

Variable Primary Approach

H E L P S R E S T O R E F U L L C A P A C I T Y

Hospital adds more than 200 tons of cooling capacity without adding a new chiller or cooling tower

The situation at Berger Hospital in Circleville, Ohio, presented a paradox. The existing chilled water system could barely meet current demand, despite the fact that the three existing chillers were only operating at 60 percent of their installed tonnage. During peak demand, chillers 1 and 2 could only achieve a 10-F ΔT . Meanwhile, a remotely located, series-piped chiller (3) with a bypass could only drop chilled water temperature 6 F, resulting in an overall 40-percent loss in capacity. An upcoming expansion to an attached medical office building prompted the hospital to look for a solution.

An analysis of the existing system (Figure 1) revealed both control and mechanical issues. There were a cou-

ple of reasons why the system could not be loaded to full capacity:

- The existing chilled water plant consisted of two 200-ton screw chillers located in one mechanical room, and a third, remotely located, 200-ton centrifugal chiller; the chilled-water distribution was piped and controlled as a primary/secondary pumping system, which required the primary pumps to pump water to the remote chiller and back again before the secondary chilled water distribution began. The 6-in. piping connecting the two separate mechanical rooms was over 100-ft long and, thus, would only allow 400 tons of cooling to be delivered to the secondary distribution system. This is based on the fact that 400 tons equates to approximately 1,000 gpm at 10-F ΔT , which was

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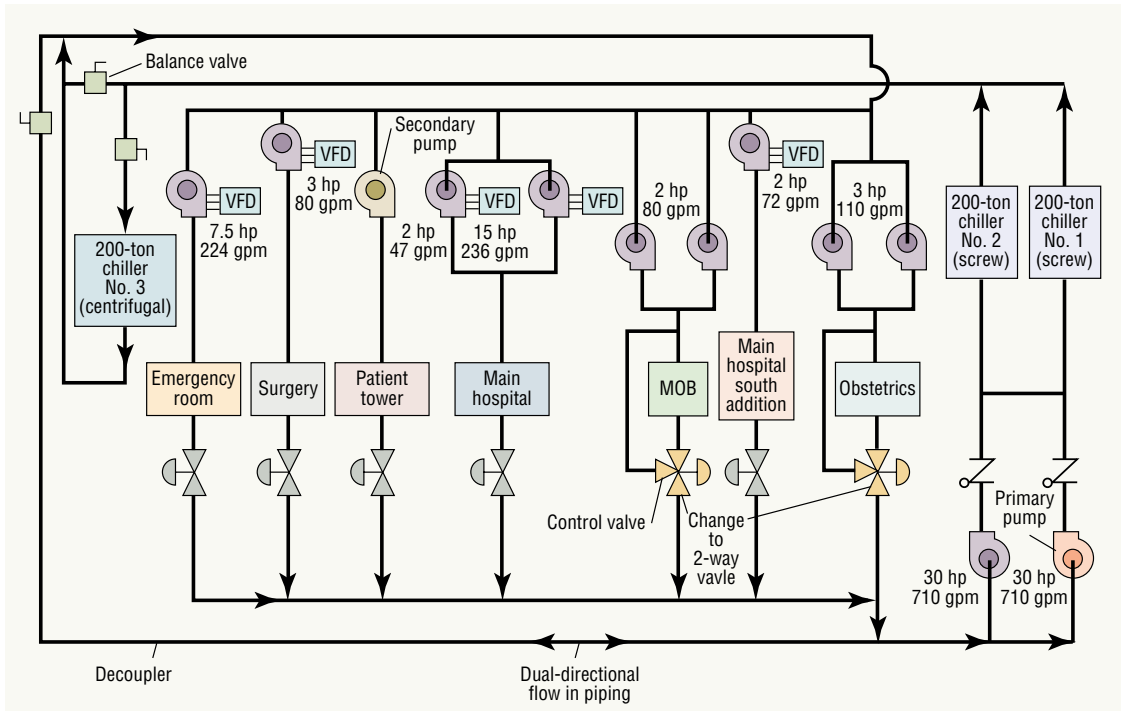


FIGURE 1. Original primary/secondary system design.

the best the hospital had ever achieved to date. Including the pressure drop through the remote chiller (approximately 16 ft of head), the piping and the fittings, the arrangement was costing the hospital an unnecessary 20.7 to 23 ft of head and subsequently increasing the need for more horsepower (Table 1).

- Chillers 1 and 2, which were piped in parallel, could not be effectively isolated from one another during periods of low demand. As a result, water from chillers 1 and 2 mixed in the common header, even if one chiller was not operating, increasing the temperature of the water going out into the system. To compensate for this loss in cooling, the supply water temperature had to be lowered on the chiller in operation so that once blending occurred in the common header, the overall supply water temperature could be maintained. This not only reduced the capacity of the operating chiller, it used more energy.

The predicament at Berger Hospital is not uncommon. Hospitals, especially, suffer the consequences of multiple expan-

sions. Without thorough master planning that is properly coordinated with hospital facilities' needs and budgets, subsequent upgrades can lack continuity. The immediate problem of meeting demand may be temporarily resolved, but existing design and operating issues (e.g., low- ΔT syndrome) are often compounded.

Given its current predicament, the hospital was considering a costly relocation of the remote chiller in order to pipe it in parallel with the other two machines. But there were disadvantages to this, including the expense of relocating a chiller, reworking the piping and electrical work, allocating space in the chiller room, and routing piping through tight areas. In addition, the main pipe size would have to be increased from 6 in. to 8 in. because a single chilled water plant would require all the flow needed to achieve 600 tons of cooling to enter the system from a single point. Given these facts, the costs would be comparable to adding a major piece of chilled water equipment.

PRIMARY CONVERSION AVERTS MAJOR RENOVATION

It looked as though Berger Hospital was headed for a major piping overhaul until the design team came up with a plan to utilize all of the capacity of the existing chillers without relocating the third chiller. Since the existing piping would only allow a little more than 400 tons of cooling, the challenge was to create a production and distribution chilled-water system capable of economically delivering 600 tons to the hospital within the existing mechanical structure and 6-in. piping.

The solution was a bi-directional-flow design, which would allow the necessary flow, thereby providing the required 600 tons of cooling (Figure 2). The design team determined that if the chilled water could be effectively distributed between two points of insertion (the separate chiller plants), then the existing primary loop pipe size would be adequate. In this type of distribution system, water flows from both chiller plants in head-on directions. Chilled water is distributed between these two insertion

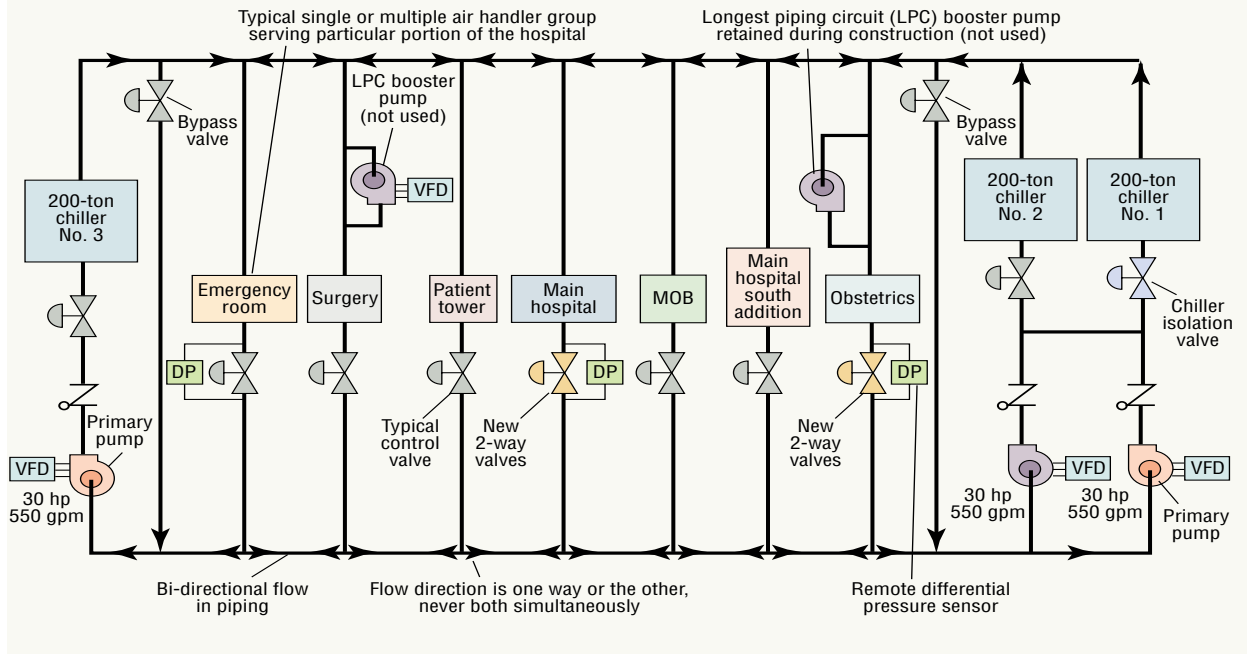


FIGURE 2. System converted to variable-primary/dual-plant system.

points so that a point of “no flow” actually exists in the chilled water supply pipe, and also in the chilled water return. The precise point of no flow is determined by the amount of flow required to meet system demand from each chiller/pump production loop. This effectively doubles the amount of water that can be distributed through the 6-in. pipe. In a typical one-way system, this would not be possible, since doubling the flow squares the pressure differential, and cubes the energy required to increase the flow.

With this in mind, the design team proposed a conversion from the existing primary/secondary system to a variable-primary flow (VPF) system in which water would be pumped into both ends of the distribution piping and disperse into the various loads located between the chillers. Under these conditions, chilled water would flow from each chiller as required and in both directions through the connection piping to achieve the design capacity of 600 tons. The design also provided an adaptive

control method to ensure equal loading of the chillers regardless of the chiller’s location within the system.

HOW IT WORKS

The new chilled water system eliminated all but two of the existing secondary pumps. These remaining two pumps were to be used as booster pumps during extremely high loads, as the design team determined it would be more cost-effective to employ booster pumps than to increase the main primary-pump sizes. Ultimately, the system did not require the extra pressure to achieve proper coil flow performance, and the two booster pumps were abandoned in place.

Instead of relying on secondary pumping, variable-speed primary pumps were placed at each of the three chillers, utilizing the existing direct piping tying the two plants together as the new bi-directional flow header. Because the chillers were no longer piped in series, the consequential additive pressure drops were eliminated. Instead, with the system being fed from both sides,

the flow in any one section of the primary piping was reduced—an effect similar to drinking out of two straws at once.

Isolation valves were added upstream of chillers 1 and 2 to prevent chilled-water bypass if only one chiller was operating. This prevents return water from mixing with the water from the active chiller’s discharge. Additionally, remote differential-pressure transmitters (DPTs) were added to measure and control pressure differential at selected major circuits for proper speed control of the variable-speed pumps. The DPT with a reading that is farthest below its setpoint is used to control the speed of the main chilled water pumps.

Each chiller is assigned to be part of the lead or lag loop, based on the remote differential-pressure setpoint, chilled-water flow, and/or tonnage demand. Once the lead chiller is activated, the subsequent machines come on-line according to remote sequencing controls that simultaneously access load, set-points, and operating

conditions. Adaptive controls were custom designed and implemented to meet the unique operating characteristics (pressure, flow, tonnage) of the system and the hospital (start/stop and outdoor temperature sequencing of machines).

A bypass valve was added downstream of each plant supply header for low-load periods when system two-way valves are primarily closed. The bypass allows a minimum flow of water to each operating chiller evaporator and prevents chiller low flow safeties from tripping-off the machine. The minimum flow required for each chiller was approximately 1 gpm, based on information provided by the chiller manufacturers. One of the unique characteristics of this particular system is the fact that the base load, which is nearly 200 tons, never requires the bypass valve to open.

Once the commissioning period was over, neither bypass valve was observed open at any time by facility personnel, or control and balance contractors, during the entire cooling season of summer 2003.

CONTROLLING THE NEW SYSTEM

After the mechanical configuration was determined, the control system was designed and specified based on the following requirements:

1) Control pump speed and cycling to satisfy the chilled water distribution remote DPTs. Setpoints were chosen based on historical operational data and then fine-tuned to minimize pump-horsepower usage.

2) Sequence chillers according to system load and the minimum and/or maximum flow requirements through the condenser barrels.

3) Operate the chiller pumps to produce equal loading of all chillers as though they were installed in the same equipment room. Proportional pressure

drops were maintained through each machine as the system pressures raised or lowered according to loading or pumping flows.

4) Provide control redundancy to assure hospital operations continue under all conditions.

5) Tie the new central plant control system in with the existing BAS.

6) Produce a more direct communication link with all operating staff, including a "touch screen" controller to simplify training.

7) Provide the capability to monitor and adjust the supply water-temperature setpoint while also monitoring its effect on kW usage per ton. This was accomplished with a flow meter with redundant temperature sensors on the supply and return piping on each circuit.

The control system continually monitors flow and ΔT and automatically adjusts operation so that the best combination of equipment is used for any given load condition. In this case, the hospital wanted to use chillers 1 and 2 whenever possible to avoid maintenance cost (based on hours of run time) of chiller 3. At the same time, the control system enhances performance by keeping equipment operating at its most efficient point.

The control system was also custom designed to meet the client's need for redundancy. This was especially critical in certain areas of the hospital. For instance, because operating rooms are economically essential to a hospital, it is important that the control system can provide back-up cooling service to this area's air handling units. To meet this need, a new central plant control system was designed with a separate, redundant controller dedicated to the entire chilled water plant. The redundant controller automatically "picks up the ball" should the central system fail, so that surgery schedules are maintained.

To help operators with day-to-day operation, the controller provides a user-friendly graphic interface with the system, allowing them to change setpoints, tonnages, and sequences. A user can observe the entire system from a single screen or click on individual components to get more detailed subscreens. This visual presentation of the system allows facility personnel to quickly get on track with the new control system.

200 TONS RESTORED

The Berger Hospital conversion from primary/secondary to VPF not only saved the hospital the cost of a major piping overhaul, it allowed the hospital to retrieve unused capacity from the existing chillers. More than 200 tons of cooling were added to the system without adding a new chiller or cooling tower. The hospital was also able to meet the increased load imposed by the office building expansion, and achieve the goal of 200 tons of back-up capacity. The chiller isolation valves eliminated any return water from bypassing chillers, resulting in lower discharge temperatures and better chilled-water coil performance. Further, increasing the primary pump flow (Table 1), allowed each machine to better accommodate the real-time system ΔT and, in combination with lower supply water temperatures, helped to rectify the chiller capacity reductions caused by low ΔT .

The alternative of adding chilled water equipment to the system or relocating the chiller could easily have doubled the project cost. The VPF conversion cost the hospital approximately \$300,000 to implement. If the hospital had alternatively purchased 200 tons of capacity to meet its need, it would have had to undergo a major chilled water-plant renovation, which would have cost an additional \$200,000 to \$300,000, includ-

Previous system							
Circuit	Flow (gpm)	Pressure (ft hd)	Design Delta T	VFD	hp	Yearly kw ⁴	Yearly cost ⁵
Primary loop	710	90	14	No	30	131,295	\$7,878
Secondary loops							
ER	224	68	14	Yes	7.5	32,824	\$1,969
Surgery	80	45	15	Yes	3	13,130	\$788
Patient tower	47	40	11	No	2	8,753	\$525
Main hospital	236	60	11	Yes	15	65,648	\$3,939
MOB	80	40	10	No	2	8,753	\$525
South addition	72	32	10	Yes	2	8,753	\$525
OB	110	48	10	No	3	13,130	\$788
Totals	849¹	158²	11.8³	--	64.5	282,285	\$16,937
Revised system							
Circuit	Flow (gpm)	Pressure (ft hd)	Design Delta T	VFD	hp	Yearly kw ⁴	Yearly cost ⁵
Entire system	550 × 2	135	8.7	Yes	30 × 2	131,295	\$7,878
Totals	1100	135	8.7	--	60	131,295	\$7,878

Notes:
¹Sum total of secondary only.
²Sum total of primary and largest secondary circuit pressure.
³Average Delta T of entire system.
⁴Hospital has 8-month cooling season. KW usage of pump with VFD is estimated to be 50 percent of constant speed pump operation based on pump affinity laws being 1/2 speed is only 1/8 of horsepower.
⁵Cost is based on 6 cents per kw.

TABLE 1. Pumping analysis of previous vs. revised system.

EWT	LWT	System Delta T	kw per ton ¹	Capacity (tons)	Efficiency reduction	Average annual load (tons) ²	Cooling operation (hours) ³	Cost savings potential for elevated LWT ³
57	44	13	0.662	207	--	325	5,869	--
57	43	14	0.671	207	1.36%	325	5,869	\$1,030
56	42	14	0.686	207	3.63%	325	5,869	\$2,747
54.7	41	13.7	0.696	204	5.14%	325	5,869	\$3,891
53	40	13	0.71	200	7.25%	325	5,869	\$5,493
52	39	13	0.724	196	9.37%	325	5,869	\$7,096

Notes:
¹Data provided by York International.
²Load ranges from 200 to 450 tons.
³Cost based on 6 cents per kw average electrical cost.
⁴Based on 8-month cooling season at 24-hr building operation.

TABLE 2. Existing screw chiller performance analysis.

ing the cost of construction phasing necessary to minimize system downtime. Rising pump maintenance costs were also curtailed, as four of the 14 previous pumps were at or beyond their expected service life.

ADJUSTING TO THE BIG CHILL

There were some minor, unanticipated adjustments that had to be made after the project was complete. The thermostats and discharge air sensors on the air handlers had to be recalibrated due to colder water temperatures at the coils since the elimination of primary/secondary blending and low ΔT. Previously, some ther-

mostats had been set at their lowest point just to maintain cooling. So when the new system came online, there was briefly some increased energy usage due to overcooling. Once the adjustments were made, energy consumption stabilized. In fact, thanks to new VFDs and the reduction in pump horsepower, the converted chiller plant's total annual load profile is now more efficient than the previous configuration. Total KW usage was reduced as a result of the reduction in total pumping horsepower and the increased discharge temperatures on the chillers.

THE RESULTING SAVINGS

Because the new system helps eliminate the blending of return water with supply water, the chiller supply water temperature can be raised without compromising the entering coil temperatures. Table 2 demonstrates the effect of raising supply-water temperature on chiller efficiency, and the resulting capacity of the existing chillers.

LOOKING AHEAD

Having accomplished all its goals and more, the hospital plans to add another 200-ton chiller to the loop, creating equal sides of the integrated system, which will help it meet its increasing needs of yet another expansion. The chiller addition will be remarkably simple, requiring only one new chilled-water pump and no modifications to the existing distribution system beyond the supply and return connections to the new chiller. A larger, higher efficiency 400-ton cooling tower is also being added to replace the existing 200-ton tower serving the older centrifugal chiller.

There are also plans to convert the condenser water system to a variable flow to increase overall efficiency (Figure 3). Because varying flow through cooling towers can compromise distribution, it is essential that the tower's minimum flow requirement be verified by the manufacturer. In this case, it was determined that the tower required a minimum of 50-percent flow.

The existing controls will be modified to provide fully integrated control of the new equipment. The controls will continually assess usage of cooling tower fan KW, condenser and chilled water pump KW, and chiller KW to determine the most effi-

cient combination of equipment for any given load. The control system will also allow the hospital to have Web-based access for remote monitoring and adjustment. The goal is to further improve operation and reduce maintenance cost. The staff can immediately troubleshoot the system from a PC connected to the hospital's IT network or from any remote location.

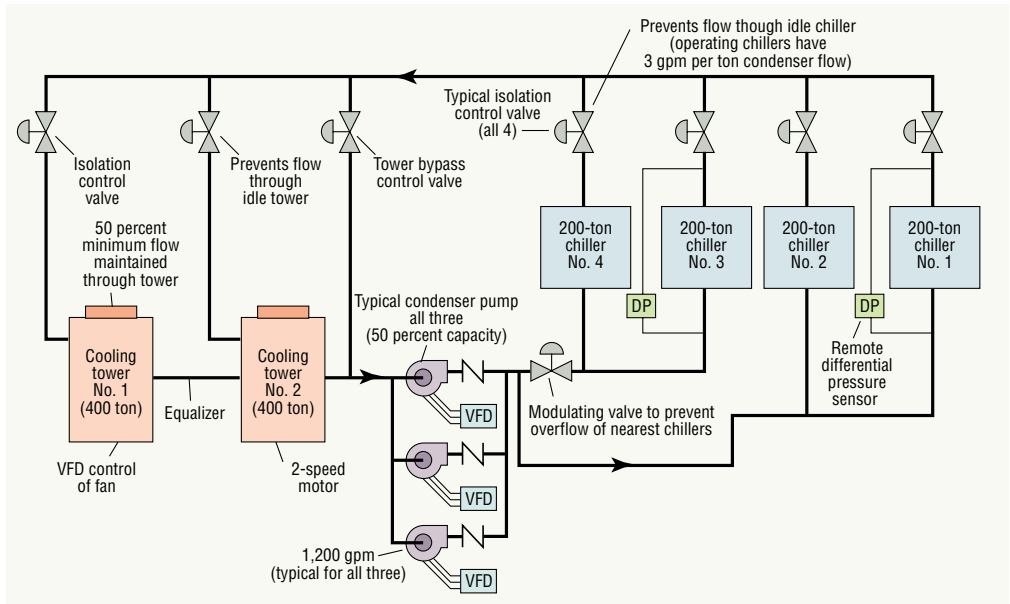


FIGURE 3. VP flow condenser water.

As facilities struggle in the current economy to meet their most basic needs for renovation, creative solutions such as this one can help keep costs

under control. In addition, the overall success was enough to earn the project an ASHRAE Regional Technology Award in the Existing

Healthcare Facilities category.

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