Cooling Data Centers with Cooling Towers

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ABSTRACT

Thousands of data centers and server farms have been installed in the last 10 years. Continued growth is certain. Each data center requires a reliable cooling system to prevent the computers from overheating. From an energy use perspective, evaporative heat rejection using cooling towers seems well-suited for data center cooling, yet design engineers often specify dry condensers instead, even for large cooling plants.

The paper presents an example application from California's Silicon Valley, where a customer upgraded from an air-cooled to a water-cooled HVAC system for their new data center. The customer's electricity usage budget for data-center cooling dropped by half. They realized a 50 percent internal rate of return and a $9 million present value. There were barriers to implementing the upgrade, however, few of which were technical or economic.

This paper examines the barriers and describes how they were overcome. The lessons learned lead to unconventional energy-efficiency program policy recommendations regarding maintenance of objectivity in program administration and regarding standardized incentives. Specifically, the authors recommend encourage allowing advocacy when operating utility programs, rather then just objective arbitration, and recommend reconsidering prescriptive incentives for large high efficiency air-cooled packaged air conditioners. The recommendations apply to data center cooling in particular but also to the topic of large industrial upgrades generally.

Background

An energy study was performed at an office building leased by a computer hardware design firm in California's Silicon Valley. The building was less than 6 years old and opportunities discovered were unremarkable. In the course of the study, the tenant noted that they recently had secured a new long-term lease to an adjacent building and were converting it to a large data center. Build-out and design engineering were underway. The heat load was forecast to be continuous, large, and intense—ultimately reaching 1,440 tons and over 160 W/sq. ft. Plans called for the immediate installation of two 500-ton air-cooled chillers and two more 500-ton chillers over the next 4 years as the data center load increased. Once at design capacity, annual energy costs were expected to reach $1.2 million per year, or $40 per square foot.

Savings Potential

Preliminary analysis indicated that installing a high-efficiency (0.50 kW/ton) water-cooled centrifugal chiller with a cooling tower and VFDs controlling the tower fans and compressors instead of the two-stage air-cooled screw chiller systems would reduce electric costs by half. Table 1 shows the basic system efficiency calculations and figure 1 illustrates the full- and part-load savings potential graphically.

Table 1. Chiller System Efficiency Calculations, Per Ton Basis

Annual Energy Cost Savings Per Ton

Trane RTAC 500-ton Air-Cooled Chiller

	Load: 50%	75%	100%	
	0.720	0.875	1.158	kW/ton multiple 2-stage screw chillers
	0.088	0.088	0.088	kW/ton condenser fans
+	0.008	0.006	0.004	kW/ton external controls
	0.816	0.968	1.250	kW/ton to remove heat from evaporator
	= 14.7 EER	= 12.4 EER	= 9.6 EER	
x	8,760	8,760	8,760	hr/yr
	7,148	8,481	10,949	kWh/ton/yr
x	$0.076	$0.076	$0.076	/kWh
	$543	$645	$832	/ton/yr

Trane CVHF 500-ton Water-Cooled Chiller

	Load: 50%	75%	100%	
	0.340	0.420	0.501	kW/ton VSD chiller
+	0.008	0.006	0.004	kW/ton controls
+	0.063	0.042	0.031	kW/ton CS condenser water pump
+	0.020	0.013	0.010	kW/ton CS tower water filter pump, vent fan
+	0.011	0.025	0.045	kW/ton VSD tower fan & sump pump
=	0.442	0.506	0.592	kW/ton to remove heat from evaporator
	= 27.1 EER	= 23.7 EER	= 20.3 EER	
x	8,760	8,760	8,760	hr/yr
=	3,875	4,433	5,182	kWh/ton/yr
x	$0.076	$0.076	$0.076	/kWh
=	$295	$337	$394	/ton/yr

$249	*$308*	*$438*	*/ton Annual water-cooled energy savings if*
46%	*48%*	*53%*	*all hrs at noted load*

Notes

(1) Economizers are not required in data centers per Title 24 Exception 4 to Section 144.e.1. Incorporation of water side economizer operation to the central plant would increase savings and, if a larger tower is purchased, cost. If air-side economizers were added for in the air-cooled option, savings would be reduced.

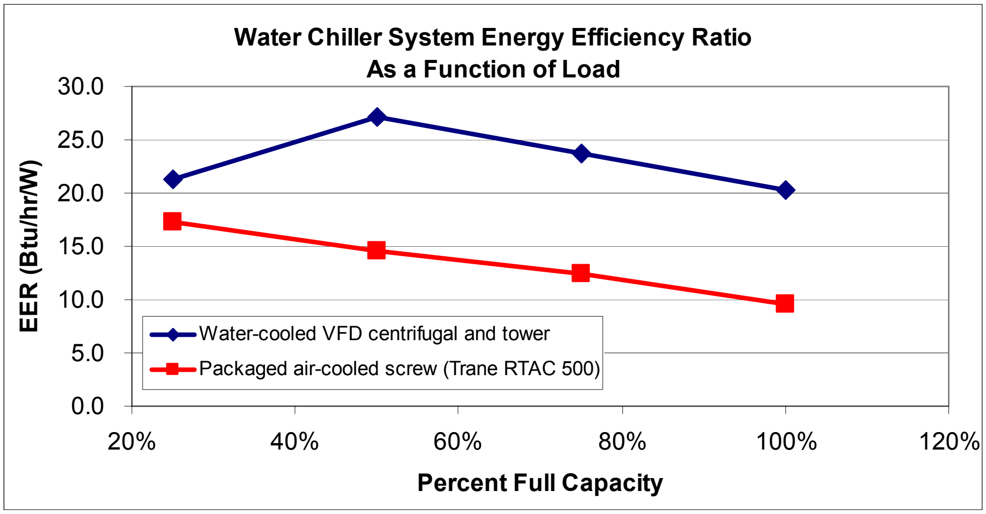
(2) SVP CB-1 at 90% load factor, including taxes and 12 kV discount.

(3) The water-cooled system would have water treatment maintenance costs that the air-cooled system would not.

(4) The air-cooled packaged system would have 8x as many compressors, condensers, fans, and motors to maintain.

(5) No credit or penalty has been taken for differing equipment life.

Figure 1. Chiller System Efficiency Curves



Tower water evaporation added $61/yr./ton to the water-cooled option operating costs. The data center designers forecast a first year load of 360 tons with gradual increases until reaching a total load of 1,440 tons. Four 500-ton chillers would allow 100 percent redundancy. Table 2 shows the projected load increase, savings potential, and assumed chiller configuration.

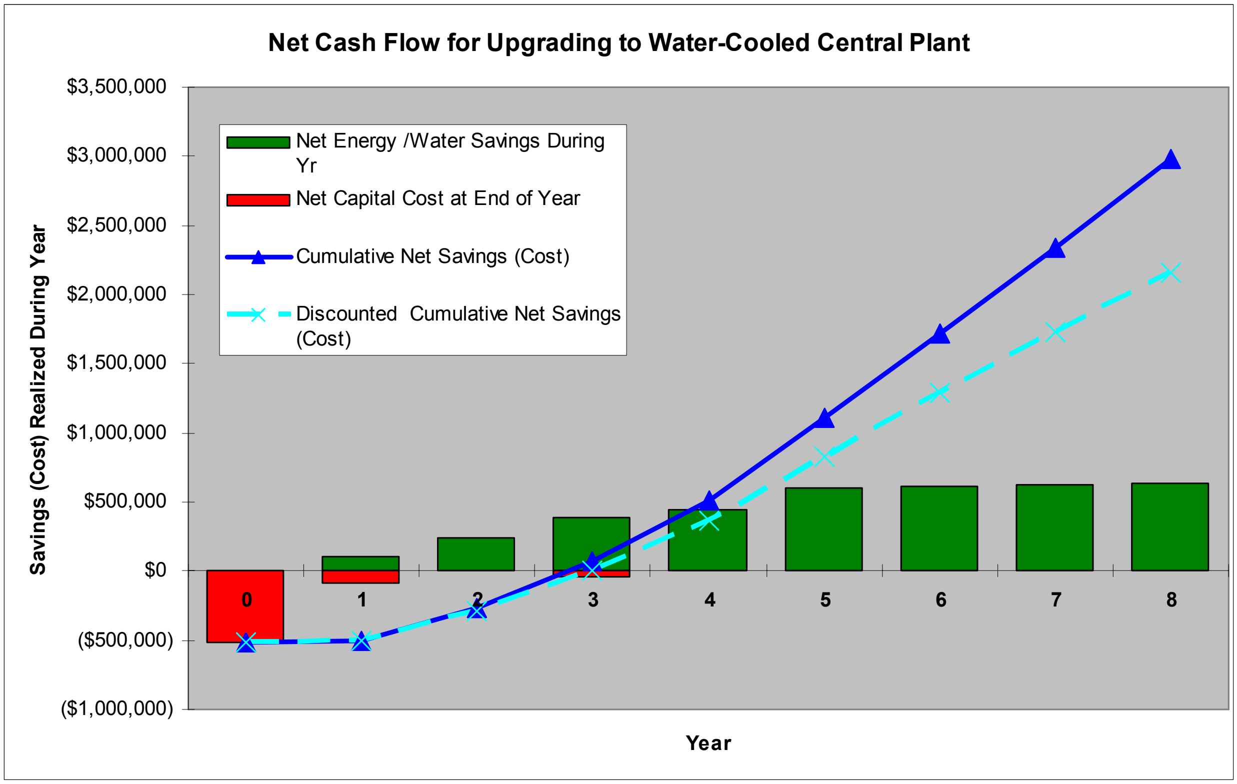
Table 2. Total Annual Load and Savings

Year	Load Range (Tons)	Avg. Load (Tons)	Annual Savings	Load Configuration	Backup Capacity
1	240—480	360	$127,000	50%, 75%, 100% of one chiller	0%-50% of one chiller plus an additional chiller
2	480—960	720	$270,000	100% of one chiller, 50% of another	0%-100% of one chiller plus an additional chiller
3	960	960	$421,000	100% of two chillers	one chiller
4	960—1440	1200	$480,000	100% of two chillers, 50% of another	0%-100% of one chiller plus an additional chiller
5 +	1440	1440	$631,000	100% of three chillers	one chiller

The price premium was considerable, over $500/ton after deducting the avoided costs of the air-cooled plant not purchased. The price included a new $200,000 building shell to house the plant. Even so, the financial benefits were impressive.

Figure 2 shows the forecast cash flows and valuation for the customer. Similar charts based on financing instead of capital funding were also provided that demonstrated immediate positive cash flow. In summary, the project offered a 48 percent rate of return, a $9 million present value over 20 years, and a simple payback time of between 1.6 and 2.8 years for what would eventually grow to 950 kW and 8.3 million kWh/yr. of savings.

Figure 2. Investment and Return



By most standards the upgrade to a water-cooled plant made financial sense. The customer's design engineering firm agreed the proposal was technically feasible and economically sound, but it almost wasn't executed and it certainly hadn't been planned initially. The next section addresses the barriers to implementing this project.

Barriers to Implementation

The common energy efficiency project barriers of payback time, capital availability, and lack of time were minor obstacles for this project but not major impediments. Technical competence was not a barrier at all. In fact, the major reasons this customer did not originally plan to build a water-cooled system may surprise some readers. They were as follows:

- Parking lot space
- Earthquake threat
- Long lead times
- Savings awareness

Parking lot space. The data center roof could have supported the planned air-cooled boxcar units but would have required cost-prohibitive modifications to bear the alternative chillers, tower, and auxiliary equipment load. This meant that a new central plant would need to be placed in the parking lot, which would eliminate about a dozen parking spots. The site met the city of Santa Clara's minimum municipal standard for parking lot spaces per square foot of commercial office space with the existing surface, but did not have spaces to spare. The prospect of eliminating parking spaces constituted a barrier to the project.

Earthquake threat. The customer is an international firm with offices in Asia and customers around the world that depend on the data center 24 hours a day, 7 days a week. They wanted to be able to continue data center operation through a major seismic event. To that end the facility was installing large capacity uninterruptible power supplies, battery backup, backup generators, and feeds from two different branches of the utility distribution system. Furthermore, since the local utility, Silicon Valley Power, had proved resilient during the 1989 Loma Prieta earthquake, site selectors considered the facility to be well protected from electric utility loss. Telecommunications wiring was equally redundant, and the facility was not designed to be dependent on gas or water. Thus, as long as the building could structurally withstand an earthquake, operations would not be affected during an event. Adding a cooling tower with its need for water to function at most times appeared to immediately add a point of vulnerability. This was a barrier.

Long lead times. In the recent past the engineering design firm had experienced long lead times for centrifugal chillers, particularly the high efficiency versions. The project could not bear the risk of long chiller lead times.

Savings awareness. While the customer understood generally that packaged air-cooled systems were less efficient, until they were presented with the savings analysis, they did not realize the magnitude of future cash flow that was at stake.

Other barriers for similar projects. The design firm cited lead time, first cost, and long-term business uncertainty as the three most prominent reasons that air-cooled data-center cooling is found throughout California. The fact that tenants often lease rather than own their buildings is also a likely contributing factor.

Overcoming the Barriers

In a conventional utility audit program the consulting service ends with the audit report. In an incentive processing or performance contracting program the utility service starts upon receipt of a developed project application and focuses on reviewing claimed savings. This opportunity required active involvement from conceptualization through to the beginning of implementation. In particular it required involvement of the nature that makes some energy efficiency program managers and evaluators uneasy—advocacy.

Fortunately for the customer, Silicon Valley Power has a flexible contract with their program service provider that allows provision of facilitation services and other roles that a contractor with a limited scope cannot offer.

Before attacking the barriers the program lead engineer and facilitator met with the customer's design engineer at his office to discuss the reasonableness of the savings analysis and the practicality of the proposed new approach. He responded favorably and encouraged the customer to pursue the matter, with cautions regarding the schedule and certain increased re-design costs. This endorsement was critical to project success.

Next, with the blessing of the customer, the facilitation leader met with the city of Santa Clara's buildings and codes department to inquire about a possible variance on the parking ruling. Officials were most cooperative. The rationale for asking for a variance was both practical (the data center would not have anywhere near the occupant density as an office, and the building was unlikely to revert from a data center to an office in the near future) and altruistic. The city had made a major push to support sustainability practices across the full range of provided municipal services. The request for a variance that would save so much energy—and was made with the support of the municipal electric utility—fell on receptive ears and ultimately was approved.

Regarding water supply, the engineers identified three different potential backup water sources: a well, a connection to an alternate water main, and a temporary line running from the adjacent building (which was on the other distribution main) in the event primary makeup water was lost. We believe that the demonstrated and implicit support of the power utility facilitated the decision-making process for all parties.

Finally, the engineers talked with Trane and discovered that due to the then-current economic slowdown lead times had dropped considerably – to 10 weeks – which made lead time a non-issue.

Armed with these solutions and the powerful economic message, the customer facilities manager and the utility-sponsored engineer met with the chief financial officer to present the business case for a major capital increase in the build-out cost. The change was approved virtually immediately. The entire process lasted less than 6 weeks.

The design firm immediately overhauled the chilled water plant design documents and informed the project architect of the need for a new building to be built in the parking lot. The resulting plant is shown in figure 3.

Figure 3. New Central Cooling Plant

Program Design Ramifications and Recommendations

Energy efficiency program models driving utility and government offerings have evolved over the last 25 years but tend to have at least one common theme: commitment to objectivity without advocacy or direct project facilitation. While admirably defensible and undoubtedly of great comfort to program evaluators and legal departments, such focus may not be the best way to garner the savings from the biggest industrial projects—the fattest fruit on the tree. Projects that cost and save millions of dollars tend to have unique obstacles that involve people, policy, and persuasion. They need an advocate. Sometimes that advocate is neither the customer nor a vendor. Silicon Valley Power allowed the energy efficiency program administrator to act as an owner's advocate, not just an adjudicator. In fact utility company employees became directly involved with the other municipal agencies. This upgrade never would have happened otherwise.

The authors believe that program designers should consider allowing utility representatives to act as advocates for certain large unique industrial energy efficiency projects, if not other projects as well. This role may be more plausible in a municipal environment than in an investor-owned utility program.

Program funding structure was a second program design characteristic that affected this project. Many utility companies contract for energy efficiency services on an almost entirely unit price basis. This protects the buyer from excessive costs and gives more certainty to the program's final benefit-cost ratio. This project illustrates the benefits of funding a material portion of program operations on a time-and-materials-not-to-exceed basis. The effort needed to get the project approved was unique and needed immediate execution. If the program had been funded entirely on a unit price basis there would have been no incentive or mechanism for the contractor to provide the needed services and the opportunity would have been lost.

Finally, the dramatic savings potential of a water-cooled system over an air-cooled system (50 percent) illustrated in this project contrasts with the modest incremental improvement of a high efficiency air-cooled system over a baseline air-cooled system (10 to 15 percent in this size range). It raises the question of whether incentives should be paid for high efficiency packaged air-cooled systems in the size range where water systems are available (nominally 300 tons and up).

Summary

A new 2,000-ton data center chiller system was upgraded from air-cooled to water-cooled chillers. The internal rate of return on the upgrade cost was 48 percent.

This was a significant project in terms of magnitude of savings realized. For a municipal utility company with average customer benefits program savings of 14 to 37 million kWh/yr., this project alone will save 8 million kWh/yr.

The project happened because the municipal utility company permitted their program providers to perform non-standard program tasks and advocate for the project's success to other allies and municipal agencies whose cooperation was needed for implementation.

Acknowledgments

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