TECO: A deep dive into optimization data yields unexpected savings

Layered efficiencies drive down costs while maintaining reliability

By Michael P. Manoucheri and Ben Erpelding

TECO

Thermal Energy Corporation's district energy system serves 51 buildings on the campus of Texas Medical Center.

A three-phrase initiative to explore and implement cost savings across the largest district cooling system in North America has paid off handsomely – and quickly – bringing significant system improvements even in the midst of the COVID-19 pandemic. Efficiency gains have been seen in condenser management, chiller operations and thermal energy storage.

The project's genesis can be traced to IDEA's annual conference in June 2019, when representatives from Thermal Energy Corporation (TECO) and Optimum Energy struck up a conversation about the pitfalls of drawing electricity from the grid in the sweltering heat of a Texas summer.

The TECO team wondered if the company could decrease electrical consumption from its main site before June 2020, the start of the next peak demand season. Customer chilled water demand was growing rapidly enough to soon exceed on-site generation resources.

TECO needed a solution that would maintain reliability, keep costs down and conserve resources. That initial conversation, in 2019, turned into a multiphase, plant-wide optimization journey that now saves TECO $550,000 and 16.1 million kWh of energy annually – even as customer demand for chilled water continues to rise.

TECO, named IDEA's System of the Year in 2019, provides chilled water and steam to Texas Medical Center in Houston, which – as the world's largest medical campus – requires reliable, economical heating and cooling and has growing needs.

Peak chilled water demand has increased by 9,000 tons over the past four years and is expected to grow by an additional 9,000 tons over the next three years. TECO has found that the most cost-effective way to manage district growth while maintaining its historical reliability of 100%, with no unplanned outages since 1992, is to layer on new efficiency measures.

MAINTAINING RELIABILITY, EVEN AS DEMAND RISES, THROUGH INNOVATIVE EFFICIENCY MEASURES.

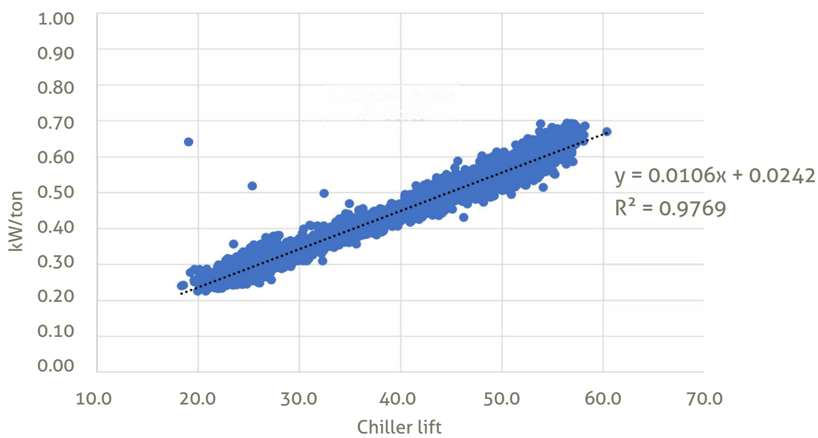
Partnering with Optimum Energy, TECO's engineering team developed a three-phase plan. First, for the condenser water system to conserve more energy and reduce costs; second, to have the chiller staging procedures better handle changing loads; and third, to take advantage of real-time electricity pricing for the thermal energy storage (TES) tank dispatch.

Two years down the road, TECO has improved control over the energy balance of its CHP system and its TES tank, reducing the chiller plant's electrical demand. In the first seven months of optimization – from June to December 2020 – TECO lowered peak demand by 2 MW, saving nearly 10.5 million kWh, and reduced the plant's energy consumption by 6%. Now, TECO can avoid spot-purchasing power from the sometimes unreliable public grid and more easily keep up with customer demand. By reducing peak demand, TECO also bought time to develop a new master plan, including how and when to add power production capacity.

PHASE 1: CONDENSER-SIDE OPTIMIZATION

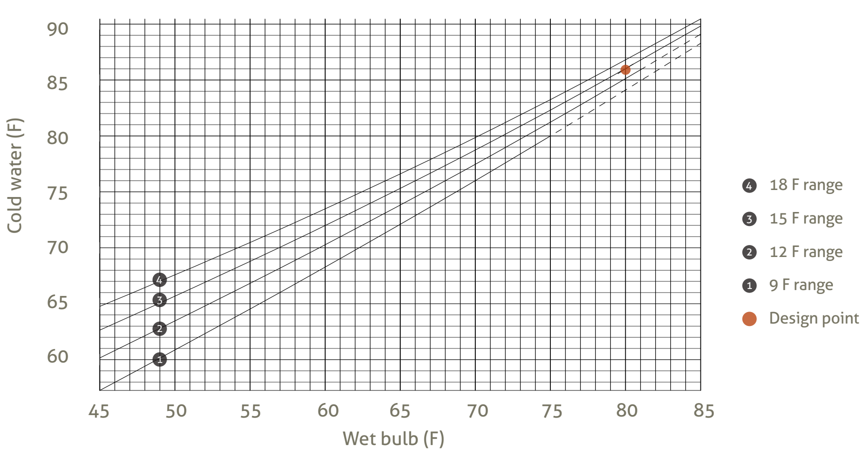
TECO has two interconnected plants housing 27 chillers, nine boilers and one TES tank, managed by a Toshiba distributed control system. System capacity is 120,000 tons, with a peak load of 78,600 tons and 345 million ton-hours per year of annual load. The system's latest chilled water expansion, called the East Chiller Building, consists of four 8,000-ton variable-speed York Titan chillers; four variable-speed, primary-only chilled water pumps (24,000 gallons per minute, or gpm, 1,000 horsepower (hp), 138 feet head; four fixed speed condenser water pumps (16,300 gpm, 600 hp, 112 feet head) and six variable-speed cooling tower fans (16,300 gpm, 101-86 degrees F, 80 F WB, 250 hp).

FIGURE 1. 2019 trends for variable speed chiller #4 efficiency (kW/ton) vs. lift (deg F).



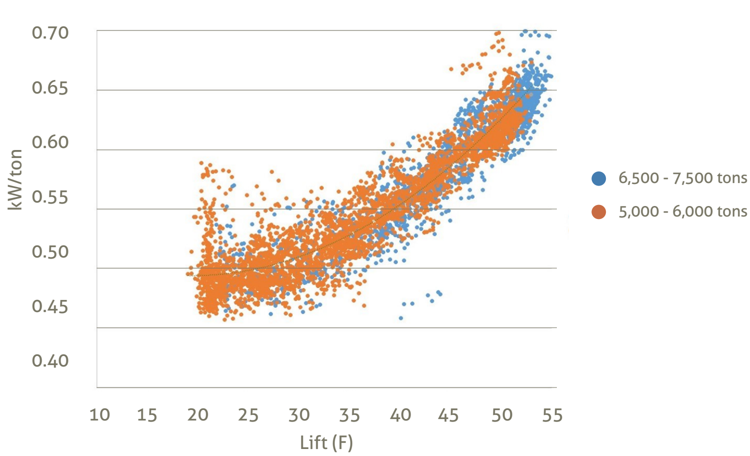
Source: TECO

FIGURE 2. ECHB Cooling Tower Performance; leaving condenser water temperature vs. outdoor wet bulb temperature at different delta Ts.



Source: TECO

FIGURE 3. 2019 trends for constant speed chiller #9 efficiency (kW/ton) vs. lift (deg F) and two different loading bins.



Source: TECO

The East Chiller Building condenser water system was considered a low-risk, high-reward starting point. Improvements focused on reducing chiller lift, which is defined as the leaving condenser water temperature minus the leaving chilled water supply temperature. (High chiller lift reflects hot, humid ambient conditions that are typical in the summer, when demand for low-temperature chilled water is high. Conversely, in winter, lift is lower.) For example, a chiller with a supply temperature of 40 F and a leaving condenser water temperature of 95 F would have a design lift of 55 F.

Figure 1 shows one of the 8,000-ton chiller's trended data for efficiency (kW/ton) versus chiller lift. If TECO's chiller were operating at 6,500 tons, a 2 degree F reduction in lift would save 137.8 kW of energy.

Conditions were ripe for optimization: The four 8,000-ton chillers in the East Chiller Building were designed for a 2 gpm/ton condenser water system. The remaining 23 chillers in the two plants were designed for a 3 gpm/ton system. Automated balancing valves maintained design flow through the condenser bundle on each East Chiller Building running chiller. In general, the cooling tower fans were often operating at 100%.

The Optimum Energy and TECO team developed a consistent, real-time, digital standard operating procedure that included automation, operator prompts and screens, and energy conservation measures. The plan included increasing setpoints so that all condenser water balancing valves were near 100%.

A deliberate commissioning process ensured that condenser water pump motors did not over-amp as they rode down their pump curve, that there was no excessive pump/motor vibration, that header pressures stayed high enough for other auxiliary equipment served by the condenser water system, and that the flow stayed below the maximum allowable for each chiller. The new operating procedure includes running as many cooling towers as possible while staying above minimum flow requirements and implementing power-based relational control of the cooling tower fan variable frequency devices (VFDs).

Because of the interdependencies of the energy conservation measures (ECMs) above, the energy savings are compounded. When the condenser valves are opened to 100%, the 16,300 gpm pumps produce 19,500 gpm with no amp or vibration issues. The extra 3,200 gpm in flow results in a 16% reduction in chiller lift and a smaller condenser water delta T (differential). The smaller delta T improved the cooling tower's performance. Figure 2 shows the cooling tower leaving condenser water temperature versus outdoor wet bulb (WB) temperature at 100% flow and 100% fan speed.

At 70 degrees F WB, for example, the cooling tower approach with a 15-degree F range is 8.7 F, while the approach with a 12 F range is 7.5 F. The cooling tower approach also improves as flow is reduced. Running more towers creates a larger surface area, and at 80% flow, the approach at 70 F WB with a 12-degree F range is 4.5 F. The improvement in lift in this example is 8.7 – 4.5 = 4.2 F. Using the result from Figure 1 yields a 0.0445 kW/ton improvement in efficiency.

Finally, the engineering team improved tower fan speed control. While conventional cooling tower control involves delivering a specific condenser water temperature to the chillers, holistic optimization achieves the best overall total plant efficiency when calculated relationships between fan energy and chiller energy are maintained. The TECO systems employ a patented speed control method for tower fans that is based on chiller power (kW).

This first phase, from programming to commissioning, was completed in March 2020. In just the first year of improved operations, TECO saved 6,656,000 kWh.

PHASE 2: CHILLER-STAGE OPTIMIZATION

As the engineering team moved to the second phase of optimization, it realized that TECO's shift operators were using different ways of staging and running the chillers – adding or shedding chillers by looking at the chiller amps, chiller vanes and district chilled water end-of-line differential pressure (DP). High amps, vanes near 100% or a low DP could trigger the operator to initiate a chiller add; low amps, vanes near 20% or a high DP could trigger the operator to initiate a chiller shed. They maintained end-of-line differential pressure

In just the first year of improved efficiencies, the company saved 6,656,000 kWh. TECO can now avoid spot-purchasing power and more easily keep up with customer demand.

About TECO

Houston-based Thermal Energy Corporation's 48 MW combined heat and power-based district energy system provides chilled water and steam to 51 buildings totaling 24.3 million square feet at Texas Medical Center. The chilled water system consists of 27 chillers and an 8.8 million-gallon thermal energy storage tank. The equipment is controlled by a Toshiba distributed control system.

Cooling capacity is 120,000 tons at 40 F. Annual chilled water production is 345.1 million ton-hours.

Benefits of optimization

- Improved plant efficiency
  - 7% annually
- Energy savings
  - Electrical: 16.1 million kWh/year
  - Demand reduction: 2,112 kW
- Cost savings
  - Annual operations: $550,000
  - Simple payback: 1.9 years
- Lower CO_2 emissions totaling 13,685,000 lbs/year
- Enhanced maintenance prioritization

Texas Medical Center

- 10 million patient encounters annually
- 180,000+ surgeries annually
- 9,200 patient beds
- $2 billion of annual life science research

by increasing or decreasing the chillers' evaporator flow set points.

TECO employed several ECMs to standardize procedures. First, the team began automating the chiller add/shed decision criteria – screen graphics in the Toshiba distributed control system interface now tell the operators the next chiller to stage on or off, and the optimum flow setpoints on chilled water and condenser water. TECO runs the older constant-speed chillers as close to full amps and full vanes as possible. These machines are served by 900 hp constant-speed condenser water pumps and 500 hp and 600 hp constant-speed chilled water pumps. Figure 3 trends the 7,000-ton constant speed York chiller efficiency (kW/ton) versus lift (degrees F) at different loading bins (6,500- to 7,500-ton bins and 5,000- to 6,000-ton bins). Also, TECO now allows the East Chiller Building to modulate chilled water flow to make up the difference and maintain the end-of-line DP at 7 psi. The district chillers are staged by looking at the tons, amps and VFD speed of the East Chiller Building chillers.

A NEW ALGORITHM OFFSETS INCORRECT WEATHER FORECASTS AND KEEPS UP WITH ELECTRICITY RATE CHANGES.

Along with the ECMs, TECO integrated the Optimum Energy Plant Diagnostics tool into its work to help maintain business continuity. TECO engineers have traditionally collected monitoring data; adding data rationalization and diagnostics allows the team to mine those assets and prioritize opportunities to increase reliability and efficiency and to track key performance indicators and monitor each piece of equipment in the plant.

Even with Covid-19 restrictions in place, the second phase was completed by June 2020 – in time to maintain operational reliability and avoid the high demand charges of a Texas summer.

TECO saved 9,491,000 kWh of energy in the first year of chiller stage optimization. After completing the first two phases, electrical demand was reduced by 2,112 kW.

PHASE 3: TES SYSTEM OPTIMIZATION

A deep dive into data collected over the first year of operations revealed a source of additional savings: TECO's 150-foot, 8.8 million-gallon TES tank, the tallest thermal energy storage tank in the world when it was installed. It has a capacity of 76,000 ton-hours, a maximum flow of 16,500 gpm and a maximum output of approximately 8,250 tons (at a 12-degree F chilled water delta T).

The TES tank allows TECO to serve its customers with absolute reliability, even in the case of chiller plant equipment failure, using stored energy when it's less expensive and reducing electrical demand during peak chilled water usage. TECO was surprised to discover that charging the tank every night was much more expensive than expected – and the data showed that significant cost savings could be gained by using real-time pricing information to automatically charge and discharge the tank at optimal times.

TECO had been following the generally accepted practice of charging the tank at night when electricity prices are lower and discharging it during the day. In Texas, real-time pricing can change every five minutes. The operations team was relying on weather forecasts, electricity market price predictions and manual calculations to estimate the most advantageous times for charging and discharging. Those methods couldn't offset incorrect forecasts or keep up with rapid changes – but a clever algorithm could.

Optimum Energy engineers reasoned that the tank could be even more cost effective with an automated algorithm, which would allow the Toshiba distributed control system to automate the TES charge/discharge decision criteria. Optimization would also include graphics screens in the Toshiba human-machine interface that could tell operators when, how and why to use the tank. Called economic dispatch, the solution uses historical data and actual electric market pricing to calculate the true costs of charging the tank at night with power from TECO's local grid and using the stored chilled water during the day.

The algorithm takes into account the kilowatts needed to charge the TES tank and the real-time electrical rate from TECO's utility. It then calculates the comparative cost of discharging the tank and using the stored water during the day. This gives TECO the real price of the stored energy as it comes in every five minutes. Done correctly, it is much like successful stock trading: buy low, sell high.

If the real-time cost of electricity is greater than the trigger cost and the time is within the appropriate window of operation, operators will receive a message to discharge the tank at a specified flow rate.

CONTINUOUS IMPROVEMENT, ALWAYS

As TECO has discovered, the result of chiller plant optimization is not necessarily a one-time gain.

Lasting value often comes from implementing standard operating procedures, maintaining consistent operations across all shifts and accruing multiple continuous savings, such as the daily trimming of TECO's electrical bill through predictive TES dispatch.

Progress may start with a big bang – a revamped chiller plant that immediately drops cooling costs – but continual data-driven efficiencies can save hundreds of thousands of dollars annually as well.

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