the capacity of the CRAH unit. As more mixing occurs, more CRAH units are required to remove the same amount of heat while maintaining the appropriate IT inlet air temperature.

In order to comprehend the effect of air leakage, the analysis above was repeated using various air leakage percentages. Because of the increased fan energy needed for the extra CRAH units, the energy increase for CACS was higher than for HACS. This is because more cold air mixes into the hot aisle with CACS than it does with HACS. The hot aisle in HACS is only affected by leakage from the cable cutouts at each rack; whereas the hot aisle in CACS is affected by cable cutouts at the rack, cutouts around the data center perimeter, and cutouts under PDUs. This equates to about 50% more cold-air leakage compared to HACS. The cooling energy for HACS savings over CACS remained about the same (38% cooling system savings and 11% total energy savings).

Comparison summary of CACS and HACS

Table 4 summarizes CACS and HACS based on the characteristics discussed in this paper. The green shaded cells indicate the best choice for that particular characteristic.

Table 3

Summary of cold-aisle containment vs. hot-aisle containment

Characteristic	CACS	HACS	Comment
Ability to set work environment temperature to 75°F/24°C (standard indoor design temperature)	No	Yes	With HACS, cooling set points can be set higher while still maintaining a work environment temperature of 75°F/24°C and benefiting from economizer hours. Increasing CACS cooling set points results in uncomfortably high data center temperatures. This promotes a negative perception when someone walks into a hot data center.
Take advantage of potential economizer hours	No	Yes	The number of economizer hours with CACS is limited by the maximum work environment temperature in the hot aisle (the work environment) and by temperature limitations of non-racked IT equipment.
Acceptable temperature for non-racked equipment	No	Yes	With CACS, because the cold aisles are contained, the rest of the data center is allowed to become hot. Perimeter IT equipment (i.e., tape libraries) outside of contained areas would have to be evaluated for operation at elevated temperatures. Risk of overheating perimeter IT equipment increases with decreased cold-air leakage.
Ease of deployment with room cooling	Yes	No	CACS is preferred when retrofitting a data center with raised floor, room-level cooling with flooded return (draws its warm return air from the room). A HACS without row-oriented cooling or dropped ceiling would require special return ductwork.
New data center designs	No	Yes	The cost to build a new data center with CACS or HACS is nearly identical. Specifying HACS for a new data center will improve the overall efficiency, work environment, and overall operating cost.

Fire suppression considerations

Depending upon the location of the data center, fire detection and/or fire suppression may be required inside the enclosed area of the HACS or CACS. The primary suppression mechanism is usually sprinklers, which are heat activated. Gaseous agents are usually a secondary system which can be initiated by smoke detectors. The National Fire Protection Association standard NFPA 75 does not state an opinion as to whether sprinklers or gaseous agents should be provided in a HACS or a CACS. However, NFPA 75 documents the following two requirements that could be applied to both HACS and CACS:

- "Automated information storage system (AISS) units containing combustible media with an aggregate storage capacity of more than 0.76m^3 shall be protected within each unit by an automatic sprinkler system or a gaseous agent extinguishing system with extended discharge." This is significant because it sets a precedent for fire detection and suppression in an enclosed space in a data center.
- "Automatic sprinkler systems protecting ITE rooms or ITE areas shall be maintained in accordance with NFPA 25, Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems."

In practice, HACS and CACS have been successfully installed and approved with sprinklers and gaseous-agent suppression in various sites. APC Application Note 159 provides more detail on challenges and common practices for deploying fire suppression in hot-aisle contained environments. The AHJ should be contacted for specific requirements in a given location.

Note that any plenum (i.e., raised floor or dropped ceiling) must be rated for air distribution.

Conclusion

Prevention of hot and cold air mixing is a key to all efficient data center cooling strategies. Both HACS and CACS offer improved power density and efficiency when compared with traditional cooling approaches. A hot-aisle containment system (HACS) is a more efficient approach than a cold-aisle containment system (CACS) because it allows higher work environment temperatures and increased chilled water temperatures which results in increased economizer hours and significant electrical cost savings. Cooling set points can be set higher while still maintaining a comfortable work environment temperature (i.e., cold-aisle temperature).

Deploying CACS in an existing raised floor, room-oriented perimeter cooling layout is easier and less costly. However, HACS provides significantly more energy savings over CACS while maintaining a comfortable data center work environment temperature for perimeter IT equipment and workers. Retrofitting an existing perimeter-cooled, raised floor data center with HACS instead of CACS can save 40% in the annual cooling system energy cost corresponding to 13% reduction in the annualized PUE. This paper concludes that all new data center designs should use HACS as the default containment strategy. In cases where containment is not initially required, the new data center design should incorporate provisions for future HACS deployment.

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Appendix: Assumptions used in analysis

The following assumptions were used in the analysis for the HACS, CACS, and uncontained traditional raised-floor data center.

- Data center dimensions: 36ft x 74ft x 10ft (11m x 22.6m x 3m)
- Data center capacity: 1,400 kW (no redundancy)
- Location: Chicago, Illinois, USA
- Average cost of electricity: $0.12 / kW hr
- Total IT load: 700 kW
- Power density: 7 kW / rack average
- Quantity of IT racks / cabinets: 100
- Room-oriented perimeter unit cooling with 24 inch (61cm) raised floor
- Average temperature delta across servers: 25°F/13.9°C
- Server inlet air at 45% relative humidity
- Raised floor cold-air leakage with uncontained: 40%
- Hot-air leakage with uncontained: 20%
- Raised floor cold-air leakage with CACS: 0%
- Raised floor cold-air leakage with HACS: 0%
- CRAH coil effectiveness: 0.619
- Economizer heat exchanger effectiveness: 0.7
- Design chilled water delta-T: 12°F / 6.7°C
- Chiller plant dedicated to data center
- Chiller COP: 10.5
- Chilled water plant load: 52%
- Minimum tower water temperature: 40°F/4.4°C limited by basin heater to prevent freezing
- Cooling tower design range: 10°F/5.6°C
- Constant speed IT equipment fans (variable speed fans increase IT power consumption as IT inlet air temperature increases beyond a set threshold)
- 100% sensible cooling (i.e., no dehumidification and humidification is required)