The University of Texas at Austin

Large-Campus District Cooling

How university is meeting growing cooling needs using less energy

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In 2000, The University of Texas at Austin (UT) was paying about $2 per million British thermal units of natural gas, its primary fuel. By September 2006, the cost had risen to more than $14; over the next two to three years, it averaged about $8. In less than a decade, UT's annual gas budget had gone from about $9 million to approximately $36 million.

At the same time, the UT campus was experiencing significant growth. Over the span of 15 years, the area served by UT's combined-heat-and-power district energy plant had grown from approximately 13 million sq ft to nearly 20 million sq ft (Figure 1).

Looking to meet its growing cooling needs using less power, UT recently embarked on a district-cooling-optimization project that has seen gas-use quantities return to 1970s levels.

Central Utility Plant

With a peak load of 61,000 kw and total annual output of 350 million kwh, UT's central utility plant provides 100 percent of the power, steam, chilled water, deionized laboratory water, and compressed air for the 350-acre, 200-plus-building campus. The peak steam load is 220,000 lb per hour, with total annual output of 750 million lb and about 95 percent of condensate being returned. The cooling system consists of four central chilling stations with 45,000 tons of capacity tied into 6 miles of chilled-water-distribution-system piping. The four central chilling stations serve 135 buildings—more than 17 million sq ft—with a peak load of 35,000 tons and growing. Annual

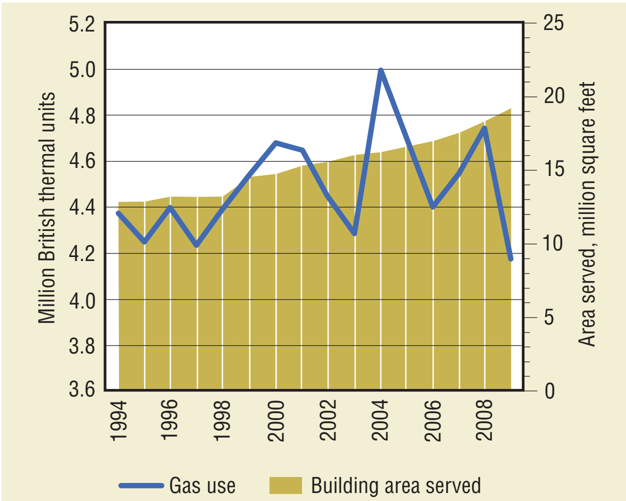

FIGURE 1. Fuel consumed and building area served at The University of Texas at Austin.

The associate director of chilling stations for The University of Texas at Austin, Kevin M. Kuretich, PE, has more than 25 years of plant-facilities experience encompassing design, maintenance engineering, project management, and operations. He has led or been an integral member of teams that received U.S. Environmental Protection Agency (EPA)/U.S. Department of Energy (DOE) Energy Star Partner of the Year, DOE/EPA Energy Star CHP (combined heat and power), and Texas Environmental Excellence awards. The director of engineering for Optimum Energy LLC and a member of HPAC Engineering*'s Editorial Advisory Board, Ben Erpelding, PE, CEM, has more than 13 years of experience related to energy efficiency, demand response, HVAC design, measurement and verification, and commissioning. To date, he has worked on more than 1,000 chilled-water plants throughout the United States, China, and the Middle East.*

UT UTILITY OPERATIONS AT A GLANCE

- Total installed cooling capacity: 45,000 tons.
- Peak cooling load: 35,000 tons.
- Peak chilled-water flow: 70,000 gpm.
- Average supply temperature: 39°F.
- Average return temperature: 49°F.
- Average supply pressure at plants: 100 psig.
- Peak supply pressure at plants: 125 psig.
- Average return pressure at plants: 40 psig.
- Total installed supply- and return-piping length: 12 miles.
- Total installed piping capacity: 1.1 million gal.
- Total annual cooling produced: 145 million ton-hr.
- Total annual power consumed by chilling plants: 108 million kwh.
- Average plant efficiency: 0.75 kw per ton.
- Average campus cooling load: 16,500 tons.
- The production of chilled water consumes approximately one-third of the energy produced by the combined-heat-and-power plant.
- Cooling is required on campus 24 hr a day, seven days a week, 52 weeks a year.
- Minimum campus cooling load: approximately 5,000 tons.
- The campus cooling load had been increasing by about 3 percent annually for several years.
- Of the 12 miles of supply and return piping installed, approximately 90 percent is in walkable tunnels.

chilled-water production in 2008 was 143 million ton-hr.

The central utility plant is fueled with natural gas, with No. 2 diesel the emergency backup fuel. Natural gas is fired in a combustion-gas turbine capable of generating up to 45,000 kw. Heat in exhaust gas from the combustion turbine is captured in a heat-recovery steam generator that produces up to 288,000 lb of 425 psig/710°F steam per hour. A natural-gas-fired boiler tied into a high-pressure-steam (HPS) line is left at low fire to ensure continuous delivery of steam to the campus in the event the combustion-gas turbine trips offline. Steam from the HPS line drives a 27,000-kw, single-stage steam-turbine generator. Medium-pressure steam (MPS) is "extracted" from the steam-turbine generator at 155 psig and approximately 565°F. This MPS is distributed for various uses, including domestic water heating. It is used directly (process steam in laboratories) or converted to high-temperature hot water and used indirectly to heat buildings.

Compressed air is drawn from the final stage of the compressor in the combustion-gas turbine or air compressors located in the central utility plant and four chilling stations. Deionized water is provided from the central utility plant's boiler makeup-water system, which uses reverse-osmosis trains and demineralizing beds. This water is of sufficient quality for use in many of the laboratories across campus and the production of high-quality water in various special-use laboratories.

The central utility plant's electrical distribution grid is tied to the City of Austin through four 50-mva transformers. The university maintains a standby agreement with the city that virtually ensures nearly 100-percent reliability in campus electrical service.

The four chilling stations house 11 electric centrifugal chillers ranging in size from 3,000 tons to 5,000 tons. A 4-million-gal., 36,000-ton-hr thermal-energy-storage tank is being constructed to provide capacity and backup to ensure the campus is never without cooling. Approximately 33 percent of the central utility plant's output is consumed by the chilling stations. At their peak load of 35,000 tons, the chillers use 20,000 kw, and their associated auxiliaries (chilled-water pumps, condenser-water pumps, and cooling-tower fans) use more than 8,000 kw.

Despite differences in equipment, systems, pressures, temperatures, and distribution methods, the central utility system at UT is similar to the systems on hundreds of other university and industrial campuses throughout the United States.

Challenges

In the four chilling stations, both new and old technologies were used to optimize efficiency and operation. The challenge was integrating the four chilling stations and optimizing their combined operation. Over time:

- Attempts to save energy had resulted in frequent "hot calls" from building occupants, for which chilled-water operation was blamed.
- Cooling demand had increased as buildings in older areas of the campus were replaced or renovated. Management was concerned about the capacity of the existing infrastructure.
- Aging building mechanical sys-

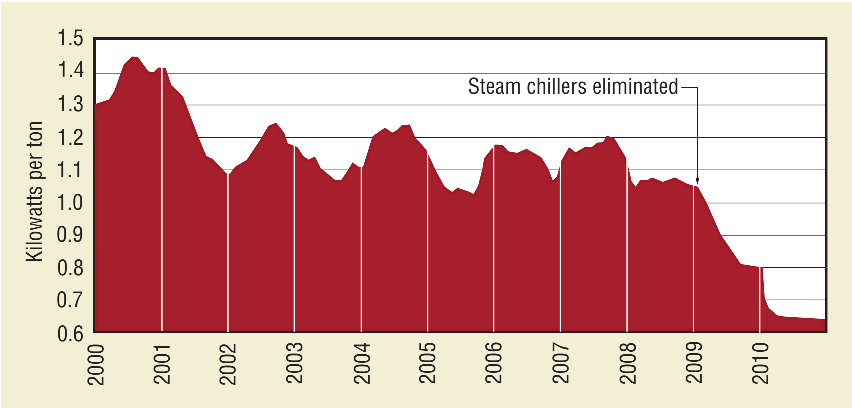

FIGURE 2. The University of Texas at Austin total campus chilled-water-plant efficiency.

tems had begun returning chilled water well below design, resulting in low-delta-T syndrome.

With a peak electrical load for chilled-water production of nearly 30,000 kw and annual consumption of nearly 110 million kwh, a significant opportunity for cost savings existed. Figure 2 shows total campus plant efficiency from 2000 through 2010. The first large dip, in 2009, occurred when steam chillers were eliminated from operation, while the second dip, in 2010, was the result of the addition of a new chilling station, Station 6.

New Chilling Station

The $39.25 million Station 6 was funded to make way for a new computer-science building. Station 2 was to be demolished. Plans called for the replacement of the 7,800 tons of steam-driven centrifugal chillers in Station 2 with new electricity-driven centrifugal chillers and the installation of a 3,000-ton inlet air coil on the combustion-gas turbine to boost summer capacity from 36 Mw to 45 Mw. Based on an extensive 30-year life-cycle-cost analysis, a 15,000-ton all-variable-speed system was selected.

Station 6 (left circle and inset) replaced Station 2 (right circle), which is to be demolished.

Station 6 incorporates:

- 15,000 tons of cooling capacity.
- A primary-only all-variable-speed system.
- Three 5,000-ton variable-speed electric chillers with 39°F chilled-water design.
- Three variable-speed condenser-water pumps (15,000 gpm, 110 ft head, 500 hp).
- Three variable-speed chilled-water pumps (10,000 gpm, 250 ft head, 800 hp).
- Three variable-speed counter-flow cooling-tower cells (15,000 gpm

each, 250-hp fans, 85°F to 95°F, 78°F wet bulb).

• A programmable-logic control system.

Figure 3 shows the efficiency difference between a 5,000-ton constant-speed chiller and a 5,000-ton variable-speed chiller with entering condenser-water temperature (ECWT) ranging from 55°F to 85°F and load ranging from 50 percent to 100 percent. Note that the only point at which the constant-speed chiller is more efficient than the variable-speed chiller is at design (100 percent capacity and 85°F ECWT).

To operate the four chilling stations at the lowest kilowatts-per-ton level possible, relational controls based on the Equal Marginal Performance Principle[1] were selected. Relational-control algorithms use mathematical relationships between subsystems.[2] At UT, the algorithms took full advantage of the existing supervisory-control-and-data-acquisition system integrating all of the systems and equipment in the chilling stations. Through that integration, UT has been able to optimize system operation without compromising safety or reliability. Figure 4 shows the total efficiency of Station 6 based on outdoor wet-bulb temperature and given plant capacities. The typical annual wire-to-water performance range is 0.33 to 0.78 kw per ton.

Today, UT's on-site utility system self-generates 100 percent of needed electricity, steam, and chilled water using the same amount of power the university consumed in 1977, despite the addition of 8 million sq ft. The efficiency improvements have added value to the campus, enabled self-funded improvements, and provided significant emissions reductions (Figure 5).

References

1) Hartman, T. (2005). Designing efficient systems with the equal marginal performance principle. *ASHRAE Journal, 47*, 64-70.

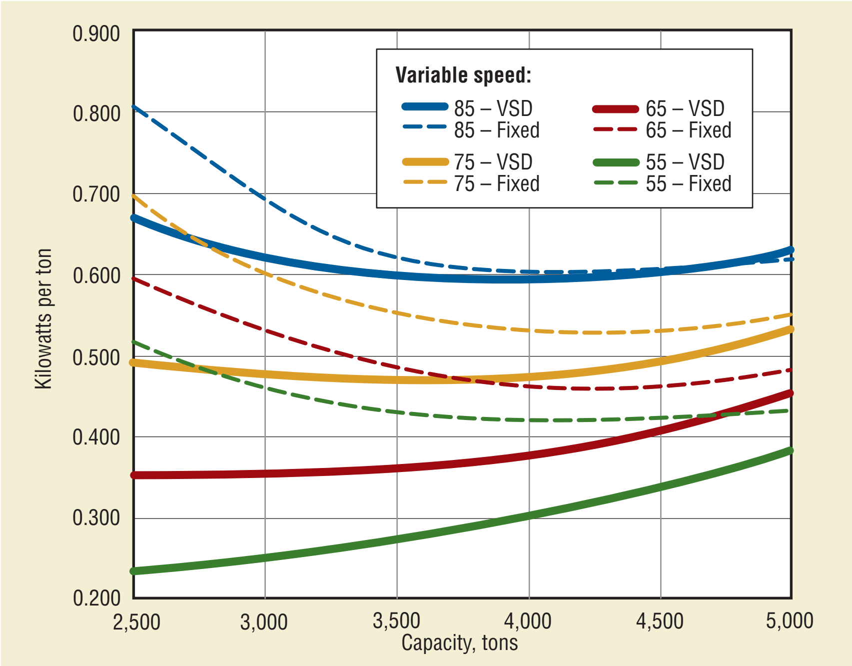

FIGURE 3. Performance of 5,000-ton centrifugal chiller at The University of Texas at Austin.

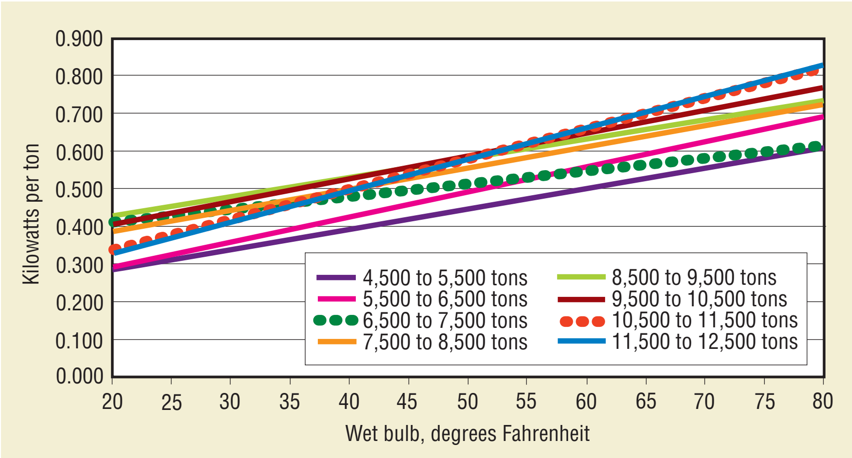

FIGURE 4. The University of Texas at Austin Station 6 total plant performance (includes chillers, chilled-water and condenser-water pumps, and cooling-tower-fan energy).

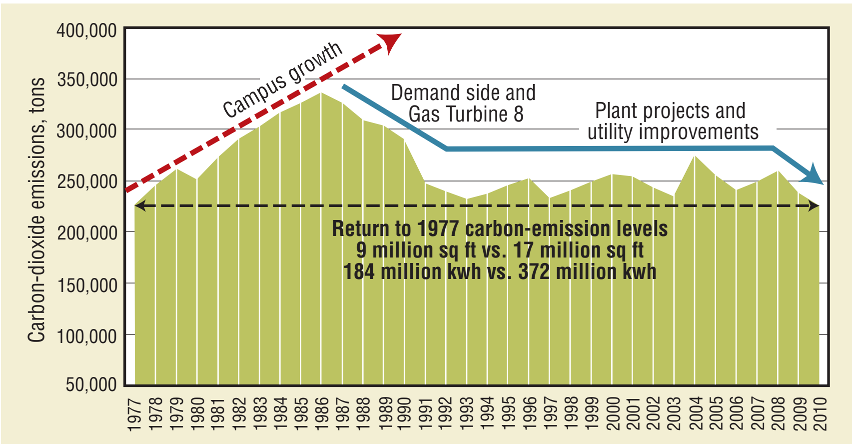

FIGURE 5. The University of Texas at Austin carbon emissions.

A BIT OF HISTORY

From its founding in 1883 until 1928, The University of Texas at Austin (UT) used power from the City of Austin and coal-fired boilers in each of its buildings for heating. In 1928, a central heating plant was constructed.

At UT, as on most large university and industrial campuses throughout the United States, demand for mechanical cooling of buildings did not emerge until the 1940s, when owners took one of two considerably different paths:

- Construct a central cooling plant at or near the central heating plant and use the steam-production equipment that provided heating during winter to drive cooling during summer. Many of the first central cooling plants contained steam-turbine-driven centrifugal chillers or steam absorption chillers.
- Install a chiller in each building, using the existing steam supply as the prime mover. Because steam typically was delivered to buildings at a pressure lower than that at central heating plants, low-pressure steam absorption chillers frequently were chosen for building cooling. This type of system required chilled-water pumps, condenser-water pumps, and cooling towers at each building.

In the ensuing years, the demand for comfort cooling exploded, and those who had chosen the central-cooling-plant approach found themselves rapidly adding capacity to their original central plants and building additional plants in other locations on campus, a highly capital-intensive proposition.

Around 1980, chillers purchased during the 1940s and '50s were reaching the end of their useful life, and chiller-maintenance needs rapidly increased, as did chiller outages, and the replacement of chillers became a high priority for owners. Finally, the wisdom of the central-plant concept was realized. When a chiller in a central plant fails, it still is possible on all but the hottest design day to provide cooling; when a chiller in a building fails, that building is without cooling until the chiller can be repaired or replaced.

At the same time, another variable—energy costs—was entering the equation. The energy required to cool 15 buildings each with a load of 500 tons using 15 individual 500-ton chillers and associated equipment was far greater than the energy required to serve those same 15 buildings with a central cooling plant that might contain three 3,000-ton chillers. The central cooling plant, as with the central heating plant, also provided a much higher degree of reliability and reduced maintenance.

During the 1980s, those who had chosen the one-building, one-chiller approach began to run chilled-water piping between buildings and replace failing chillers with larger chillers, creating a "distributed chiller plant." While that did not provide all of the advantages of a central plant, it was a significant step forward in terms of reduced energy, reduced maintenance, and higher reliability.

A minority of one-building, one-chiller owners decided to "bite the bullet" and construct central plants serving all or part of their campuses, quite probably arguing that the reduced operation and maintenance costs, as well as the higher reliability, of a central plant would offset the higher capital investment required to "loop" together building chillers.

2) Erpelding, B. (2009, Fourth Quarter). How high can you go? New approaches for cooling system efficiency. *District Energy*, pp. 13-16. Available at http://bit.ly/8wbxP5

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