Managing Energy Costs for Chillers

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Water-cooled electric chilled-water systems typically account for 15 percent of a building's annual energy consumption. In addition, they are complex—with several interdependent subsystems—so there's a lot that can go wrong if equipment isn't properly operated and maintained. This means there are many opportunities to achieve energy savings and to improve occupant comfort through better operations and maintenance practices.

Getting Started with the Basics

Although chilled-water systems are complex, there are some steps you can take to reduce energy use that are fairly straightforward or require minimal analysis.

Prevent fouling of the cooling towers and heat exchanger tubes with automated water-treatment systems. As a chiller operates, water may leave behind scale, algae, or slime on the inside of the condenser tubes and in the cooling towers. These deposits can decrease efficiency and capacity of the chiller by reducing heat-transfer effectiveness. For example, a condenser fouled to the point that the condensing temperature increases 5° Fahrenheit results in a 5 percent decrease in capacity and a 5 percent increase in power requirements. To counter fouling, water is typically treated by manually adding biocides to inhibit biological growth, corrosion inhibitors to maintain equipment surfaces, and other chemicals to maintain proper pH levels.

Though this traditional approach of manually treating the water can be effective, automated water-treatment systems offer several advantages over it. Automated systems continually monitor the level of chemicals in the water and automatically add more of any chemical whose concentration drops below predefined levels. They can also determine when to use "blowdown" (deliberate water overflow) to purge built-up pollutants. Automated systems eliminate the need to manually test the water, which incurs both labor and material costs and is typically not performed often enough. It also ensures that chemicals aren't over-applied, which would increase not only the cost of chemicals used, but disposal costs of the excess chemicals as well when water is purged from the system. Both of these features improve the effectiveness of water treatment and thus the performance of the chiller system. According to one industry expert, the reduced labor and excess use of chemicals as well as the improved system performance can generate a 25 to 30 percent monetary savings compared to manually treating the water. Automated systems also create a safer work environment for building operators by eliminating the potential exposure risks when chemicals are manually applied.

Condenser tube fouling can also be reduced by using automatic cleaning equipment. This equipment consists of thumb-sized nylon brushes that are inserted into each condenser tube, and catch baskets epoxied to the ends of the tubes to collect the brushes. The brushes, which are slightly larger than the inside diameter of the tubes, are propelled by the water flow to clean the length of the tubes.

Sequence chillers on and off to maintain efficiency loading. Operators often run too many chillers for a given load. Because every chiller has a range of loading conditions wherein it operates most efficiently, to maximize system efficiency, turn chillers off to keep the remaining operating ones in their most efficient zone—typically, above the 30 to 50 percent loading mark. As cooling loads increase, bring additional chillers on-line when the others are leaving their most efficient loading zone. If one chiller is significantly smaller than the rest (often referred to as the "swing" chiller), it can be brought on- and off-line first to keep the larger chillers more fully loaded.

To inexpensively estimate savings from different sequencing strategies, use these four steps to manually experiment with the system:

- *Observe operation of inlet vanes or slide valves.* Inlet vanes modulate centrifugal chiller capacity, and slide valves modulate screw chiller capacity. Many new chillers can display cooling capacity based on the position of these devices. If this capability is available, start logging chiller capacity using the energy-management system or a stand-alone data logger. If not, find out from the manufacturer what modulating device positions are associated with 50 percent and 90 percent loading, and then log chiller capacity manually. Take note of whether chillers regularly operate below 50 percent load.
- *Sequence chillers based on capacity.* When the inlet vanes or slide valves indicate that all operating chillers are at about 90 percent load, turn on another chiller. When the operating chillers drop below 50 percent load, turn off one of the chillers. If the chillers are equally efficient but not equally sized, turn on the smallest chiller first. When it's time to shut down a chiller, turn off the smallest operating chiller first.
- *Block flow through turned-off chillers.* Close manual or automatic valves on chillers that aren't operating. Alternatively, turn off the pumps for individually pumped chillers.
- *Estimate savings.* Using information from the manufacturer, estimate the chiller load, efficiency, and power associated with each capacity level. Then estimate what the loading, efficiency, and power would have been under the original strategy. The difference between the two power estimates represents your savings.

Run as many cooling towers as possible to save on fan power. In a way, cooling towers are the opposite of chillers—while it's good to run as *few* chillers as possible, it's also good to run as *many* cooling towers as possible. Most chilled-water plants have excess capacity, and during low-load hours, one or more cooling towers aren't operating. To make the most of existing cooling towers, simply run condenser water over as many towers as possible, at the lowest possible fan speed, and as often as possible.

Energy savings can be significant. For example, with one cooling tower we looked at, when its fan runs at half speed, the tower rejects 55 percent of its rated heat capacity but only draws 25 percent of its rated fan power. As a result, if two such cooling towers run at half speed (instead of one at full speed), together they would reject slightly more heat than single-tower operation while drawing only *half* the power.

This strategy is feasible only for chilled-water systems that include multiple chillers and towers plumbed in parallel. In such systems, open all the condenser-water isolation valves at the cooling towers—and leave them open. To avoid additional pumping power costs, run only enough condenser-water pumps to maintain adequate flow through the chillers. This strategy does have one drawback: It causes additional fan cycling (between half speed and off and between half speed and full speed), leading to additional wear and tear on motors and gears. However, this problem can be avoided by adding variable-speed drives to the fans.

More Complex Operational Changes and Retrofit Opportunities

Many other, more advanced opportunities exist to capture substantial energy savings with chiller systems. To maximize savings and to avoid inadvertently increasing system energy use (modifying one set of components often affects others), evaluate these opportunities using an integrated system approach. This typically involves considering energy and demand prices, building load characteristics, local climate, building design, operating schedules, and the part-load operating characteristics of the available chillers, pumps, and fans. To account for all of these variables, use a building energy performance simulation package and a professional trained in its use. Several of these opportunities involve optimizing chilled- and condenser-water temperatures and flow rates.

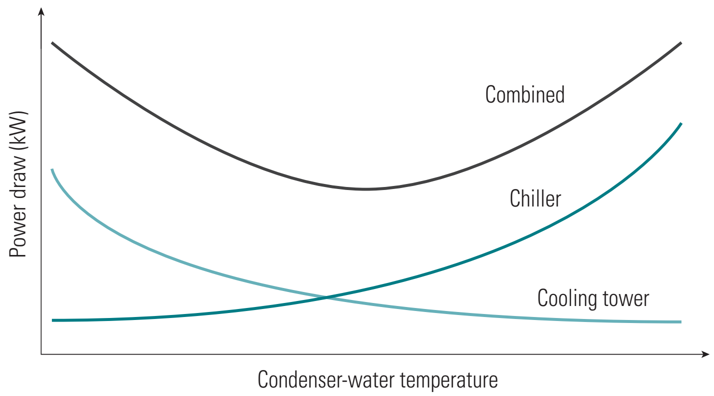
Reset the chilled-water temperature based on feedback from chiller loads and outdoor conditions. Where sufficient feedback is available on actual chiller loads, using this data along with that of the outdoor conditions allows one to reset the chilled-water temperature. Resetting to a higher or lower temperature depending on whether loads are decreasing or increasing can save energy by only working the chiller as hard as needed. If load feedback isn't available, the outdoor air temperature alone can be used to match chiller output to the actual load. Note that this strategy is often disabled by chiller plant operators trying to rectify unrelated plant problems. To help prevent this, show plant operators how to apply and maintain this strategy and explain why it's valuable.

Reset the condenser-water temperature based on outdoor conditions. Producing colder condenser-water temperatures reduces the power drawn by the chiller. Keep in mind that this strategy increases the power needed for the cooling tower fan. The optimum operating temperature occurs at the point where these two opposing trends combine to produce the lowest total power draw (**Figure 1**). However, this point changes with outdoor conditions, so the setpoint needs to be adjusted continuously using automated controls to maintain efficiency.

Reduce chilled- and condenser-water flow rates to below standard conditions. Lower either the chilled- or the condenser-water flow rates, or both, below the rates specified for standard conditions as defined by the Air-Conditioning, Heating, and Refrigeration Institute. This strategy effectively works the chiller harder while saving pump and fan energy. The energy savings from this approach can be substantial. **Table 1 (page 4)** displays data for an example chiller plant, showing an estimated annual energy savings of $17,000 to $37,800, depending on building location.

FIGURE 1: Finding the optimum condenser-water temperature

Chiller efficiency increases and cooling tower efficiency decreases as condenser-water temperature is lowered. The optimum operating point is found in the trough of the combined-power curve. This point will change with operating conditions, so this analysis must be conducted for a wide range of operating conditions to determine the reset parameters.



Note: kW = kilowatts.

TABLE 1: Low-flow design raises chiller power but reduces system power

This is an estimate of savings that could be reaped in four cities by varying the condenser- and chilled-water flow rates. The chiller plant uses two 800-ton chillers, pumps that are 82 percent efficient, and motors that are 93 percent efficient.

	Chilled-water flow rate (gpm)[a]	Condenser-water flow rate (gpm/ton)	Chiller power (kW)	Total power (kW)	Estimated annual energy use (MWh): Chicago, Illinois	Lake Charles, Louisiana	Miami, Florida	San Francisco, California
Option 1	1,920	3	436	563	1,177	1,897	2,288	1,057
Option 2	1,067	2	476	541	1,007	1,618	1,910	837
Percent change between options 1 and 2	–44	–33	9	–4	–14	–15	–17	–21
Savings difference between options 1 and 2 (MWh)					**170**	**279**	**378**	**220**
Annual savings ($)					**17,000**	**27,900**	**37,800**	**22,000**

Notes: Savings based on $0.10 per KWh electricity rate; F = Fahrenheit; MWh = megawatt-hours; kW = kilowatts; gpm = gallons per minute

a. Option 1 corresponds to a temperature difference of 10˚F between the entering and leaving chilled water. Option 2 corresponds to an 18˚F difference.

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