TRANE

engineers newsletter

providing insights for today's hvac system designer

don't overlook optimization opportunities in "Small" Chilled Water Systems

from the editor …
HVAC-system design engineers and their clients share a common desire: To be more competitive and profitable. Design engineers pursue this goal by tailoring a combination of equipment and system-level options to the unique requirements of the application. Often the solution uses chilled water to provide high-quality, cost-effective air conditioning. When the application is a central chilled water plant, the design is likely to include one or more optimization strategies, such as variable flow or temperature reset.

But chilled water cooling isn't limited to large installations and water-cooled chillers. In this issue, veteran applications engineer, Don Eppelheimer, considers the relevance of three popular optimization strategies—low flow (wide ΔT), variable flow, and chilled water reset—in "small" chilled water systems.

The simplicity, reliability, and low installed cost of chilled water make it a viable option for applications as small as 10 tons. Ironically, though, "chilled water" often is equated with "central chilled water plant"—a term that conjures up visions of voluminous cooling towers, rows of large, high-capacity chillers, and batteries of variable-speed pumps sending chilled water throughout a hospital or campus.

Applications of this type are particularly well-suited for centrifugal chillers because of the compressor's variable-volume load characteristic. At the time of manufacture, the centrifugal chiller can be designed for a specific lift and capacity by changing the impeller diameter. Inlet vanes efficiently regulate compressor capacity, while tip speed control enables the compressor to respond to seasonal changes in lift.

Previous issues of the *Engineers Newsletter* discussed strategies to optimize pumping, plant partitioning, and cooling tower operation (see "Engineers Newsletter archive" below). All of these strategies share the same design goal: *Reduce the cost of owning and operating the HVAC system*. These strategies favor large chilled water plants and centrifugal compressors, where chiller efficiency provides operating cost savings that help offset the cost of additional pumps and controls.

But in small chilled water applications, it may not be possible to rationalize the higher price tag for a centrifugal chiller or an elaborate automation system.

"Small" chilled water applications commonly employ chillers with screw, scroll, or reciprocating compressors.[1] These positive-displacement compressors respond differently than centrifugal compressors to changes in

Engineers Newsletter archive

In recent years, we've published a number of articles describing ways to optimize the performance of chilled water systems. You can find the following articles on chilled-water plant design in our online archive at http://www.trane.com/commercial/library/archived_newsletters.asp:

- Variable-primary-flow systems revisited (2002: volume 31-4)
- Cold air makes good $ense (2000: volume 29-2)
- Chilled water plants and asymmetry as a basis of design (1999: volume 28-4)
- An idea for chilled-water plants whose time has come: Variable-primary-flow systems (1999: volume 28-3)
- How low-flow systems can help you give your customers what they want (1997: volume 26-2)
- Tower water temperature: Control it how? (1995: volume 24-1)
- How much ice? (1990: volume 19-1)
- An engineering strategy for ice storage (1987: volume 16-6)

You'll also find past *EN*s on design considerations for air-distribution and refrigerant-to-air systems, as well as on relevant industry standards and codes, acoustics, energy, and the environment. ■

---

[1] "Small" and "large" are highly subjective terms. For the sake of this discussion, a "small chilled water system" uses chillers with positive-displacement compressors. "Small" might also describe an application where variable-flow pumping is difficult to justify or implement, as in the 30-ton system discussed at the end of this newsletter.

leaving chilled water temperature and leaving condenser water temperature.

While the massive flow rates of large chilled water plants make it easy to justify variable-flow chilled water distribution, smaller chilled water systems may not consume enough pump energy to warrant the added cost and complexity of variable-flow pumping schemes. Nor are some small-capacity chillers equipped to tolerate variable water flow through the evaporator. Moreover, the popularity of air-cooled chillers in small chilled water systems makes the debate about chiller efficiency versus condenser pump efficiency moot.

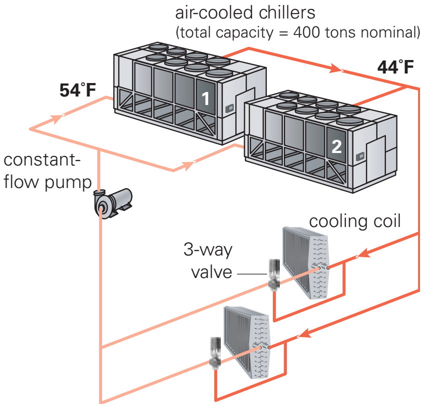
Which, if any, of the design and control concepts that work so well in large chilled water plants are suitable for smaller systems? To find out, let's compare the benefits of reduced chilled water flow, variable chilled water flow, and series evaporators, as well as chilled water reset when variable flow isn't an option.

Parallel or Series?

Base case. Our example is a conventional, "no frills" chilled water system that uses air-cooled chillers with positive-displacement compressors. The design is based on a 10°F rise in chilled water temperature (ΔT) and constant water flow. Three-way valves regulate flow through the cooling coils. These criteria result in the chiller and pump selections in Figure 1.

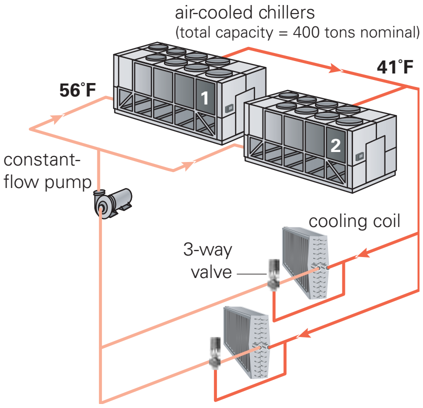
What is the pumping cost in such a system? At 10 cents per kilowatt-hour, the cost of running the constant-volume pump amounts to $1.39 per hour. If the pump operates 2000 hours annually (typical loading for comfort cooling), then the annual pumping cost is about $2800. What can be done to reduce this expense?

Figure 1. Parallel chillers with 10°F ΔT



	unit 1	unit 2	
leaving water	**44**	**44**	**°F**
chiller efficiency	**10.1**	**10.1**	**EER**
chiller capacity	**204**	**204**	**tons**
pump power		**17.2**	**hp**

Figure 2. Parallel chillers with 15°F ΔT



	unit 1	unit 2	
leaving water	**41**	**41**	**°F**
chiller efficiency	**9.9**	**9.9**	**EER**
chiller capacity	**194**	**194**	**tons**
pump power		**7.6**	**hp**

Colder water, lower flow. Producing colder water (Figure 2) would allow us to circulate less chilled water without compromising coil capacity.[2] Circulating less water substantially lowers the pressure drop through the chiller, cooling coils, and distribution piping. Dropping the chilled water temperature, by 3 degrees in this case, reduces the required pump power by more than half. Now the annual cost of moving chilled water is less than $1240 … that's more than $1500 *less* than the annual pumping cost in the original design.

Basing the design on constant flow means that it is compatible with the unit controllers on most chillers; it also avoids the expense of a variable-speed drive on the chilled water pump. But this low-flow solution is not without disappointments: Chiller *efficiency* drops by 2 percent and chiller *capacity* decreases by 20 tons. Given the operating characteristics of positive-displacement compressors, simply switching from one compressor type to another is unlikely to avoid these losses. (See "Compressor axioms," p. 3.)

Colder water, series evaporators. Is it possible to recover the lost chiller capacity and efficiency and still produce colder chilled water? Absolutely. The key is to *pipe the evaporators in series* (Figure 3). This design strategy trades increased pressure drop for improvements in chiller capacity and efficiency.

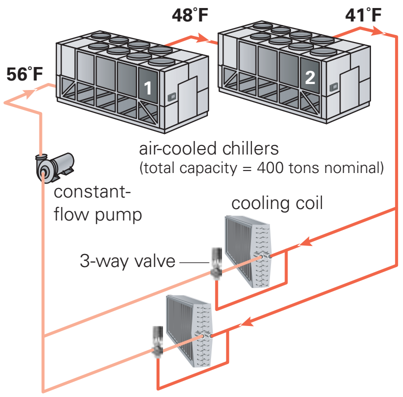
Although the annual pumping cost climbs to $2570, which only trims about $200 from the original design (Figure 1), piping the evaporators in series improves the chiller efficiency of the design in Figure 2 by 3 percent—*and* adds 24 tons of capacity.

What about variable flow? If the chiller controls can accommodate variable water flow through the evaporator, altering the series low-flow design (Figure 3) to include variable

---

[2] D. Eppelheimer, "Cooling-coil heat transfer: Keystone of system performance," Trane *Engineers Newsletter* 31-1, 2002. [online; cited 13 Nov 2003] <http://www.trane.com/commercial/library/vol31_1/adm_apn002_en_021302.pdf>

Figure 3. Series chillers with 15°F ΔT



	unit 1	unit 2	
leaving water	**48**	**41**	**°F**
chiller efficiency	**10.5**	**9.8**	**EER**
chiller capacity	**219**	**193**	**tons**
pump power		**15.8**	**hp**

primary flow could halve the annual pumping expense and make an acceptable payback more likely. Otherwise, implementing a variable-flow pumping scheme will require a primary–secondary piping arrangement. It's unlikely that annual savings of only $1400 will justify the upfront investment in both a constant-flow primary pump *and* a variable-flow secondary pump.

Weighing the options. So which design is "best" for our example system: Low ΔT or high ΔT? Parallel chillers or series chillers? Will an investment in variable flow provide a satisfactory return?

Fortunately, this dilemma is easily resolved with the help of a simple energy study. Most of the software tools available from chiller manufacturers perform an hour-by-hour load analysis, making the guesswork of bin methods unnecessary. Table 1 summarizes the results of such an analysis for our hypothetical system.

Table 1. Projected energy use of a hypothetical, 400-ton air-cooled-chiller system[a]

		Annual energy consumption, kWh[b]		
Design option		Pumps	Chillers	System
Parallel chillers, 10°F ΔT, constant flow	(Figure 1)	28,897	335,684	405,187
Parallel chillers, 15°F ΔT, constant flow	(Figure 2)	12,617	340,512	393,850
Series chillers, 15°F ΔT, constant flow	(Figure 3)	26,658	325,480	392,501
Series chillers, 15°F ΔT, variable flow	(not shown)	16,108	325,480	381,951

[a] The effects of the design variations for this hypothetical system were estimated with the help of chiller-plant analysis software. Such software can help you quickly identify viable system design options.

[b] Pump energy is based on a motor efficiency of 92%. System energy consumption includes condenser fans, pump, and chillers (compressors).

Chilled Water Reset

It may be easy to generate an attractive payback for a series evaporator arrangement and variable flow when the chillers are large enough, with sufficiently sophisticated controls to accommodate variable evaporator flow. But what options exist for small chillers and simple controllers that preclude variable evaporator flow?

Series evaporators and a wide ΔT remain viable concepts for even the smallest chillers. But perhaps there's another way to recoup the cost of pumping energy in lieu of a variable flow scheme …

Most chiller controls readily support chilled water reset (see sidebar on p. 4). Implementing chilled water reset is particularly easy when two small chillers are piped in series: *Use a warmer setpoint to control the upstream chiller and a colder setpoint to control the downstream chiller* (Figure 4, p. 4).

During humid weather, cold chilled water (42°F in this case) allows proper dehumidification and assures ample cooling capacity at all coils. The off-peak cooling season (spring and autumn) often requires less dehumidification. For the 30-ton system in Figure 4, supplying the coils with 48°F to 50°F chilled water may provide enough capacity to satisfy most off-peak cooling needs. Chilled water reset can be achieved simply by turning off the downstream chiller.

Savings made simple. Circulating the chilled water in this small system requires less than 1 kilowatt of power,

Compressor axioms

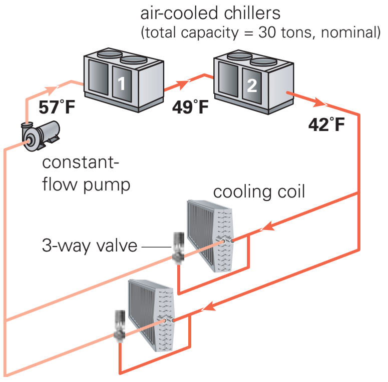
Compressor capacity increases as suction temperature rises (assuming that the condensing temperature remains constant). Therefore, control strategies that result in lower suction temperature will also decrease the available cooling.

Compressor efficiency increases as head pressure decreases. So, control strategies that result in a higher head pressure will make the compressor work harder (consume more energy).

The magnitude of these effects is significantly less for chillers that use centrifugal rather than positive-displacement compression. That's because centrifugal compressors increase the temperature and pressure of refrigerant by dynamically converting flow velocity to static pressure. Positive-displacement compressors (screw, scroll, reciprocating) "work" on the refrigerant by trapping it and shrinking its volume. For more information about compression technologies and their operating characteristics, see Chapter 34, "Compressors," in the *2000 ASHRAE Handbook–HVAC Systems and Equipment*. ■

"providing insights for today's HVAC system designer"

Figure 4. Series chillers and 15°F ΔT in a 30-ton chilled water system



	unit 1	unit 2	
leaving water	49	42	°F
chiller efficiency	12.0	11.0	EER
chiller capacity	14.9	13.1	tons
pump power		1.2	hp

or about 10 cents per hour. An energy study estimates the pumping cost at slightly more than $200 per year. A study of the same system with chilled water reset (that is, shutting off the downstream chiller during off-peak cooling) projects annual savings of $160. In this case, intelligent sequencing of series-piped chillers saved enough chiller energy to offset a sizable portion of the pumping costs. *Finding* the potential savings, however, demanded a simple-but-necessary energy analysis.

Closing Thoughts

Many of the energy-conserving strategies developed for large chilled water plants transpose easily to small chilled water systems. The potential benefits of implementation are the same, whether the installation is “large” or “small.”

Your challenge as a design engineer is to leverage the compressor’s operating characteristics in each application. When properly selected, a centrifugal chiller will readily provide money-saving efficiency at virtually any temperature condition. By comparison, a chiller with a positive-displacement compressor will respond to changes in water temperature with a more dramatic loss or gain in capacity and efficiency.

Remember, too, that optimization strategies are not exclusive to central chilled water plants. Simple energy studies that project the effect of series evaporators and chilled water reset may help you justify the advantages of chilled water in smaller comfort cooling applications. ■

By Don Eppelheimer, applications engineer, and Brenda Bradley, information designer, Trane.

You can find this and other issues of the Engineers Newsletter at http://www.trane.com/commercial/library/newsletters.asp. To comment, e-mail us at comfort@trane.com.

Chilled water reset

Chilled water reset (CWR)—that is, raising the chiller’s control setpoint—is common practice in many chilled water plants as a means of reducing *chiller* energy consumption. In constant-flow applications, CWR is relatively easy to implement and can be controlled based on the drop in return-water temperature.

In variable-flow systems, however, raising the supply-water temperature increases pumping energy. While *chiller* COP ranges from 2.80 to 6.10[1] (depending on compressor type), *pump* COP is only about 0.65. Often the increased pumping energy will more than offset the savings in chiller energy—especially if the chiller typically operates at part-load conditions.

Of course, circulating warmer chilled water through the cooling coils also raises the leaving-coil air temperature, perhaps to the point that it can no longer adequately dehumidify the space.

Although ASHRAE/IESNA Standard 90.1–2001 (Section 6.3.4.3) requires use of chilled-water-temperature reset in systems larger than 25 tons (88 kW), it exempts variable-flow systems and systems in which CWR would compromise space humidity control. ■

Pro:

- Reduces chiller energy

Cons:

- Increases pump energy in variable-flow systems
- Can interfere with control of space humidity
- Complicates chiller sequencing

---

[1] COP range brackets Standard 90.1’s minimum efficiency requirements for air- and water-cooled chillers with reciprocating, screw, scroll, or centrifugal compressors.

Trane
A business of American Standard Companies
www.trane.com

For more information, contact your local district office or e-mail us at comfort@trane.com