DISTRIBUTED ENERGY
THE JOURNAL OF ENERGY EFFICIENCY & RELIABILITY
January-February 2008

Big-Picture Retrofitting

An engineering team improves one university's cooling and heating efficiency by focusing on several buildings' impact on the distribution network.

By Don Talend

A recent retrofit of the cooling and heating system at the Lakeshore Campus of Chicago's Loyola University demonstrates how a holistic approach to configuring such a system at an operation consisting of multiple buildings can provide a tremendous boost to efficiency at a minimal cost.

The 100-year-old campus, which serves about 7,500 students, has more than 50 buildings, including the library and sports center, spread throughout 100 acres on the city's north side. Like many multifacility properties, it has experienced incremental construction of buildings and campuswide infrastructures throughout the years. As is often the case on such a property, the construction was done in piecemeal fashion by various contractors and within budgetary constraints at various times. The result, an architectural consultant for Loyola notes, was a campus-wide HVAC system that operated with less-than-ideal efficiency and thus generated higher-than-necessary energy costs.

Nancy Hamill Governale, owner of architectural firm Facilities Research and director of facilities and adjunct faculty member at the Illinois Institute of Technology (IIT), says that she found out about opportunities for efficiency improvements at Loyola through a chance meeting with the university's vice president of facilities back in 2000. "We started talking about some of the energy conservation work that I was doing at IIT at the time, and we felt that it was really a good fit that I start consulting up at Loyola —Loyola was actually my first assignment," Hamill Governale notes, regarding the founding of the consulting firm.

"Nancy's a very interesting woman; she's not like any other architect I've ever met. She's extremely mechanically oriented and inclined and extremely knowledgeable about energy," says Charlie McLauchlan, president of Delta Controls Chicago, which supplied control systems and engineering for the reconfiguration of the HVAC distribution network for Loyola. The team consisted of Delta Controls Chicago and Elara Engineering of Hillside, IL, which was retained for mechanical and electrical engineering services on the project.

Energy audits of both the Water Tower (downtown) campus and the Lakeshore campus were the first instance of Facilities Research's approach to consulting. Because energy costs were extremely high at both campuses and it would be impossible to rectify the situation in one fell swoop, "I wanted to put together more of a package that would allow a facilities group to implement projects on an ongoing basis," says Hamill Governale. Wayne Sliwa, senior project manager with Loyola, worked with Hamill Governale in developing a project-specific matrix that the University could implement over time according to available funds.

One study that Hamill Governale oversaw was whether or not the Lakeshore campus' existing chiller plant was operating at optimal energy efficiency while supplying chilled water to nine of the largest existing academic and athletics buildings and would do the same for some new buildings that would be added to the campus in the future. An upgrade of the existing chiller plant and chilled-water distribution network eliminated the need for Loyola to have a new $750,000 underground pipe network constructed, saving the university about $30,000 in energy costs every month, and winning a First Place Engineering Excellence Award from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Illinois Chapter in 2003.

Existing System

The chiller plant was equipped with a 1,250-ton-capacity centrifugal chiller that appeared to be about 30 years old with no records to indicate the unit's operating condition, along with two relatively new 750-ton centrifugal chillers. These chillers were the central equipment in a traditional constant-flow chilled-water distribution network that prioritized chiller preservation, by maintaining design flow at all times, over energy savings.

Until recently, when energy efficiency became a higher priority than ever, chilled-water distribution networks had been designed to maintain a more or less constant flow rate in order to minimize peak loading on chiller pumps, explains McLauchlan. “Up until a few years ago, all of the chiller manufacturers had this mantra that the water flow through the chiller had a very strict, constant volume requirement; they had a certain range, but it was a very tight range of flow that was safe and appropriate,” he says. “So nobody wanted to go outside that box.”

At Loyola and many other chilled-water distribution networks, this constant flow rate was maintained with a primary-secondary-tertiary piping configuration whereby chilled water is pumped and distributed via three-way valves at air handlers. The primary or main piping loop carried chilled water from the plant to three-way valves at the air handlers. At each building served by the main loop, the secondary pumps took chilled water off of the main loop and redirected the appropriate volume of chilled water for the building’s heating and cooling design load; the return water flowed back to the plant via the main loop after going through the coil three-way valves. This design resulted in large quantities of unused chilled water going directly back to the plant via the three-way valve bypass port. The water returning via the bypass had a temperature that was only about 3 or 4 degrees Fahreheit higher than the chiller output water (described as the temperature differential or delta-t), making the chiller consume more energy to lower the chilled water temperature. The warmer the return water, the more efficient the chiller operates, because heat from the return water is essentially transferred to the chiller in the form of kinetic energy.

Hamill Governale brings up a typical problem that resulted from the piecemeal fashion in which new buildings were constructed on campus throughout the years. “It was pretty obvious from a master planning perspective that when buildings had been put in over the years, they were put in on a one-by-one basis, and as those buildings were added on, the valving, the distribution, and the route that the chilled water had to take really didn’t benefit that continuous delta-t,” she says. “It detracted from the efficiency—that goes back to the ’60s and ’70s, when those buildings were added on.” As a result, some buildings were cooled less efficiently than others, leading to numerous comfort complaints from students and staff.

Typical of older multifacility properties, the campus also lacked central HVAC control, a major contributing factor to the distribution network’s inefficiency. Various nonintegrated, building-specific control systems had been installed throughout the years. “They had a handful of systems around that were aging extremely,” notes McLauchlan. “They had some of the original Honeywell ‘Delta’ controllers that were 20-plus years old and some pneumatic controls—it was primarily pneumatic.”

Hamill-Governale’s study indicated that replacing the old 1,250-ton chiller with two new 750-ton chillers would supplement two 750-ton chillers installed the previous year. The existing chilled-water distribution system was found to be deficient. “It was like having a Corvette with four flat tires—if you don’t have four wheels, it doesn’t matter what kind of engine you’ve got,” McLauchlan argues. “The distribution system was similar to the wheels in this case.” Other additions to the chiller plant were a 3,000-ton, three-cell cooling tower with 30-horsepower fans equipped with variable frequency drives (VFDs); three 100-horsepower chilled-water pumps shared by the four 750-ton chillers in a vari-prime piping arrangement to the campus buildings and air-handler cooling coils; and three 75-horsepower condenser water pumps equipped with VFD motors and shared by the four 750-ton chillers in a vari-prime piping arrangement to the cooling towers.

With plans to build a new Life Science building that had a relatively high chilled-water demand, and given the inefficiency found in the distribution network, the owner assumed that an entirely new underground piping network would have to be constructed at a cost of roughly $750,000.

“We looked at a number of different options,” Hamill Governale reports. “We looked at the possibility of making that building independent of the system from the chilled-water building. As it turned out, it made more sense to get rid of [the 1,250-ton chiller] at the central plant, increase the capacity, increase the efficiency and also deal with the delta-t issue on the distribution of the chilled water.”

The Solution

To make the distribution network upgrade work, the team recommended the use of a variable-prime or vari-prime system. In contrast to the traditional constant-volume system that uses secondary pumps at each building, the vari-prime system relies on centralized control of all equipment that affects the flow of chilled water throughout the distribution network. With this centralized control—provided by a BACnet Internet-capable central computer that receives signals from flow sensors on chillers and condensers and sends commands to VFDs on tower and chiller pumps—the system continuously adjusts to the varying flow demands throughout the network.

In a campus environment, for example, a building such as the one for life sciences has a relatively high chilled-water demand to begin with, and for a few days a week during each semester, the demand might remain steady until 10 p.m. with night classes in session. Between semesters, however, this building might be closed, while administrative buildings remain open, pushing their chilled-water demand beyond that of the life sciences building. A BACnet software program can adjust the operation of pumps, condensers, or cooling tower fans according to the signals received from the flow sensors measuring the demand throughout the network, or the facilities staff can manually adjust the chiller plant equipment from any campus computer on the local area network or from a handheld wireless device such as a BlackBerry.

The vari-prime system would prove to allow Loyola to use the existing underground distribution network. A fair amount of work would be involved in reconfiguring the network, however. “The first thing we recommended was to go to variable flow everywhere —through the chillers and the air handlers—so it eliminated all of the three-way valves, and we were actually able to turn off all of the distribution pumps in all of the buildings,” says McLauchlan. “They found that on many days, the campus was able to run with two chillers running, and they found that there were 14 or 15 degrees of delta-t. We were able to use just the 150-horsepower pumps at the plant because they had enough head on them to handle the load.”

Since the constant-volume system was incrementally developed at the campus, studies showing the ability of chillers to handle varying flow rates have been conducted. “The manufacturers said [previously] we don’t want you to vary the flow in our machines because they don’t respond well to varying flow conditions,” says Don McLauchlan, principal with Elara Engineering. “So designers went around and said, even though we’re varying the flow at the coil based on the load, the excess capacity that we don’t need, we’ll just bypass it back to the plant. They weren’t thinking of energy; they were just thinking of maintaining constant flow at the chillers.


The project team installed two new 750-ton chillers to replace an antiquated 1,250-ton chiller and, more importantly, central control of distribution system components. These upgrades saved Loyola $750,000 in capital costs and $30,000 a month in energy costs.

“With the advent of the computerized control that we have today, the manufacturers are saying we can accept a variable flow on our chiller as long as it isn’t too rapid and as long as it’s within a certain range. So that, combined with the fact that we’ve got multiple chillers, means that we can come up with a control scheme where variable primary flow is feasible.”

Elara Engineering had experience with converting constant-volume networks to vari-prime systems and the tasks inherent in modifying equipment at the building level. “We modeled the buildings and field-investigated every single area of the campus,” says Don McLauchlan. “The key was really evaluating the coil performance at all of the various buildings and the chilled water loads. The second part of that evaluation was to eliminate all of the bypass and eliminate all of the three-way valves, which eliminated the chilled water being sent around campus and coming back without picking up any BTUs.”

These changes were crucial to improving the efficiency of the chillers, he adds. “The way you increase delta-t is twofold. It’s a function of going to every air handler and in this case changing out the three-way valves to two-way valves—that was probably the biggest thing we did. The other thing we did was make the water supply colder than what they used to supply. They used to supply water at around 44 degrees Fahrenheit and we lowered it to around 42 degrees Fahrenheit. Some coils were designed for water entering at 44 degrees Fahrenheit and leaving at 54 degrees Fahrenheit; we could get the same cooling out of those coils by supplying 42 degrees Fahrenheit water that leaves at 56 degrees Fahrenheit.

“Making colder water at the plant has a tendency to increase chiller energy, but the fact that the chiller return water is warmer reduces energy demand. If we have 56 degrees Fahrenheit water going into the chiller and 42 degrees Fahrenheit water going out, which would be a 14-degree delta-t; therefore, the average is 49 degrees Fahrenheit. If they had 44 degrees Fahrenheit water going out but 48 degrees Fahrenheit water coming back before, the average was 46 degrees Fahrenheit. We actually raised the average temperature of the chilled water in the evaporator and subsequently improved the overall efficiency of the chiller.” He adds that a more precise analysis involves log mean temperature differences, although the results of such analysis would be the same.

Making the chillers operate more efficiently is only a part of the overall energy savings that the vari-prime system has provided the campus. By eliminating the bypass to maintain the constant chilled water flow rate throughout the distribution network in favor of precise control of pumps, condensers, air handlers, and cooling towers to optimize the flow rate in dynamic operating conditions, the consulting team has saved Loyola even more in energy and capital costs. Over the past five years, the system has been equipped with more than 30,000 BACnet control points and three more large buildings have joined the distribution network, with a fourth soon to be added.

“We left all of the three-way valves there, and had a pipefitter come in and block off the bypass port so we could use the three-way valve as a two-way valve,” reports Charlie McLauchlan. “The university didn’t have the cost of replacing all of these valves, which would have been huge. And, we were actually able to turn off all of the distribution pumps in all of the buildings with very little pressure drop.” The pressure drop through the old pumps was so minimal (less than 1 psi) that it did not make economic sense to remove them. “The three plant pumps, which are 100 horsepower each, handle the load. Depending on how many chillers we have online, we have one, two, or three pumps running at variable speed.”

In buildings with dual-temperature hydronic systems, the pumps that are kept off during cooling are then turned on during heating to circulate the water in a closed loop within the building through existing steam to hot-water heat exchangers. In these buildings the pumps were equipped with VFDs to provide variable flow in those buildings during heating. Due to the fact that there are larger potential temperature differences in heating, the flow can be reduced more than in cooling, further reducing pumping energy.

The means of addressing HVAC problems has also become more efficient with the upgrade at Loyola, he points out. “Before, there were situations where they would get a hot complaint and a maintenance guy would have to stop what he was doing, go out of the building to where this was, and try to address it, whereas now, half the time they can make an adjustment from the computer. In the cases where they can’t, they at least have a sense of what the problem could be because they’ve got the data—they can see whether or not there’s amperage on the pump or the fan or they can see if there’s a temperature issue. Now, you can go to any computer on campus and call it up on Internet Explorer, and so it’s not like they have to go to a boiler room. So it’s 21st century versus Stone Age.”

Another significant benefit of the vari-prime system is the comfort of the students and staff. Charlie McLauchlan reports that comfort complaints have virtually disappeared since the new system was implemented. “Chuck Jenkins, the chief campus engineer, told us that his boss, who is the campus facility director, called him at the end of that first cooling season and remarked that they basically didn’t get any hot complaints all summer. Before, what would happen was that somebody would complain and be told that it’s getting worked on—and they wouldn’t think anything was being done, so they’d start sending e-mails and calling as high up on the food chain as they could. The facilities director said, I don’t even remember the last time I got a call like that—this is unbelievable. He didn’t notice it until the summer was almost over.”

The lesson of this project, the consulting team stresses, is that achieving a significant energy savings in a complex, multifacility operation such as a college campus requires an integrative approach to energy infrastructure upgrades. This is in contrast to the traditional piecemeal approach of constructing new buildings entirely separately from each other. “One takeaway is the significance of transport energy—the pumping energy in this case—of moving BTUs around a campus,” says Don McLauchlan. “That transport energy is a very, very significant portion of the total energy needed. It presents an opportunity for saving energy. And then there’s the opportunity for just getting global and intelligent control of a campus where you don’t have all of these standalone controls. There are significant opportunities for getting a global control system where everything is talking to everything else and you’re making smart global decisions back at the central plant.”

“You need to continuously look at the big picture,” argues Hamill-Governale. “People will look at their building and look at the central facility as just a place to tap in. The fact is, there are many, many ramifications in the bigger system that can affect it, depending on how you tap in. Don’t forget about the big picture and continue to do master planning for every project you do.”

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