Engineers who design chilled water distribution systems have strong opinions on the proper design approach and on how to avoid problems or solve them if they arise. We begin with an article by Wayne Kirsner, PE that expounds on his earlier article on Low ΔT Syndrome. James (Burt) Rishel, PE follows with a response. After studying these differing viewpoints, you, our readers, may wish to weigh in with your opinions via our "Open for Discussion" department.

A Check Valve in the Chiller Bypass Line?

Two Views on This Question

Rectifying the Primary-Secondary Paradigm for Chilled Water Plant Design To Deal with Low ΔT Central Plant Syndrome

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The problem with the primary-secondary design of chilled water systems, as shown in Fig. 1, is that it cannot deal effectively with "Low ΔT Central Plant Syndrome." This is the point made in my article "The Demise of the Primary-Secondary Pumping Paradigm for Chilled Water Plant Design" (*HPAC*, November 1996). Low ΔT Central Plant Syndrome is the condition whereby an anemically low chilled water return (CHR) temperature causes an excessive amount of chilled water to circulate to meet system cooling loads, and chillers receiving the low temperature CHR cannot be loaded to their design capacity.

The causes of Low ΔT Syndrome are not mysterious, but they often are pervasive, and thus the problem can be hard to remedy. Every large system with which I'm familiar suffers from this syndrome to one degree or another. It's especially problematic in primary-secondary systems where excess secondary CHR flows through the crossover-decoupler pipe, diluting the temperature of chilled water supply (CHS) going out to the system. If a chilled water plant has no provision to increase primary flow through its chillers when chilled water ΔT is low, then operators often have only one option to meet the cooling load and prevent recirculating flow through the crossover—energize more chillers and their attendant pumps. The energy penalty for this Hobson's choice, in addition to the excessive secondary pumping energy, is the energy needed to run an extra set of chiller peripherals—*i.e.*, an extra condenser water pump and cooling tower fan as well as a primary chiller pump.

There is, however, a simple improvement that can be made to primary-secondary pumping of a chilled water plant that permits a system to deal with Low ΔT Central Plant Syndrome—install a check valve in the plant bypass line, as shown in Fig. 2. Gil Avery included this feature in his article "Designing and Commissioning Variable Hydronic Systems" (*ASHRAE Journal*, July 1993). Here's what the check valve does for you:

- **The chillers are protected against low flow.** A constant minimum flow is maintained through each chiller by constant flow primary pumps even though secondary flow varies. This is the main advantage cited for primary-secondary chilled water systems. Thus, there's no possibility of freezing the chiller's evaporator in an upset condition or allowing evaporator CHW flow to slip into the laminar flow region at low loads. As long as plant primary flow exceeds system flow, chiller pumps and system pumps behave as if they're decoupled.

But what about when system flow exceeds plant flow? The traditional primary-secondary logic uses this condition as a control indication. It's supposed to indicate that it's time to start another chiller and primary pump. But is it really such a positive indication? The primary-secondary control logic presumes that if secondary flow exceeds primary flow, then system load exceeds on-line chiller capacity. This assumption, the assumption on which the archetypal primary-secondary control scheme is predicated, is a poor approximation to the true state of chiller loading in most real chilled water plants. This is for two reasons. First, if outside wet bulb temperature is below the design value, as it is over 95 percent of the year, then cooler tower water will depress the chiller condensing temperature, giving each chiller additional capacity. At a 65 F entering condenser water temperature, for example, chiller full load capacity will increase at least 7 percent due to refrigerant cycle considerations and up to another 10 percent depending on where the compressor was selected on its compressor curve. If extra chilled water can be put through the chiller, this extra capacity can be tapped. The archetypal primary-secondary control logic design, which uses constant flow pumps, doesn't take advantage of this extra capacity.

Second, if the plant suffers from Low ΔT Syndrome, flow will have little functional dependence on load. At part load, flow will not vary proportionately from its full load value. In fact, system flow will almost always exceed primary flow. Thus, secondary CHR will flow through the crossover-decoupler, which will generate a blending problem but no loading information.

What plant operators would like to do in the case of low ΔT is to increase primary chilled water flow through the chillers to load them fully and stop secondary recirculating flow through the crossover. How does one do this without adding complication to the system? It's simple—the check valve will do it for you.

- **The check valve puts system pumps in series with chiller pumps.** When secondary system flow exceeds primary flow, the check valve closes, placing system pumps in series with the primary pumps. Thus, the excess pumping capacity of the system pumps is put to work as variable speed boosters for the primary chiller pumps. The pumps only need to be oversized somewhat to include the head to pump through the primary piping and chillers in the event that low ΔT is a problem. In a sense, the backup capacity needed in case of Low ΔT Syndrome is stored in the variable speed system pumps instead of the primary pumps.

If flow is not used as an indication of load as in the traditional primary-secondary system, how does one know when to activate an additional chiller? The best way to do this is the way most plant operators do it now—monitor leaving CHS temperature from the chillers. When the on-line chillers can't hold the CHS temperature set point any longer, the chillers are fully loaded and another chiller should be turned on. With this method, chiller activation is controlled by monitoring the chiller's ability to achieve leaving CHS set point temperature, not by monitoring chilled water flow through a crossover pipe.

How does one know when to take a chiller off-line? The traditional primary-secondary logic says to measure the flow and when primary flow exceeds secondary flow by the capacity of one primary pump, shut down a pump and chiller. In actuality, systems with low ΔT never see this condition. Shutting down a primary pump will often lead to recirculating flow through the crossover-decoupler. The check valve, of course, prevents this.

But even if low ΔT is not a problem, flow is not a good indicator of load or available chiller capacity. The simplest indicator of available chiller capacity is percent full load motor amperage, not because it's such a straightforward mea-

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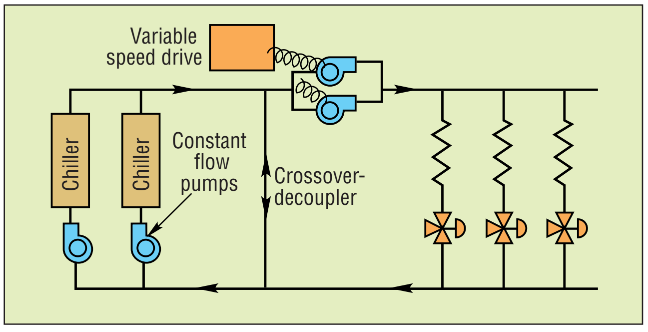
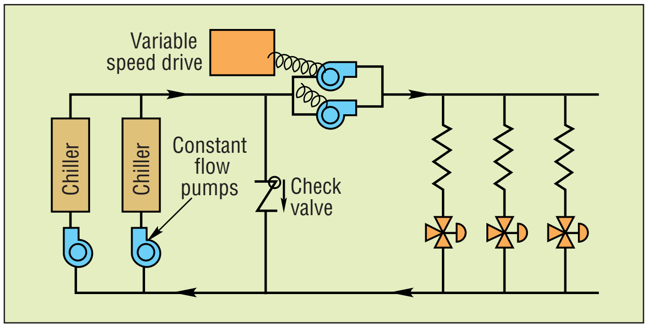


1 The "archetypal" primary-secondary CHW plant design.



2 The "improved" primary-secondary CHW plant design incorporates a check valve.

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sure of available chiller capacity but because it's generally available on the chiller starter panel. Correlating this measure to chiller loading is complicated by the influence of power factor, part load chiller efficiency, and capacity increase due to condenser water reset, so some judgment or, in the absence of judgment, cyberprocessing is necessary to gauge accurately when $n - 1$ chillers can handle the load being carried by n chillers.

Lowering CHS temperature

When low ΔT is a problem, there's another strategy operators can pursue to increase chilled water ΔT in the system—reduce CHS temperatures at all but full load chiller capacity. This can easily be accomplished by lowering the CHS set point temperature on each chiller's control panel. Then at part load, the chillers will produce colder chilled water but as chiller load increases will automatically reset CHS up to design temperature. With a further increase in load, leaving CHS temperature will exceed the desired design value, thereby signaling that the chiller is fully loaded and that an additional chiller is needed.

The advantage of lowering the CHS temperature supplied to cooling coils is that it reduces their CHW flow requirement and raises the CHW ΔT across the coil. For example, lowering CHS temperature from 45 to 42 F reduces the coil flow requirement for the same load to roughly two-thirds and increases ΔT by roughly 150 percent. If coils are under control, lowering CHS temperature *will* increase chilled water ΔT. But if the root cause of low ΔT is that coils are running wild due to wide open throttling valves or open bypasses, as I believe is most often the case (see my article "Troubleshooting CHW Problems at the NASA Johnson Space Center," *HPAC*, February 1995), then colder chilled water supply will not reduce overall system flow appreciably. Nonetheless, this strategy is a good one to try if for no other reason than to troubleshoot the source of your low ΔT problem. If lowering the CHS temperature results in one-half the expected flow reduction, then you know that roughly one-half of your control valves are under control. If there's no change in flow, everything is running wild, and nothing is under control.

The disadvantage of lowering CHS temperature is the energy penalty for a chiller operating at reduced chilled water temperature. The penalty is at least 0.012 KW per ton per deg F depression of evaporating temperature in the ideal case—*i.e.*, assuming no degradation in compressor efficiency. But compressor efficiency will generally fall off as the chiller is asked to operate at an off-design condition. I can't predict how much compressor efficiency will degrade for an existing machine, but I have done the calculation for two new chiller selections optimized for 42 and 45 F CHS temperatures. The 42 F chiller will typically have a compressor efficiency reduction of 1 to 3 percent. If we assume a 3 percent reduction for an existing chiller, the penalty for a reduction in CHW temperature from 45 to 42 F would be 0.041 KW per ton. If all flow actually reduced to approximately two-thirds due to the lowering of CHS temperature from 45 to 42 F, I calculate there could be a net saving for pump energy over chiller penalty if pumping head is well in excess of 100 ft. However, I would speculate that this degree of improvement in CHW flow is unlikely in most systems with Central Plant Syndrome.

Conclusion

To my way of thinking, the "checked" primary-secondary design is a cheap and simple improvement to primary-secondary design of chilled water plants that allows a plant to deal positively with Low ΔT Central Plant Syndrome while preserving the protective features of primary-secondary design. Lowering CHS temperature to improve ΔT may be worth a try if your plant's problem is particularly severe, but I don't believe it will generally pay out.

System Analysis vs. Quick Fixes for Existing Chilled Water Systems

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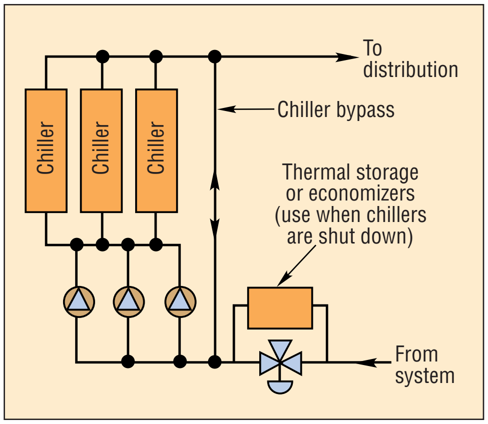
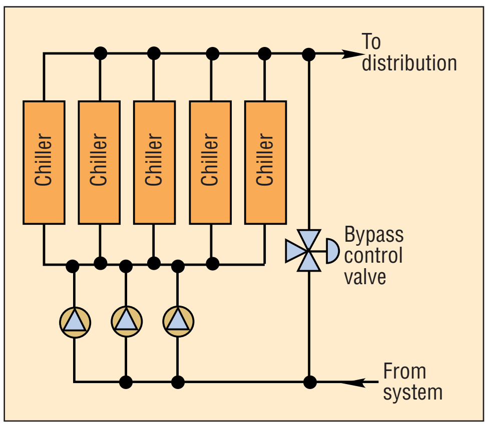
There are many existing chilled water systems, designed in the era of mechanical control, that utilize a number of safeguards to protect chillers, cooling towers, and chilled water pumps. The advent of digital electronics has enabled us to rethink these safeguards and determine if they are needed now that we have more precise and reliable control.

This discussion deals with the suitability of using a check valve in chiller bypasses as a quick fix for control of chilled water in existing chilled water systems. The check valve does stop reverse flow in the chiller bypass, which is a problem in many traditional primary-secondary systems. However, there is much more than dealing with reverse flow that must be done to improve the performance of many existing chilled water systems.

Today, we live in a world of design changes that have resulted in



1 Installation utilizing energy storage systems or water side economizers.



2 Bypass control valve functioning with several chillers.

more efficient chilled water systems. Typical of this is the article, "Retrofitting a 30 Year-Old Chilled Water Distribution System," by Gregory Karalus, PE (*HPAC*, September 1997). This article demonstrates the care that must be addressed to the redesign of existing chilled water systems.

A nagging problem that exists in so many existing chilled water systems is low temperature in the water returning from these systems. This has been reiterated by Wayne Kirsner, PE, in several articles published in *HPAC*, including ("The Demise of the Primary-Secondary Pumping Paradigm for Chilled Water Design" (November 1996). This is a complicated problem that cannot be easily fixed. Many of the existing systems require detailed evaluation to eliminate low return water temperatures.

Following are situations where a check valve may not be the answer:

- When reverse flow is required in the bypass. This may be so in installations utilizing energy storage systems or water side economizers (Fig. 1).
- When under some procedures for sequencing chillers, reverse flow in the bypass may be a signal to add a chiller. Many designers do not like this procedure and just use it as the basis for an alarm signal that proves that the chillers or chilled water pumps are not functioning properly.
- The check valve does not reduce direct flow in the bypass. There are many installation operations that require this.

A better solution for many chilled water systems is the installation of a modulating control valve on the chiller bypass. This control valve overcomes some of the above deficiencies of the check valve. It has the specific duty of allowing a chiller to operate at its full range of flow in the evaporator. This is one answer for many chilled water systems with low return water temperatures, but it is not a universal answer. For example, the article in the September issue of *HPAC* mentioned above demonstrates an alternative design where no valve of any design was required in the bypass.

The bypass control valve functions well on chiller plants with a number of chillers (Fig. 2). The flow in each chiller, from minimum to maximum, is utilized to eliminate almost all flow in the chiller bypass. The specific duty of this valve as mentioned above is clarified by the following statements.

- It prevents flow in any of the chiller evaporators outside their allowable operating ranges.
- It reduces all flow in the chiller bypass to only that required to keep chiller flow within the allowable operating ranges.
- It can open to allow reverse flow on energy storage systems as shown in Fig. 1.

In a way, this discussion about valves in the chiller bypass is putting the cart before the horse. Long before any work is done in a central chiller plant, the following efforts should be made on the chilled water system itself to eliminate low return water temperatures and higher operating costs.

- There are different types of existing chilled water systems that require different treatments. Two of the most prevalent systems are the constant volume, three-way valve systems that have only chiller pumps and no secondary or system pumps and

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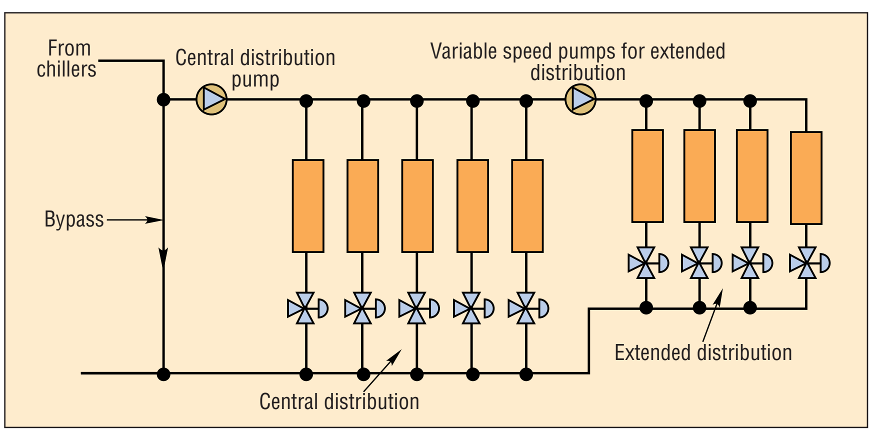

3 Variable speed booster pumps can improve the overall operating efficiency of the system.

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the standard primary-secondary systems with both chiller pumps and system pumps. Each type of system requires a different procedure for achieving an economical and efficient chilled water system.

- Eliminate all three-way valves on any of the cooling coils. Replace them with two-way valves of a quality that will withstand all water pressures imposed upon them.
- If wild coils (without control valves) exist in the system, determine if other procedures for these coils can be applied that will reduce the constant flow through them.
- Verify that all coils have interlocking controls that insure that the control valve is closed whenever the fan supplying air to the coil is stopped.
- Check thermostat settings that may be lower than the design value, causing the control valve to open and pass an excessive volume of water, at low temperatures, to the return system.
- Install "Pete's" plugs on the return piping from all cooling coils so that all coils can be checked for poor operation—that is, with low return water temperature.
- Determine if the coils are dirty in either/both air side or water side. Dirty coils or damaged coil fins can be the cause for low return water temperatures.

There are problems that can cause higher energy costs. One is when the design pump head is excessive. Determining the actual required pump head for a chilled water system is difficult for the design engineer. Once the system is in operation, it is easier to determine the true system head.

Another may be found in older systems. These often utilize central pumps to pump the entire system. Various procedures are used to tie together several pumping systems. The advent of the variable speed pump has enabled designers to use variable speed booster pumps (Fig. 3) to improve the overall operating efficiency of the system. There are many such booster pump systems in operation, proving that this is an efficient procedure for some applications.

This article has only highlighted the problems that can occur in existing chilled water systems. Every system needs a total evaluation, not a quick fix. There is no universal answer for all installations. **HPAC**