Enlisting the Pareto Principle

80/20 rule can help optimize chilled water operations

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Simple modifications to chilled water plants and their control algorithms can slash energy use and enhance performance.

Companies committed to carbon reduction would do well to take a hard look at their high-energy-consuming chilled water plants, where optimization strategies can be put into place without much risk of hurting operations.

According to the U.S. Energy Information Administration, buildings account for 40% of total energy consumption. The commercial sector used approximately 153 billion kWh for cooling in 2021, or about 12% of all commercial sector electricity consumption. These figures point to chiller systems for the bulk of utility plant consumption. Process Cooling magazine reported in 2020 that industrial chillers used approximately 20% of the total electrical power generated in North America, with up to 30% of it lost to inefficiency.

Being fully cognizant of one's chilled water system and its operations is the first step toward reducing its energy consumption. Ambient conditions, operational sequencing, demand matching and quality of maintenance can all affect chiller plant efficiency.

INTRODUCING THE PARETO PRINCIPLE

Many facility managers engage outside engineering firms and control contractors to develop optimization strategies in concert with their internal teams. Others outsource it to third-party vendors who provide stand-alone control platforms that integrate with existing systems. Costs and complexities of options can create barriers for many managers and operators: Initial expenses may be too high for a plant manager to justify when competing against other projects for capital; or, the system or strategy, once installed, may be too complicated, cumbersome and costly to manage or maintain, often negating any savings from reduced energy consumption.

ACCUMULATED ENERGY AND CAPITAL COST SAVINGS THAT, OVER DECADES, EXCEED ORIGINAL EXPECTATIONS.

However, the Pareto Principle – which holds that 80% of results can be achieved at 20% of the input; in this case, the cost – can often apply beneficially to central plant optimization. Simple modifications to chilled water plants and their control algorithms can slash energy use and enhance performance while maintaining continuity of operations and minimizing up-front and maintenance costs. Whether via an overarching sustainability strategy led by the C-suite or initiated by an energy-conscious facility management team, optimization need not take a one-size-fits-all approach. As the Pareto Principle implies, straightforward techniques often provide the best bang for the buck.

PLANT MODERNIZATION

Simple physical changes can modernize a central utility plant and offer financial and energy-efficiency benefits. To contain costs, chilled water plant upgrades can be planned and phased in through a utility master plan and executed over time. Some examples:

- **Upgrade equipment.** Chiller fouling can degrade performance by 5% or more in extreme cases. Like-for-like equipment replacements can recover this loss and provide improved overall efficiency. New onboard controls allow chillers to unload faster and more reliably than older models and can handle colder condenser water temperatures. Consider installing new chillers, pumps or towers to reap efficiency gains.
- **Incorporate VFDs.** Variable frequency drives (VFDs) adjust a motor's speed to closely match output requirements. Variable-speed chiller compressors allow a chiller to unload effectively while saving energy. Variable-speed pumps provide flow only in quantities needed to meet requirements. Variable-speed tower fans enable analog control of the leaving condenser water temperature.
- **Convert the hydraulic/pumping strategy.** Converting from primary-secondary, constant flow to a variable primary system will be most efficient at providing chilled water to large

To constrain costs, upgrades like those shown here can be incorporated over time through a strategic utility master plan that ensures changes align with facility growth (or contraction) plans.

buildings or campuses. Adding integrated booster pumps can increase flow to large users or hydraulically remote buildings. Although a detailed explanation of how to do this in an existing plant is beyond the scope of this article, it often can be accomplished with surprisingly minimal modifications.

- **Remediate low system temperature differential (low delta-T).** Delta-T is the difference between return and supply chilled water temperatures. Chillers are designed with certain delta-T and chilled water flow rate values. If the temperature differential between the supply and return water lines is lower than designed, the condition is called Low Delta-T Syndrome. When this occurs, chillers and pumps cannot be fully loaded, causing additional equipment to be energized to accommodate demand. The tremendous energy efficiency losses make remediation the highest priority. A common technical problem in many chilled water systems, low delta-T can be addressed by fixing poorly performing controlling valves and by removing system bypasses Each of these strategies will help ensure chilled water delta-T stays at or close to design year-round.
- **Take an integrated utilities approach.** The motive force for a chiller compressor may be steam or electric. Although steam typically offers less efficiency as an energy source, it may be freely generated as a waste product in a facility that incorporates on-site cogeneration. By integrating steam-driven machines powered by waste steam, a facility may optimize the system and reduce carbon. An integrated approach to optimizing all utilities simultaneously often can lead to more comprehensive savings.
- **Design for flexibility.** Heat recovery chillers can now produce hot water up to 170 F, making them viable options to integrate with most existing building hot water systems. An all-electric plant may also incorporate on-site renewables.

CONTROL SEQUENCE CHANGES

Most chiller control sequences are designed to do the minimum amount of work to meet load requirements. By reviewing and adjusting control sequences, facility managers may find an opportunity for better performance. In fact, many energy codes have begun

Third-party optimization case study comparison

	A	B	C
Site	Connecticut pharmaceutical Site	New Jersey pharmaceutical Site	New Jersey pharmaceutical Site
Size	6,925-ton chiller plant	1,700-ton chiller plant	1,700-ton chiller plant
Scope	Third-party optimization	Third-party optimization	Physical/sequence changes using existing control system including pump staging, CHW pump pressure reset, and CHW temperature setback
Service footprint	1 million square feet of air-conditioned space; requires cooling year-round	980,000 square feet of air-conditioned space (majority office, minimal lab/production space); requires cooling year-round	980,000 square feet of air-conditioned space (majority office, minimal lab/production space); requires cooling year-round
Peak plant load	4,687 tons	1,000 tons	1,000 tons
Annual load	9.6 million ton-hours	955,000 ton-hours	955,000 ton-hours
Energy usage savings	1.9 million kWh/year	478,000 kWh/year	369,000 kWh/year
Utility rate	$0.1514 per kWh	$0.0734 per kWh (blended rate: solar/utility grid)	$0.0734 per kWh (blended rate: solar/utility grid)
Energy cost savings	$287,246	$35,082	$27,101
Implementation cost	$1.07 million	$425,385	$26,675*
Simple payback	3.5 years	12.2 years	0.9 years (no VFDs) 2.5 years (new CHW pump VFDs)

**VFDs (variable frequency drives) were existing on pumps, on/off and limited to 60 Hz operation. With purchase of new pump VFDS, implementation cost increased to $68,620*

Precis Engineering

to incorporate optimization control sequences for new chilled water plants. Some proven methods:

- **Optimized staging.** Managers can source optimization staging based on cogeneration or utility drivers and by turning on the most efficient equipment to meet the load. Constant-speed equipment will not unload as efficiently as equipment on variable-speed drives. It is advisable to operate the less efficient equipment so that it is fully loaded and to make up the remainder of the load requirement with equipment that part-loads most efficiently. For example: If the load is 150%, rather than running two devices at 75% each, run the less efficient equipment at 100% and make up the remaining 50% with the more efficient part-loading equipment.
- **Resetting temperature and pressure.** Resetting chilled water temperatures to meet the highest allowable discharge temperatures in the air handling units to still meet loads is advisable. We also suggest pumping differential pressure controls to lower system pressures when peak flow/cooling are not required and resetting tower water temperature based on an ambient wet bulb offset. This will ensure the towers provide water at achievable temperatures and fans don't run to reach a temperature not achievable by the physics of the evaporative cooling process.
- **Producing chilled water when demand is low.** We suggest managing utility demand charges by producing chilled water when electric demand is lowest and generating the chilled water into a thermal storage tank that can act as a battery. Water can be discharged during peak cooling hours and to offset additional chiller installations.

OEM OPTIMIZATION PACKAGES

Provided by many major chiller manufacturers and third-party controls companies, original equipment manufacturer (OEM) optimization packages integrate with existing and new equipment. The third-party controls packages include combinations of all the above optimization strategies while adding predictive algorithms to maximize efficiency for equipment staging. These look at real-time usage data and performance curves of each piece of equipment to run individual devices at their maximum efficiency at the most efficient times.

OEM optimization may seem like an easy solution; however, the packages' level of complexity may make it cost-prohibitive, depending on initial expense or the increased facility management time to operate/maintain the new controls. A variety of case studies demonstrate third-party optimization statistics for comparison.

In the first two examples (columns A and B in the table on Page 51), the OEM optimization package included converting the chiller plant to an all-variable speed system and updating the control strategy. In the third example (column C), the package included physical and sequence changes using the existing control system including pump staging, chilled water pump pressure reset, and chilled water temperature setback.

CHOOSING THE RIGHT APPROACH

OEM optimization is best suited for plants operating multiple chillers, pumps and cooling towers with varying load conditions. For smaller plants operating less than 3 million ton-hours per year, third-party optimization systems are not typically recommended. Instead, similar energy savings can be achieved by implementing the strategies laid out above for much less cost than OEM. The cost barrier to employ a third-party package is often too high relative to the achievable savings, so consider a variety of factors to select the specific optimization strategies that may be best:

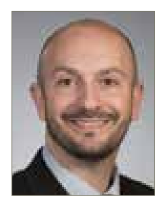
- **Size matters.** Plant size in annual ton-hours and energy costs will dictate the cost-effectiveness of making third-party control modifications. According to a General Services Administration (GSA) study published in 2016, optimization via third-party control modifications provides the best return on investment at greater than 3 million ton-hours at or above $0.11 kWh cost or greater than 4 million ton-hours if electric cost is less than $0.11 kWh. Although the GSA test site experienced a payback of seven years, the study indicated an average five-year payback. According to the report, "The technology is not as likely to be cost-effective for screw chiller plants or facilities with a cooling season of less than six months."
- **Mission-critical means limitations.** Mission-critical and process-driven facilities present limitations to optimizing control sequences and other strategies. Often, process loads do not allow for chilled water temperature reset; a constant design supply temperature is always required. Process loads on the condenser water system may not permit the implementation of free cooling, so it is ideal to segregate process loads to a process cooling loop.
- **Operations add complexity.** Balancing the number of chillers, pumps and cooling towers against the site and building load requires control algorithms to be built specifically for all equipment. Chillers would utilize kW/ton performance data based on load and condenser water temperature. The addition of new equipment – free cooling, thermal storage, VFDs, flow meters or instrumentation – will require new system functions to optimize the chiller plant. Also consider chiller energy source redundancy (steam turbine vs. electric) and whether the chilled water plant is capable of staging steam and electric chillers based on real-time utility costs.
- **Maintenance.** Optimizing the chiller plant will help reduce operating hours, resulting in less wear on the equipment over time. Performance metrics and trend data may improve the facility management team's ability to provide preventive maintenance. Dynamic trending may enable a quicker response time in identifying issues, causes and remediation that can minimize or eliminate extended downtimes. However, additional control devices required for some optimization strategies will require increased preventive maintenance, such as quarterly or yearly calibrations. Consider how each strategy will impact the facility management team's capabilities and capacity.
- **Growth.** To allow for future growth and scalability of the chilled water plant, it is recommended that pumps, chillers and towers have similar design performance. For example, each pump should have similar flow rates and design head to others in the same lineup. Chillers should have similar nominal tonnage, temperature differential design and chilled water/condenser water pressure drops. Cooling towers should also have similar flow rates and temperature differential. Chilled water generation and its associated equipment will always present a large energy demand. Evaluate central plant automation to improve chilled water efficiency and allow for growth.

BACK TO PARETO

Each of the strategies listed above will provide some operational and energy efficiency, thus cost and carbon savings. Improving chilled water plant efficiency should not be an all-or-nothing approach.

From the equipment installed and the controlling methodologies to the operators and the appetite for cost and change, every facility is unique. A simple review and modeling of the system by a qualified engineer can complete a cost-benefit analysis of each of the options listed above to create the optimal and facility-customized approach.

Armed with this information, organizations can implement strategies in a prioritized fashion, garnering the highest savings with the lowest cost and utilizing the Pareto Principal to avoid diminishing returns over time.



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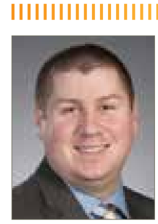

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