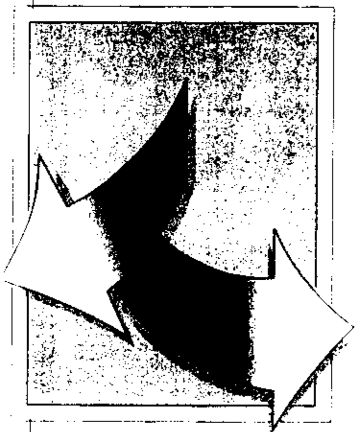

DON'T IGNORE VARIABLE FLOW

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While variable flow chilled water systems have been a bone of contention among HVAC system designers for many years, experience shows that they can and do live up to their billing.

Building owners who often don't include enough money for system design in their projects perpetuate "cookie-cutter" designs -- they leave no room for innovation.

Among those old standard practices is constant flow chilled water. As shown in **Figure 1**, this means one or more constant speed pumps are used to pump chilled water directly through the chiller and then on to air handling units equipped with three-way control valves. These valves have three connections which allow them to direct all the constant water flow through the coil in the air handler or to completely bypass the air handling unit and go back to the cooling plant.

Replacing this standard practice is a concept called variable flow. **Figure 2** shows a fairly common variable flow layout with two piping or flow loops.

In the chiller loop, constant flow pump(s) send water through the chiller(s). Interconnected to this loop is another loop for the building. The building loop has its own variable speed pump(s) which takes cold water from the chiller and sends it to the air handling units.

At the air handlers, two-way valves modulate open or closed as needed to maintain the desired supply air temperature, varying the flow through the coil and through the building loop.

Monitoring this loop is a differential pressure transmitter which sends a signal to the variable speed pump telling it to speed up or slow down to maintain the desired pressure differential between the supply and return lines.

The question arises, why would you want to have variable flow in the system in the first place? After all, all this "variable" stuff is very confusing, since you really never know for sure just where the water is going at any given point in time, nor does it seem that you can be sure that it's working right. So there had better be some good reasons for messing with a tried and true practice.

Well, there are. Constant flow systems are sensitive to design flow rates for each air handling system. If the designer oversizes the flow rate, the air handling system will always use too much of the plant's chilled water forever, or until the system is re-balanced. Conversely, if the flow rate is undersized, the air handling system will always be short of cooling — until the system is re-balanced.

By contrast, variable flow systems

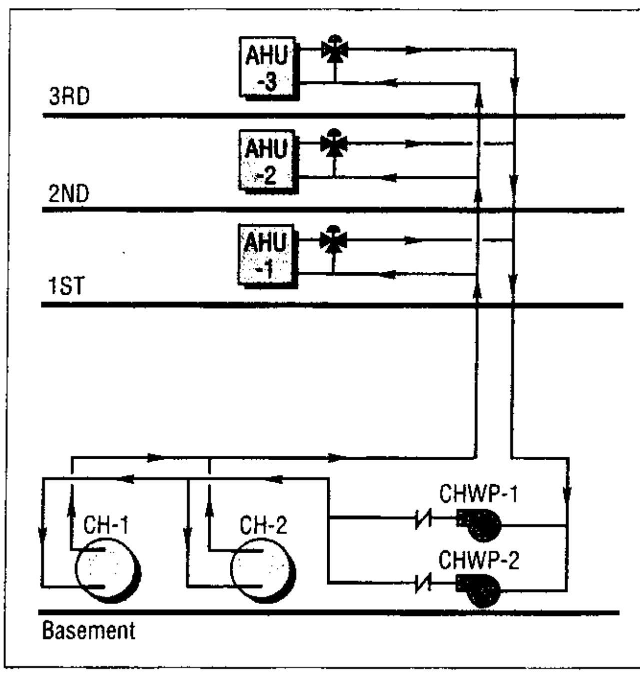

Figure 1. A constant flow chilled water system.

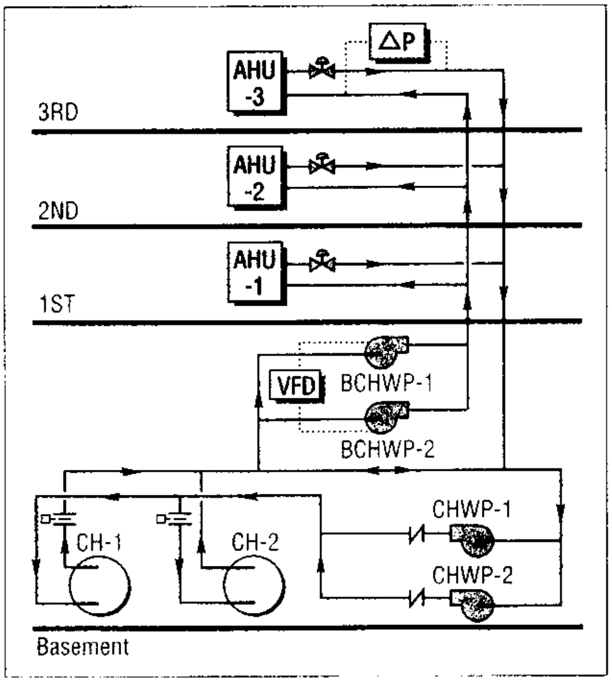

Figure 2. A dual-loop/decoupled variable flow chilled water systems.

respond to each air handling system's demand for cooling and provide as little or as much (within limits) as the air handling system needs, pretty much regardless of what the design engineer calculates.

Let's say the designer hit the nail on the head, but the balance company was asleep at the switch and balanced the system incorrectly. Just as above, short systems will always be short and over systems will always be over until a good balance guy comes along. Or until another not-so-good balancer comes along and "fixes" the short air handling system by robbing flow from somewhere else.

Again, by contrast, variable flow systems send the water where it's needed, not where someone accidently sent it when the building was built.

Let's say that both the designer and the balance company did perfect work. But now, along comes the building's first remodel or addition. You know, that printing department that moves into the corner of the garage, with their own air handling unit. You also know what happens. Robbing Peter to pay Paul, the remodelers adjust to whatever they have to to give their air handler the right flow.

Why, maybe, the designer even included a booster pump just to make sure that his project would work. Once again, variable flow systems assume the total plant capacity is sufficient and simply speed up their pump(s) and send the water to where it's needed.

Another common problem with constant flow systems is high supply water temperatures. Many chilled water systems are built just like that shown in **Figure 1**.

Now, unless there are automatic shut-off valves to stop the flow to one of the chillers when the plant load is low, chilled water is allowed to pass through that off-line chiller. This results in warm return water mixing with cold water from the running chiller, making the supply temperature to the air handling units 50F or higher. If one air handler serves an interior area or one with a high internal heat gain, it'll need a lot of water and/or cold water to do its job. Frequently, operating engineers solve this problem by leaving both pumps on all the time, or by turning the leaving water controller on the lead chiller way down (40F perhaps), or both.

Once again, variable flow allows the water distribution system to adjust automatically to the diverse needs of each of the air handling units, without having to bypass water through an off-line chiller, just to get sufficient flow to do the cooling job.

Virtually all constant flow systems suffer from low temperature differentials at less than full load (sometimes even at full load on an oversized plant). Assuming a design supply temperature of 45F and a 10F rise at 50% load the return temperature would be 50F and the mean temperature in the chiller evaporator would be 47.5F. The result of this is much higher pumping horsepower and higher KW/ton on the chiller than is really needed.

Of course you're going to add chilled water reset. But what about that one air handler that just has to have 47F water or it just won't keep that little computer room on the 10th floor happy?

Well, it's not a problem with variable flow. First of all, most coils are actually oversized for the cooling task they've been given — meaning that the water flow required at low load is very low and water trickles through the coil, heating way up, closely approaching the entering air temperature. The result is that return temperatures in excess of 60F are common all the time on variable flow systems (especially if supply air temperatures are reset). Combined with a variable speed pump, this means that pumping power goes way down, and the mean temperature in the evaporator can be very high (but usually only on single-loop systems), resulting in superior KW/ton operation of the chiller.

Another problem constant flow systems have is limited control options.

Let's say you want to shut down cooling to all the air handlers in the

Comparing variable flow and constant flow chilled water systems

Constant Flow	Variable Flow
Design-sensitive (over or under design is essentially permanent)	Water goes where needed regardless of "design" flows
Balance-sensitive	Essentially self-balancing
Remodel-sensitive (robbin' Peter to pay Paul)	Adapts automatically (within limits)
High supply temps (when bypassing at plant)	Lower supply temps
Low ΔT's (=higher chiller & pump power)	High ΔT's (=lower chiller & pump power)
Fewer control options ("emergency" system isolation)	Unlimited control options
Poor comfort & high operating costs	Excellent comfort & low operating cost

Types of Variable Flow Chilled Water Systems

Name/Type	Minimum Flow?	Comments
Dual-loop/decoupled	none	Chiller loop maintains chiller minimum flow
Triple-loop/decoupled	none	Also known as cascade, tertiary or series pumping
Single-loop/fixed minimum	fixed	The "cheapest"
Single-loop/incremental minimum	incremental	Requires automatic control of bypass valves
Single-loop/no minimum	none	A Texas invention (?)

building except one, either after normal business hours, or in the event of an emergency (say one of the chillers in the plant loses a starter). With constant flow, you might be able to reset the supply air temperature controllers to get the air handlers you want off to bypass all their water. But let's say you have only one chiller and one chilled water pump available. Now, you just can't get enough water to the critical air handler to keep it operating properly. You're stuck with constant flow.

With variable flow, however, when you close the control valves, not only does the air handler not use any cooling, but it doesn't use any water flow either. All the available cooling and water flow now can be directed to the critical portions of the building that need it. Of course, this all assumes that you have a control system capable of sending these commands. With variable flow the chilled water system can respond to a much wider range of possible control scenarios than with constant flow.

The bottom line is that constant flow systems almost always provide poorer comfort and higher operating cost than variable flow systems. Furthermore, variable flow's a lot more fun to work with (one building owner likened it to having a "hydromatic transmission" for his chilled water plant). It just takes some getting used to.

Types Of Systems

What? Not only do we have this weird thing called variable flow, but there's even different types? Sorry, the answer's yes. There are a whole lot of ways you can assemble a variable flow system, as summarized in **Table 2.**

The dual-loop/decoupled system, shown in **Figure 2**, is the ideal variable flow chilled water system. By decoupling the chiller plant from the building, you allow the chiller pumps to maintain constant and safe flow through the chiller. Fortunately, these pumps need only overcome the resistance to flow in the plant piping and the chiller's evaporator, and are therefore usually low horsepower. This arrangement is easy to design, start up, and balance (the plant, that is) and hard to screw up from an operating point of view.

The principal drawback to this arrangement is that it requires extra equipment and piping to make it work. If you're starting from scratch in a new plant design, it's very hard to argue with (especially from an engineering and/or construction liability point of view).

As a note of interest, one section of piping shown in **Figure 2** has two flow arrows. Indeed, it's possible for this piping to experience flow in either direction, though the solid arrow shows the normal direction of flow. This pipe is called the "bi-directional" or the "bridge" by some. Designs typically include two flow switches in this pipe, one facing each way, so that correct and reverse flow can be positively detected by the control system.

The triple-loop/decoupled system, shown in **Figure 3,** comes into play when you need to integrate multiple chiller plants and make them run like they're a single plant. It also works if you've got a remote cooling load you don't want the main building's chilled water pumps to have to work hard to serve.

Figure 3 is a simplified schematic of the chilled water system at the John Muir Medical Center in Walnut Creek, CA, (as featured in the Winter, 1996 issue of ***Contracting Business Magazine's*** sister publication *Energy & Environmental Management*). The facility had a new wing added without interconnecting it to the main chilled water plant. Part of the project to replace the

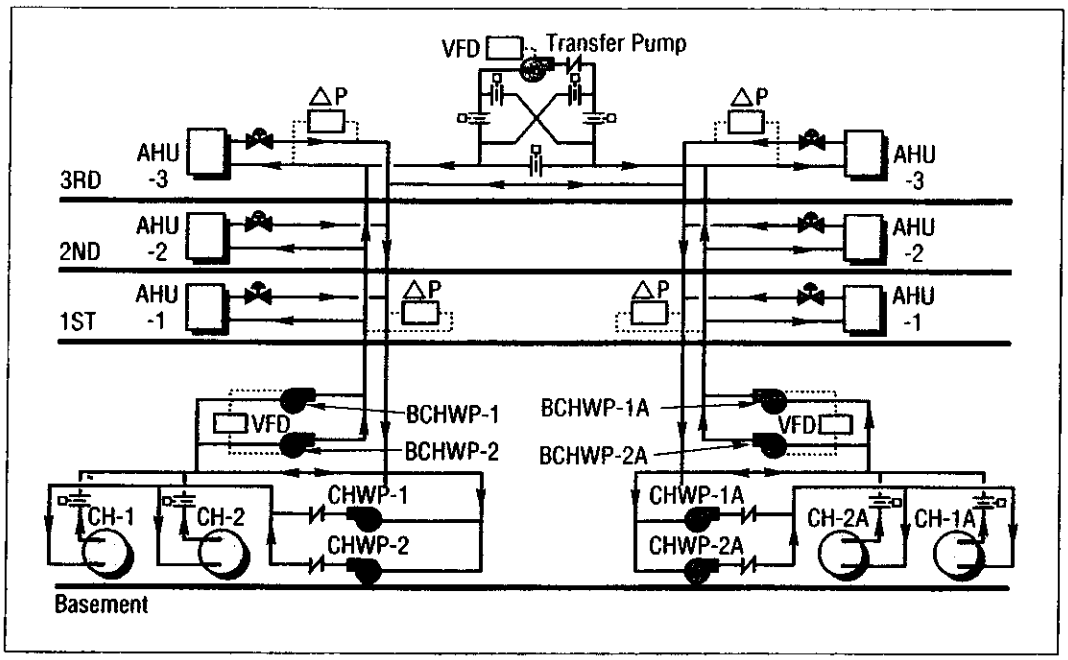

Figure 3. A triple-loop/decoupled variable flow chilled water system.

older plant included providing for interconnection of the two plants, and automating them so they could run as though they were a single plant.

Fortunately, variable flow makes this much easier than might be expected. The key, in this design, is the transfer pump in the pipeline which interconnects the chilled water system in the two buildings. It should be noted that the interconnecting pipeline could not be installed so it tied the two plants together at the plants themselves. The only physically available location to tie the chilled water systems together was near the end of the chilled water piping in each of the two wings of the facility. While this might seem like a potential problem, variable flow makes it work.

The big benefit of interconnecting the plants is to reduce operating costs and provide operating flexibility and reliability. When they weren't tied together, the two plants and all their auxiliaries had to be started up as soon as the weather got warm. By tying them together, only one plant need be started in mild weather. Furthermore, since each wing has its own electric meter, keeping one plant off allows the demand charges for that plant to be avoided (which would otherwise be incurred even if the plant operated for only 15 minutes a month in the utility company's on-peak period).

Finally, forgetting operating costs, when a patient is lying on the operating table, the last thing you want is for the air conditioning to give out. By fully automating the plant, critical portions of the facility can always receive cooling regardless of which or how many chillers might have broken down. In order to achieve these goals, a triple-loop, or tertiary pumping system had to be devised.

Assuming that you want to operate the plant from chillers CH 1 and CH 2, the first thing you do is turn on the chiller pumps (CCHWP 1 and 2) and the chillers themselves. Next, you start up the building pumps (BCHWP) 1 or 2 in that wing. They're redundant and share a variable frequency drive (VFD). Finally, turn on the transfer pump and arrange its valves so it pumps from the left side of the figure to the right side.

What makes this work is the way the building and transfer pumps are controlled. BCHWP-1 is programmed to vary its speed according to the differential pressure observed by the delta-P transmitter A. The transfer pump is programmed to vary its speed according to the differential pressure observed by the ΔP transmitter B. The location of these transmitters is important. Generally, they should be located at or very near the end of the piping system they serve. This is important, for example, because if the pressure differential near the suction side of the transfer pump is not kept positive, this pump will actually cause chilled water to flow *backwards* through AHU 3. This would result in AHU 3 malfunctioning.

Incidentally, it's not uncommon to find reverse flow conditions in constant flow systems that have been adorned with booster pumps. Now, assuming you want to run from the other plant, you simply reverse the transfer pump's direction and have the controls find the correct differential pressure transmitters. Fortunately, all these control gyrations can be handled easily by a building automation system.

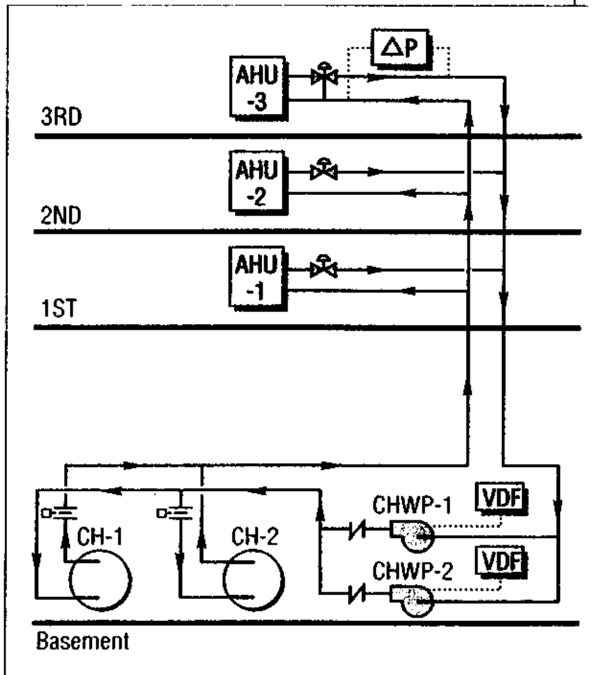

Figure 4. A single-loop/fixed minimum flow variable flow chilled water system.

It's also possible to do variable flow with the single-loop/fixed minimum flow shown in **Figure 4,** without decoupling the chillers and the building.

This alternative is particularly attractive when converting existing buildings to variable flow, as it considerably reduces the conversion cost by eliminating the chiller pumps and their associated piping. The principal difficulty with this system is ensuring that there's enough chilled water flow to keep the smallest chiller on line when first bringing the plant into operation.

By examining the chiller manufacturers' data, you can determine if the chillers can be successfully operated as low as 30 to 40% of nominal design flow (basically as long as turbulent flow is maintained in the tubes of the evaporator). Realizing that there will or should be some demand for cooling in the building, if the chiller plant is to be brought on line at all, providing roughly 30% flow in a bypass somewhere in the system has generally been successful.

As shown in **Figure 4,** this often can be achieved by leaving one or more chilled water control valves as three-way valves. To avoid short-cycling the chiller when it's first brought on line, these bypasses should be as far away from the plant as possible.

Pump control is again accomplished by means of a differential-pressure transmitter communicating with the VFD on the pump. Incidentally, when converting a plant with unequal chillers and trying to keep costs to a minimum, it's usually best to put the VFD on the larger pump. This way only one VFD will be necessary, but this pump can serve both the small chiller and the large chiller. If both chillers are needed, the smaller pump can be started, the VFD put at maximum speed, and the system be allowed to simply ride the pump curves. This assumes that the chillers are headered together as shown.

One alternative to fixed minimum flow is a single-loop/incremental minimum flow configuration. This is accomplished by installing one or more actuated, bypass valves out in the system.

The advantage of this approach is that the minimum flow can be tailored to actual plant needs, and as soon as the load (and flow) on the plant builds up, the bypasses can be shut down, in turn, until there's no bypass at all. This saves even more pump energy, and permits automatic controls to establish a number of different bypass flow rates (which might be needed for various chillers or chiller combinations).

Some chilled water systems, known as single-loop/no minimum flow systems, are built without variable speed pumps and without minimum flow provisions.