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Hybrid Chilled Water Plant

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The central chilled water (CHW) plant was not meeting the needs of Capital University's 1.2 million-ft^2 (111 480 m^2) campus in Columbus, Ohio. Failure of one of the two 750-ton (2638 kW), 35-year-old single-stage steam absorption chillers caused the university to rent a chiller during summer 1998.

CHW loads were expected to increase due to a soon-to-be-built 126,000-ft^2 (11 705 m^2)sports and recreation facility and the air conditioning of other campus buildings. The cooling towers and other ancillary equipment were degraded. The constant-flow CHW pumping system and lack of controls at each of the 10 buildings on the system resulted in wasted energy and comfort problems.

The university's natural gas contract provided a monetary incentive for consuming 30% of the annual gas consumption during the summer months.

An analysis showed that upgrading the central plant was the most cost-effective option. A life-cycle cost analysis was done to select the best central plant system. The design firm then designed and led the turnkey (i.e., design/build) replacement of the old central chiller plant with a new hybrid plant, consisting of the following:

- Two 1,000-ton (3517 kW) electric centrifugal chillers,
- Two 1,000-ton (3517 kW) cooling towers,
- A 560-kW natural gas engine-generator set connectable to either chiller,
- Variable-primary CHW pumping system,
- An energy delivery station at each building to convert the campus system to variable flow,
- Networked digital controls to monitor/control the entire system,
- New electrical substation,
- New plant roof and repainting of interior, and
- Demolition of old equipment.

The entire system retrofit was completed by May 1, 1999 at a cost of $2.1million and has been operating flawlessly since that time (almost two full cooling seasons).

Energy Efficiency

Real-time flexibility gives Capital University control of its energy costs. The lowest-cost energy source can be selected for the lead chiller. By repositioning valves and transfer switches with the digital control system, the chillers can be preferentially loaded to use either more natural gas or more electricity.

When the cost of electricity is low, one or both of the chillers can be powered from the electric utility company. When the cost of electricity is high or when gas needs to be burned in the summer to meet gas-rate requirements, one of the chillers can be fully loaded and powered from the natural gas engine-generator set while the electric utility company powers the second chiller.

Each building's energy-delivery station throttles the CHW flow in proportion to the load. This reduces CHW pump energy during all part-load hours. The variable CHW flow also increases the return water temperature, which makes the chillers more efficient. Cooling to each building can be scheduled by time-of-day.

The CHW flow through the chillers varies (no separate constant-flow primary pumps). This reduces pump energy during part-load hours and first cost. Only when the flow falls to less than 50% of one chiller is a bypass valve modulated open (25% of the total plant capacity).

The differential pressure setpoint for the CHW distribution system is continuously reset based on each building's energy delivery station valve positions. The differential pressure is lowered until one valve in the system is nearly wide open. This reduces pump energy throughout the year.

The two variable-speed CHW pumps operate simultaneously (in parallel) when the control system determines that the efficiency of running two pumps at a lower speed is better than running one pump at a higher speed.

The engine jacket heat is rejected to the condenser water loop in series with the chillers. This raises the water temperature sent to the cooling towers without raising the water-flow rate. The cooling towers reject the heat more efficiently than if a separate water loop in parallel with the chillers was used. Less fan energy is also needed.

The cooling tower variable-speed fans are controlled using an open-loop control algorithm rather than wet-bulb temperature or other commonly used temperature-based methods. The algorithm, presented in a 1990 ASHRAE technical paper, optimizes the energy consumption of the chillers and cooling towers as a system.

A central plant computer model estimates the new plant to use $100,000/year less energy than the single-stage absorption chiller plant it replaced (on an equiva-

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lent-capacity basis). Actual utility data for summer 1999 vs. previous years has not been included in this application since the old chiller plant was not meeting the loads in the buildings and more space has been added to the system.

Thermal Comfort

The variable-flow CHW distribution system delivers cold water to any building that needs it at any time. This allows the building air handlers to better dehumidify than the old constant-flow/variable-temperature system.

The condenser water system is winterized. The system can instantly begin making CHW on occasional warm winter days to satisfy building-comfort needs. The old cooling tower system was drained in the winter so the plant was not operable without several days notice.

The central plant has a multi-point refrigerant monitor and dedicated exhaust system with cross-ventilation designed per ANSI/ASHRAE Standard 15-1994, *Safety Code for Mechanical Refrigeration*.

A separate transfer fan cools the engine-generator room by pulling outdoor air through the chiller room and pushing it through the engine-generator room to the outdoors. This cools and ventilates the chiller room while getting double duty from the fan energy.

The water treatment chemical drums are stored in containment tubs to eliminate spills and contamination of the sanitary sewer system.

Innovation

The preferential loading and sequencing of the chillers was accomplished using only two modulating valves and two two-position valves. Other more complicated schemes use more valves to accomplish the same effect. This arrangement is easy for the operators to understand.

The hybrid chiller arrangement provides fuel flexibility.

The reset of the CHW pump setpoint takes advantage of the networked control system to squeeze more savings out of the system.

The electrically operated transfer switch scheme was so unique that the chiller manufacturer did not anticipate it in the design of the chiller controls. We convinced them it would work, and developed our own control wiring diagrams to safely transfer not only the power feeds, but also all of the control signals, between the engine-generator and each chiller. Simple latching relays and interlock wiring were provided to avoid trying to energize a chiller from two power sources if a control component fails.

During the initial feasibility analysis, many alternatives with significant energy impacts were considered. Alternatives consisted of nine chiller combinations including single and two-stage steam absorption chillers, electric chillers, engine-driven chillers, and direct-fired absorption chillers. A thermal storage system was also evaluated. A local chiller plant vs. a larger central chiller plant was analyzed to serve the new sports and recreation facility. The life-cycle cost analyses enabled the university to select the system which best met project objectives. Energy usage (including part-load effects), operating costs, maintenance costs, and first costs were included.

Operation and Maintenance

The natural gas-fired engine-generator can provide emergency power for the campus.

The chillers were connected to the campus digital control system through a BACnet® interface. This allows dozens of chiller operation and maintenance parameters to be accessed from any facilities department workstation on campus.

The energy delivery stations allow each building to be remotely monitored. Problems can be spotted before they impact comfort.

The chillers can operate from utility power if the engine-generator fails. This is not the case with engine-driven chillers.

Side-stream filtration is used on both the CHW loop and condenser water loop to reduce the buildup of solids in the systems. The side-stream arrangement minimizes both the filter size and the pumping energy.

The pair of CHW pumps, pair of condenser water pumps, and pair of CHW strainers are manifolded so any device can be used with any chiller. This provides a higher level of reliability than when devices are dedicated to a particular chiller.

Industrial-grade differential pressure sensors are used as a “pseudo flow meters” on each chiller evaporator. DP sensors are more reliable and more easily calibrated than flow meters.

Cost Effectiveness

The natural gas-fired, engine-generator/chiller combination had the best or second best life-cycle cost for 18 different utility rate scenarios. The net present value of this chiller combination was \$70,000 – \$160,000 less than the second-best chiller combination for the utility current rate structures. The system enables the university to retain its favorable transport gas rate (which saves over \$80,000 per year) by allowing sufficient gas to be consumed during the summer. As electric deregulation takes place, the real-time utility pricing flexibility will be even more valuable to the university.

The chillers and cooling towers were selected for 2 gpm/ton (0.1262 L/s per 3.517 kW) condenser water flow. This allowed a two-cell cooling tower to be installed at significantly lower cost than the three-cell tower that would have been required with the typical 3 gpm/ton (0.19 L/s per 3.517 kW) flow rate. Pumps, piping, VFDs, and electrical feeders were also smaller. The full-load power consumption of the system is about the same.

The chillers and cooling towers were pre-purchased using the “lowest life-cycle cost” method. No one has sufficient knowledge of the marketplace to set an arbitrary minimum efficiency target that results in the lowest life-cycle cost. The purchasing method allowed bidders to submit multiple bids with varying first-costs and efficiencies, so the best option could be selected.

Variable-speed drives were incorporated on the primary CHW pumping system to reduce operating costs and deliver CHW only to the needed loads.

The use of variable primary pumping eliminated the need for two pumps that would normally exist in a primary/secondary system.⬢