Growing campus meets thermal energy needs without new power production

An enduring partnership enables UT Austin to deliver innovation, efficiency and energy savings.

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Courtesy The University of Texas at Austin.

Chilling Station 7 and Thermal Energy Storage Tank 2, The University of Texas at Austin.

In 2007, The University of Texas at Austin (UT) was on the brink of massive change. With the campus expanding and its cooling systems at capacity, UT's energy management team built a new chiller plant – and then took a chance on cutting-edge optimization software, betting that it would help keep costs down and conserve resources. It was the first step in what turned into a 13-year journey to implement increasingly complex and innovative energy efficiency measures across a steadily growing campus.

The initial chiller plant optimization project led to an ongoing engineering partnership between the UT Utilities and Energy Management (UEM) team and Optimum Energy that is reducing costs by $15 million a year and has turned the university into one of the world's most efficient utilities.

By combining efficiency measures with two thermal energy storage (TES) systems, UT is managing load growth, saving money and energy, and supporting the university's sustainability goals. It has managed to reduce the chilled-water system's overall energy usage and avoid investing in new power production capacity – even as the campus has grown by over 30 percent.

The UT and Optimum teams' collaboration and methodical – almost religious – approach to gathering accurate data have allowed them to stretch the boundaries of what's possible with optimization, building on each successful incremental change until, in 2019, UT achieved an average efficiency of 89 percent for all systems.

ONE OF THE LARGEST, MOST INTEGRATED U.S. MICROGRIDS

The flagship institution of the University of Texas system, UT has the nation's seventh-largest single-campus enrollment, with more than 50,000 graduate and undergraduate students plus 24,000 faculty and staff. The campus also operates one of the largest and most fully integrated microgrid and district energy systems in the U.S., providing 100 percent of the university's power, heat and cooling for a diverse stock of 160 buildings totaling 19.8 million sq ft, including academic, research, residential, health care, and events and sports facilities.

The campus is served by a robust network of utilities, including 134 MW of on-site power generation, 63,000 tons of chilled-water capacity, two hot water plants, 9.6 million gal of TES tank capacity, a steam-to-hot water plant, 30 miles of underground high-voltage (12 kV and 4.16 kV) duct banks and 9 miles of underground tunnels that distribute chilled water, steam, compressed air, demineralized water for laboratory use and recovered water throughout the campus.

These systems generate massive amounts of data, which helped lay the foundation for the partnership between the two engineering teams.

THE START OF THE JOURNEY

Improving system efficiency began in 2007 with the elimination of a steam turbine chiller plant and the installation of a new all-electric, all-variable-speed, 15,000-ton, three-chiller plant, Chilling Station 6 (CS6). This project improved annual average campus chilled-water system efficiency from 0.84 kW/ton to 0.79 kW/ton.

During 2009, the UEM and Optimum teams optimized the chilled-water plant at CS6. The optimization algorithms holistically manage staging equipment, setpoints and the speeds of the variable-speed condenser water pumps, cooling tower fans and chilled-water pumps. Optimizing CS6 improved total campus chilled-water efficiency to as low as 0.30 kW/ton in the winter with chillers operating at less than 0.17 kW/ton (fig. 1). The annual campus efficiency improved again, from 0.79 kW/ton to 0.72 kW/ton.

The success of CS6 and the optimization project sparked the UT team's ambition, leading them to ask, "How could we achieve further efficiencies?"

GAINING EFFICIENCY FROM AN ALREADY-EFFICIENT SYSTEM

The next challenge was to address the physical hydraulic constraints affecting flow in the campus's chilled-water distribution loop. Using a real-time hydraulic flow model, the team identified a solution: adding new, strategically located campus-wide instrumentation and a coordinated multiple-plant chilled-water distribution pumping algorithm. Project engineers developed a strategy using CS6 to control system differential pressure throughout the campus while using the other chilling stations to control flow, keeping chillers loaded in their sweet spot.

The hydraulic flow model also revealed that the system was overpressurized. Pumping too much water created false building cooling loads, so the system produced excess steam (for reheat) to compensate. Now the optimization regimes are using real-time campus data to run the system at an 8 psi differential pressure at peak loads and a 2 psi differential pressure in the winter. That cut 1,500 HP of pumping energy, and the campus chilled-water and steam usage dropped.

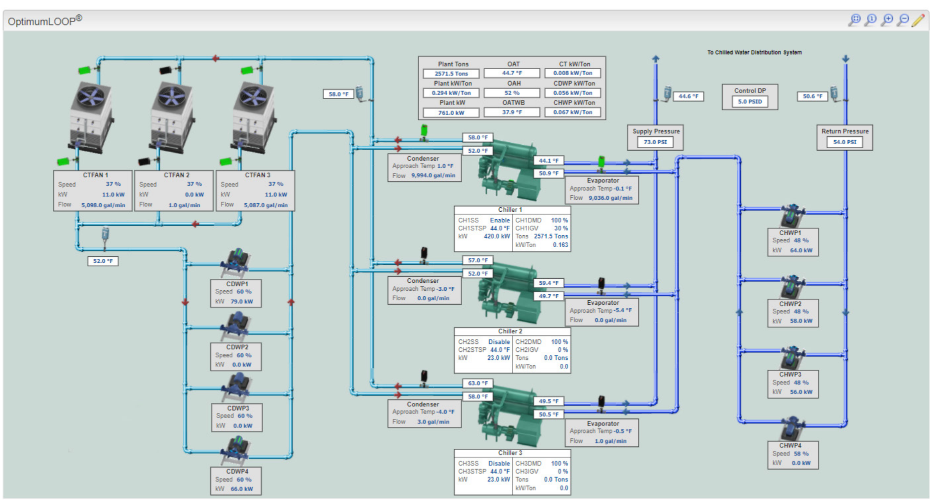
In addition, better visibility into campus loads via monitoring software allowed the UEM team to dynamically raise the chilled-water temperature as high as 44 degrees F based on real-time information and conditions, compared with the previous 39 F year-round. This further improved campus efficiency, from 0.72 kW/ton to 0.63 kW/ton.

GOING THE LAST MILE: PREDICTIVE TES DISPATCH

From 2016 to 2018, UT expanded the campus chilled-water system to accommodate a new medical school and additional new buildings as the campus grew from 18.3 million sq ft to 19.8 million sq ft. The university added a second TES tank (5.33 million gal) and the new six-chiller, 15,000-ton, all-electric, all-variable-speed Chilling Station 7 (CS7). With the full optimization of CS7, the campus achieved annual efficiency of 0.61 kW/ton by 2018 (fig. 2).

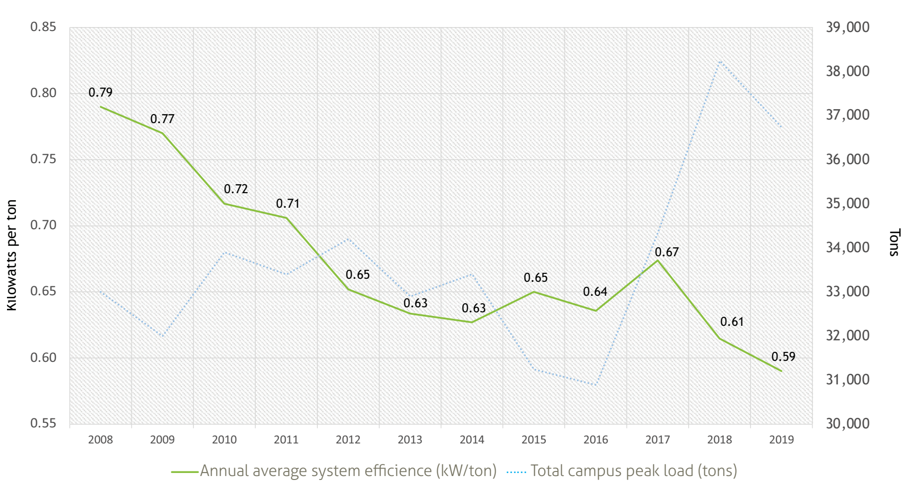
The UEM team faced an additional challenge, however: With the new medical district operating, campus electrical loads were on the rise. The team knew it would be far more economical to increase

FIGURE 1. Screenshot of Chilling Station 6 plant overview, operation and efficiency metrics during winter operation, The University of Texas at Austin.



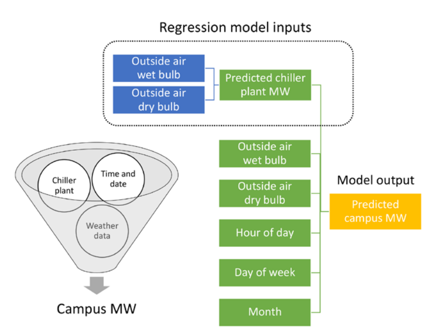
Source: Optimum Energy.

FIGURE 2. History of annual average campus chilled-water system efficiency and peak load, The University of Texas at Austin (2008-2019).



Source: The University of Texas at Austin.

FIGURE 3. Diagram of the multivariable regression analysis applied to historical data to predict campus electrical and chilled-water loads, The University of Texas at Austin.



Source: The University of Texas at Austin.

The University of Texas at Austin Chilled-Water System

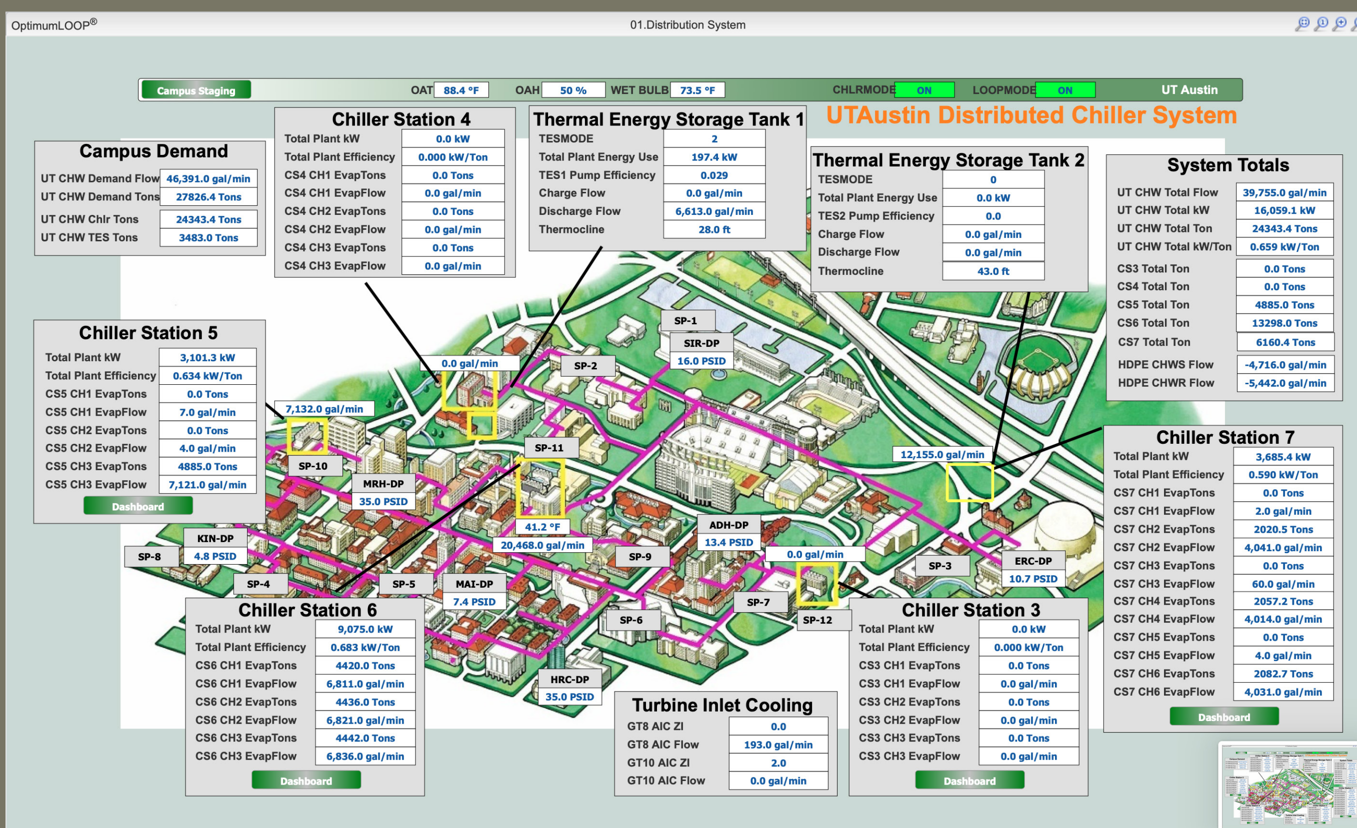
The UT chilled-water system consists of five chilling stations and two thermal energy tanks totaling 63,000 tons of firm chiller capacity:

- Chilling Station 3 – 3 chillers totaling 11,000 tons
- Chilling Station 4 – 3 chillers totaling 9,000 tons
- Chilling Station 5 – 3 chillers totaling 13,000 tons
- Chilling Station 6 – 3 chillers totaling 15,000 tons
- Chilling Station 7 – 6 chillers totaling 15,000 tons
- Thermal Energy Storage Tank 1 – 4.33 million gal with 15,000 gpm discharge capability
- Thermal Energy Storage Tank 2 – 5.33 million gal with 20,000 gpm discharge capability

Together, the two TES tanks create about 22,000 tons of cooling capacity for over 4.6 hours. An Allen-Bradley programmable logic controller automation system, integrated with Optimum Energy's optimization solution, controls the equipment.

In 2019, annual chilled-water production was 146 million ton-hr, with 36,322 tons of peak cooling delivered. The 2019 annual average total chilled-water system efficiency was 0.59 kW/ton.

Screenshot of chilled-water network operations, The University of Texas at Austin. This graphic gives the UEM team a real-time snapshot of what is happening and allows it to immediately see and address issues.



Source: Optimum Energy.

efficiency than to invest in new power production capacity, so Optimum Energy and UT engineers again came together to boost the efficiency of a system that was already operating at peak performance. They believed they could develop a solution that would use power generation data and the local weather forecast to predict how to dynamically handle cooling and optimize TES capabilities.

On very hot days, the campus electrical load could quickly jump from 40 MW to 65 MW. If the system knew ahead of time how much stored water to discharge during the day, it could flatten the curve using the two TES tanks (a total of 9.6 million gal) – without running short or leaving precious stored cooling within the tanks, the engineering teams reasoned.

First, the team captured three years of historical plant data and weather data, including the range of seasonal conditions and other variables affecting campus power production. The team used this data to create a regression model to predict overall campus power draw with a high degree of accuracy. The model can then forecast demands in the future by knowing the upcoming hour, day and expected weather climate (as shown in figure 3). As new data is collected, or deviations between expected model power output and actual production are observed, the base regression model can easily be fine-tuned for greater accuracy. Unusual trends, or major deviations from the expected values that would warrant retuning the model, could include an event such as additional buildings being added to the chilled-water loop.

Optimum Energy then built an automated strategy that uses weather forecast information to determine power requirements for the entire campus 48 hours in the future. As seen in figure 4, which graphically compares the output of the regression model to the actual observed campus electrical usage for the month of October 2019, the forecast model tracked well to the actual demand. Figure 4 also includes outside air wet-bulb temperature to illustrate the strong impact climate conditions have on the overall campus power usage, irrespective of other factors such as occupancy or date.

Finally, Optimum created TES dispatch algorithms that dynamically solve for balancing loads on the combustion turbine and steam turbine. Running the turbines higher at night improves efficiency, and lowering the daytime peak creates capacity for the campus to continue to grow. Because the combustion turbine produces 85 percent of the steam for the steam turbine, operating the combustion turbine at higher baseloads also improves power generation efficiency.

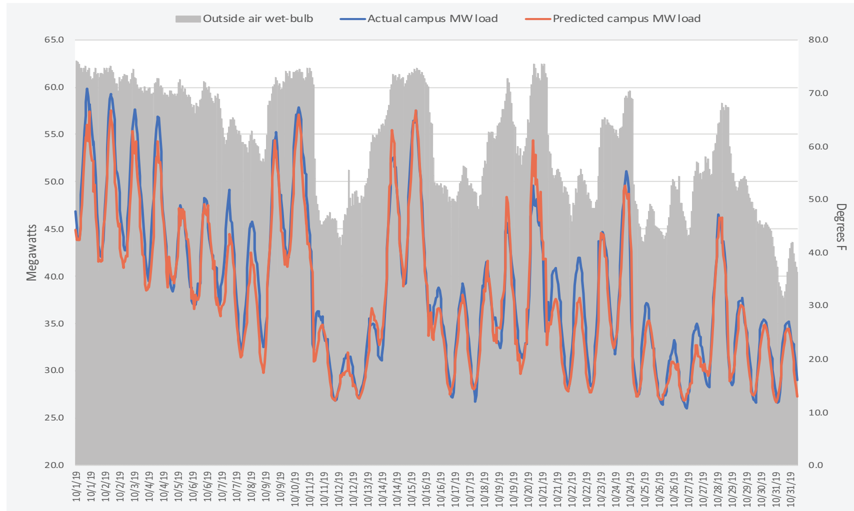
The TES control strategy is a four-step process:

1. Project the average campus megawatt usage for the next 48 hours.
2. Calculate the difference between the predicted and the average megawatt usage (fig. 5).
3. Calculate the tonnage required to reduce or increase megawatts to achieve the average.
4. Calculate the flow required to reduce or increase tonnage from each tank.

In its simplest form, the solution raises the cooling load at night, running the most efficient chillers to charge the tanks. During the day, the system discharges the stored chilled water and continues to run the most efficient chillers while keeping backup machines on standby.

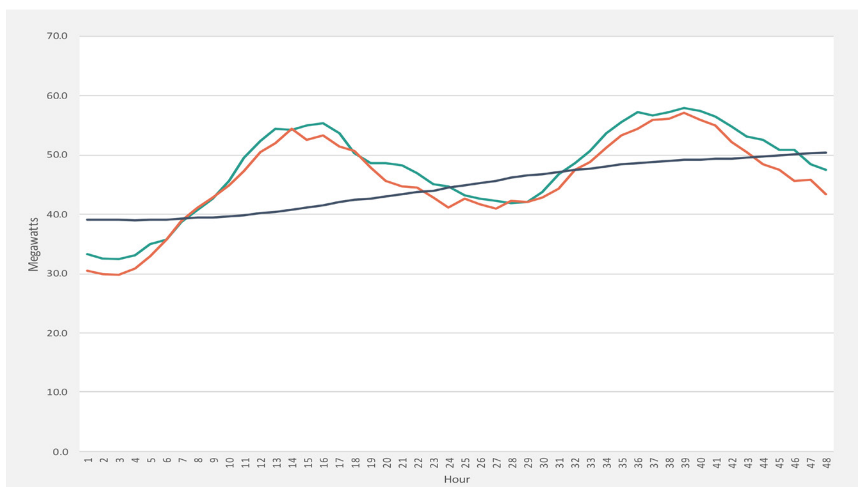
The results have surprised the UT team. Previously, UT saw differential loads of 20 MW, but now those have dropped to 4 MW or 5 MW. Also, the peak electrical load in 2018 was 68.8 MW; the peak load in 2019 was 61.94 MW. Figure 6 demonstrates how increased efficiency has helped flatten the load during peak season (shown in watts per square foot). The team's ultimate goal is to get the load completely flat to baseload the combustion turbines. This will reduce stress on the machines as well as continue improving efficiency. Operations can now depend on a lower steady load for the power plant, while the chilling stations and thermal storage tanks absorb the daily load swings.

FIGURE 4. Example of regression analysis results for campus electrical usage (MW) using the forecast outdoor wet-bulb temperatures, October 2019.



Source: Optimum Energy.

FIGURE 5. Example of 48-hour forecast, actual and mean campus electrical loads (MW).

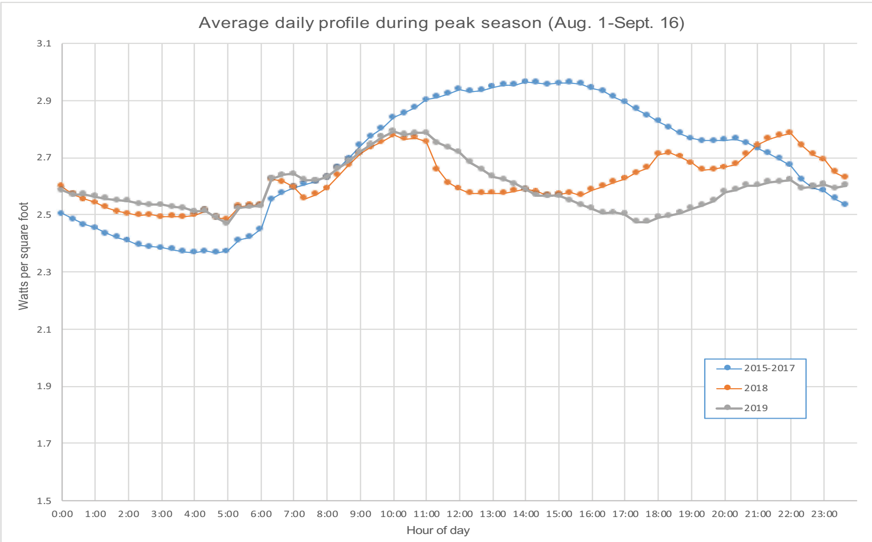


Source: Optimum Energy.

ACHIEVING THE SUPPOSEDLY IMPOSSIBLE

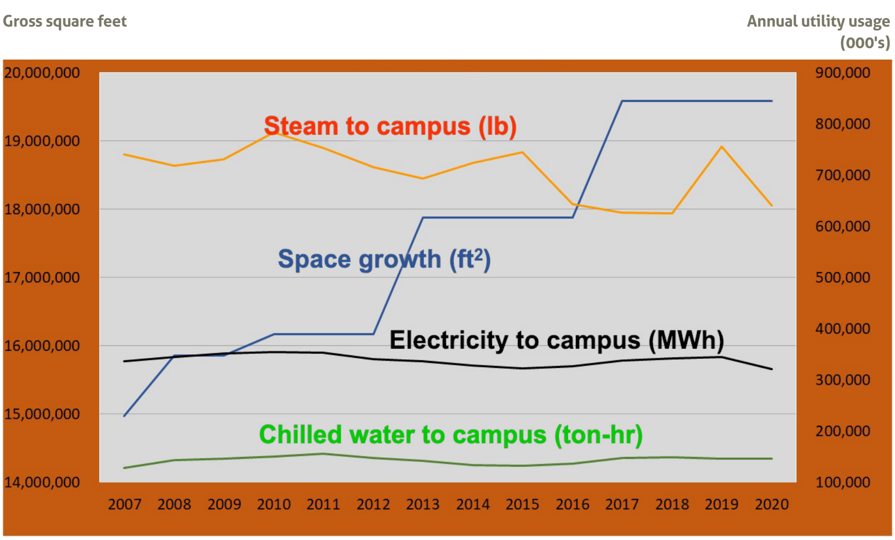
Collaborative problem-solving and dynamic optimization solutions are paying off for UT. Overall annual chilled-water plant production efficiency is now 0.59 kW/ton (as shown in fig. 2). Total annual power plant operating efficiency is 88.59 percent. Since 2007, the chilled-water production's overall energy use has remained flat, despite the school's construction of an additional 4.8 million sq ft of buildings. (See figure 7 for a comparison of histori-

FIGURE 6. Comparison of average daily profile results during peak season from thermal energy storage system optimization, 2015-2017, 2018 and 2019, The University of Texas at Austin (watts/sq ft versus time of day).



Source: The University of Texas at Austin.

FIGURE 7. Historical campus steam, power and chilled-water usage per year, 2007-2020, The University of Texas at Austin. As campus building space has grown in square footage, energy usage has remained flat.



Source: The University of Texas at Austin.

cal annual campus utility usage versus space growth.)

Since 2007, chilled-water plant optimization has saved UT 704,934 MWh, which has led to a natural gas savings of $28,076,800. In addition, since 2015, eliminating the false cooling loads has saved the campus an estimated 38.5 million lb of reheat steam worth about $6.42 million over the period. Finally, the peak electrical load in 2007 with 15 million sq ft was 59 MW, compared with the 2019 peak load with 19.8 million sq ft of 62 MW.

From UT's perspective, the secret to success has been having the right balance of plant equipment, marrying it with the optimization and dispatching opportunities Optimum provides and doing that in a way that avoids compromising any aspect of the system or forcing one to work against another. Both the UT and the Optimum Energy teams take a holistic approach to heating and cooling systems, united by a dedication to measurement and constant innovation, which has allowed them to turn theory into practice with impressive results. And they're still thinking about how they can do even better.

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