

## An Idea For Chilled-Water Plants Whose Time Has Come... Variable-Primary-Flow Systems

from the editor...

Chilled-water systems that vary flow through chiller evaporators have caught the attention of engineers, contractors, building owners, and operators. Chiller manufacturers are increasingly receptive to this interest, thanks to ongoing advancements in control technology. If asked about variable evaporator flow ten years ago, many of these manufacturers would have simply declared, "No, you can't do that!" Five years ago, they would have counseled, "You probably shouldn't do that." Today they will point to existing installations that successfully use variable evaporator flow.

This issue of the Engineers Newsletter considers several aspects of the **variable-primary-flow (VPF) system**, including: its benefits and complexities; criteria that can help you recognize when a VPF design is a viable option; and tips for its successful implementation.

### What Is A VPF System?

Conceptually, the variable-primary-flow (VPF) system resembles the familiar constant primary-variable secondary design more commonly known as the "decoupled" system. A comparison of the schematics in Figures 1 and 2 (pages 2–3) reveals the similarities between "decoupled" and VPF systems. For example, both require a bypass. Each chiller in the arrangements shown has a dedicated pump whose operation coincides with the chiller it serves. Differences between the two systems become apparent upon closer examination.

The "**decoupled**" system shown in Figure 1 uses **constant water flow through each chiller evaporator** and **variable water flow through each cooling coil** to satisfy space loads. Implementing this design requires:

- a constant-speed, essentially constant-volume pump (and check valve) for each chiller;
- two-way control valves to regulate the amount of chilled water that flows through the cooling coils;
- a variable-flow distribution pump to serve the coils (flow modulation is usually accomplished by providing the pump with a variable-frequency drive);
- a bypass to hydraulically decouple the primary (production) and secondary (distribution) sides of the system.

As each two-way valve adjusts the flow of chilled water through the coil to satisfy the existing load, the distribution

pump responds by regulating the amount of chilled water delivered. Water flows through the bypass in either direction as needed to balance the system.

Contrast this with the **VPF system** in Figure 2, which **varies water flow throughout the entire system**—that is, through the evaporator of each operating chiller as well as through the cooling coils.

Two-way control valves, check (or isolation) valves, and a bypass are required to implement a VPF system. However:

- Variable-flow chiller pumps eliminate the need for a separate distribution pump.
- The bypass can be positioned either upstream or downstream of the cooling coils.
- A control valve in the bypass ensures that the amount of flow that returns

### Dispelling A Common Misconception

True or false: "Chillers operate more efficiently in a system with variable rather than constant primary flow because of the greater **log mean temperature difference (LMTD)**."

It is true that the return water temperature in a properly operating VPF system remains constant as the amount of flow changes. It is also true that the LMTD can be increased by changing the production (primary) side of the chilled-water loop from constant to variable flow. But there are other facts to consider.

- In a system with **variable primary flow**:
- The convective heat transfer coefficient decreases with a reduction in flow.

- Reduced flow decreases the overall heat-transfer effectiveness of the chiller evaporator.

In a system with **constant primary flow**:

- Entering-evaporator temperature and LMTD fall as the cooling load diminishes.
- The convective heat transfer coefficient, like the primary flow, remains constant despite reductions in load.

The net effect is that the **power consumption for a given chiller is virtually the same** whether the system's primary flow is variable or constant.

to the operating chiller(s) never falls below the minimum limit.

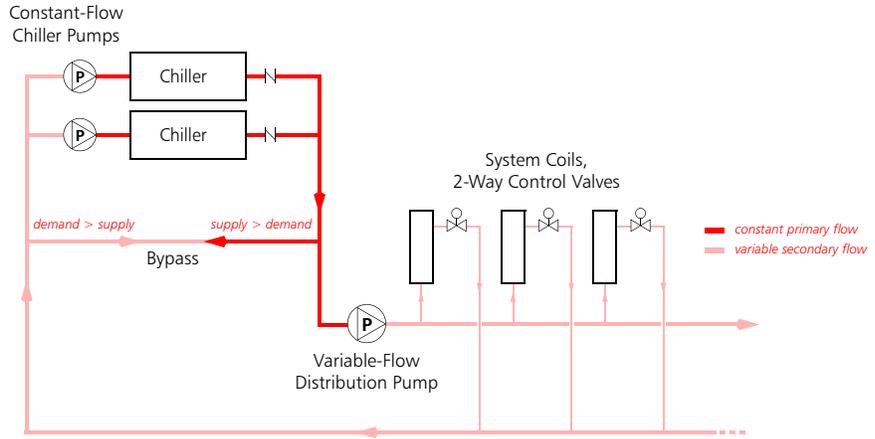
**Paradigm Shift.** For many years, chiller manufacturers encouraged cooling-plant designers and operators to maintain a constant flow of water through the chiller evaporator. The overriding concern was one of protection since reducing water flow too quickly (that is, faster than the chiller safeties could respond) could result in nuisance shutdowns; perhaps even freezing temperatures, ruptured evaporator tubes and costly equipment downtime.

What “suddenly” made variable primary flow feasible? Recent advances in control technology improved chiller operating stability. The strategically placed sensors and real-time response of today’s control systems let the chiller perform its primary function—producing cold water—even when evaporator flow rates vary.

## Weighing The Pros And Cons

VPF systems present building owners with several cost-saving benefits that are directly related to the pumps. The most obvious cost savings result from eliminating the secondary distribution pump, which in turn avoids the expense incurred with the associated piping connections (material, labor), electrical service, and variable-frequency drive.

**Figure 1**  
“Decoupled” (Constant Primary–Variable Secondary Flow) System



Building owners often cite pump-related energy savings as the reason that prompted them to install a VPF system. With the help of a software analysis tool such as System Analyzer™, TRACE®, or DOE-2, you can determine whether the anticipated energy savings justify the use of variable primary flow in a particular application. (See “A Comparison Of Pump Operating Costs.”)

It may also be easier to apply variable primary flow in an existing chilled-water plant. Unlike the “decoupled” design, the bypass can be positioned at various points in the chilled-water loop and an additional pump is unnecessary.

**Caveats.** While modern chiller controls have dramatically improved operating stability, the laws of physics still apply. To be successful, a VPF system must comply with the design rules identified below:

- Each chiller has a design operating range that is defined, in part, by minimum and maximum flow rates. The fact that there *is* a minimum flow rate necessitates a bypass somewhere in the chilled-water loop in case the required system flow falls below the minimum flow required by the chiller.
- A bypass is required whether the primary flow is constant or variable. (Chillers have minimum flow rates in either case.) The position of the

## A Comparison Of Pump Operating Costs

Energy-and-economic-analysis software can help engineers quickly and accurately assess the appropriateness of alternative designs. In this case, we used Trane’s System Analyzer™ software to compare the energy and related operating costs of three pumping strategies.

As the analysis results show, a “decoupled” (constant primary–variable secondary) or VPF system can yield substantial savings when compared with a constant-flow design.

### Design Criteria

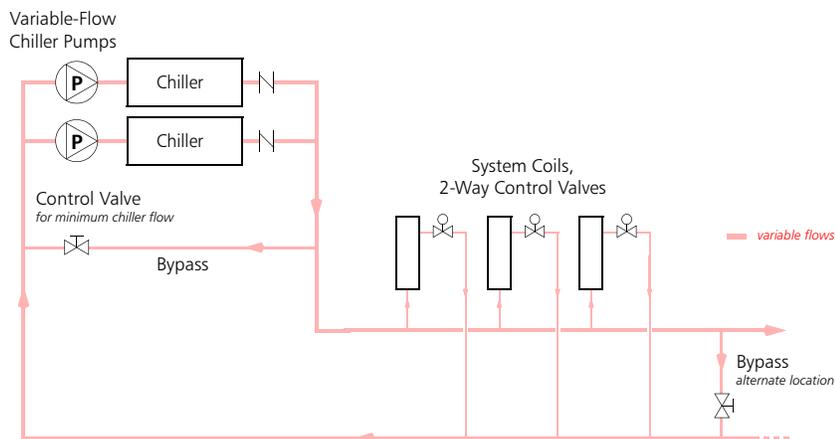
- Medical office building in Atlanta, Georgia (USA)
- Design load is 470 tons of cooling [1560 kW refrigeration]

- Two air-cooled helical-rotary chillers piped in parallel
- One pump per chiller
- Alternative pumping strategies: constant flows; constant primary–variable secondary flows; and variable flows

### Annual Analysis Results

System Flow Alternatives	Pumping Energy Consumed	Operating Costs, US Currency
Constant primary, constant secondary	52,588 kWh	\$4,522
Constant primary, variable secondary (“decoupled”)	32,819 kWh	\$2,822
Variable primary, variable secondary (VPF)	26,614 kWh	\$2,289

**Figure 2**  
**Variable Primary–Variable Secondary Flow (VPF) System**



smaller bypass required for a VPF system can be the same as the position of the bypass in a “decoupled” system. Some designers prefer, instead, to use three-way valves at the system coils. While this approach ensures minimum chiller flow, it also reduces the pump operating-cost savings by increasing the system flow.

- Measurements of evaporator flow are critical to VPF control. One common practice relies on direct measurement using flow meters. (Be aware that some flow meters require, but seldom receive, frequent calibration.) Another measures water-side pressure drop and estimates evaporator flow based on manufacturer data.
- Determining when to turn off a chiller requires a thorough understanding of system dynamics since flow rates will vary through every operating chiller. The already-complex control strategy needed to avoid cycling (restarting the chiller too soon) becomes even more complicated as the number of chillers or chiller capacities increases.

- Fluctuating flow rates can be critical. For applications that require strict chilled-water temperature control, limit fluctuations to less than 10 percent of design chiller flow per minute.

Relaxing this limit to 30 percent of design flow per minute is permissible in most comfort-cooling applications. If the chiller is properly controlled, the leaving-evaporator water temperature will not deviate from set point for more than a few minutes, if at all.

- Operators must understand how VPF systems work. Training is mandatory.

### What About The Real World?

So far, our discussion has provided an abstract look at VPF system design and operation. Questions of a more practical nature are “Do they really work?” and if so, “How well?” For answers, we spoke to several engineers who have applied systems with variable primary flow. Two of them share their experiences below.

“We installed a variable-primary-flow system in a mall. During operation, we were surprised to find that the pumps never operated below 60 percent flow. We discovered that the anchor tenant had disconnected their valve controllers, were running the coils wide open, and were

varying airflow to maintain a constant leaving-air temperature and humidity.

“Though we weren’t allowed to change this setup, the good news is that we had already saved almost 80 percent of our pumping energy since the pumps were operating at about 60 percent of their design flow and at about 20 percent ( $0.6^3 = 0.216$ ) of their design power.”

The second engineer recounts a similar story, again reminding us that the real world is less than perfect:

“We recently applied a VPF system in a hospital. We replaced the major air handlers and used two-way modulating valves, but the patient rooms are still served by fan-coils with three-way valves. The good news is that the fan-coils act as the bypass and keep us above the minimum chiller flow rates. The not-so-good news is that we’ve saved a lot of pumping energy, but not as much as we could.”

### Implementing A VPF System

Variable primary flow can be economically appealing when designing a chilled-water system. We have also seen that the financial benefits depend on the appropriateness of the application and the care with which the system is designed, installed, and operated. As Steven T. Taylor, Principal, Taylor Engineering, aptly states:

“Because of their lower first costs and lower energy costs, variable-primary-flow systems are clearly the right choice for many applications, but not all. They require complex staging control sequences and minimum flow (bypass) controls, so the designer and operator of the system have to be more sophisticated if the system is to be a success. On some projects, the ‘fail-safe’ nature of primary–secondary systems may offset their energy and first-cost disadvantages.”

With that in mind, we offer the following advice to help you determine when a VPF design is practical and how to assure a successful application...

#### Do not use VPF if:

- System chilled-water temperature is critical, for example, in a “clean-room” or process (computer-chip-making) application.
- Only three-way valves are used; that is, the system flow rate does not vary.  
A design with *some* three-way valves is permissible. In fact, if you can reach 60 percent of design flow, you will have saved nearly 80 percent of the pumping power.
- It is unlikely that the owner/operator will run the plant as designed
- Existing chiller controls are old and inaccurate (a 30-year-old chiller with pneumatic controls, for example).

#### Consider VPF if:

- System flow can be reduced by at least 30 percent of design.
- It provides greater cost savings than a “decoupled” design.
- Operators will understand how the system works and will run it properly.
- The system can tolerate a modest variation in supply water temperature.
- A single chiller is being replaced *and* the primary flow can be varied. (Previously considered “too small,” such applications may be ideal for VPF designs.)

#### During design and installation:

- Use energy-analysis software to determine the payback period or return-on-investment. Be sure to account for reduced piping and electrical connection costs.
- Remember to design a bypass into the system to provide minimum chiller flow.

- Size each chiller pump to accommodate the pressure drop of the system *plus* the evaporator.
- Specify high-quality flow meters if you decide to use these devices; they require less calibration and are more accurate. Also pipe the flow meters in accordance with the manufacturer’s instructions.
- Invest the extra time needed to determine the control points at which chillers should be turned off. This design task is critical to successfully reduce operating costs ... and its complexity will increase with the number (and differing sizes) of chillers.
- Teach the operating staff about their VPF system: how it operates and why it works as it does. Help the building owner design a program for ongoing training.
- Work with businesses that can supply and integrate the entire hydraulic system (chillers, pumps, and controls) during construction *and* actual operation. The financial benefits of a VPF design can only be obtained if the individual components operate as a system.

#### During plant operation:

- Maintain evaporator flow between the minimum and maximum limits. The cataloged range for many chillers is 3–11 fps [0.9–3.4 m/s]. Ask the chiller manufacturer for the actual values for your machine.
- Keep changes in flow rate through the evaporator within manufacturer-set limits. With sophisticated chiller controls, a 30-percent-per-minute change in the rate of flow should work well in most applications.
- Continue to work with the operating staff and provide additional training as needed.

- Calibrate the flow meters when required (if used).
- Use the automation system to monitor system (chiller plus pump) performance. Document the operating costs.

#### A Parting Thought...

Variable flow through chiller evaporators is no longer heresy now that chiller controls can quickly adapt to changing operating conditions. Use an analysis tool to determine the economic viability of variable primary flow. When appropriate, offer it to building owners and operators as a value-added option in your system designs. ■

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