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White Paper

Comparison of energy consumption in kW per ton of cooling

Real Time Data Center Cooling System compared to the 12 most common traditional data center cooling methods

Based on the attached Rittal White Paper by Daniel Kennedy

Rittal White Paper 507: Understanding Data Center Cooling Energy Usage & Reduction Methods

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R4 Ventures LLC

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R4 Ventures LLC

Real Time Data Center Cooling System (RTDCCS)

R4 Ventures LLC is applying semi-conductor clean room process cooling methods to Data Center / Mission Critical environments providing real time … load based process cooling at the Rack and eliminating hot isles and cold isles by combining the Multistage Evaporative Cooling System (MECS*),* Individual Server Enclosure Cooling System (ISECS), and Real Time Monitoring and Control System (RTMCS). The first patented system is the Multistage Evaporative Cooling System (MECS). Notice of Allowance was issued by the USPTO in August 2014 on our Advanced Multi-Purpose, Multi-stage Evaporative Cold Water/Cold Air Generating and Supply System US Patent Application Number 13/624912 and a US Patent Number 8,899,061 published on December 2 2014. The second patented system is the Real Time Individual Electronic Enclosure Cooling System (hereinafter Individual Server Enclosure Cooling System or ISECS). Notice of Allowance was issued by the USPTO in August on our Real Time Individual Electronic Enclosure Cooling System – US Patent Application Number 13/748088 and US Patent Number 8,857,204 published on October 14, 2014. A Real Time Data Center Cooling System (RTDCCS) is created by combining ISECS with MECS.

The RTDCCS recaptures <u>"Lost Capacity" or "Stranded Capacity"</u> in Data Centers as electric loads per rack increase due to increased densities due to lack of cooling resulting.

"Lost Capacity" / "Stranded Capacity" and its Capital Cost to a Data Center

Based on Future Facilities White Paper "The Elephant in the Room is Lost Capacity" and the Uptime Institute Analysis of 1.3 MW Data Center

MWs	1.3	
KWs	1300	
Annualized CAPEX	$6,300,000	
Annualized OPEX	$3,100,000	
Load Dependent OPEX	$1,400,000	
Total Annual Capital Deployed	$10,800,000	
Total Annual Capital Deployed per KW	$8,308	
Lost Capacity / Stranded Capacity - Cost of Losing 20% of a Data Centers Capacity for 1 year and for 5 years	**$2,160,000**	**$10,800,000**
Lost Capacity / Stranded Capacity - Cost of Losing 30% of a Data Centers Capacity for 1 year and for 5 years	**$3,240,000**	**$16,200,000**
Lost Capacity / Stranded Capacity - Cost of Losing 40% of a Data Centers Capacity for 1 year and for 5 years	**$4,320,000**	**$21,600,000**

<u>Multistage Evaporative Cooling System</u>

- **Scalable from 10 to over 1000 tons.**
- **Based on Phoenix AZ Summer Ambient Air Design Conditions for cooling applications are 110.2°FDB and 70°FWB, MECS delivers 57°F cold water, 53°F cold air, or both at the same time.**
- **First costs for the RTDCCS are within ±10% of traditional mechanical refrigeration systems**
- **Simple ... practical design provides ease of monitoring, control, and maintenance.**
- **60 to 85% less power usage / energy savings compared to traditional mechanical refrigeration systems in Data Centers**
- **NO Compressors and NO Refrigerants**
- **Process cooling approach leads to NO over sizing of Data Center cooling systems and therefore reduces up front capital requirements by 20% to 40% (typically by 150% to 200% when cooling Data Centers with Air (Comfort cooling))**

<u>Individual Server Enclosure Cooling System</u>

- **Process Cooling of Individual Racks with loads of 3 KW up to ± 35 KW on a Real Time basis**
- **Uses 65°F ± 4°F cool water from MECS to provide ±70°F cool air back to Data Center White Space while maintaining ± 1°F**
- **Eliminates hot aisles and cold aisles in White Space and eliminates the need for hot aisle / cold aisle containment equipment Restores "Lost Capacity" or "Stranded Capacity" in the Data Center due to lack of cooling (cold air flow to individual racks) as rack load densities increase through the individual cooling high load density Racks**
- **Increases Data Center Floor Area and Capacity in White Space by eliminating CRACs and CRAHs in the Data Center**
- **Provides significant energy savings of 60 to 80%**
- **Can be incorporated into raised floor designs or placed above the Racks over the aisles**

<u>Real Time Monitoring and Control System</u>

- **Incorporates a programmable logic controller (PLC) or programmable controller that is a digital computer used for automation of electromechanical processes**
- **PLC is designed for multiple inputs and output arrangements**
- **Multiple sensor inputs monitors air and water temperature; air and water flows, differential air and water pressures, air humidity; electric power consumption (loads) of racks, servers, power distribution units, uninterruptable power supplies, lighting, transformers and switchgear, and pumps, fans, and motors.**
- **<u>Controls air and water flow in real time to automatically adjusts water temperature and flow, air temperature and flow, and motor and fan speeds to meet the immediate electric power consumption (loads) of each individual server enclosure / rack and the immediate cooling needs of the space.</u>**

Real Time Data Center Cooling System Energy and GHG (Carbon Footprint) Savings

Comparing Various Data Center Cooling System Energy Usage in KW / Ton

KW / Ton data from Rittal White Paper 507: Understanding Data Center Cooling Energy Usage & Reduction Methods by Daniel Kennedy

Worst Case Scenario - Phoenix Summer Design Conditions for Average Data Center

Note 1: Rittal Corporation White Paper Data -The impact of these energy savings is dependent on the installation location because of the variances in ambient outdoor temperatures in different parts of the world. The average annual hourly energy usage analysis figures for six major cities (New York, Chicago, San Francisco, Phoenix, Miami and Atlanta) were used in developing this analysis and KW / Ton calculations. On the whole, these cities average approximately 2,856 hours of free cooling, or 33% of the year. The summer design criteria for each city was not used, only the annual averages. We have contacted Rittal Corporation and requested the actual average DB and WB temperature design criteria used in developing the data.

Note 2: R4 Ventures LLC data and analysis for determining energy usage of the Real Time Data Center Cooling System (RTDCCS), which incorporates the Multistage Evaporative Cooling System (MECS) and the Individual Server Enclosure Cooling System (ISECS), is based similar conditions to those stated in Note 1 above.

		KW per Ton Analysis Comparing Various Data Center Cooling Mehtods vs. Real Time Data Center Cooling System									
		Condensor Fan / Cooling Tower	**Compressor**	**Evaporator Fan**	**Chilled Water Pump**	**Refrigerant Pump**	**Pumped Refrig Fan**	**Humidification**	**Liquid Cooled Svr Pump**	**Server Fans**	**Total KW / Ton**
System 1	CRAC Cooled System	0.24	1.29	0.51				0.58		0.26	2.88
System 2	CRAH Cooled Systems – Chilled Water Based	0.16	1.12	0.51	0.10			0.58		0.26	2.73
System 3	CRAC Cooled System w Containment	0.21	1.25	0.45				0.50		0.26	2.67
System 4	CRAH Cooled System w Containment	0.15	1.08	0.45	0.10			0.50		0.26	2.54
System 5	Liquid Cooled Racks Unoptimized	0.15	1.08	0.28	0.10			0.50		0.26	2.37
System 6	Liquid Cooled Racks Chilled Water Temperatures Optimized	0.13	0.96	0.28	0.09					0.26	1.72
System 7	Liquid Cooled Racks Chilled Water Temperatures Optimized and Free Cooling Systems	0.13	0.63	0.28	0.09					0.26	1.39
System 8	Liquid Cooled Racks Chilled Water Temperatures Optimized and **Evaporative** Free Cooling Systems	0.22	0.36	0.28	0.09					0.26	1.21
System 9	Active Liquid Cooled Doors, Chilled Water Temp Optimized, & Evaporative Free Cooling Systems	0.22	0.36	0.24	0.09					0.26	1.17
System 10	Passive Liquid Cooled Doors Chilled Water Temp Optimized & Evaporative Free Cooling Systems	0.22	0.36		0.09					0.26	0.93
System 11	Pumped Refrigerant Systems	0.16	1.12		0.10	0.04	0.06			0.26	1.74
System 12	Air Side Economizing	0.05	0.37	0.51	0.03			0.19		0.26	1.41

Natural Cycle Energy Inc

Real Time Data Center Cooling System (RTDCCS) -
All components are included in this analysis

Multistage Evaporative Cooling System (MECS)	**Total KW / Ton**
Cooling towers all with fans, pumps, etc.	0.29

Individual Server Enclosure Cooling System (ISECS)

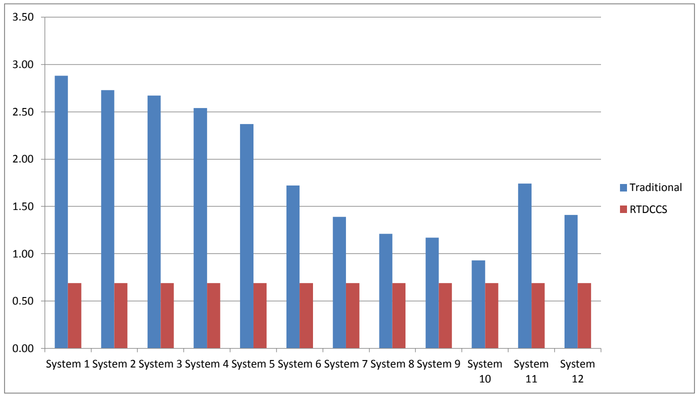
Rack Fan Coil Unit	0.14
Server Fans	0.26

Total Real Time Data Center Cooling System KW per Ton **0.69**

R4 Ventures LLC
Energy Usage Comparison of Traditional Data Center Cooling Systems to the R4 Ventures LLCRTDCCS

		Trad'l Mechanical Cooling KW / Ton	RTDCCS KW / Ton	KW / Ton Savings	% Energy Savings
System 1	CRAC Cooled System	2.88	0.69	2.19	**76.0%**
System 2	CRAH Cooled Systems – Chilled Water Based	2.73	0.69	2.04	**74.7%**
System 3	CRAC Cooled System w Containment	2.67	0.69	1.98	**74.2%**
System 4	CRAH Cooled System w Containment	2.54	0.69	1.85	**72.8%**
System 5	Liquid Cooled Racks Unoptimized	2.37	0.69	1.68	**70.9%**
System 6	Liquid Cooled Racks Chilled Water Temperatures Optimized	1.72	0.69	1.03	**59.9%**
System 7	Liquid Cooled Racks Chilled Water Temperatures Optimized and Free Cooling Systems	1.39	0.69	0.70	**50.4%**
System 8	Liquid Cooled Racks Chilled Water Temperatures Optimized and **Evaporative** Free Cooling Systems	1.21	0.69	0.52	**43.0%**
System 9	Active Liquid Cooled Doors, Chilled Water Temp Optimized, & Evaporative Free Cooling Systems	1.17	0.69	0.48	**41.0%**
System 10	Passive Liquid Cooled Doors Chilled Water Temp Optimized & Evaporative Free Cooling Systems	0.93	0.69	0.24	**25.8%**
System 11	Pumped Refrigerant Systems	1.74	0.69	1.05	**60.3%**
System 12	Air Side Economizing	1.41	0.69	0.72	**51.1%**

Comparison Energy Usage in KW / Ton

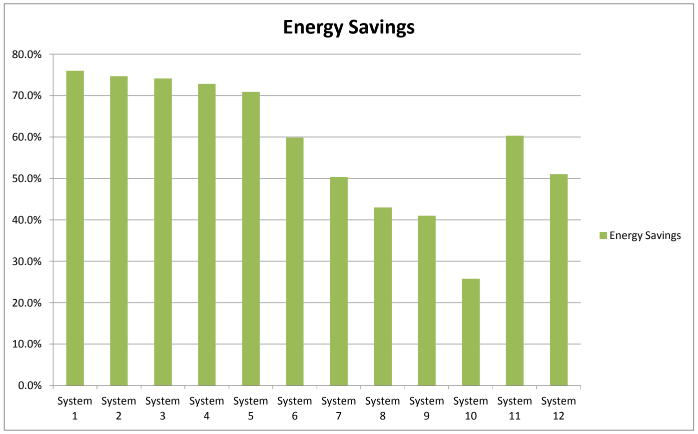


R4 Ventures LLC
Energy Usage and Savings Comparison of Traditional Data Center Cooling Systems to the RTDCCS

Annual Cooling Energy cost Per Year Calculation	
Energy Cost kW/Hr	**$0.10**
kW of IT Load	**2000**
Tons of Cooling Required	**569**

		Energy Usage KW / TON				Annual Energy Cost		
		Trad'l Mech. Cooling KW / Ton	RTDCCS KW / Ton	KW / Ton Savings	% Energy Savings	Trad'l Mech. Cooling $/Yr	RTDCCS Cooling $/Yr	$ Savings
System 1	CRAC Cooled System	2.88	0.69	2.19	**76.0%**	$1,434,101.64	$343,926.36	($1,090,175.28)
System 2	CRAH Cooled System - Chilled Water Based	2.73	0.69	2.04	**74.7%**	$1,350,885.88	$343,926.36	($1,006,959.52)
System 3	CRAC Cooled System w / Containment	2.67	0.69	1.98	**74.2%**	$1,331,452.26	$343,926.36	($987,525.90)
System 4	CRAH Cooled System w/ Containment	2.54	0.69	1.85	**72.8%**	$1,262,413.07	$343,926.36	($918,486.71)
System 5	Liquid Cooled Racks Unoptimized	2.37	0.69	1.68	**70.9%**	$1,179,695.60	$343,926.36	($835,769.24)
System 6	Liquid Cooled Racks Chilled Water Temperature Optimized	1.72	0.69	1.03	**59.9%**	$857,072.56	$343,926.36	($513,146.20)
System 7	Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	1.39	0.69	0.70	**50.4%**	$694,428.09	$343,926.36	($350,501.73)
System 8	Liquid Cooled Racks Chilled Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	1.21	0.69	0.52	**43.0%**	$600,548.75	$343,926.36	($256,622.39)
System 9	Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	1.17	0.69	0.48	**41.0%**	$583,008.66	$343,926.36	($239,082.30)
System 10	Passive Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	0.93	0.69	0.24	**25.8%**	$463,417.14	$343,926.36	($119,490.78)
System 11	Pumped Refrigerant Systems	1.74	0.69	1.05	**60.3%**	$865,543.63	$343,926.36	($521,617.27)
System 12	Air Side Economizing	1.41	0.69	0.72	**51.1%**	$705,988.61	$343,926.36	($362,062.25)

RTDCCS Energy Savings vs. Traditional Mechanical Systems

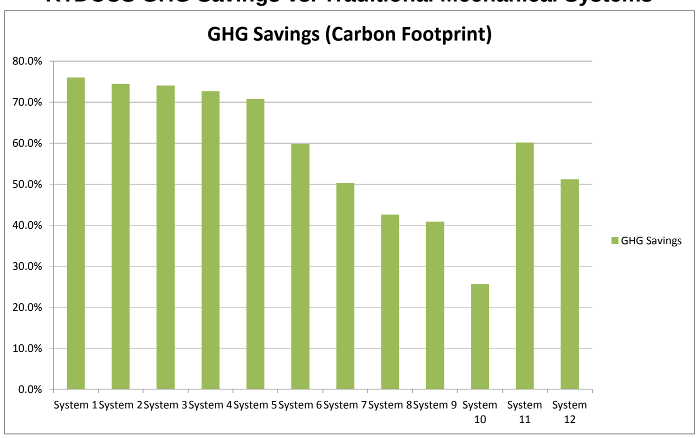


R4 Ventures LLC
Carbon Footprint Comparison of Traditional Data Center Cooling Systems to the R4 Ventures LLCRTDCCS
(From example above: 2000 KW and 569 tons of cooling)

The carbon output per kWHr assumed is 0.524 pounds per kWHr based on Pacific Gas and Electrics published numbers.

							Carbon Calculator (1000 miles driven per month)		Environmental Impact per KW of Energy Savings		
		Trad'l DC Cooling LBs of CO^2 Released	RTDCCS LBs of CO^2 Released	Reduction in CO^2 Footprint LBs Released	% Reduction in CO^2 Footprint	2000 Tons of CO^2 Reduced	6.6 Equivalent Mid Sized Cars	33 # of Trees to Offset / YR	2000 Tons of CO^2 Reduced	Equivalent Mid Sized Cars	# of Trees to Offset / YR
System 1	CRAC Cooled System	7,541,693	1,806,864	(5,734,829)	76.0%	2867	434	14,337	**1.43**	**0.22**	**7.17**
System 2	CRAH Cooled System - Chilled Water Based	7,078,642	1,806,864	(5,271,778)	74.5%	2636	399	13,179	**1.32**	**0.20**	**6.59**
System 3	CRAC Cooled System w / Containment	6,976,810	1,806,864	(5,169,946)	74.1%	2585	392	12,925	**1.29**	**0.20**	**6.46**
System 4	CRAH Cooled System w/ Containment	6,615,044	1,806,864	(4,808,180)	72.7%	2404	364	12,020	**1.20**	**0.18**	**6.01**
System 5	Liquid Cooled Racks Unoptimized	6,181,605	1,806,864	(4,374,741)	70.8%	2187	331	10,937	**1.09**	**0.17**	**5.47**
System 6	Liquid Cooled Racks Chilled Water Temperature Optimized	4,491,060	1,806,864	(2,684,196)	59.8%	1342	203	6,710	**0.67**	**0.10**	**3.36**
System 7	Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	3,638,803	1,806,864	(1,831,939)	50.3%	916	139	4,580	**0.46**	**0.07**	**2.29**
System 8	Liquid Cooled Racks Chilled Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	3,146,875	1,806,864	(1,340,011)	42.6%	670	102	3,350	**0.34**	**0.05**	**1.68**
System 9	Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	3,054,965	1,806,864	(1,248,101)	40.9%	624	95	3,120	**0.31**	**0.05**	**1.56**
System 10	Passive Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	2,428,306	1,806,864	(621,442)	25.6%	311	47	1,554	**0.16**	**0.02**	**0.78**
System 11	Pumped Refrigerant Systems	4,535,449	1,806,864	(2,728,585)	60.2%	1364	207	6,821	**0.68**	**0.10**	**3.41**
System 12	Air Side Economizing	3,699,380	1,806,864	(1,892,516)	51.2%	946	143	4,731	**0.47**	**0.07**	**2.37**

RTDCCS GHG Savings vs. Traditional Mechanical Systems



Rittal White Paper 507: Understanding Data Center Cooling Energy Usage & Reduction Methods

By: Daniel Kennedy

Executive Summary

Data center energy usage has risen dramatically over the past decade and will continue to grow in-step with the processor-intensive applications that support business and day-to-day life in the modern world. The growth of technology has driven the data center into a new phase of expansion, and while data centers themselves may vary over different industry segments, there are common factors influencing all of them including a need to do more with the same resources, or in some cases, even less. To this end, much has been done to increase server efficiency and IT space utilization, but the actual space and cooling infrastructure supporting these intensified loads has often not been properly addressed to keep pace with these developments—an important oversight since cooling can represent up to 42% of a data center's energy usage.

This white paper provides a clear understanding of the cooling and heat removal infrastructure requirements for the modern high density data center and methods that can be employed to reduce energy consumption and costs while increasing performance and operational efficiency.

Available Cooling Systems

Over the years, many methods have been used to cool IT loads in the data center environment. The master table below lists the methods discussed in this paper. These products are available from various manufacturers—some have been available for quite some time and others have just recently been introduced. Please note that the master table is not a complete list of vendors, but is intended as a reference for some of the most commonly deployed systems.

These systems can be ranked from an energy usage standpoint by evaluating the energy required to operate the system in kilowatts (kW) versus the cooling capacity provided in tons of cooling (12,000 BTU/Hr). This paper will refer to this ratio as a kW/Ton rating.

	Availability	Manufacturers	Commonality in the Industry
CRAC Cooled System	30+ Years	Liebert, DataAire, Stultz	Very Common
CRAH Cooled System	30+ Years	Liebert, DataAire, Stultz	Very Common
CRAC Cooled System W/Containment	5-10 years	The above for Cooling units, Containment from Rittal, CPI, Polargy, APC, Knurr	Gaining Widespread Acceptance
CRAH Cooled System W/Containment	5-10 years	The above for Cooling units, Containment from Rittal, CPI, Polargy, APC, Knurr	Gaining Widespread Acceptance
Liquid Cooled Racks Unoptimized	8 years	Rittal, APC, Knurr, Liebert, HP	Common
Liquid Cooled Racks Chilled Water Temperature Optimized	8 years	Rittal, HP, Knurr	Less Common
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	8 years	Rittal, HP, Knurr	Less Common
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	8 years	Rittal, HP, Knurr	Less Common
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	5 years	Rittal	Less Common
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	8 years	Rittal, IBM, Vette	Less Common
Pumped Refrigerant Systems	5 years	Liebert	Less Common
Air Side Economizing	30+ Years	Custom Engineered Solutions with components from various providers	Common
Liquid Cooled Servers	30+ Years	Originally used in Mainframes, but proposed 100% heat removal very rare, closest manufacturer would be SprayCool	Rare

Master Table – Cooling Methods

Current Generation Cooling Systems

Consideration of currently deployed systems is necessary to determine methods of improving on these base installations. The following sections will review these systems to make it clear where and what the major energy usage devices are and how they compare to one another.

CRAC Cooled Systems – Direct Expansion

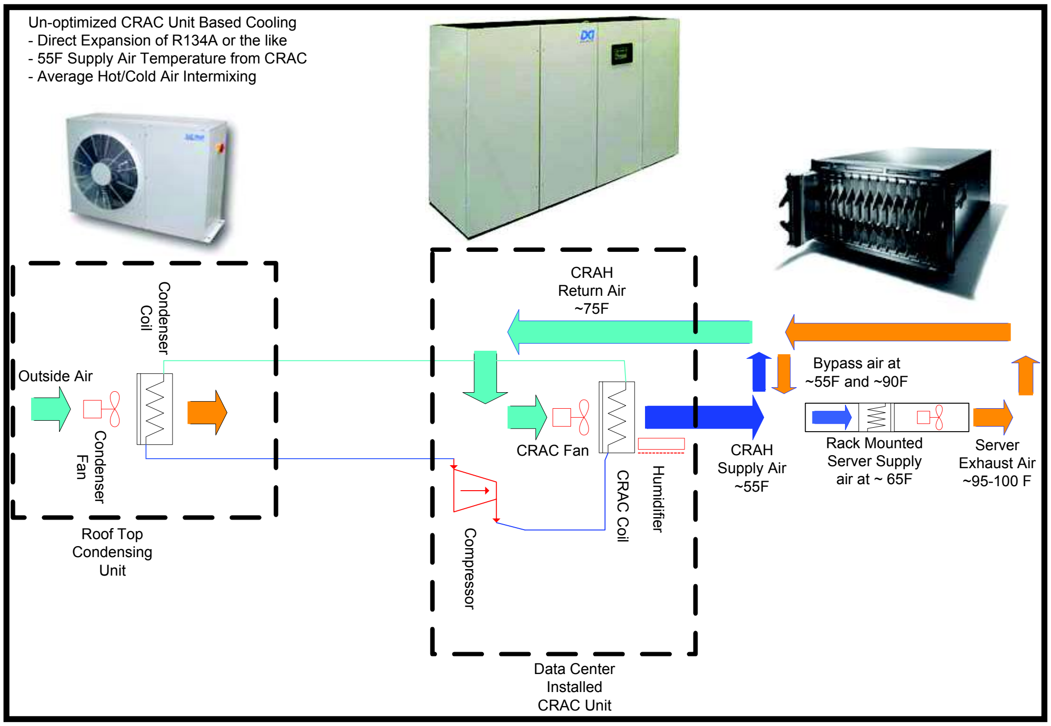


Figure 1 - CRAC Based Cooling

CRAC's (Computer Room Air Conditioners) are one of the most common cooling systems installed in current generation data centers and utilize the direct expansion of refrigerant gases to remove energy from the air inside the data center and reject it to outdoor spaces. These systems typically take the form of a relatively small (30 Tons sensible capacity) compressor system and evaporator coil installed in the data center space, and a condensing unit installed outdoors to reject the energy from the room. Sufficient units must be installed in an IT space to handle the actual or planned heat loads.

Figure 1 shows that the first energy user is the condensing coil fan, followed by the compressor, then the evaporator fan responsible for moving air through the data center space. Due to the low temperature of the evaporator coil, a humidification system is also needed to ensure that moisture condensed out of the air on the evaporator coil is added back to keep the humidity level within a specified range. Next, air is heated by and exhausted from the servers utilizing relatively small fans installed in the component chassis. The evaporator fans in the CRAC unit draw the air back in, and the process is repeated.

Evaluating this system from an energy standpoint shows that there are at least five energy-consuming components. Of these components, four are in the CRAC unit itself, and can be evaluated from a kW/Ton standpoint to determine the efficiency of the system overall. Averaging published data on these systems suggests the following kW/Ton breakdown for an overall number of 2.88 kW/Ton.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88

Table 1 - CRAC Based Cooling - kW/Ton

The CRAC-based approach to cooling is currently the most common method for cooling data centers. It is at some disadvantage to other systems because of smaller compressors and the lower entering air temperatures caused by the mixing of cold and hot air streams that are likely to occur in this type of data center cooling strategy.

CRAH Cooled Systems – Chilled Water Based

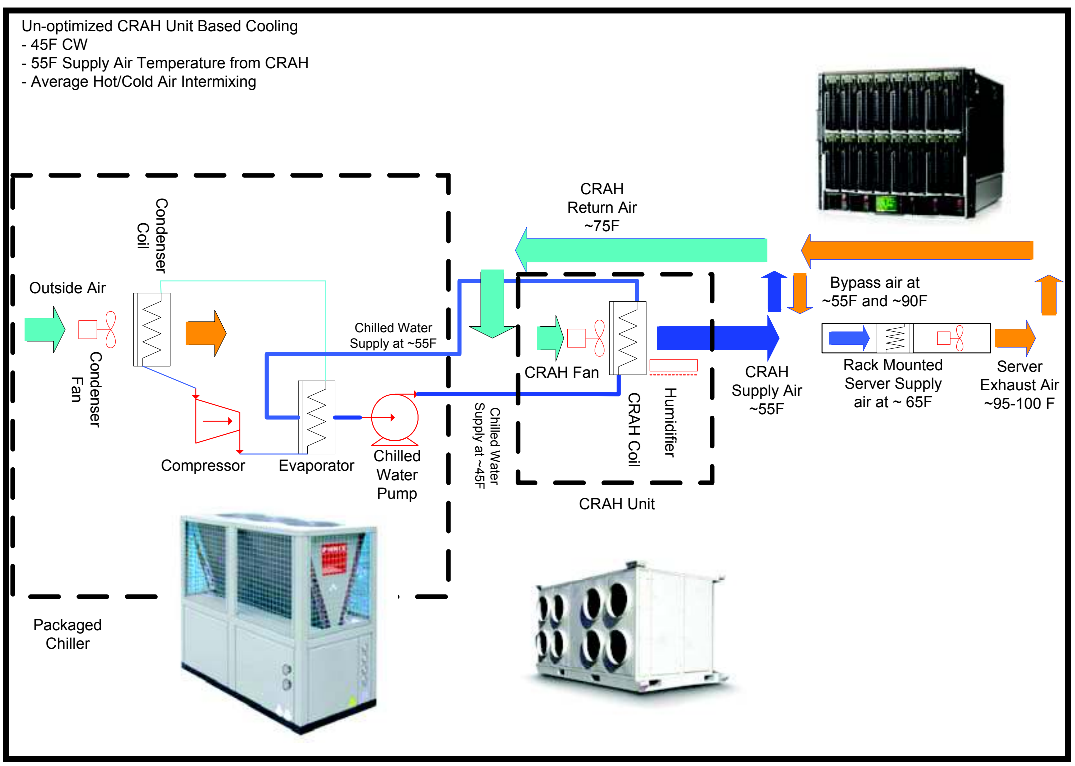


Figure 2 - CRAH Based Cooling

The chilled water-based CRAH (Computer Room Air Handler) units are the other most common approach to cooling the data center space. Instead of utilizing the direct expansion method of cooling with refrigerants, chilled water cooled data centers utilize chillers to produce cold water through the refrigeration process, but usually on a much larger scale then the CRAC units discussed above (100-1000 tons). This large scale allows for more efficient energy usage at the compressor and fan levels.

Figure 2 illustrates this process. Outside air is passed through a condensing coil, or sometimes a cooling tower, to remove the rejected heat energy from the refrigerant gases. The compressor then liquefies the gas from the condenser and passes it through the evaporator coil. The evaporator coil has the chilled water from the system passed through it to remove the heat. The chilled water pump then moves the water through piping to the CRAH units. Once again a fan is used to move the air through the CRAH coil into the data center space. Since the water temperatures used in this system may be cold enough to condense moisture from the air, a humidification system is required to control the humidity level in the room. Onboard fans move the air through the servers with warm air returned back to the CRAH units.

Evaluating this system from an energy usage standpoint shows us that this configuration has approximately six primary energy consumption devices. Two of these are found in the CRAH units, three are part of the chilled water system and one is located in the servers. Table 2 shows an evaluation of the energy consumption.

Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71

Table 2 - CRAH Based Cooling - kW/Ton

From a kW/Ton perspective, using a CRAH-based chilled water system offers an improvement over the CRAC unit method. The extra step in the cooling does not impact the overall number and the larger size of the system results in lower compressor kW/ton and condenser kW/ton values. This scale factor provides a more efficient system overall, making the initial argument for chilled water systems more plausible for larger data centers. The evaluated system still suffers from lower entering air temperatures than the systems were designed for, but this is common in a typical data center due to the intermixing of hot and cold air.

Improved Current Generation Cooling Systems

Slight changes to the systems described above can result in clear advantages in terms of energy savings and more efficient use of existing equipment. Typical CRAC and CRAH units are designed with much higher entry air temperatures than typically seen in data centers. As shown above, the average return air temperature to the CRAC and CRAH units was only 75°F. If this number is increased to bring the units in line with their rated capacity, efficiency gains should be easily realized without major changes to the system or investment in new infrastructure. Other system improvements include cold or hot aisle containment which would also include ducted type return systems that utilize a drop ceiling return path to the CRAC/CRAH units.

CRAC/CRAH Cooled Systems – Chilled Water-Based with Containment

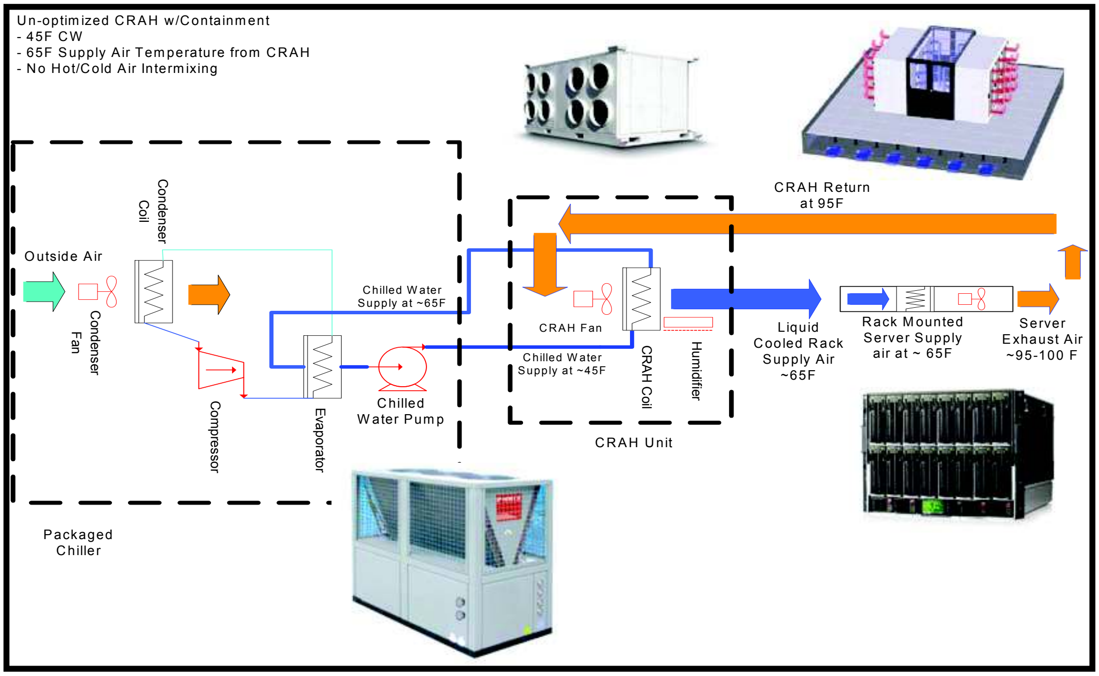


Figure 3 - CRAH Cooled Data Centers with Containment

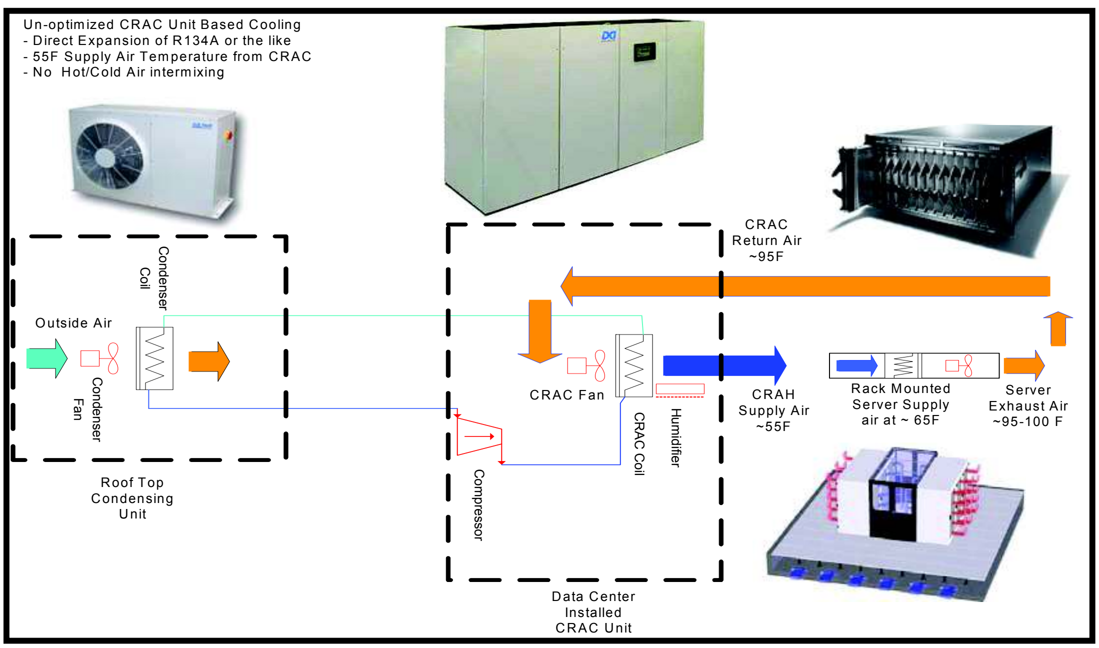


Figure 4 - CRAH Cooled Data Centers with Containment

These systems build upon the previous reviews of CRAH and CRAC units. The main advantage of this configuration is that return or entering air temperature to the CRAC/CRAH unit equals the server air exhaust temperature. This physical separation of the air streams can be accomplished through the use of cold aisle containment on a raised floor system, hot aisle containment when used with a ducting mechanism, or directly ducted racks to serve the same purpose. The increased efficiencies are shown in Table 3.

Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53

Table 3 – CRAH/CRAC Based Cooling with Containment - kW/Ton

Key Point: The noticeable decrease in kW/ton is entirely related to the increased return/entering air temperature at the CRAC or CRAH unit.

This increase in air temperature permits existing cooling units to operate as designed and rated, resulting in a lower overall ratio of energy consumed versus cooling capacity provided. It is important to note that the components used to separate the air paths are unimportant when considering this method of cooling. However, the existing cooling and building infrastructures are major factors. Sites with raised floor and no ceiling return path to the CRAC units may only be able to utilize cold aisle containment. Sites without raised floor and/or with hot air return paths above may find hot aisle containment or directly ducted racks more cost effective.

Adoption of Optimized Cooling Solutions

The cooling approaches discussed to this point primarily illustrate the efficiency of traditional air-cooled infrastructures and one method to demonstrate the optimization of existing systems. When considering more effective means of cooling a data center, or to provide additional cooling capacity, other systems may prove more efficient and cost effective. These will be covered in the following sections.

Liquid Cooled Rack Systems and Inline Units – Chilled Water Based with Containment

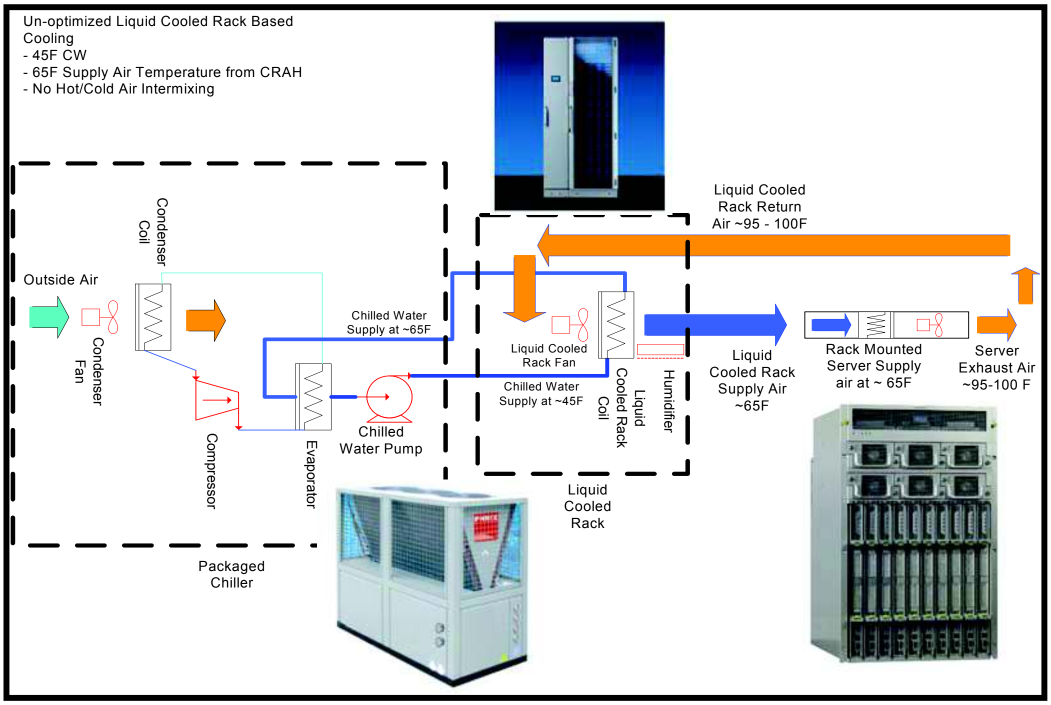


Figure 5 – Liquid Cooled Racks or Inline units with Containment

Liquid cooled racks and contained cold or hot aisle systems have been available for the past 4-6 years. These systems can be compared to the CRAH units discussed above, but instead of being installed in a distributed layout (perimeter or in-aisle) like CRAH units normally are, they are installed directly in the row with the racks and loads they are meant to cool. The primary efficiency gains seen in these systems come from the significant reduction in distance for air flow to reach the intended load and return, as well as the ability of some systems to handle a greater range of chilled water temperatures above the typical 45°F used in the above examples. The use of cold or hot containment, or even both, also results in additional operational efficiencies. The overall energy user count is identical to the CRAH units above. See Table 4 for system values operating on a conventional 45°F chilled water system.

Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53
Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26	2.37

Table 4 – Liquid Cooled Racks or Inline units with Containment - kW/ton

Liquid Cooled Rack Systems and Inline Units – Chilled Water Based with Containment and Optimized Chilled Water Temperatures

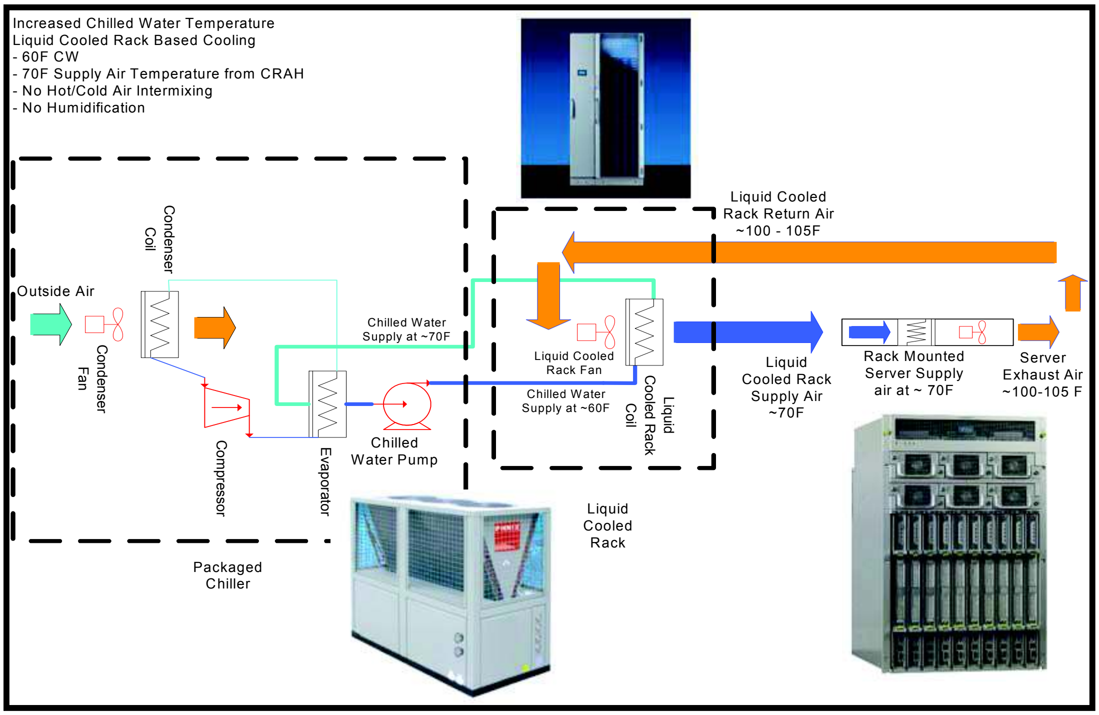


Figure 6 – Liquid Cooled Racks or Inline units with Containment and Optimized Chilled Water Temperatures

As previously discussed, some liquid cooled rack systems offer the advantage of utilizing higher chilled water supply temperatures. These higher water temperatures result in greater efficiencies at the chiller level, primarily related to the ability of the system to provide additional capacity using the same amount of energy. The increased water temperature no longer requires the use of a direct humidification system, due to the fact that the heat exchanger coil surface temperature would be well above the condensing temperature, resulting in 100% sensible cooling. The energy savings are shown in Table 5.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA
CRAH Cooled System	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26
CRAC Cooled System W/Containment	Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA
CRAH Cooled System W/Containment	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26
Liquid Cooled Racks Unoptimized	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26
Liquid Cooled Racks Chilled Water Temperature Optimized	Condenser Fan	0.13	Compressor	0.96	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26

Table 5 – Liquid Cooled Racks or Inline units with Containment and elevated water temperature - kW/ton

Liquid Cooled Rack Systems and Inline Units – Chilled Water Based with Containment, Optimized Chilled Water Temperatures and Water Side Economizing

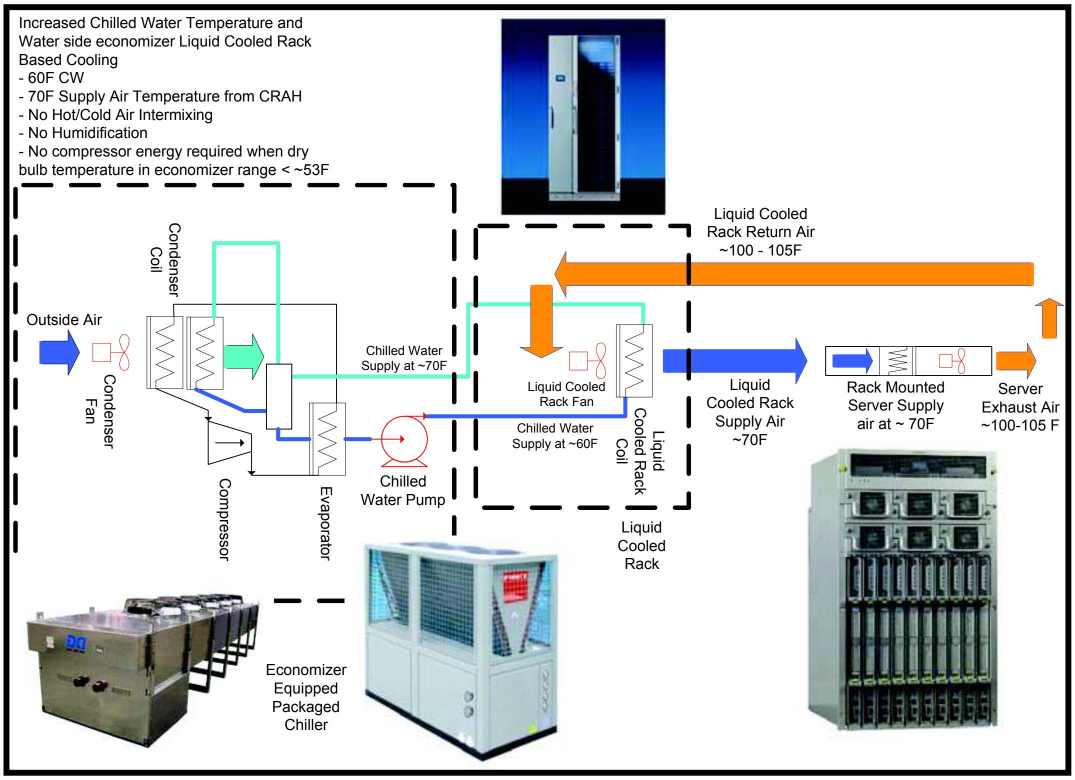


Figure 7 – Liquid Cooled Racks or Inline units with Containment, Optimized Chilled Water Temperatures, and Water Side Economizing

This next section will discuss "Free Cooling." Essentially, free cooling is provided to the heat transfer and removal process when large energy using components in a facility's cooling infrastructure can be turned off without adversely affecting cooling performance. The key component to idle is the compressor in the chiller plant. With a compressor turned off, and with appropriate ambient conditions (to be described below), the cooling system will still be able to provide the required heat removal capacity but with significantly lower energy usage. The metric used to record these savings is typically referred to as "Hours of Free Cooling."

Figure 7 shows another advantage of utilizing a higher chilled water temperature with the addition of a waterside economizer (based on a dry type coil). This system is operated in parallel with the existing condensing coil, even to the point of using the same fan system (depending on design of the unit). For the purposes of this paper, assume that the fan energy required on the condenser coil and economizer coil are equal. The major advantage of this system is that the compressor in the chiller can be turned off whenever the outdoor temperature drops below the design set point of the waterside economizing coil. Generally speaking, this approach temperature typically runs from 7-10°F below the desired water temperature. For example, to produce water of 60°F to the cooling system, the outdoor ambient temperature must be less than 53°F. The impact of these energy savings is dependent on the installation location because of the variances in ambient outdoor temperatures in different parts of the world. The average hourly energy usage analysis figures for five major cities (New York, Chicago, San Francisco, Phoenix, Miami, and Atlanta) are reflected in Table 6. On the whole, these cities average approximately 2,856 hours of free cooling, or 33% of the year.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
CRAH Cooled System	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
CRAC Cooled System W/Containment	Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
CRAH Cooled System W/Containment	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53
Liquid Cooled Racks Unoptimized	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26	2.37
Liquid Cooled Racks Chilled Water Temperature Optimized	Condenser Fan	0.13	Compressor	0.96	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.72
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	Condenser Fan	0.13	Compressor	0.63	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.39

Table 6 – Liquid Cooled Racks or Inline units with Containment, elevated water temperature, and waterside economizer - kW/ton

Waterside economizing can be done with multiple types of systems, the dry cooler being one of the least expensive configurations available. Evaporative economizing systems such as cooling towers can provide additional benefits. Some currently available systems can realize a two-degree approach temperature, and since evaporative type systems are concerned with wet bulb temperature as opposed to dry bulb temperatures for dry type coolers, further free cooling hours can be realized. The impact of the larger operating window can be seen in Table 7.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
CRAH Cooled System	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
CRAC Cooled System W/Containment	Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
CRAH Cooled System W/Containment	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53
Liquid Cooled Racks Unoptimized	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26	2.37
Liquid Cooled Racks Chilled Water Temperature Optimized	Condenser Fan	0.13	Compressor	0.96	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.72
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	Condenser Fan	0.13	Compressor	0.63	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.39
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.21

Table 7 – Liquid Cooled Racks or Inline units with Containment, elevated water temperature, and evaporative waterside economizer with tight approach - kW/ton

Liquid Cooled Rear Door Units Active and Passive – Chilled Water Based, Optimized Chilled Water Temperatures and Water Side Economizing

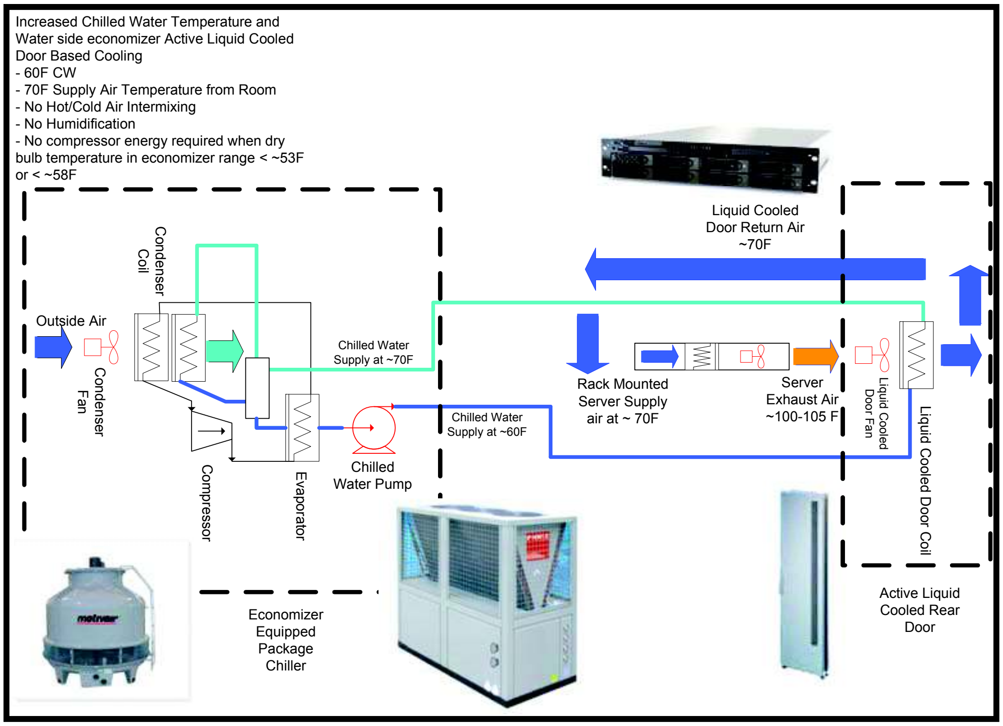


Figure 8 – Active Liquid Cooled Rear Door, Optimized Chilled Water Temperatures and Water Side Economizing

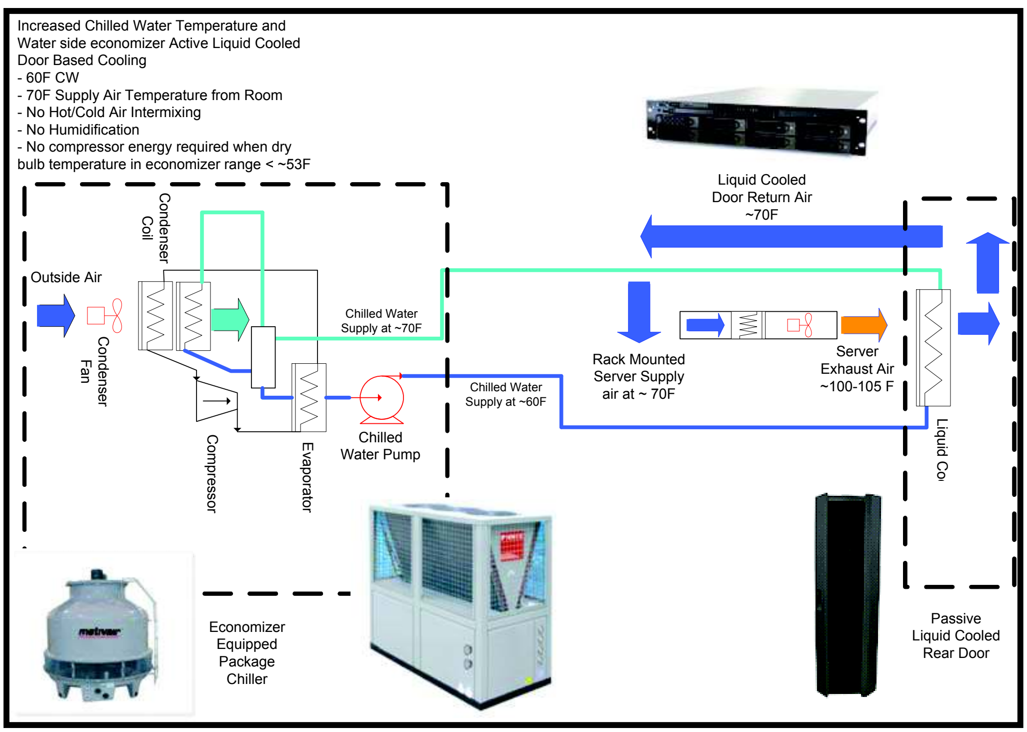


Figure 9 – Passive Liquid Cooled Rear Door, Optimized Chilled Water Temperatures and Water Side Economizing

Liquid cooled rear door units have been available for the past few years. These systems attach directly to the rear doors of equipment racks. Hot air from the servers is pulled through the air/water heat exchanger coil and passed into the space in an active system (Figure 8). In a passive system (Figure 9), the coil requires no extra fan power above the server fans themselves.

These systems take advantage of warmer water temperatures mentioned previously, and waterside economizing can also be utilized. The overall system efficiencies increase due to the power draw reduction of the fan system or the elimination of fans altogether. These results are shown in Table 8.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
CRAH Cooled System	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
CRAC Cooled System W/Containment	Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
CRAH Cooled System W/Containment	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53
Liquid Cooled Racks Unoptimized	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26	2.37
Liquid Cooled Racks Chilled Water Temperature Optimized	Condenser Fan	0.13	Compressor	0.96	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.72
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	Condenser Fan	0.13	Compressor	0.63	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.39
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.21
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.24	Humidifcation	0.00	Server Fans	0.26	1.17
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.00	Humidifcation	0.00	Server Fans	0.26	0.93

Table 8 – Active and Passive Liquid Cooled Doors, elevated water temperature, and evaporative waterside economizer with tight approach - kW/ton

Pumped Refrigerant Based Cooling Systems

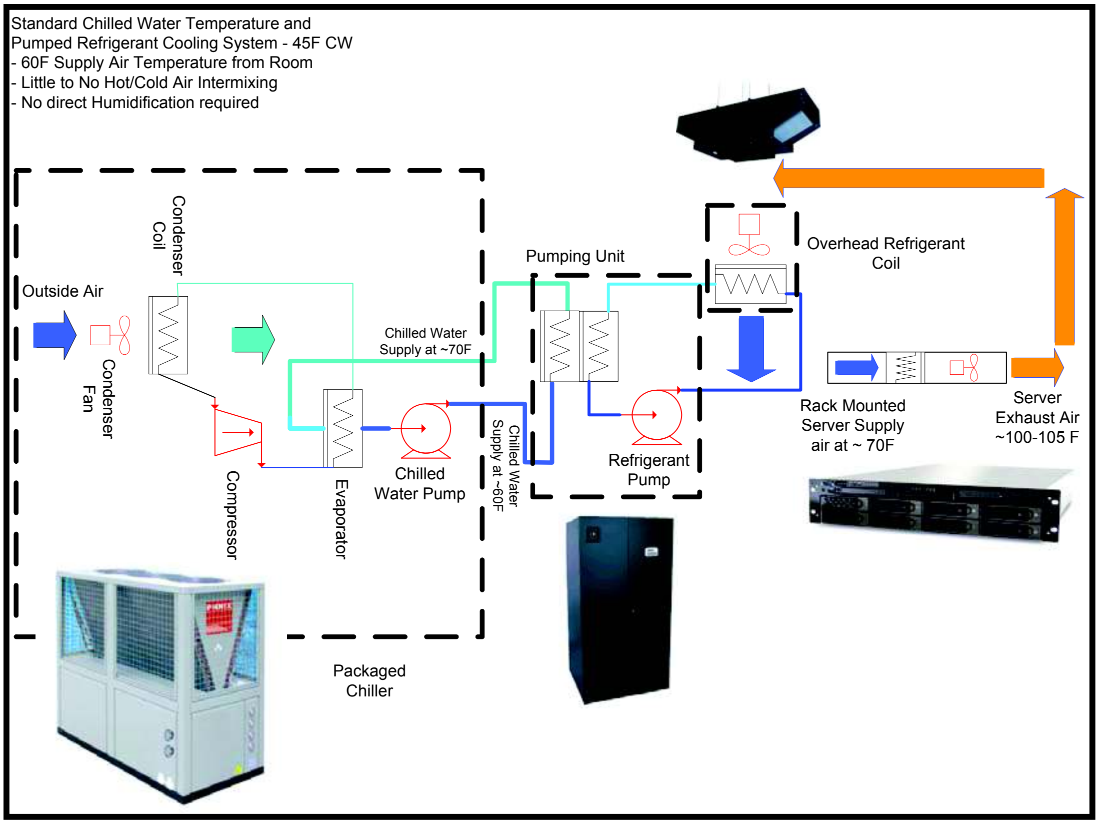


Figure 10 – Pumped Refrigerant Cooling System

As implied by the name, pumped refrigerant cooling systems rely on the use of a pumped refrigerant as the heat exchange medium to cool server equipment. Refrigerant is pumped from a central pumping unit to the cooling systems, capturing heat from the active components. The warmed refrigerant is circulated back to a pumping unit that is typically coupled to a chilled water circuit that transfers and rejects the heat entrained in the refrigerant.

This system has one more step when compared to the previously mentioned systems—the additional refrigerant pump shown in Figure 10, but because of the 100% sensible cooling provided by these units (energy usage for the evaporator fan is low, there is no need for humidification) the pump doesn't really add much to the overall energy consumption. However, even with these advantages, this system's reliance on 45°F chilled water handicaps it when compared to other systems utilizing warmer water temperatures as shown in Table 9.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
CRAH Cooled System	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
CRAC Cooled System W/Containment	Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
CRAH Cooled System W/Containment	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53
Liquid Cooled Racks Unoptimized	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26	2.37
Liquid Cooled Racks Chilled Water Temperature Optimized	Condenser Fan	0.13	Compressor	0.96	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.72
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	Condenser Fan	0.13	Compressor	0.63	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.39
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.21
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.24	Humidifcation	0.00	Server Fans	0.26	1.17
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.00	Humidifcation	0.00	Server Fans	0.26	0.93
Pumped Refrigerant Systems	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Refrigerant Pump	0.04	Pumped Refrigerant Fan	0.06	Server Fans	0.26	1.74

Table 9 – Pumped Refrigerant Cooling Systems - kW/ton

Air Side Economizing Cooled Data Centers Approach

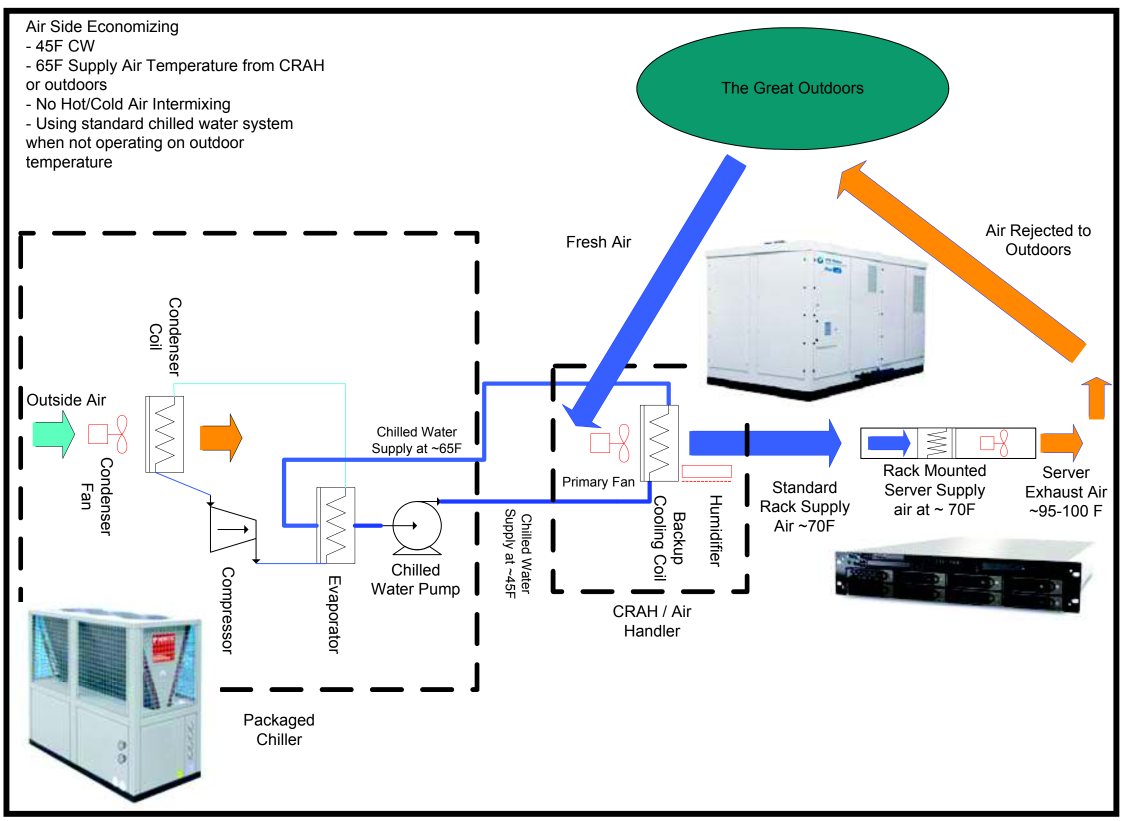


Figure 11 – Air Side Economization

Airside economizing utilizes outdoor air to provide cold air to the servers and rejects the heat from the servers back into outdoor spaces. This approach can be used whenever outdoor dry bulb temperatures lie within an acceptable server air inlet temperature. For the case of this study, assume 70°F supply air is desired and that the system is utilizing a form of aisle containment. The same cities evaluated above for water side economizing were used to determine how many hours a year the system could run with air side economizing, as opposed to using a chilled water infrastructure. Assume humidification of the space will be controlled only when CRAH units are operational.

Taking the average of the 5 cities shows that, on average, the system could function using outdoor air for 66% of the year. It is also assumed that no extreme measures are taken to filter the air or remove or add humidification to the space during economizing operation. If it was deemed necessary to filter the air entering the data center beyond the normal filtration methods applied in a data center and used in earlier analyses, or if humidity control was desired, this approach could quickly become impractical. These assumptions are used to calculate the values in Table 10.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
CRAH Cooled System	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
CRAC Cooled System W/Containment	Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
CRAH Cooled System W/Containment	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53
Liquid Cooled Racks Unoptimized	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26	2.37
Liquid Cooled Racks Chilled Water Temperature Optimized	Condenser Fan	0.13	Compressor	0.96	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.72
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	Condenser Fan	0.13	Compressor	0.63	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.39
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.21
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.24	Humidifcation	0.00	Server Fans	0.26	1.17
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.00	Humidifcation	0.00	Server Fans	0.26	0.93
Pumped Refrigerant Systems	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Refrigerant Pump	0.04	Pumped Refrigerant Fan	0.06	Server Fans	0.26	1.74
Air Side Economizing	Condenser Fan	0.05	Compressor	0.37	Chilled Water Pump	0.03	Evaporator Fan	0.51	Humidifcation	0.19	Server Fans	0.26	1.42

Table 10 – Air Side Economizing - kW/ton

Direct the Chip and other Heat Producing devices internal to the server Cooling Approach

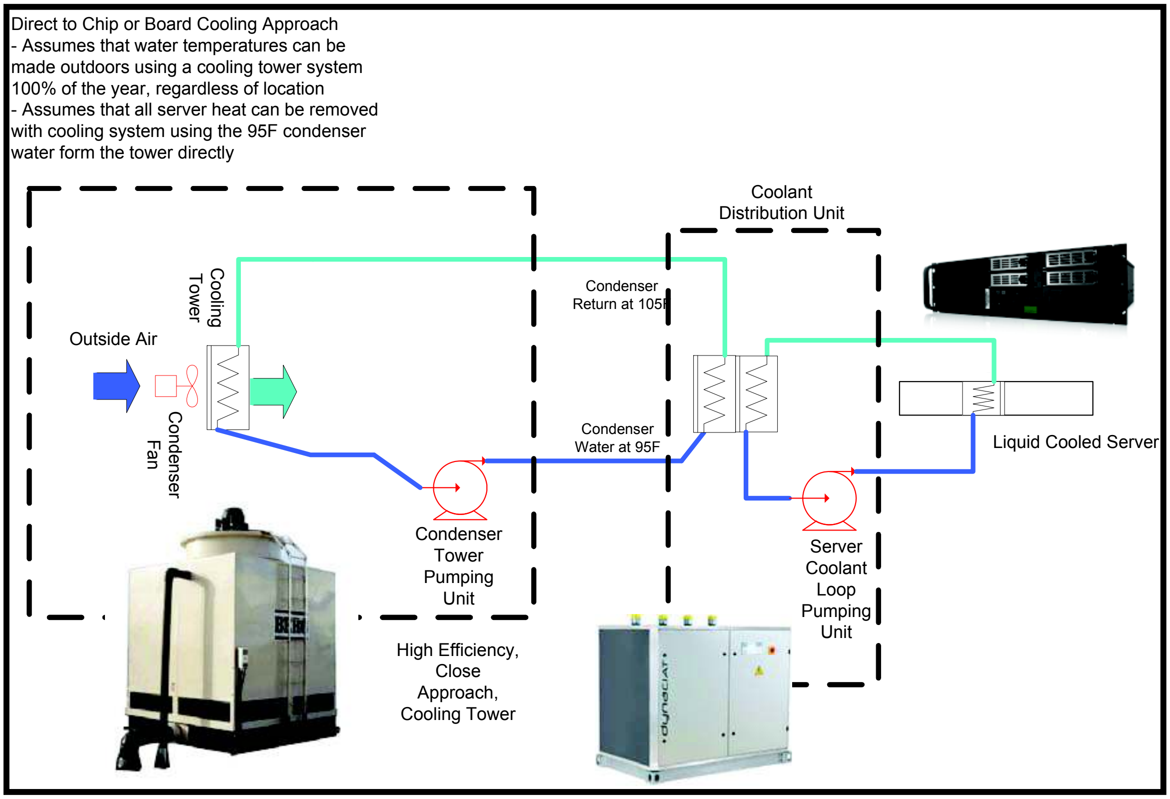


Figure 12 – Direct to chip cooling

Direct-to-chip, or direct-to-board cooling technologies rely on directing coolant to the heat producing devices internal to the servers themselves as opposed to air-cooling the system in any way. These systems are often built in conjunction with air-cooling as well. For this paper, we will assume 100% removal of heat from the system is possible in this type of system.

Figure 12 depicts a possible system configuration. The condenser water system would provide water less than 95°F to the water/water heat-exchanging device, which would regulate the temperature of the secondary water supply to the servers themselves. A pump would be required on this circuit to route the cooling medium through the server, and remove the heat from them, returning it to the water/water heat exchanger, which would then reject it to the cooling tower. The number of steps involved in this system is far less than others that have been evaluated to this point—please review Table 11 for further information.

	Step 1 Type	Step 1 kw/Ton	Step 2 Type	Step 2 kw/Ton	Step 3 Type	Step 3 kw/Ton	Step 4 Type	Step 4 kw/Ton	Step 5 Type	Step 5 kw/Ton	Step 6 Type	Step 6 kw/Ton	Total kw/Ton
CRAC Cooled System	Condenser Fan	0.24	Compressor	1.29	Evaporator Fan	0.51	Humidification	0.58	Server Fans	0.26	NA	NA	2.88
CRAH Cooled System	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Evaporator Fan	0.51	Humidifcation	0.58	Server Fans	0.26	2.71
CRAC Cooled System W/Containment	Condenser Fan	0.21	Compressor	1.25	Evaporator Fan	0.45	Humidification	0.50	Server Fans	0.26	NA	NA	2.67
CRAH Cooled System W/Containment	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.45	Humidifcation	0.50	Server Fans	0.26	2.53
Liquid Cooled Racks Unoptimized	Condenser Fan	0.15	Compressor	1.08	Chilled Water Pump	0.10	Evaporator Fan	0.28	Humidifcation	0.50	Server Fans	0.26	2.37
Liquid Cooled Racks Chilled Water Temperature Optimized	Condenser Fan	0.13	Compressor	0.96	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.72
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	Condenser Fan	0.13	Compressor	0.63	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.39
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.28	Humidifcation	0.00	Server Fans	0.26	1.21
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.24	Humidifcation	0.00	Server Fans	0.26	1.17
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	Condenser Fan / Cooling Tower	0.22	Compressor	0.36	Chilled Water Pump	0.09	Evaporator Fan	0.00	Humidifcation	0.00	Server Fans	0.26	0.93
Pumped Refrigerant Systems	Condenser Fan	0.16	Compressor	1.12	Chilled Water Pump	0.10	Refrigerant Pump	0.04	Pumped Refrigerant Fan	0.06	Server Fans	0.26	1.74
Air Side Economizing	Condenser Fan	0.05	Compressor	0.37	Chilled Water Pump	0.03	Evaporator Fan	0.51	Humidifcation	0.19	Server Fans	0.26	1.42
Liquid Cooled Servers	Condenser Fan / Cooling Tower	0.22	Compressor	0.00	Chilled Water Pump	0.10	Liquid Cooled Server Pump	0.20	Humidifcation	0.00	Server Fans	0.00	0.52

Table 11 - Liquid Cooled Servers – kW/ton

Cost Comparison

Putting all of the data into practical terms is important to understanding the bottom line results of implementing any of the aforementioned cooling strategies. Table 12 includes the cost breakdown for operating the individual cooling systems previously discussed. The table assumes a 2,000 kW data center based in an average location for economizing considerations.

Annual Cooling Energy cost Per Year Calculation	
Energy Cost kW/Hr	**$0.10**
kW of IT Load	**2000**
Tons of Cooling Required	**569**
Annual Energy Cost	
CRAC Cooled System	$1,434,101.64
CRAH Cooled System	$1,350,885.88
CRAC Cooled System W/Containment	$1,331,452.26
CRAH Cooled System W/Containment	$1,262,413.07
Liquid Cooled Racks Unoptimized	$1,179,695.60
Liquid Cooled Racks Chilled Water Temperature Optimized	$857,072.56
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	$694,428.09
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$600,548.75
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$583,008.66
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$463,417.14
Pumped Refrigerant Systems	$865,543.63
Air Side Economizing	$705,988.61
Liquid Cooled Servers	$259,114.96

Table 12 – Annual Energy Cost to operate various cooling systems

Data Center Cooling and Carbon Footprint Reduction

On a fundamental level, when discussing data center cooling methods, “cold” does not exist—it is an absence of heat. “Cold” cannot be made, but is the direct result of removing heat. Even though we think of these various products as “cooling” systems, they are actually heat transfer and removal systems. Their design goal is to transfer the heat from IT components, through IT spaces, then through climate control products and ultimately, to the outdoors. While all of the systems described in this paper maintain this hot air flow direction, the data shows that some of them provide these capabilities with much greater efficiencies than others.

Carbon footprint reduction is a major focus of industry, non-profit and government organizations throughout the world, and since the heat removed by these systems is transferred to the outdoors, environmental impacts must also be considered. Taking care to choose a cooling method that best suits the needs of your application as well as those of the environment can save you money in operational expenses, preserve natural resources and provide the performance you require. Table 12 clearly shows potential energy and cost savings of the various systems. Table 13 further expands this data to cover the carbon reduction in pounds per year that can be realized in a modestly sized data center using the alternate technologies discussed. The carbon output per kWHr assumed is 0.524 pounds per kWHr based on Pacific Gas and Electrics published numbers.

Annual Cooling Energy cost Per Year Calculation		
Energy Cost kW/Hr	$0.10	
kW of IT Load	2000	
Tons of Cooling Required	569	
Annual Energy Cost		**Pounds of Carbon Released**
CRAC Cooled System	$1,434,101.64	7,514,693
CRAH Cooled System	$1,350,885.88	7,078,642
CRAC Cooled System W/Containment	$1,331,452.26	6,976,810
CRAH Cooled System W/Containment	$1,262,413.07	6,615,044
Liquid Cooled Racks Unoptimized	$1,179,695.60	6,181,605
Liquid Cooled Racks Chilled Water Temperature Optimized	$857,072.56	4,491,060
Liquid Cooled Racks Chilled Water Temperature Optimized and Free Cooling Systems	$694,428.09	3,638,803
Liquid Cooled Racks Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$600,548.75	3,146,875
Active Liquid Cooled Doors, Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$583,008.66	3,054,965
Passive Liquid Cooled Doors Chilled Water Temperature Optimized and Evaporative Free Cooling Systems	$463,417.14	2,428,306
Pumped Refrigerant Systems	$865,543.63	4,535,449
Air Side Economizing	$705,988.61	3,699,380
Liquid Cooled Servers	$259,114.96	1,357,762

Table 13 – Annual Energy Cost and Carbon Footprint to operate various cooling systems

Practical Application of the Considered Cooling Technologies – A Review

There are many factors that must be considered before deciding on a cooling approach to use in a given data center. Energy usage, installation specifics such as the location of the data center itself, the density of the data center on a per rack and kW/square foot level and other user-specific requirements will all impact this decision.

CRAC/CRAH

The most common method, CRAC and CRAH units have been successfully deployed in a variety of installations, and for most legacy data centers, provide a reliable approach to data center cooling. Reliability aside, in light of the energy requirements discussed earlier, these systems may not be the most cost effective way to cool a data center.

Containment offers some energy benefits, even when used with CRAC/CRAH technology. It would appear that a minimum of a 7.3% savings could be realized when evaluated against a standard CRAC/CRAH deployment. The data center size will impact the overall savings, but even a small data center could reduce its overall energy usage with this approach. Cold aisle containment can be retrofitted into any data center with traditional raised floor cooling. Hot aisle containment or a chimney approach could make sense in those data centers with a duct return infrastructure already in place.

Liquid Cooled Racks

Traditional liquid cooled racks offer the energy benefits as shown above. A typical retrofit into a data center with standard 45°F chilled water and no other optimization could expect to see an 18% savings as opposed to deploying more CRAH type units and without the retrofit required for containment. These types of racks also offer the advantage of greater per-rack density when compared to that usually seen in a traditional CRAC/CRAH deployment (30kW vs. 4-6kW). This may offer a benefit when considering available floor space and may make it possible to extend the life of an existing data center instead of building a new one.

The requirements for installation are typically just a chilled water source or the space to install such a unit. The heat rejection for these units is the outside air so the chiller installation must be carefully considered. Once the chilled water system is in place, it becomes as simple as connecting the units to the chilled water source.

The true energy savings potential for this type of system becomes clear when chilled water temperature is increased in systems that can accept warmer temperatures without derating capacity. Compared to traditional CRAH units, the energy savings would increase to almost 40%. The addition of free cooling units increases the savings to 49%, and going to an evaporative free cooling system expands it further—to 55% versus the traditional CRAH approach.

Free cooling systems are location-dependent in regards to operational windows. The user should evaluate the data center location against readily available bin data from ASHRAE to determine the feasibility and potential ROI (Return On Investment) for these systems (the averages presented here are representative for the US and should only be considered as such).

Active and Passive Rear Door Cooling Units

The data contained in this paper shows that these units performed the best of the readily available technologies. Active and Passive rear door units can take advantage of all the technologies discussed including waterside economizing (with an improvement), or elimination of one of the fan sources. Active systems show a 57% improvement versus traditional water-cooled CRAH units, and passive systems deliver a 66% improvement. It is clear that this approach may make the most sense in those data centers capable of deploying these components.

From an installation perspective, chilled water is required in some form. The economizing side of the installation should also be planned to take full advantage of system capabilities. Installation on existing racks may drastically reduce the installation process time since there is no need to move equipment into new racks.

Pumped Refrigerant Based Systems

As a supplemental solution, these systems offer some clear energy savings when compared to conventional CRAH type systems. A 36% savings can be realized with this type of system, due to the more effective means of moving the energy from the servers and the absence of continuous humidification of the air stream due to the 100% sensible cooling provided. The location of the units in relation to the racks also provides for a reduction in fan energy usage, even with the additional pump required moving the refrigerant.

These systems also offer relatively simple retrofit capability. Installation typically takes place over the rack or on top of the rack and provides cool air in close proximity to the servers. The system does, however, rely on 45°F chilled water to provide cooling, which limits the possibility for the use of waterside economizing.

Air Side Economizing

When it comes to energy usage, airside economizing offers some clear benefits. A 48% energy savings can be realized when implementing this type of system.

This type of system would typically require a new data center build, as large volumes of air must be brought into and out of the data center (most data centers utilizing this approach are built without exterior walls). Due to the fact that the data center space becomes, more or less, an extension of the outdoors, more fluctuation in internal temperature and humidity levels should be expected. This paper did not evaluate the additional filtration that may or may not be required for this installation, and humidity control, outside of the traditional cooling windows, was not considered either (the numbers presented represent a best-case scenario for this type of cooling and should be considered as such).

Direct-to-chip or Board Cooling

This technology is used to a limited extent for IT component cooling, but typically in a hybrid air/direct approach only. This approach still requires less efficient cooling technologies, but this paper considers the best-case scenario of how a system may possibly perform if 100% of the heat rejection was realized through the direct method.

The savings are quite large, as many steps of the cooling process are entirely eliminated as seen in the tables above. 82% of the energy required in the cooling process is entirely eliminated, dramatically reducing the costs required to cool the data center.

This approach does come with drawbacks. Currently there are few commercially available servers that are directly cooled 100% by liquid. This type of design would require a dramatic rethinking of the server design criteria, and would create a subset of servers that are cooled in this manner as air cooled systems would still be required for those that will not adopt the technology. While the energy savings are very large, it is the author’s opinion that the full application of this technology in everyday data center use is still a few years off.

Conclusion

There are many methods available to cool a data center, all with varying degrees of effectiveness and energy efficiency. Traditional CRAC/CRAH systems now deployed are reaching the limit of their capacity—requiring the adoption of new technologies to enable the efficient cooling of growing data center loads. Although these technologies differ in some ways, they often share many common components to reduce the difficulty in installing these systems into existing infrastructures. It is clear that a single system approach may not make sense for every user, but the integration of these systems is key to successfully reducing energy costs while handling the increasing requirements of the users and applications.

There are many benefits of deploying environmentally responsible data center cooling technologies, and their importance will continue to grow moving forward. The products and techniques described in this paper can help with many of the critical issues facing the IT industry and the world at large including saving energy and money, reducing carbon footprints and limiting greenhouse gas emissions.

About the Author

Daniel Kennedy is Rittal Corporation's RimatriX Solution Center Coordinator and has been with the company since 2003. He holds a degree in Electrical Engineering and is the lead engineer for the design, implementation, and support of high density IT deployments in North America.