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Two Good Old Ideas Combine to Form One New Great Idea

Old Idea #1

Over the past several years, this newsletter has featured a chilled water system based on a **primary/secondary** piping system. This arrangement, shown in Figure 1, has also been called a “decoupled” system because the primary and secondary pumping duties are **hydraulically decoupled**. While this arrangement is certainly not new to system designers, until four or five years ago it was rarely used for conventional multiple chiller systems. Since then, however, it has become the **system of choice** for a majority of chilled water system designers. This shift in attitude among designers is largely due to the simplicity and flexibility of the decoupled system concept.

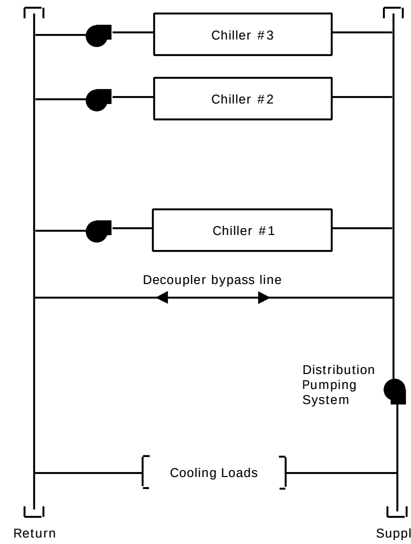

Figure 1. Primary/Secondary (Decoupled) Chilled Water System

Old Idea #2

The idea of employing **heat recovery** from water-cooled chillers is also an old one. The first heat recovery chillers used in a commercial building were four Trane TurboVacs installed in the late 1930s in Portland, Oregon, Figure 2. Heating and cooling requirements of this building are still served today with the same system.

During the energy crisis of 1974–76, a great number of chillers were applied in heat recovery systems. Some worked better than others because the system designers understood the concept and the limitations of the chosen machinery. Today, the use of chillers in heat recovery systems continues to be a highly engineered application. There are more ways to go wrong than right with such designs. Consequently, we continue to see heat recovery systems that fail to reach their initial financial objectives. There is a need to **simplify**.

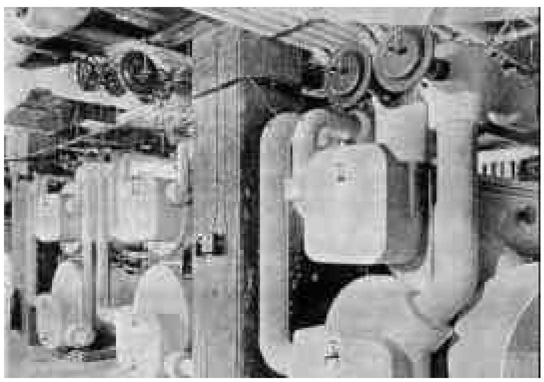

Figure 2.

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The Combination

A chiller is a chiller, even if it is designed to recover heat. This philosophy simply places heat recovery chillers in the same piping arrangement as those that don't recover heat. Figure 3 shows this arrangement. There is nothing wrong with this placement, so long as we understand its limitations:

1 All operating chillers "see" a proportional load. Since all operating chillers are supplied with return chilled water at the same temperature, they are proportionally loaded. "Preferential" chiller loading is not a feature of this arrangement. This means if one of the operating chillers is designed to recover heat, it can only be "loaded" to the extent that all of the other operating machines are loaded. Its heat output is thus restricted to the amount of evaporator load (not capacity) provided to this chiller at a specific time.

If the quantity of heat to be recovered is thought of as a by-product, as in the case of "auxiliary condenser" applications, this arrangement is satisfactory. If, however, the amount of heat to be recovered is a primary system responsibility, the objective may not be reached. Chiller output is determined by the instantaneous cooling load imposed on it. Figure 4 provides a visual accounting of representative values. Clearly, heat recovery is of secondary importance in such an arrangement.

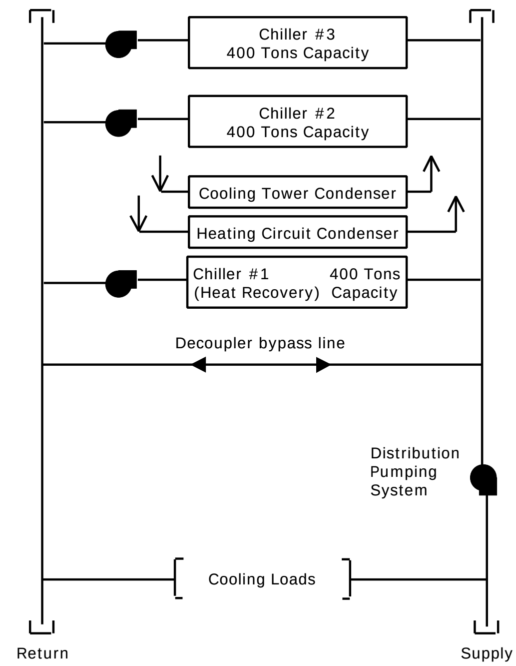

Figure 3. Decoupler System with Heat Recovery Chiller #1

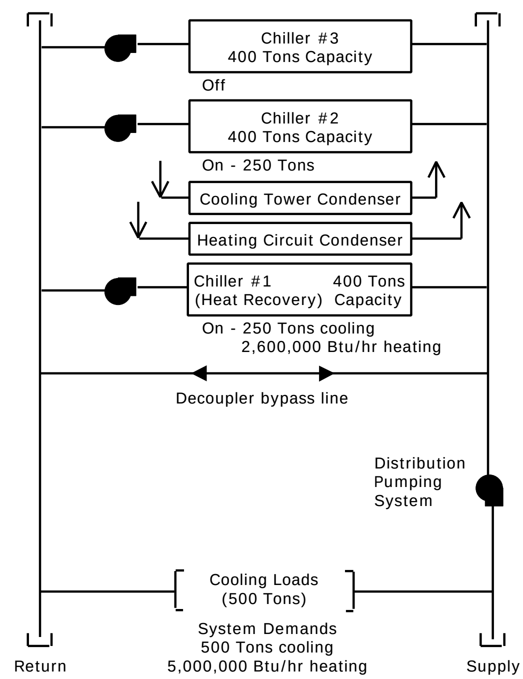

Figure 4. Decoupler System with Heat Recovery

2 Likewise, this same piping arrangement can result in surplus rejected heat, as shown in Figure 5. The traditional method of dealing with this mismatch is to equip the chiller with two condensers ... one for heat recovery and another for conventional (cooling tower) heat rejection. When surplus heat needs to be rejected to the tower circuit, a controller operates a combination of valves to modulate and balance this heat supply/demand relationship. Due to the wide variety of possible operating conditions, this control arrangement often becomes complicated. Control of heat recovery systems is **the major pain** for most system designers.

Further, the **temperature** of rejected heat is established by the heat recovery system. Even a small heating demand establishes the temperature for all rejected heat, because a chiller has only one condensing pressure/temperature. Since the machine's entire cooling performance (kW/ton) is determined by condensing pressure/temperature, a great deal of power is unnecessarily consumed and wasted in the cooling tower circuit.

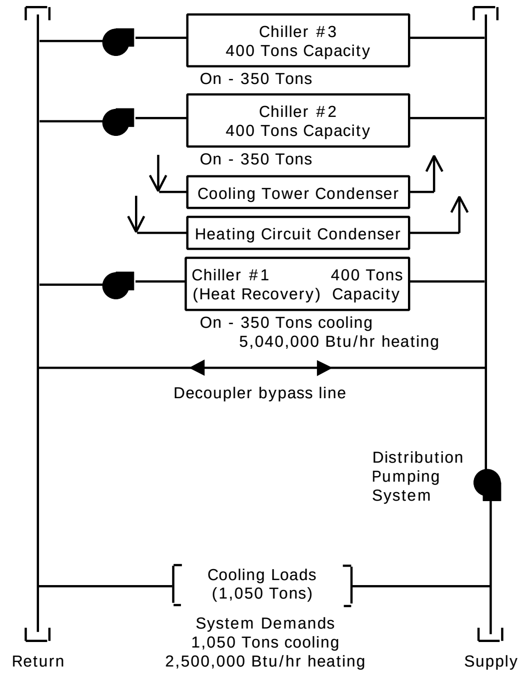

Figure 5. Decoupler System with Heat Recovery

Preferential Loading

One of the advantages of decoupled systems is the ability to preferentially load chillers by repositioning the decoupling (bypass) pipe. Figure 6 shows one possible way to accomplish this. By placing the heat-recovery chiller "upstream" from the point of bypass mixing, it is supplied with warmer return water than the remaining chillers. Therefore, it is preferentially loaded. At first, this would seem to solve all the problems associated with the arrangement shown in Figures 4 and 5. **But it does not:**

1 In order to meet the temperature needs of the chilled water system, this chiller must be operated to hold the system supply water temperature. This indeed accomplishes preferential loading, whether we need it or not, for heat recovery.

2 This control strategy adequately handles the issue of **enough heat**, but does nothing about **too much heat**. The basic problem of surplus heat rejection outlined above still exists, only worse! Now, in Figure 6, we see the possibility of rejecting even more of the heat from the cooling load at an artificially high condensing pressure/temperature.

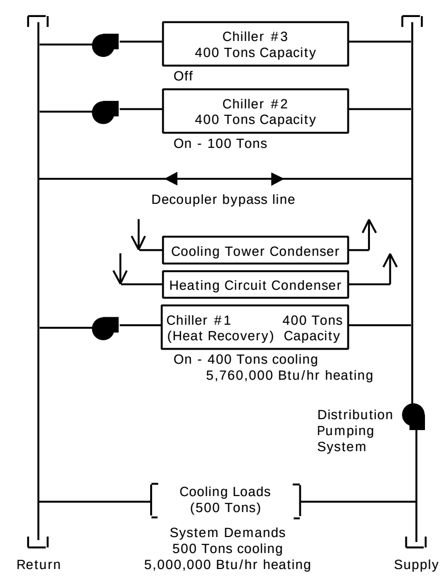

Figure 6. Decoupler System with Preferentially Loaded Heat-Recovery Chiller #1

Faulty Logic

The basic problem is one of **objective**. The primary objective of all of the chillers in the previously described system is to chill water, as required by the system. Heat recovery is a secondary objective, but assumes primary importance in establishing machine operating parameters (kW/ton) through the mechanism of condensing pressure/temperature.

If we decide to make heat recovery a primary objective, why not **dedicate** a machine to recover heat from the system? If we do this properly, it might be possible to overcome each of the operating problems cited **and** reduce plant cost.

A New Twist

The scheme shown in Figure 7 is not really new. It has been used on a number of occasions by insightful designers. After evaluating the performance of systems using this design concept, we reach some interesting and surprising conclusions. Equipment costs are reduced. Operating (power) costs are reduced. Control is simplified. An explanation follows.

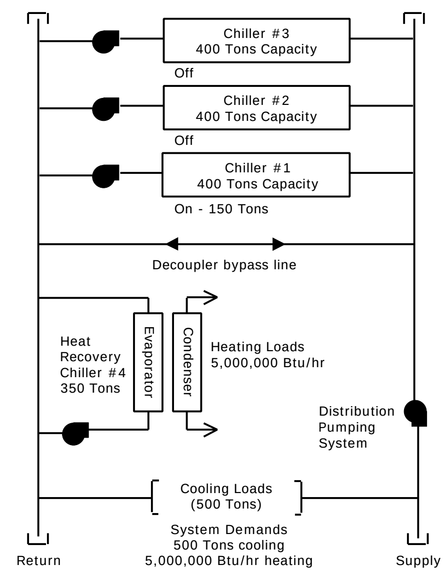

Figure 7. Decoupler System with Dedicated Heat Recovery

Consider the return water main from the system as a “river” of warm water. By using a variable flow distribution (secondary) system, we have tried to establish the highest possible temperature for this return “river.” Its quantity is unknown at any instant, but we do know that this stream contains the warmest chilled water in the entire system. This fact is important to efficient heat recovery, since the temperature level of the “heat source” is one parameter affecting power consumption.

The “source” is water taken from the river by a separately pumped “bridge,” or common piping circuit. The hydraulics of the main system are not altered in the least by the bridge. In fact, the flow in and out of the bridge is exactly the same whether or not the pump is operating. This arrangement permits constant flow through the evaporator circuit, even if there is zero flow in the “river.” The hydraulics are independent from the thermodynamics of heat recovery. The only added pumping energy is that required to push water through the evaporator circuit of the heat recovery chiller.

Since this machine’s primary objective is to heat, we should control its heating output, not its cooling. Instead of using a chilled water temperature controller, use a hot water controller. The sensed variable can be either supply or return hot water, depending on the system and the type of machinery used. Controller output establishes machine loading, just as it does when a chilled water controller is used.

Further, we are not at all interested in the temperature of the “chilled” water leaving this machine. It need not be controlled, except to verify that it does not drop dangerously low. For this, we suggest a low limit control that restricts machine output in the event of exclusively low evaporator temperature. In this way the heat-recovery machine output perfectly balances the relationship between heat supply and demand. Neither too much nor too little heat is recovered, so long as there is sufficient cooling load to provide the heat.

Since there is never a surplus of heat recovered, there is no need to equip this chiller with two condensers. The cooling capacity of this “heater” simply reduces the temperature of the return water stream without altering its flow rate. In effect, its cooling output is “free cooling” while heating occurs at the cost of electricity to power only the heating output. Heating COP becomes an important performance value only if the free cooling output is “netted out.” A **system approach** is mandated.

And the main chillers are likewise standard single condenser machines, not burdened with the cost or power demands of heat recovery.

A Comparison or Two

The economics of this scheme vary significantly, depending on the relative size and duration of heating and cooling loads. A comprehensive analysis program such as TRACE® 600 is required for an accurate evaluation. For our purposes here, a “snapshot” calculation comparing the arrangement shown by Figures 5, 6, and 7 demonstrates the process.

In this example, we have chosen a condition as follows. System cooling load: 500 tons. System heating load: 5,000,000 Btuh.

To “load” Chiller #1 to the point where it will reject 5,000,000 Btuh, we must pipe it so that it can be preferentially loaded, as shown in Figure 6. In doing this, we automatically place a maximum load of 400 tons (its maximum capacity) on Chiller #1, assuming the system return water temperature is maintained at the design value. At this cooling load, about 5,760,000 Btuh is rejected by this machine. Consequently, a surplus of 760,000 Btuh must be wasted to the cooling tower condenser circuit. We are prevented from producing less than 400 tons of cooling with this machine because of the consequential increase in supply chilled water temperature. Table 1 summarizes the power inputs that result at this condition.

Table 1

Chiller	Cooling Tons	Heating Btuh	kW/Ton	kW
#1	400	5,000,000	0.90	360
#2	100		0.75	75
#3				
Total	500	5,000,000		435

By comparison, refer to Figure 7. The system loads are identical. But, Chiller #4 (the added heating machine) is “loaded” by virtue of a hot water demand of 5,000,000 Btuh. This corresponds to a cooling load on the evaporator of about 350 tons. The remaining 150 tons are handled by Chiller #1, a cooling-only unit; see Table 2.

Table 2

Chiller	Cooling Tons	Heating Btuh	kW/Ton	kW
#1	150		0.72	108
#2				
#3				
#4	350	5,000,000	0.90	315
Total	500	5,000,000		423

The second comparison evaluates a totally different condition of relative loads. Here, the loads shown in Figure 5 are used in a preferentially loaded chiller system (like Figure 6) and compared, Table 3.

Table 3

Chiller	Cooling Tons	Heating Btuh	kW/Ton	kW
#1	400	2,500,000	0.90	360
#2	325		0.65	211
#3	325		0.65	211
Total	1,050	2,500,000		782

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The same conditions are compared in Figure 8. The heating machine need only take 175 tons from the system cooling load in an effort to meet the 2,500,000 Btuh heating demand. The remaining 875 tons of cooling demand is divided equally among the three cooling-only chillers, Table 4.

Table 4

Chiller	Cooling Tons	Heating Btuh	kW/Ton	kW
#1	292		0.65	190
#2	292		0.65	190
#3	292		0.65	190
#4	175	2,500,000	0.90	158
Total	1,050	2,500,000		728

While these two examples show the significant energy advantage of this arrangement, they do not prove that every condition will exhibit similar reductions in power consumption. But, we have not found any condition, where loads are met, that reverse the obvious conclusion.

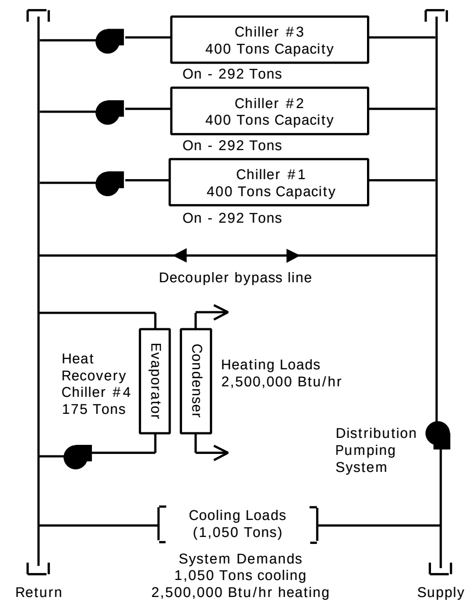

Figure 8. Decoupler System with Dedicated Heat Recovery

Where Is This Best Applied?

Five general applications immediately come to mind. Size of the plant **is not** a factor.

1 Combination resort/convention hotels located in moderate or warm climates.

2 Hospitals and nursing homes with significant water heating demands.

3 Processes that involve small but continuous heating loads and continuous cooling requirements.

4 Processes that require refrigeration and reheat systems for humidity control.

5 Athletic facilities located in warm climates.

Earlier in this newsletter, we referred to a change in logic that considered the cooling output of the heating machine as free cooling. One important characteristic of this form of free cooling is the fact that control of the evaporator leaving water temperature is completely unnecessary. Further thought on this distinction leads us to another, but unrelated, use for this particular hydraulic arrangement … free cooling via direct heat exchange with cooling tower water. This will be the subject of a later *Engineers Newsletter* (see Vol. 20, No. 3, “A New Era of Free Cooling”, 1991).