How Higher Chilled Water Temperature Can Improve Data Center Cooling System Efficiency

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Executive summary

Alternative data center cooling approaches such as indirect air economization are calling into question the economic justification for using traditional chilled water cooling in new data centers, especially those in mild climates. This paper describes some innovative approaches to chilled water cooling, where the chiller is used only to boost cooling capacity on the hottest days. A capex and opex analysis describes how these approaches can save 41%-64% opex, with 13% increase in capex with assumption of using the same chiller. We also discuss the design considerations for these new technologies.

Introduction

Return-on-investment analysis drives an ongoing industry effort to reduce data center operation costs by reducing the cooling system energy consumption. A revision to ASHRAE standard TC9.9, released in 2011[1], encourages increasing the number of hours on economizer mode as an effective means of lowering cooling system energy consumption. In this revision, ASHRAE continued to expand the environmental range for data centers to where an increasing number of locations throughout the world are able to operate with more hours of economizer mode. In other words, reducing the number of hours in full mechanical (i.e. compressor) mode can achieve significant energy savings.

In order to leverage economization to reduce energy cost, some IT server vendors are also trying to design server models which can run at higher temperatures and humidity[2]. Furthermore, improved monitoring and airflow management allows data center operators to be more aggressive with higher IT inlet temperatures. However, increasing IT inlet air temperatures must be balanced against the potential increase in server fan energy which can actually increase total data center energy consumption. For more information on this topic, see White Paper 221, *The Unexpected Impact of Raising Data Center Temperatures.*

Chillers require a large amount of electricity to operate, for example, chillers consume about 60%-85% of the total cooling system energy consumption, which depends on chiller type and cooling architecture. Therefore, data center operators are trying to seek ways to reduce chiller

[1] ASHRAE. 2011, Thermal Guidelines for Data Processing Environments, Developed by ASHRAE Technical Committee 9.9.
[2] http://en.community.dell.com/techcenter/extras/m/white_papers/20102656.aspx

energy consumption. One way to do this is to increase the chilled water (CHW) temperature[3], traditionally set to 7°C (45°F). The original purpose of using lower CHW temperature was to provide latent cooling capacity (dehumidification) in commercial buildings for human comfort. However, data center environments mainly have a sensible cooling capacity requirement. So, higher CHW temperatures can be used to enhance the chiller efficiency for chilled water plants dedicated to data centers. Why isn't this best practice widely adopted? One reason is that data center designers and operators have some concerns over higher CHW temperatures including:

- How much energy can I actually save by increasing my CHW temperature?
- Will raising CHW temperature increase the cooling system capital cost?
- How high can I increase my CHW temperature?
- Will raising CHW temperature impact the reliability of my chillers?
- Will raising CHW temperature impact the reliability, capacity, and energy consumption of my CRAH units?
- Will raising CHW temperatures impact the IT inlet temperature, so as to increase the energy consumption of my IT devices?

This paper studies the impact of higher CHW temperature and provides answers to the questions above. This paper also discusses other approaches to improve the CHW cooling system efficiency. We use a packaged air-cooled chiller with economizer mode to illustrate how higher CHW temperature can improve cooling system efficiency, reduce the energy cost, and impact capital cost. Finally, we discuss design considerations for these new technologies.

How to improve chilled water system efficiency

This paper is written with the assumption that the reader has knowledge of how CHW systems and economizer modes work. See sidebar for an overview of heat rejection with CHW systems. For more information, see White Papers 59, The Different Technologies for Cooling Data Centers and White Paper 132, Economizer Modes of Data Center Cooling Systems. Energy savings for CHW cooling systems can be achieved through many approaches. This paper reviews the following energy saving strategies and discusses the first four in detail:

- Use higher CHW temperatures
- Redesign CRAH coil to compensate for higher CHW temperatures
- Increase CHW deltaT
- Use adiabatic cooling to further improve heat rejection efficiency
- Improve device efficiency
- Improve control methodology
- Improve hydraulic architecture

Architecture analyzed

In order to quantify the energy saving comparisons with different optimized ap-proaches, for this analysis, we chose what we believe to be a very common cooling architecture deployed in data centers today – a packaged air-cooled chiller

[3] Chilled water temperature here means the chilled water setpoint of the chillers. It is also called chilled water supply temperature or leaving chilled water temperature of the chillers.

Heat rejection with CHW systems

The components of the refrigeration cycle are located in a device called a water chiller. The function of the chiller is to produce chilled water which is pumped in pipes from the chiller to the CRAH units located in the IT space.

CRAH units cool the hot air (remove heat) by drawing warm air from the IT space through chilled water coils filled with circulating chilled water. Then, heat removed from the IT space flows out with the (now warmer) chilled water exiting the CRAH units and returning to the chiller. The chiller then removes the heat from the returning chilled water and transfers it to another stream of circulating fluid which flows through a device known as a cooling tower, a dry cooler or a condenser.

In full economizer mode, the chiller is bypassed by the cooling tower or dry cooler to reject the heat.

with economizer mode (Figure 1). The dry cooler, integrated with the chiller and utilized during full and partial economizer modes, is a heat exchanger that directly cools or precools the data center CHW when the outside air conditions are within specified setpoints. Two pumps combined with specific piping designs are used to move the CHW through the indoor CRAH, dry cooler and chiller to let the cooling system operate under mechanical, partial or full economizer modes respectively to save energy.

The following sub-sections will analyze how higher CHW temperatures, or combination of technologies can improve cooling system efficiency and energy consumption. Note that we keep the chiller model same and assume it could work with all CHW temperatures in this paper because we want to keep everything constant and just change one variable at a time to achieve apples to apples comparisons.

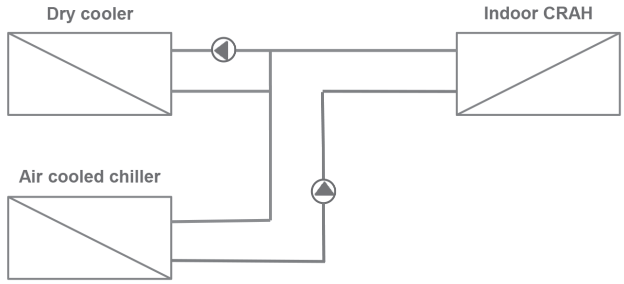

Figure 1 Packaged air-cooled chiller architecture analyzed

Use higher CHW temperatures

Higher CHW temperatures can improve the chiller efficiency and also prevent unnecessary and wasteful dehumidification. This is because higher CHW temperatures mean lower lift (difference between the evaporator refrigerant and condenser refrigerant pressure). In other words, the compressors don't need to work so hard to reject heat energy. Meanwhile, the chillers can also operate in economizer mode for a larger portion of the year. However, the chillers must be capable of operating at higher water temperatures (see sidebar).

Increasing CHW temperatures requires that we look at the entire cooling system holistically as the system dynamics are complex. Table 1 shows the impact of increasing CHW temperature in Frankfurt, Germany (see Appendix for more assumptions). In the analysis for Table 1, we kept everything constant, including IT inlet air temperature fixed at 23°C (73.4°F), while increasing the CHW temperatures, which means the energy consumption of IT devices remains constant.

Operating tempera-tures of chillers

Every chiller has a maximum chilled water temperature it is capable of supplying. This is limited by the type and design of the chiller. Depending on the chiller type, the chiller components may require special features which allow for higher chilled water supply temperatures. We recommend you consult with your chiller vendor before increasing your chilled water setpoints.

The CRAH unit here is designed to work with a range of CHW temperatures which can provide roughly the same cooling capacity with the same power consumption when the CHW temperature is below about 13°C (55°F). When the CHW temperature is increased above 13°C (55°F), the smaller delta T between the two fluids (airflow and chilled water) reduces the cooling capacity of the CRAH unit. When the CHW temperature is increased to about 20°C (68°F) or above, we can't achieve the same IT inlet air temperature with this CRAH unit and the CRAH coil must be redesigned to compensate for higher CHW temperatures. The next sub-section will discuss this behavior in detail. From Table 1, as the CHW temperature increases, we can conclude the following:

- The chiller energy decreases due to improved chiller efficiency and increased economizer hours. However, as the chilled water increases to 15°C (59°F) or above, more CRAH units must be added to provide enough cooling capacity and also to achieve the same IT inlet supply temperature. As more CRAH units are added, the CRAH fan speed is reduced to further reduce energy consumption. However, the CRAH capital cost increases.
- The chiller capacity increases with warmer CHW temperatures. Although we kept the same chiller size (for an apples to apples comparison), it's possible to reduce the chiller size at higher CWH temperatures, thereby reducing the cooling system capital cost.
- The total cooling system energy decreases. These savings depend on many factors like data center location, cooling system configuration, etc.

Table 1 Impact of chilled water temperature on cooling system (Frankfurt, Germany)

Chilled Water Temp.	Chiller Max. Cap. (kW)	Full / Partial Economizer Hours	Total Chiller Energy (kWh)	CRAH Unit Capacity & Quantity	Total CRAH Energy (kWh)	Total Cooling Energy (kWh)	Total Energy Savings
7°C (45°F)	903	246 / 3,650	2,349,926	200 kW (5)	353,028	3,051,602	**Baseline**
10°C (50°F)	1,002	1,451 / 3,706	2,001,754	200 kW (5)	353,028	2,703,430	**11%**
13°C (55°F)	1,109	2,324 / 3,530	1,676,653	200 kW (5)	353,028	2,378,329	**22%**
15°C (59°F)	1,184	3,236 / 3,377	1,468,820	166 kW (6)	325,872	2,143,340	**30%**
17°C (63°F)	1,261	3,896 / 3,393	1,279,330	125 kW (8)	226,358	1,854,337	**39%**

Redesign CRAH coil to compensate for higher CHW temperatures

In this section, the CRAH coil is essentially "tuned" for a particular CHW system. For our analysis, the IT inlet air temperature is kept constant, which has the effect of decreasing the CRAH coil capacity as the CHW temperature increases. In the previous subsection, we increased the number of CRAH units to compensate for this. However, the best approach is to redesign the CRAH coils to compensate for the higher CHW temperatures, although these CRAH coils will typically cost more. To illustrate the impact of the CRAH coil on the total cooling energy, we started with the analysis from Table 1, except that we replaced the original CRAH coil with the optimal CRAH coil for the two highest CHW temperatures. These results are shown in Table 2. Note that the CRAH coils for Table 1 are already designed and optimized for CHW temperatures below 13°C (55°F), therefore, the total CRAH energy for these chilled water temperatures are the same in Tables 1 and 2.

With optimal CRAH coils, as the CHW temperature increases from 17°C (63°F) to 20°C (68°F), the CRAH energy is further reduced to achieve more energy savings. However, even with the optimized coil at 21°C (70°F) CHW temperature, the CRAH fan energy increases slightly. Despite this increase, the total cooling energy is the lowest because the energy savings from the chillers offset the CRAH energy increase. We could have added more CRAH units to achieve lower CRAH energy, but this increases CRAH capital cost. This tradeoff should be evaluated to determine the optimal CRAH quantity.

Increase CHW delta T

The power consumption of chilled water pumps and the CRAH unit fans, is directly proportional to the cube of the motor speed (specifically the shaft speed). The motor speed is proportional to the water (or air) mass flow rate, which means the power consumption is proportional to the cube of the mass flow rate. From the formula, cooling capacity (Q) in units of kW:

Q = Mass Flow Rate × DeltaT × Specific Heat of Fluid

Table 2 Impact of CRAH coil on cooling system (Frankfurt, Germany)

Chilled Water Temp.	Chiller Max. Cap. (kW)	Full / Partial Economizer Hours	Total Chiller Energy (kWh)	CRAH Unit Capacity & Quantity	Total CRAH Energy (kWh)	Total Cooling Energy (kWh)	Total Energy Savings
7°C (45°F)	903	246 / 3,650	2,349,926	200 kW (5)	353,028	3,051,602	**Baseline**
10°C (50°F)	1,002	1,451 / 3,706	2,001,754	200 kW (5)	353,028	2,703,430	**11%**
13°C (55°F)	1,109	2,324 / 3,530	1,676,653	200 kW (5)	353,028	2,378,329	**22%**
15°C (59°F)	1,184	3,236 / 3,377	1,468,820	166 kW (6)	325,872	2,143,340	**30%**
17°C (63°F)	1,261	3,896 / 3,393	1,279,330	125 kW (8)	226,358	1,854,337	**39%**
20°C (68°F)	1,350	5,157 / 3,009	1,044,646	125 kW (8)	203,232	1,596,526	**48%**
21°C (70°F)	1,428	5,854 / 2,312	950,191	125 kW (8)	222,854	1,521,693	**50%**

We see that the mass flow rate and delta T are inversely related (specific heat of fluid is a constant for a specific fluid at a given temperature). For a given amount of heat energy (Q) rejected, if we increase delta T, the mass flow rate is reduced which reduces the energy consumption of the pump and the CRAH unit fans.

Figure 2 shows the reduction in pump or fan energy (measured in % of rated power consumption) as the mass flow rate is reduced (or delta T is increased). For example, reducing the mass flow rate from 100% to 80% in pump or fan speed results in an energy saving of 49%.

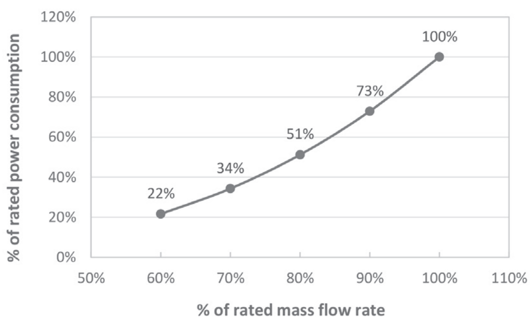

Figure 2 Performance curve of pumps or fans (power vs. mass flow rate)

To illustrate the impact of CHW delta T on cooling system energy, we start with the analysis from Table 2, except that we vary the CHW delta T. We choose the 20°C (68°F) CHW setpoint scenario, and change the CHW delta T from 5°C (9°F) to 7°C (13°F) and to 10°C (18°F) to assess the delta T impact on cooling system energy. Note that the return chilled water temperature from the IT space equals the setpoint plus the delta T. These results are shown in Table 3.

From these results we can conclude the following:

- As the CHW delta T increases, a significant amount of the pump energy is saved due to lower pump speed.
- The chiller energy decreases further due to improved chiller efficiency (de-pendent on the chiller type and system design) and increased economizer hours. Although the smaller chilled water mass flow rate reduces the effectiveness of the chillers, the increased chilled water return temperatures compensate for this reduction. Meanwhile, the increased chilled water return temperatures leads to more economizer hours.
- The CRAH energy increases because the heat transfer effectiveness of the CRAH coil is reduced due to the lower chilled water flow rate. In order to provide the same cooling capacity, the CRAH fans need to spin up which means more fan energy. However, in this case, in order to achieve constant IT inlet temperature,

Table 3 Impact of chilled water deltaT on chiller efficiency and pump energy (Frankfurt, Germany)

Chilled Water DeltaT	Chiller Max. Cap. (kW)	Full / Partial Economizer Hours	Total Chiller Energy (kWh)	CRAH Unit Capacity & Quantity	Total CRAH Energy (kWh)	Total Pump Energy (kWh)	Total Cooling Energy (kWh)	Total Energy Savings
5°C (9°F)	1,350	5,157 / 3,009	1,044,646	125 kW (8)	203,232	348,648	1,596,526	**Baseline**
7°C (13°F)	1,365	5,157 / 3,267	973,625	125 kW (8)	250,186	127,020	1,350,830	**15%**
10°C (18°F)	1,400	5,157 / 3,522	872,756	111 kW (9)	228,636	75,336	1,176,728	**26%**

the proper design practice is to increase the number of CRAH units and lower the airflow per CRAH as shown in 10°C (18°F) delta T scenario.

- Compared to the baseline case, the total cooling energy is further reduced, although the increased CRAH energy offsets some portion of the chiller and pump energy savings.

Use adiabatic cooling to further improve heat rejection efficiency

Adiabatic cooling is a temperature reduction approach, also known as evaporative cooling or evaporative adiabatic cooling (see sidebar). This approach is typically used in warm dry climates and where there are also sufficient water resources to improve the heat rejection efficiency. Water is misted into the air stream entering condenser's airflow via a high-pressure spray system. The water evaporates into the airstream, which reduces the dry bulb temperature and raises its humidity. Lowering air temperature to the condenser reduces the chiller energy consumption and increases economizer hours. The larger the temperature difference between the ambient dry bulb and wet bulb temperature, the larger the energy benefit.

Principle of adiabatic cooling
Adiabatic cooling is a natural physical process where air passing through water droplets, evaporates the water causing a reduction in air temperature. Water requires heat to evaporate. The air provides this heat which causes a reduction in air temperature. This is known as the heat of vaporization and is the same phenomenon we experience when we sweat and feel cooler when a breeze passes over our skin. Note that the energy within the air does not change and this is known as a constant enthalpy line.

For the cooling architecture discussed above, there are two approaches to adiabatic cooling (shown in Figure 3): Dry cooler with evaporative pads; dry cooler with high pressure spray system. Both approaches have advantages and disadvantages. For example, the pad system doesn't need water treatment but represents a permanent resistance to airflow through the dry cooler, while the high-pressure spray system doesn't add resistance but requires water treatment. Both approaches also have other benefits like removing particulate from the airstream. Its major drawback is water usage, but it consumes much less water for the same amount of cooling than a standard cooling tower.

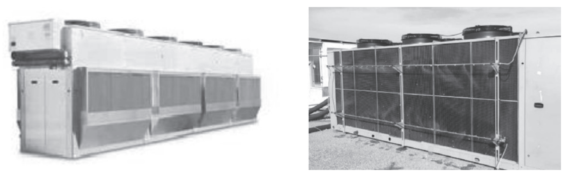

Figure 3 Examples of adiabatic cooling application
Left: dry cooler + wet pad
Right: dry cooler + high pressure spray nozzle

To illustrate the impact of adiabatic cooling on the cooling system, we started with the analysis for Table 3, except that we add the impact of adiabatic cooling and fix the deltaT to 10°C (18°F). These results are shown in Table 4.

From these results, we can conclude the following:

- The chiller energy can be reduced further due to lower lift and more economizer hours.
- The total cooling energy is reduced further due to lower chiller energy. Note that the water usage will increase the operation cost, which is discussed in detail in next section.

Table 4 Impact of adiabatic cooling on chiller efficiency (Frankfurt, Germany)

Cooling System	Chiller Max. Cap. (kW)	Full / Partial Economizer Hours	Total Chiller Energy (kWh)	CRAH Unit Capacity & Quantity	Total CRAH Energy (kWh)	Total Pump Energy (kWh)	Total Cooling Energy (kWh)	Total Energy Savings
Without Adiabatic	1,400	5,157 / 3,522	872,756	111 kW (9)	228,636	75,336	1,176,728	**Baseline**
With Adiabatic	1,460	3,896 / 4,528	803,015	111 kW (9)	228,636	75,336	1,106,987	**6%**

Improve device efficiency

Another way of reducing cooling energy consumption is to choose cooling devices with higher efficiency. Improving device efficiency is an ongoing effort for cooling device manufactures. For example, adding variable frequency drive (VFD) to an existing chiller model, or designing a new chiller model with VFD, or designing a CRAH with variable speed fans. VFD matches the chiller motor speed to the cooling load which reduces the chiller power consumption, especially as the load on the compressor varies. For information on the characteristics of different types of compressors, see White Paper 254, The Different Types of Cooling Compressors. VFD can also be added to CHW pumps and CRAH unit fans to optimize the performance as the load varies (discussed in "Increase CHW deltaT" section).

Improve control methodology

Cooling devices are normally controlled manually in a standalone and decentralized mode based on their return air temperature and humidity, or chilled water setpoints. For example, cooling devices like CRAHs/CRACs are adjusted manually by data center operators who change the setpoints, or turn the devices on based on their knowledge or intuition. These control practices lead to poor cooling system performance. The best practice is to adopt effective cooling control systems to reduce the energy consumption of the entire cooling system. For more information on this topic, see White Paper 225, *Optimize Data Center Cooling with Effective Control Systems.*

Improve hydraulic architecture

By "hydraulic architecture" we mean the architecture of the CHW pumping system. The original intent of innovations in hydraulic architecture is to reduce the energy consumption of the pumps as the load varies. Since the pumps in the data center environment need to work all through the year, a variable speed pumping system is preferred in order to reduce the operation cost.

Design principle of the chillers

Chillers are normally optimized to operate with a specific chilled water deltaT (the temperature difference between supply and return chilled water). Chillers normally have a minimum allowable chilled water flow rate requirement, which depends on the chiller type, to ensure the reliability of the chillers.

For partial load conditions, the water flow rate of the chillers must be reduced to achieve the specific water deltaT while keeping the flow rate above the minimum allowable range.

An efficient pumping system allows chillers to operate at or close to its design deltaT over all expected load conditions while never allowing the flow rate to drop below the minimum to ensure chiller reliability (see sidebar). There are two typical hydraulic architectures in data centers – primary variable speed pumping system and primary-secondary variable speed pumping system. A "primary-only pumping system" means that there is only one piping loop where the pumps change speed to reduce water flow rate under partial load conditions. Doing this can save pump energy although the chiller efficiency is slightly reduced. A "primary-secondary pumping system" means that there are two piping loops. The water flow rate in the primary loop is constant to ensure the reliability and efficiency of the chiller. The secondary loop changes water flow rate to save pump energy while ensuring the cooling requirement during partial load conditions. Both approaches can save pump energy through changing the speed or the quantity of running pumps. The selection between these two pumping systems are beyond the scope of this paper and is not discussed.

Analysis of data centers with higher chilled water temperature

The impact of raising CHW temperatures on total cost of ownership (TCO) can vary significantly depending on the cooling architecture and the climate. In this section, we modeled the packaged air-cooled chiller architecture described in this paper in two data center locations – Frankfurt, Germany and Miami, U.S. Figure 4 shows the variation in BIN data for these two locations to show how the distribution of temperature varies significantly. The number of hours at different temperature bins drives how many economizer hours you can gain when you raise the chilled water temperature. Meanwhile, it also drives how much water usage for adiabatic cooling. Based on the Köppen climate classification, we know that Frankfurt has a temperate oceanic climate and Miami has a tropical monsoon climate[4]. A data center with four cooling system variations are modeled – traditional with / without adiabatic cooling and optimized with / without adiabatic cooling (see Appendix for more assumptions).

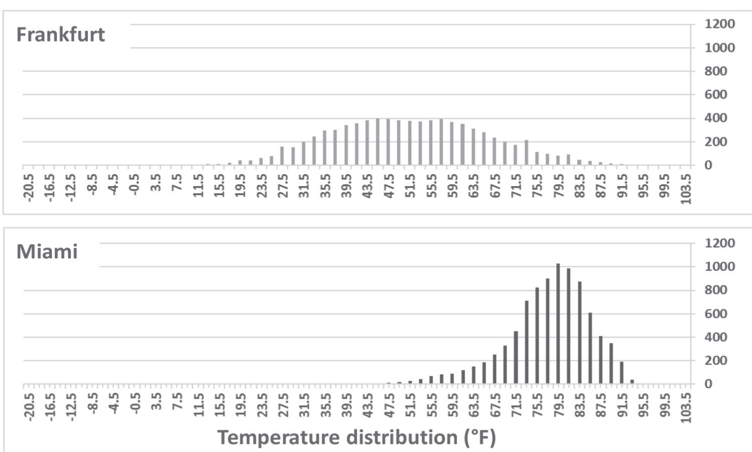

Figure 4 Variation in BIN data for two locations: Frankfurt and Miami (Vertical axis represents number of hours)

[4] https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification "Tropical monsoon climates have monthly mean temperatures above 18°C in every month of the year and feature wet and dry seasons." "Temperate oceanic climates have the "coldest month averaging above 0°C (32°F), all months with average temperatures below 22°C (71.6°F), and at least four months averaging above 10°C (50°F). No significant precipitation difference between seasons".

Findings

Tables 5 and 6 summarize the energy consumption of a data center with the four cooling systems in two locations (Frankfurt and Miami respectively). From these results, we can conclude the following:

- Compared with the traditional CHW system, the optimized CHW system reduces energy consumption in Frankfurt by about 50% using the first four energy saving strategies discussed in the "How to improve chilled water system efficiency" section (about 25% energy reduction in Miami).
- Adiabatic cooling improves these energy savings but to a lesser extent than the other energy-saving strategies. Adiabatic cooling resulted in more energy savings in Miami due to the warmer climate.
- Bin weather data is a significant driver in determining how much energy savings can be achieved.

Table 5 Cooling system energy comparison between traditional and optimized cooling system at 100% IT LOAD (**Frankfurt**)

Cooling system	Chiller Max. Cap. (kW)	Full / Partial Economizer Hours	Total Chiller Energy (kWh)	CRAH Unit Capacity & Quantity	Total Pump Energy (kWh)	Total CRAH Energy (kWh)	Total Cooling Energy (kWh)	Total Energy Savings
Traditional **without** adiabatic	903	246 / 3,650	2,349,926	200 kW (5)	348,648	353,028	3,051,602	**Baseline**
Optimized **without** adiabatic	1,400	5,157 / 3,522	872,756	111 kW (9)	75,336	228,636	1,176,728	**61%**
Traditional **with** adiabatic	969	246 / 4,323	2,308,634	200 kW (5)	348,648	353,028	3,010,310	**Baseline**
Optimized **with** adiabatic	1,460	3,896 / 4,528	803,015	111 kW (9)	75,336	228,636	1,106,987	**63%**

Table 6 Cooling system energy comparison between traditional and optimized cooling system at 100% IT LOAD (Miami)

Cooling system	Chiller Max. Cap. (kW)	Full / Partial Economizer Hours	Total Chiller Energy (kWh)	CRAH Unit Capacity & Quantity	Total Pump Energy (kWh)	Total CRAH Energy (kWh)	Total Cooling Energy (kWh)	Total Energy Savings
Traditional **without** adiabatic	909	0 / 53	3,645,814	200 kW (5)	348,648	353,028	4,347,490	**Baseline**
Optimized **without** adiabatic	1,410	126 / 7,166	2,584,876	111 kW (9)	56,414	228,636	2,869,926	**34%**
Traditional **with** adiabatic	963	0 / 53	3,479,614	200 kW (5)	348,648	353,028	4,181,290	**Baseline**
Optimized **with** adiabatic	1,470	288 / 7,004	2,277,616	111 kW (9)	56,414	228,636	2,562,666	**39%**

Tables 7 through 8 summarize the TCO of a data center with the different cooling system configurations in Frankfurt and Miami. Compared with the traditional chilled water system, the optimized system reduces cooling energy consumption by 64% in Frankfurt and 41% in Miami, with an increased cooling system capital cost of 13% for both. The 3-year TCO is reduced by 17% in Frankfurt and 12% in Miami. Note that the systems with adiabatic cooling require water, even in locations without sufficient water resource. The 13% capex premium shown in Tables 7 and 8 is attributed only to the special CRAH coil and adiabatic feature. However, in reality, you would use a lower cost chiller with 7°C water in a traditional design, which would mean that you would pay more than the 13% premium for the optimized chiller plant. **Therefore, the total cost premium for the chiller plant when considering a traditional chiller would be on the order of 15-20%.**

Table 7 Improvements for Frankfurt comparing traditional and optimized cooling systems

	Traditional without adiabatic	Optimized with adiabatic	Improvements over traditional
Total energy (kWh)	3,051,602	1,106,987	**64%**
pPUE (cooling only)	1.35	1.13	**16%**
Water usage (m^3/year)	0	1,454	-
Capex	$1,120,268	$1,265,507	**13% increase**
3-year TCO	$1,810,812	$1,519,297	**16%**

Table 8 Improvements for Miami comparing traditional and optimized cooling systems

	Traditional without adiabatic	Optimized with adiabatic	Improvements over traditional
Total energy (kWh)	4,347,490	2,562,666	**41%**
pPUE (cooling only)	1.50	1.29	**14%**
Water usage (m^3/year)	0	4,318	-
Capex	$1,120,268	$1,126,507	**13% increase**
3-year TCO	$2,104,057	$1,855,182	**12%**

Conclusion

Data center operators can achieve significant energy savings by increasing the CHW temperatures, CHW deltaT, and using adiabatic cooling for outdoor heat rejection. These combined strategies can reduce energy consumption by 41% - 64%, which depends on the data center locations and cooling system configurations, while increasing the total cooling system capital cost by 15-20%.

However, keep the following in mind before adopting the strategies discussed in this paper:

- Ensure your chillers are capable of operating at higher CHW temperatures without impacting their reliability.
- Ensure the cooling capacity of indoor CRAH coils can provide your desired IT supply setpoint at higher at higher CHW temperatures.
- Ensure that a source of low-cost water is available before using adiabatic cooling.

About the authors

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John Bean Jr. is the Director of innovation for Racks and Cooling Solutions at Schneider Electric. Previously John was World-Wide Engineering Manager for Cooling Solutions at Schneider Electric, developing several new product platforms and establishing engineering and laboratory facilities in both the USA and Denmark. Before joining APC, John was Engineering Manager for other companies involved in the development and manufacture of mission-critical cooling solutions.

Resources

The Unexpected Impact of Raising Data Center Temperatures
White Paper 221

The Different Technologies for Cooling Data Centers
White Paper 59

Economizer Modes of Data Center Cooling Systems
White Paper 132

The Different Types of Cooling Compressors
White Paper 254

Optimize Data Center Cooling with Effective Control Systems
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Cooling Economizer Mode PUE Calculator
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Appendix

Assumptions for Table 1

- 1MW data center loaded to 100% to model worst case scenario
- IT inlet air temperature is fixed at 23°C (73.4°F).
- Chilled water deltaT (difference between the supply and return chilled water temperatures) is kept constant 5°C (9°F) as CHW temperature increases.
- Same CRAH unit coil (designed for CHW temperature from 7°C to 13°C) was used as CHW temperature increases.
- Chiller model is kept same in order to support all CHW temperatures thereby isolating the effect of CHW temperature.
- CRAH redundancy: N+1
- Chillers are in an N+1 configuration, sized for 20-year extreme temperature.
- Hot aisle containment is used.
- 20% glycol for the chilled water
- Chillers are without adiabatic cooling.
- Redundant CRAH units and chillers are standby.
- The energy consumption of the chilled water pump is fixed.
- Bin data from ASHRAE Weather Data Viewer 5.0 (2013) was used to calculate the chiller energy.
- Assume variable speed drive (VSD) pumps with constant performance are used which means same energy consumption of the pumps.

Assumptions for Table 7 to Table 8

- 1MW data center loaded to 100% to model worst case scenario
- IT inlet air temperature is fixed at 23°C (73.4°F).
- CRAH redundancy: N+1
- Chillers are in an N+1 configuration, sized for 20-year extreme temperature.
- Hot aisle containment is used.
- 20% glycol for the chilled water (only for Frankfurt and no need for Miami)
- Redundant CRAH units and chillers are in standby.
- Bin data from ASHRAE Weather Data Viewer 5.0 (2013) was used to calculate the chiller energy.
- The power train losses are not included in PUE.
- 3% cost of capital used for TCO calculations
- $0.08 per kilowatt hour cost of electricity and $0.8 per cubic meters ($3 per 1,000 gallons) cost of water
- The capital expense values were estimated using component, labor, and design prices typically seen in a 1MW data center project. Most of this data came from the Data Center Capital Cost Calculator.
- For cooling systems without adiabatic cooling, the optimized chillers cost the same with the traditional chillers although their performance is enhanced.
- The capex savings of hydraulic system (i.e. piping, valves, etc.) are not con-sidered for larger CHW deltaT in these analysis.

Table A1 shows the detailed variable assumptions for the traditional and optimized cooling systems.

Cooling variable	Traditional	Optimized
IT inlet air temperature	23°C (73.4°F)	23°C (73.4°F)
CHW temperature	7°C (45°F)	20°C (68°F)
CRAH coil water temperature range	7°C (45°F) - 13°C (55°F)	20°C (68°F) or above
CHW deltaT	5°C (9°F)	10°C (18°F)
Chilled water pumps	Constant speed	Pumps with VSD
CRAH fans	Fans with VSD	Fans with VSD