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Variable-Primary-Flow Systems Revisited

from the editor…
Obtaining reliable, cost-effective HVAC performance remains a priority for building owners, facility managers, and system designers alike. A 1999 Engineers Newsletter *(volume 23, number 3) discussed one avenue for achieving that goal in a chilled water system: variable primary flow.*

The growing number of successful VPF installations has broadened their acceptance, as well as our experience with them. Yet the inherent complexity makes many building professionals reluctant to implement variable primary flow. If this describes you, perhaps this EN *will allay your fears. In it, we provide specific guidelines for designing and operating a VPF plant, and identify key equipment characteristics that are particularly critical for reliable operation.*

The desire to make or save money lies at the heart of many of our decisions. In the context of HVAC design, decisions made to save money often involve a tradeoff between acquisition expense and operating cost. If you can realize savings on both fronts, so much the better.

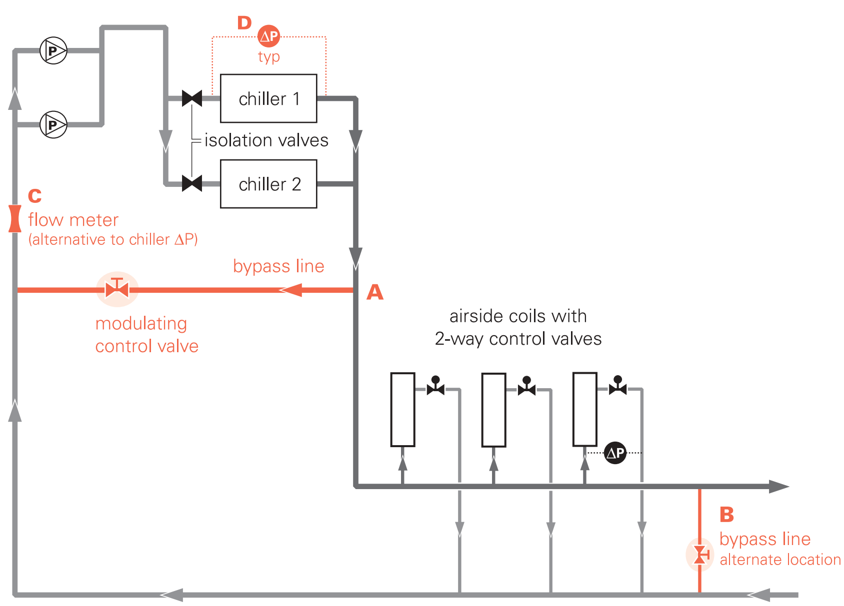
Perhaps this explains the increased interest in chilled water systems with **variable primary flow** (VPF). VPF designs use fewer pumps and fewer piping connections than primary–secondary systems, which means fewer electrical lines and a smaller footprint for the plant. These factors reduce the initial cost of the chilled water system.[1]

As for operating costs, how much a VPF design saves depends on the pressure drops and efficiency of the pumps.[2] A VPF design displaces the small, inefficient, low-head primary pumps used in primary–secondary systems. The pressure drops previously satisfied by the primary pumps are instead satisfied by the distribution pumps, permitting selection of larger, more efficient pumps (with efficiencies similar to those of the *secondary* pumps in a primary–secondary system).

[1] The savings may be partially offset by additional costs for flow-monitoring and bypass flow (bypass line and control valve). VPF designs may also require more programming for system control than other designs.

[2] Bahnfleth and Peyer discuss the operational savings of VPF designs in "Comparative Analysis of Variable and Constant Primary-Flow Chilled-Water-Plant Performance" (*HPAC Engineering,* April 2001). For most common systems, however, the primary pump power on which they base their assessment may be too high.

Figure 1. Variable-primary-flow system (chilled water loop)



What Makes VPF Systems Different

Before we identify the ingredients that go into the successful application of variable primary flow, let's review the traits that distinguish this type of system from the more familiar primary–secondary design, which hydraulically "decouples" the constant-flow production side of the chilled water loop from the variable-flow distribution side.

The VPF design *eliminates the constant-flow chiller pumps* and uses the variable-flow pumps to circulate water throughout the entire chilled water loop (Figure 1, p. 1). Both systems include a bypass line. However, notice that the VPF design adds a modulating control valve in the bypass line. At low loads, the bypass valve delivers the water necessary to maintain the minimum evaporator-flow limit of each operating chiller. By contrast, the bypass line in a primary–secondary system ensures constant chiller flow at all times.

Table 1. Flow-rate changes that result from isolation-valve operation

	Number of operating chillers				
	1	2	3	4	5
Flow-rate reduction when an isolation valve opens[a]	50%	33%	25%	20%	17%

[a] Flow-rate reduction is expressed as a percentage of the actual chilled water flow rate prior to transition:

$$\%\ \text{flow-rate reduction} = 1 - \frac{\text{number of chillers operating}}{\text{number of chillers operating} + 1}$$

A less obvious difference between variable and constant primary flow lies in system operation. In a primary–secondary system, a chiller and its primary pump typically operate in tandem. *The VPF design can separate pump control* (delivering enough water) *from chiller sequencing* (making the water cold enough).

Like the secondary pump in a primary–secondary system, the pumps in a typical VPF system operate to maintain a target differential pressure, ΔP, at a specific point in the system (Figure 1). This pressure difference tends to decrease when the air-handler control valves open in response to increasing loads. To restore the ΔP across the system, the pump controller increases the speed of the pump. Conversely, when the air-handler control valves close in response to decreased coil loads, the pump controller slows the pump speed to maintain the target ΔP.

Meanwhile, the plant controller stages the chillers on and off to match cooling capacity with system load. If the air handlers operate properly, the difference between the return- and supply-water temperatures, ΔT, remains nearly constant. Therefore, increasing the water flow through the chiller evaporators increases the load on the operating chillers.

Evaporator flow limits

Chiller manufacturers specify minimum and maximum limits for evaporator water flow. Their objective?

- To promote good heat transfer and stable control (minimum flow limit)
- To deter vibration and tube erosion (maximum flow limit)

As recently as three years ago, the typical range was 3 ft/sec to 11 ft/sec. Since then, manufacturer-conducted testing shows that specific chillers may accommodate evaporator flow rates as low as 1.5 ft/sec, depending on tube type. This is good news for VPF systems because it extends the chiller's ability to operate effectively without the addition of bypass flow.

You can lower the minimum flow limit for a chiller by selecting an evaporator with more passes (a common option for machines with cooling capacities of 150 tons or more). Granted, more passes mean a higher evaporator pressure drop and more pumping power. However, each reduction of the system flow rate also reduces the evaporator pressure drop by approximately the square of the flow rate. Therefore, the pump will require less extra power to work against the pressure drop as the system flow rate drops below the design value.

Small packaged chillers typically offer less design flexibility than larger machines. It may not be possible to select one for a minimum flow rate of less than 60 percent of the design system flow … But don't let this deter you from designing a VPF plant that includes small packaged chillers. Just be sure to devise a sequencing strategy that accommodates the chiller's minimum evaporator-flow limit. ■

Challenges of Variable Primary Flow

Varying the water-flow rate through the chiller evaporator poses two control challenges for those who design and operate VPF systems:

- Maintain the chiller flow rate between the minimum and maximum limits of the evaporator.
- Manage transient flows without compromising stable operation, especially in multichiller plants.

"Transient flows" refer to the hydraulic effects caused by an isolation valve when it opens (before the associated chiller starts) or closes (after the chiller stops). To illustrate what happens, let's look at an example.

Assume that the two-chiller VPF system in Figure 1 (p. 1) is designed for a 16°F ΔT and that it delivers 40°F chilled water. The temperature of the return water remains relatively constant at 56°F, provided that the coils and two-way valves function properly. Only Chiller 1 operates when the cooling load is low; the isolation valve for Chiller 2 remains closed.

As the cooling load increases, the pump controller increases the rate of chilled water flow through the system. Chiller 2 starts when Chiller 1 can no longer produce 40°F water. Opening the isolation valve for Chiller 2 almost instantly reduces the flow rate through Chiller 1 *by half* (Table 1), which effectively doubles the ΔT. Chiller 1's controller will unload the machine as quickly as possible, but in the interim, it will attempt to produce a 32°F ΔT and cool the water to 24°F. If the chiller cannot unload quickly enough, built-in fail-safes should stop and lock out the chiller before damage occurs … but at the expense of satisfying the cooling load.

Guidelines for Success

Designing a VPF chilled water plant that performs reliably at *all* load conditions requires careful attention to chiller selection, bypass flow, plant configuration, and system control.

Chiller selection

Select for a minimum evaporator-flow limit that is ≤ 60 percent of the chiller's design flow rate.

One benefit of VPF systems is reduced pumping energy. To accrue this benefit, chilled water flow must not remain constant. As the flow decreases, it approaches the minimum flow rate of the chillers … So, how do we select for a minimum chiller flow rate that will accrue the pump-energy savings?

The answer depends on the type of chiller, but generally speaking, *lower is better* because it extends the ability of a single chiller to operate at low loads without bypass flow. Most of the potential savings are realized by the time that the system flow rate decreases to 50 percent of design.

Holistic plant operation

Some practitioners believe that operating more chillers at the same time permits each chiller to operate more efficiently. Remember that the chillers are not the sole energy consumers in the plant. Activating the chillers also activates the condenser water pumps and tower fans.

Determine the optimum control sequence for the *entire plant* by performing a detailed energy analysis of each component. Base the analysis on realistic load profiles and ambient conditions, and be sure to account for simultaneous energy use of auxiliary equipment. ■

Our experience with actual VPF plants indicates that a minimum evaporator-flow limit of 60 percent for packaged chillers and 40 percent or less for configured chillers work well.

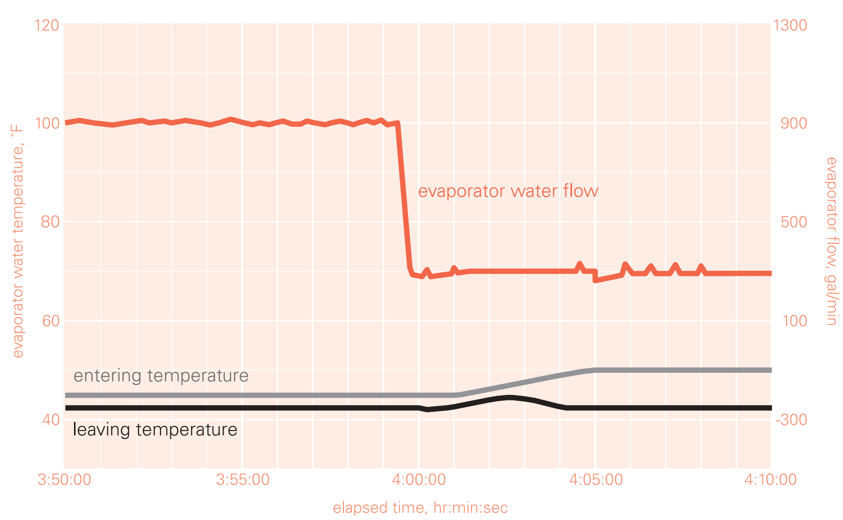
Select for the greatest tolerance to large changes in flow rate.

The objective is to simplify system control by minimizing the need for "supplemental" demand limiting or valve control as chillers come online. Chillers that are well-suited for variable primary flow can tolerate and respond to rapid flow-rate changes (Table 1). Selecting chillers with these characteristics improves the likelihood of stable, uninterrupted operation.

Estimate the expected flow-rate changes and *make sure that the chillers you select can adapt to them.* For example, one of the newest unit controllers (Figure 2) on the market can reliably maintain the desired chilled water temperature with a flow-rate reduction of 67 percent.

Another, less robust chiller controller permits flow-rate changes of less than

Figure 2. Example of chiller control responsiveness to flow-rate reduction *



* Data represents a Trane CH530 chiller controller with flow compensation.

Table 2. Effect of dissimilar evaporator pressure drops

	Capacity, tons	Flow rate, gal/min		Pressure drop, ft H_2O[a]		
		Selection	Actual	Selection	Actual	Change, %
Chiller 1	500	750	819	12	14.3	+9.2
Chiller 2	300	450	381	20	14.3	-15.3

[a] Values shown here are based on the assumption that pressure drop changes with the square of the flow rate.

2 percent per minute and would need 30 minutes to adapt to a flow-rate reduction of 50 percent. Fluctuations of 2 percent or more are typical, even during normal system operation. Attempting to limit flow-rate changes to this extent while starting or stopping a chiller is impractical, if not impossible.

When comparing prospective chillers, consider the transient-flow tolerance of the unit controllers. Then *work closely with the chiller manufacturer* to devise a flow-transition sequence that accounts for the unique operating characteristics of both the chiller and the application.

✔ *Select for nearly equal pressure drops across all chiller evaporators.*

A VPF design loads and unloads the chiller(s) based primarily on the rate of water flow through the evaporator. If a difference in size or type of evaporator gives one chiller a lower pressure drop than the others in the plant, that chiller will receive a higher rate of water flow and a correspondingly greater load.

Dissimilar pressure drops can make it difficult to provide stable plant operation. Table 2 demonstrates this effect in a two-chiller system (similar to the one shown in Figure 1). In this case, more water flows through Chiller 1's evaporator because its pressure drop is lower than that of Chiller 2. Load is proportional to flow rate and temperature difference, tons = (gpm × ΔT) / 24. Because Chiller 1 is asked to satisfy a load that exceeds its capacity, it cannot satisfy the chilled water setpoint when the return water temperature equals the design condition. Meanwhile, Chiller 2 is less than fully loaded.

Balancing the system at the design condition reduces this problem, but does not guarantee proper distribution of the flow at part load. Alternatively, you could increase the load on Chiller 2 by lowering its chilled water setpoint; however, this complicates system control. The simplest solution is to select chillers that have (nearly) equal pressure drops at their design flow rates.

Bypass flow

The sole purpose of the bypass line with modulating control valve is to assure that the rate of chilled water flow through each operating chiller never falls below the minimum limit required by the manufacturer. Delivering the appropriate bypass flow requires attention to line sizing, control-valve selection, and the response time of the system.

✔ *Select a suitable control valve of high quality.*

When the bypass line is positioned near the chiller plant (**A** in Figure 1, p. 1), as it is in many VPF installations, the control valve is exposed to comparatively high operating pressures. Selecting an appropriate valve actuator is critical because the valve must close against this pressure. As for the valve itself, choose one that maintains a linear relationship between valve position and flow rate; otherwise,

Don't scrimp on accurate flow measurement

The success of a variable-primary-flow installation depends on the quality of the flow-measuring device that controls the system bypass valve (and perhaps also indicates the plant load). Some practitioners use a flow meter[1] to directly detect the flow rate (**C** in Figure 1); others use a differential pressure sensor (**D**) that monitors the change in water pressure across the chiller evaporator and then correlates the pressure differential to a water flow rate.

Regardless of which type of device you use, the flow meter or differential pressure sensor must be of high quality; that is, the device must provide *accurate and repeatable* measurements. For the plant to operate well, the device also must remain calibrated and perform reliably over time. Purchase prices vary widely, but the adage "you get what you pay for" typically holds true. In our experience, the cost of a suitable flow-measuring device is closer to $1,000 USD than to $100 USD. Put simply, don't compromise on accurate sensing devices when negotiating potential cost reductions during the "value engineering" phase of a project.

One further caveat about measurement accuracy: Proper installation is critical to ensure accurate readings. If the manufacturer states that at least 10 pipe diameters of uninterrupted flow are required both upstream and downstream of the sensing device, then make sure that the piping layout complies. ■

[1] D. Houghton PE, "Know your flow—a market survey of liquid flow meters," E SOURCE *Tech Update* TU-96-3, March 1996.

the valve may permit too much water flow when it begins to open.

Note: A common butterfly valve won't provide the necessary flow characteristics. Verify the suitability of a particular valve by requesting flow-versus-position data from the supplier.

Locating the bypass line far from the chiller plant (**B** in Figure 1) lowers the operating pressure for the control valve.

✔ *Select flow-sensing devices that provide precise, repeatable measurements.*

Accurate flow-sensing is the linchpin in VPF applications that work well … and the root cause of most problems in those that don't. Avoid sacrificing accuracy for lower cost unless you're willing to jeopardize the reliability of the entire cooling system. (See the inset titled "Don't Scrimp on Accurate Flow Measurement" on p. 4.)

✔ *Select an accurate proof-of-flow device for each chiller.*

Flow reductions through chillers in VPF systems often cause paddle-type flow switches to flutter or open altogether, which shuts down the chiller. To avoid nuisance trips and provide accurate, reliable confirmation of flow, select a sensitive pressure-differential switch and install it properly, piping it across the evaporator.

✔ *Minimize control lag.*

Regardless of where the bypass line is situated (at **A** or **B** in Figure 1), the control valve must react quickly to changes in system flow. You can improve control response either by hard-wiring the flow-sensing device, valve controller, and valve actuator; *or* by selecting devices that communicate directly with each other. Avoid relaying input/output signals through multiple system controllers.

Chiller sequencing

Proper sequencing helps to maintain the flow rate through each evaporator within the range recommended by the chiller manufacturer. As the system flow nears the maximum limit for the operating chiller(s), another machine must be brought online. Similarly, as the system load and flow decrease, chillers must be shut down to reduce the need for bypass water flow.

✔ *Temporarily unload the operating chillers before starting the next one.*

Reduce shock resulting from transient flows by unloading the operating chillers *before* opening an isolation valve to bring another chiller online. You can accomplish this by imposing a demand limit of 50-to-60 percent on the operating chillers, or by raising the chilled water setpoint one to three minutes before the isolation valve actuates.[3]

✔ *Open the chiller isolation valves slowly to encourage stable operation.*

How slowly? That depends. If the chiller controller can only handle a flow-rate change of 2 percent per minute, then the isolation valve must take 30 minutes to open … far too long for most applications.

In our 1999 *Engineers Newsletter* on VPF systems, we noted that "[with] sophisticated chiller controls, a 30-percent-per-minute change in the rate of flow should work well in most applications." At this rate, the isolation

Flow-rate control

The *Engineers Newsletter* typically limits its discussions to system control and avoids commenting on the capabilities of specific products. However, because the stable operation of a variable-primary-flow plant relies heavily on the operating characteristics of the chillers, we offer the following profile of Trane equipment. ■

Variable-flow tolerances of Trane chillers

Chiller type	Unit control module	Allowable flow-rate change (% of design flow per minute)
Absorption	UCP1	Not recommended for VPF[a]
	UCP2	30% for comfort cooling 10% for process control
Scroll compressor	All	10%
Helical-rotary compressor	UCP1	Not recommended for VPF[a]
	UCP2, UCM, and CH530 without flow compensation[b]	30% for comfort cooling 10% for process control
Centrifugal compressor (constant- or variable-speed)	UCP1	Not recommended for VPF[a]
	UCP2	30% for comfort cooling 10% for process control
	CH530 with flow compensation (introduced in 2001)	See Figure 2, p. 3

[a] Control retrofits are available for many chillers
[b] Controller varies by chiller model

[3] In his article, "Primary-Only vs. Primary–Secondary Variable Flow Systems," (*ASHRAE Journal,* February 2002), Steven T. Taylor, Principal of Taylor Engineering LLC, notes that unloading the active chillers before starting another produces warmer chilled water. Although the temperature increase seldom causes problems for comfort cooling, it may be unacceptable in industrial/process applications.

valve will transition from fully closed to fully open in about two minutes.

Like the bypass valve, be sure to select isolation valves that maintain a linear relationship between valve position and flow rate.

Note: Slow valve operation reduces the likelihood of valve-induced water hammer in the piping system.

Let the operating chiller(s) load almost fully before starting another one.

The simplest way to control a VPF system is to monitor the leaving-evaporator water temperature and allow the operating chiller(s) to load *almost* fully before bringing the next chiller online. As long as the system can maintain the target temperature, there is no need to activate another chiller.

When the operating chillers no longer provide enough cooling, the plant controller should start the next chiller. One caveat: The next chiller should start *before* the chilled water flow reaches the maximum limit of the operating chiller(s), even if the operating chillers are not yet fully loaded.

Devise a "stop" strategy that protects the chillers from short-cycling.

Knowing when to stop a chiller (to provide sufficient downtime between chiller starts) often is more challenging than knowing when to start it. The most reliable way to do so—assuming that the VPF system is properly installed, calibrated, and maintained—is to *monitor the power draw of the operating chillers.*[4] Most unit controllers measure running load amps (RLA) at regular intervals. The %RLA (actual RLA divided by design RLA) provides a good indication of the present chiller load.

Base the "stop" strategy for a multichiller plant with *equally sized machines* on the sum of the present %RLA for all chillers divided by the number of operating chillers *minus one*. If the result is less than the desired capacity for the operating chiller(s), then stop one of the machines.

For example, suppose that a plant consists of three equally sized chillers, each of which is presently running at 60 percent of full-load capacity. If one chiller is shut off, the two chillers still online would operate at 90 percent of full-load capacity.

$$\text{3 operating chillers} \times 60\,\% \text{ per chiller} = 180\,\%$$

$$\frac{180\,\%}{\text{3 operating chillers} - \text{1 chiller}} = 90\,\% \text{ load on each chiller still operating}$$

If the desired remaining capacity is 80 percent, it is *not* appropriate to shut down a chiller. In this case, the plant controller should not turn off any of the chillers until each of them unloads to 53 percent.

Note: For plants with unequally *sized chillers, weight the %RLA value of each chiller by its design capacity and compare the weighted value with that of the chiller to be sequenced off.*

Plant configuration

Consider a series arrangement for small VPF applications.

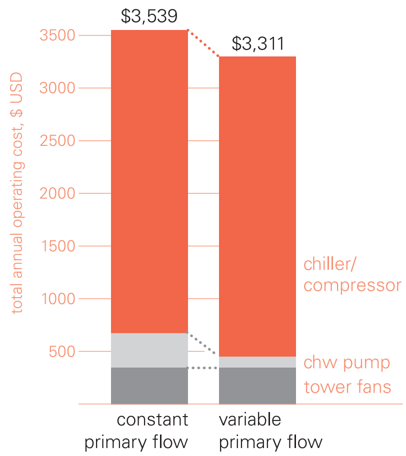
When the plant consists of only two chillers *and expansion is unlikely,* you can simplify control by piping the evaporators in series. Doing so avoids flow transitions because the water always flows through *both* chillers.

The series arrangement requires careful selection because the pump must be sized for the pressure drop through *both* chillers. However, the extra pressure quickly decreases (by roughly the square of the flow rate) as the flow rate slows. For example, at 80 percent of design flow, the evaporator pressure drop is only 64 percent of design. Given this operating characteristic, a VPF design may permit a slightly higher system pressure drop than a comparable primary–secondary system without a noticeable penalty in operating cost.[5]

[4] Some plant operators prefer to sequence chillers by comparing the actual system load with the total plant capacity that would result if a chiller is turned off. However, this method can be less reliable than one based on power draw because flow- and temperature-sensing devices require periodic recalibration to correct for drift.

[5] *Multiple-Chiller System Design and Control,* Trane applications engineering manual SYS-APM001-EN, discusses the series arrangement of chillers in greater detail. In a separate article, "Series–Series Counterflow for Central Chilled Water Plants" (*ASHRAE Journal,* June 2002), Groenke and Schwedler describe a chilled water plant that arranges both evaporators *and* condensers in series.

Figure 3. Example of operating-cost savings for a VPF, single-chiller plant



Analysis results are based on a 50-ton scroll chiller and a 5-hp chilled water pump for two-story office building in St. Louis, Missouri.

Note: To further reduce the system ΔP, lower the required rate of chilled water flow through the system by increasing the temperature difference between the supply and return. Plants that supply 40°F chilled water based on a ΔT of 16°F or more are increasingly common.

✔ ***Assess the economic feasibility of VPF for single-chiller plants.***

Although most VPF applications consist of two or more chillers, variable primary flow also offers potential operating-cost savings in a new or existing, single-chiller plant. Instead of a bypass line and flow-sensing devices, minimum flow through the chillers can be maintained by three-way valves. (Use enough three-way valves to assure that the minimum evaporator-flow rate of the chiller is always satisfied.) This simple approach will reduce pumping costs while providing the chiller with enough chilled water.

To quantify the savings potential of variable versus constant primary flow in a single-chiller plant, we examined a two-story office building in St. Louis, Missouri. The HVAC system includes a 50-ton scroll chiller and a 5-hp, chilled water pump. Figure 3 illustrates the results of our analysis. Although the absolute savings are not large, variable primary flow *did* reduce the cost of operating the chilled water system by more than 6 percent … enough to warrant further investigation. The difference in installed costs is a variable-speed drive, a differential pressure sensor, and a pump controller.

✔ ***Moderate "low ΔT syndrome" by manifolding the chilled water pumps.***

Manifolding two or more chilled water pumps (or slightly oversizing a single pump) can provide an individual chiller with more than its design chilled water flow … which means that you can fully load the chiller even if the return water temperature is colder than design. Sometimes described as "overpumping," this strategy does not cure "low ΔT syndrome"; it merely reduces the adverse effect of low ΔT on system operation.[6]

✔ ***Understand that controlling transient flows is mandatory, regardless of plant size.***

The number of chillers in the plant will not alter the degree of care needed to properly manage transient flow-rate changes because the transition from one operating chiller to two is inevitable in almost all plants.

Outside the chilled water plant

The success of a VPF application depends on more than the chilled water plant. It requires careful orchestration of the *entire* HVAC system, which means air handlers and coil-control valves as well as chillers and pumps.

✔ ***Select slow-acting valves to control the airside coils.***

Valves that open and close slowly will moderate the normal fluctuations of chilled water flow through the loop.

✔ ***Use multiple air handlers, and stagger their start / stop times.***

Unless it is programmed to do otherwise, the building automation system will simultaneously shut down all of the air handlers when the occupied period ends. If two chillers are operating when this happens—and if all of the coil-control valves close at the same time—then chilled water flow through the evaporators will drop to zero almost instantaneously. Such a dramatic change not only causes problems for the chillers, but also may deadhead the pumps.

To help assure that flow-rate changes remain within acceptable limits, "divide" the air handlers into several groups. Then implement control schedules that shut down each group individually at 10-minute intervals.

[6] Taylor describes methods to alleviate low return-water temperatures in "Degrading Chilled Water Plant Delta-T: Causes and Mitigation" (*ASHRAE Transactions,* January 2002).

Closing Thoughts

More variable-primary-flow systems exist today than when we first wrote about them in 1999. With three more years of hands-on experience comes a better understanding of how to design, install, and operate a VPF plant that performs reliably. The guidelines summarized in Table 3 supplement and further refine the recommendations in our 1999 article.

If experience has taught us anything about implementing variable primary flow, it's this: The single, most important contribution of the engineer is to **provide written, detailed descriptions of the plant's sequence of operation**. These descriptions should include control sequences for:

- Full- and part-load operation
- Minimum and maximum flow-rate management
- Transient flow-rate changes
- Starting and stopping chillers

Furthermore, this information must be shared *early in the design process*. Without specific, documented sequences of operation, it is unlikely that the controls provider will devise programs that operate the plant as intended. Bottom line: VPF plants *that work* result from close, early-on collaboration between the engineer, the chiller manufacturer, and the controls provider.

Variable primary flow is a value-added option that can help your clients curb operating costs at a lower initial cost than traditional primary–secondary designs … but only if you select the right components, install them properly, and operate them in accordance with a well-thought-out control scheme. ■

By Mick Schwedler PE, applications engineer, and Brenda Bradley, information designer, Trane.

You can find this and other issues of the Engineers Newsletter *at www.trane.com/commercial/library/newsletters.asp. To comment, send a note to Trane, Engineers Newsletter Editor, 3600 Pammel Creek Road, La Crosse, WI 56401-7599, or e-mail us at comfort@trane.com.*

Table 3. Guidelines for a successful VPF system

Chiller selection
■ Select for the *lowest possible* minimum evaporator-flow limit (no more than 40%–60% of system flow)
■ Select for the greatest tolerance to large flow-rate changes
■ Select chillers with approximately equal pressure drops across the evaporator at the design flow rate
■ Understand the specific loading/unloading characteristics of the chiller controller
Bypass flow
■ Select a high-quality control valve with linear-flow characteristics
■ Select flow-sensing devices that deliver precise, repeatable measurements
■ Minimize control lag by hard-wiring the controls or by selecting devices that communicate directly
Chiller sequencing
■ Temporarily unload the operating chillers before starting the next
■ Open chiller isolation valves *slowly* to encourage stable operation
■ Let the operating chiller(s) load *almost* fully before starting another
■ Prevent short-cycling by devising a "stop" strategy based on the power draw of the operating chillers
Plant configuration
■ Consider a series arrangement for small VPF applications to avoid transient flows
■ Assess the economic feasibility of variable primary flow for single-chiller plants
■ Moderate "low ΔT syndrome" by manifolding multiple chilled water pumps or slightly oversizing a single chilled water pump
■ Take care to properly manage transient flows regardless of the number of chillers in the plant
Airside control
■ Select slow-acting valves to control the chilled water coils
■ Use more than one air handler and stagger their start/stop times

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