Providing insights for today's HVAC system designer

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Hydronic Heat Recovery Control

To help achieve goals of reducing energy costs, energy use, and more recently emissions due to energy use, recovering heat in hydronic systems is of great interest today. This *Engineers Newsletter* builds upon information available in previous Trane publications (see References on page 7) and provides deeper information on design, operation, and control of these systems. This *Engineers Newsletter* concentrates on the heat recovery portions of the system and does not address auxiliary or supplemental heating components or control.

Background

The goal of a hydronic heat recovery system is to recover, rather than reject, heat from the condenser of a water-cooled chiller or chiller-heater. Recovering heat reduces the amount of energy needed for the heating load. In addition, cooling tower energy and water usage are also reduced since less heat is rejected. To recover heat, there must be a cooling load— this newsletter assumes cooling and heating loads are simultaneous. There are systems that allow for asynchronous heating and cooling but those systems will not be covered in this content. This *Engineers Newsletter* covers specific system configurations being used by system designers; sidestream in any system, preferential loading in primary-secondary (decoupled) systems, and cooling evaporators piped in series.

Sidestream

Figure 1 shows a variable primary flow (VPF) system using a "sidestream" configuration with two cooling-only chillers (500 tons each) and one heat-recovery chiller (200 tons, 3000MBh). The heat-recovery unit has constant-volume chilled (evaporator) and hot (condenser) water pumps. There may be multiple heat-recovery chillers in sidestream systems.

Design

The heat recovery chiller shown in Figure 1 has a single condenser, which is common for smaller units (e.g. less than 500 tons). If this unit must have the capability to satisfy a cooling load when there is no heating load, there must be a method to reject the heat to the cooling tower system—in this example a heat exchanger is shown. Alternatively, heat rejection to the cooling tower system can be incorporated into a "double-bundle" heat recovery chiller (Figure 2). This reduces the space and piping required by a separate heat exchanger. Two "double-bundle" designs are available. Figure 2 shows a unit with a separate, same-sized heat recovery condenser shell. Another option incorporates the cooling tower system and heat-recovery condensers into the same shell and keeps the water streams separate.

Figure 1. Variable primary flow (VPF) system with sidestream

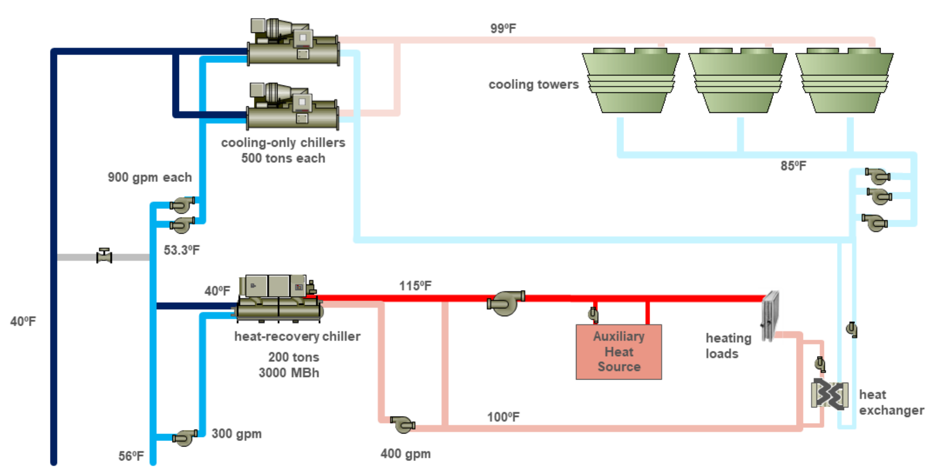


Figure 2. Double-bundle heat recovery chiller

An important aspect of the sidestream configuration is that the heat-recovery chiller reduces the return chilled-water temperature to the cooling-only chillers—to 53.3°F at design conditions for this example.

- In a VPF system, the cooling-only chillers are selected at the system design flow rate divided by the number of chillers (900 gpm) and reduced ΔT due to the cooler return-water temperature. Each cooling-only chiller can operate at any flow rate between its evaporator minimum and maximum flow rates and produce the supply chilled-water temperature until the chiller's capacity is exceeded.
- In a primary-secondary system the cooling-only chillers might incorrectly be selected using the system design ΔT—in this case resulting in an evaporator flow rate of 750 gpm each. This may cause issues with fully loading these chillers at the design-return chilled-water temperature (53.3°F). Each primary chilled-water pump should be selected at 900 gpm, the same flow rate as in a VPF system, to account for this. The bypass (decoupler) pipe must be sized to account for this increased flow.

As the heat-recovery chiller loads become a larger proportion of the total cooling load, reduced return-water temperature causes more significant design and operational issues which must be considered.

Operation

Many heat-recovery chillers have the capability to operate in either cooling mode (maintain chilled-water supply temperature) or heating mode (maintain condenser-water leaving heating temperature), and are often referred to as chiller-heaters.

Today, system designers and operators often want to maintain the heating (heat-recovery chiller condenser leaving) water temperature at the design condition—in this example 115°F. Figure 3 shows the system operating at a cooling load of 550 tons and heating load of 2600 MBh.

In a sidestream configuration, the simplest system operation is to have the chiller-heater maintain the leaving condenser (heating) water temperature. This operation requires only two chiller inputs; enable the unit in heating mode and the heating water temperature setpoint.

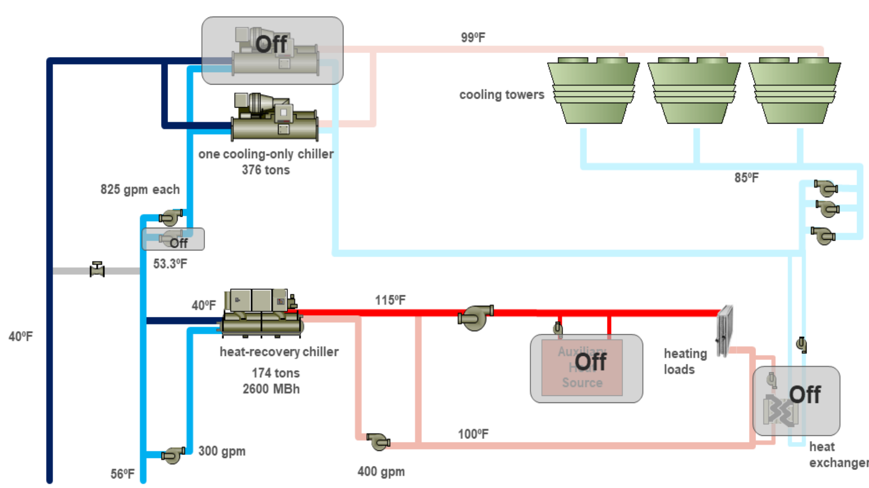
At the example conditions:

- The heat-recovery chiller loads to 174 tons and satisfies the entire heating load.
- The cooling-only chiller loads to 376 tons.

From a system perspective it is simplest to operate the heat-recovery chiller evaporator and condenser-water pumps at constant flow rates. This allows the unit to satisfy the heating load (its primary purpose in this case) and reduces its power since the unit evaporator water leaving temperature rises and results in reduced compressor lift. Allowing the chilled-water temperature to rise also increases the minimum unloading point for centrifugal chillers.

Alternatively, the chilled-water temperature setpoint can be set at design and the chilled-water pump speed varied. While this saves some chilled-water pump energy, it requires a method to maintain evaporator flow rate above the chiller-heater's minimum, which in turn requires monitoring the flow rate. This is more complex and requires additional components and calibration of those components.

Figure 3. Chilled water heat recovery with sidestream



Centrifugal chiller leaving condenser water control

Maintaining a constant-leaving condenser (heating) water temperature provides a challenge for heat recovery chillers using centrifugal compressors. The cooling load must be maintained above a minimum load to avoid surge (see *Heating with Compressors in HVAC Systems* applications engineering manual, SYS-APM005*-EN). Ask the chiller provider to provide selection data showing the minimum load—an example is shown in Table 1 and Table 2. Once the minimum unloading point is known, the chiller load must be monitored and system controls provided to maintain the minimum load. One method is to sequence a heat-recovery chiller on only when the system cooling load is above the minimum unloading point.

Table 1. Sidestream unloading (based on constant entering evaporator temperature)

Percent Load	Cooling Capacity (tons)	Heating Capacity (MBh)	Evaporator Entering Temperature (°F)	Evaporator Leaving Temperature (°F)	Heat Recovery Condenser Entering Temperature (°F)	Heat Recovery Condenser Leaving Temperature (°F)	Heat Recovery Chiller Power (kW)
100	350	5257.6	56	40.0	100.0	115	302.1
90	315	4732	56	41.6	101.5	115	269.8
80	280	4227.6	56	43.2	102.9	115	243.9
70	245	3725.5	56	44.8	104.4	115	220.1
60	210	3224.8	56	46.4	105.8	115	197.7
50	175	2722.2	56	48.0	107.2	115	174.7
40	140	2217.8	56	49.6	108.7	115	151.1
30	105	1711.1	56	51.2	110.1	115	126.5
20	70	1204.6	56	52.8	111.6	115	105.8

When a heat-recovery chiller is piped in a sidestream position, operation is simple and reliable. Furthermore, the chiller can unload to a lower operating point, as the 20 percent minimum load in Table 1 shows.) Since the leaving evaporator temperature rises, thus reducing compressor-pressure differential and avoiding surge. This is another significant advantage of the sidestream configuration.

Table 2. Parallel unloading (based on constant leaving evaporator temperature)

Percent Load	Cooling Capacity (tons)	Heating Capacity (MBh)	Evaporator Entering Temperature (°F)	Evaporator Leaving Temperature (°F)	Heat Recovery Condenser Entering Temperature (°F)	Heat Recovery Condenser Leaving Temperature (°F)	Heat Recovery Chiller Power (kW)
100	350	5257.6	56.0	40	100.0	115	302.1
90	315	4748.2	54.4	40	101.5	115	274.3
80	280	4246.3	52.8	40	102.9	115	249.1
71	248.5	3799	51.4	40	104.2	115	228.8

When piped in a parallel preferential position, the chiller is usually controlled to maintain its leaving evaporator temperature. Using the same physical chiller, the chiller can only unload to 71 percent of its design cooling load (Table 2). At this point the pressure differential causes the compressor to enter the surge region and system controls must be used to adjust; for example by increasing the evaporator leaving-water temperature, which reduces the cooling load and condenser leaving (heating) temperature. Once again this shows the advantage of piping a heat recovery chiller in the sidestream position.

Control

A single condenser heat-recovery chiller-heater with leaving condenser (heating) temperature setpoint control is simple when the unit controls capacity. An exception occurs when the unit is the only chiller operating and produces more heat than required to satisfy the heating load. In this case the condenser heat exchanger pump is activated to maintain the desired system heating supply-water temperature. Operation is similar to the preferentially loaded heat-recovery chiller in Figure 5.

Dual-Condenser Heat-Recovery Chiller Control

A heat-recovery chiller with two condensers can also maintain the heating supply temperature by varying the chilled-water temperature. With that said, sometimes the system chillers have greater heating capacity than required for the load. In such cases, it may be desirable to control the chilled-water temperature via chiller unit controls and adjust the amount of heat rejected via system controls. Care must be taken to keep from rejecting too much heat—which can occur if full flow rate passes through the standard (cooling-tower) condenser, especially if the tower water temperature is low.

The following methods provide heat recovery and reject only excess heat.

- Figure 4: At each heat-recovery chiller, install a bypass and three-way valve (or two linked valves) and control the valve (V2) to provide the heating setpoint (T1).

  Advantage: Keeps cooling tower flow rate constant, which simplifies cooling tower operation.

  Disadvantage: A bypass and control valve is required at the condenser for each chiller, which increases cost and required space.

- Figure 5: Install a modulating valve (V2) to vary water flow through the heat-recovery condenser to maintain T1.

  Advantages: Only one valve is required (reducing cost and space) and simplicity if there are multiple double bundle heat-recovery chillers.

  Disadvantage: Cooling tower water flow rate varies, which can cause improper flow distribution over the tower fill. Careful attention must be paid when coordinating variable flow rates. In very cold temperatures increased icing may occur. Consult the tower provider to understand tower capabilities and limits with respect to reduced flow rate.
- In both examples, a tower bypass and valve (V1: a three-way valve or two linked valves) ensures condenser return-water temperature to the chiller(s) is a mixture and therefore at a higher temperature. This enhances heat-recovery chiller operation, but may decrease cooling-only chiller efficiency. As mentioned previously, reduced tower flow rate must be addressed.

Operating Modes

In this example the heat recovery pump is assumed to be constant speed.

If V1 is sending all water to the cooling tower, V2 is fully open and the heating temperature (T1) is still too high, lower cooling tower leaving temperature is required. The following steps (performed in the order shown) are used to reject excess heat until T1 is at setpoint:

1. If the heat-recovery chiller is the only chiller operating, begin to close the tower bypass valve (V1) to send water over the cooling tower fill
2. Enable cooling tower fans at minimum speed
3. Tower fan speed up to full speed until an adequate tower leaving water temperature is attained. If the leaving water temperature still cannot be maintained, the tower fans ramp to full speed.

As T1 drops below setpoint, this sequence is reversed.

Figure 4. Dual condenser control, bypass control

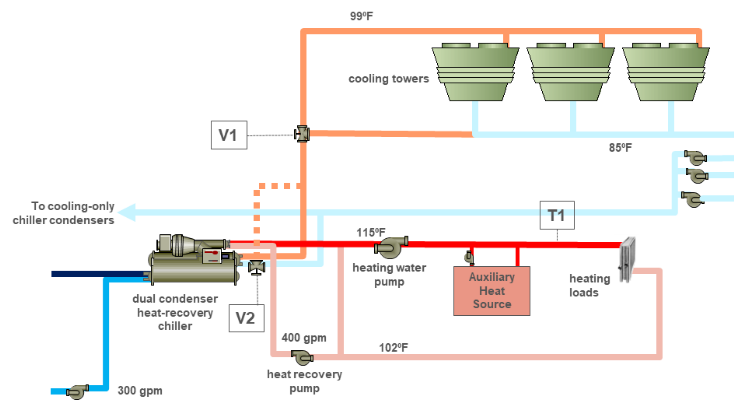
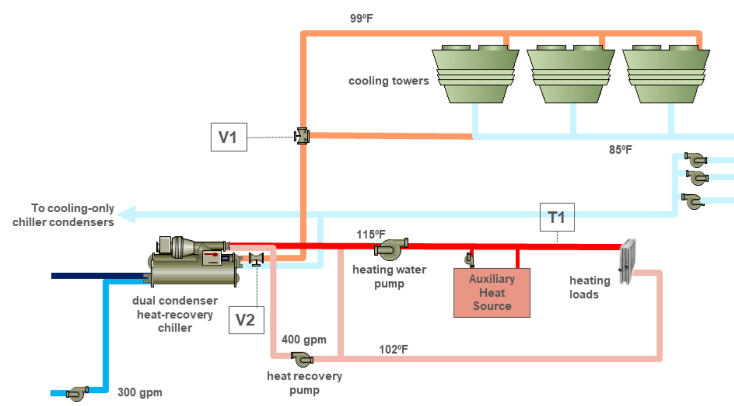


Figure 5. Dual condenser control, modulating valve control



Mode	T1	V2	Heat Recovery pump	Auxiliary heater
Heat rejected by the heat-recovery chiller is equal to or less than the heating load	≤ setpoint	Allowing all flow through heat-recovery condenser	On	Adds heat to maintain T1 as necessary*
Heat rejected by the heat-recovery chiller is greater than the heating load	> setpoint	Controlled to maintain T1	On until there is no heating load	Off

*Generally, the auxiliary heat source is enabled when T1 drops a few degrees below the desired setpoint temperature for a given period of time. This keeps the auxiliary source from “stealing” load from the heat recovery chiller.

Preferential Loading in a Primary-Secondary System

If the chilled water system is primary-secondary, recovering heat is simple when the heat-recovery chillers are piped into the proper system location. A chiller's evaporator located on the load side of the bypass line (Figure 6) loads the unit preferentially, because it receives the warmest return chilled water temperature. An additional benefit is that the heat-recovery chiller's evaporator pump adds to the chilled-water system flow rate. This allows each cooling-only chiller primary pump to be sized for 750 gpm since the cooling-only chillers experience the full system ΔT.

The examples below use the same operating conditions as the previous example, 550 tons of cooling and 2600 MBh of heating, and provide several operating options.

Chilled-Water Temperature Control

At these operating conditions and operating the heat-recovery chiller to make its supply chilled-water temperature (40°F) produces 3000 MBh of heat (Figure 6). So, 400 MBh must be rejected using the heat exchanger. Also, the cooling-only chiller load is reduced. System operation is simple; enable the heat recovery unit in cooling mode and reject excess heat to the cooling tower system. From an energy (and emissions) standpoint this operation may not be optimal, because efficiency of the heat-recovery chiller may be less than the cooling-only chiller due to the increased leaving condenser water temperature.

Hot (Condenser) Water Temperature Control

Operating the heat-recovery chiller in the heating mode increases its chilled-water leaving temperature, which reduces its cooling load. At design, the evaporator flow rate increases the evaporator leaving water temperature (to 42.9°F), which in turn increases the system chilled-water system-supply temperature (to 40.7°F). This requires increased system chilled-water flow rate and pump power and may degrade system ΔT. Controls may be used to maintain the chilled-water supply temperature at design, but they add system complexity and only work within the following limits:

- Control the heat recovery evaporator pump to maintain its leaving chilled-water temperature to the design condition, in this case 261 gpm. This works as long as the evaporator flow rate stays above the heat recovery chiller's minimum flow rate. It also requires installation and maintenance of high quality flow monitoring devices such as a flow meter or differential pressure sensor.
- Reset the cooling-only chilled-water setpoint (to 38.5°F in this case) to maintain the design system chilled-water system-supply temperature of 40°F. This increases the cooling-only chiller load and may also result in exceeding low water temperature limits, low refrigerant temperature limits, and even cause centrifugal chillers to surge. Significant examination and understanding of these and other effects should be undertaken prior to implementing this method.

Figure 6. Hydronic heat recovery in primary-secondary system, preferential with chilled-water temperature control

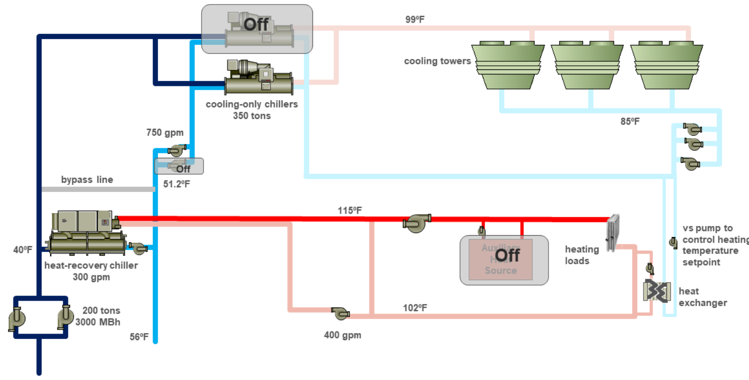
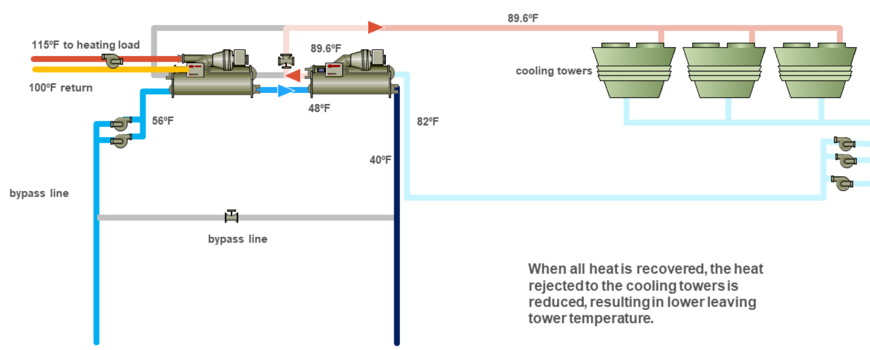


Figure 7. Series chillers with heat recovery



Series Configurations

A significant benefit of the sidestream configuration is that the heat recovery unit can be loaded to maintain hot-water supply temperature. A significant benefit of the preferential loading configuration is that the chilled water flow of the heat recovery unit is additive from a system flow rate standpoint. Putting evaporators and condensers in a "series-counterflow" configuration may provide the best of both when the heat recovery load is a significant portion of the overall system cooling load.

The series example (Figure 7) shows the series-counterflow configuration operating in full heat recovery mode:

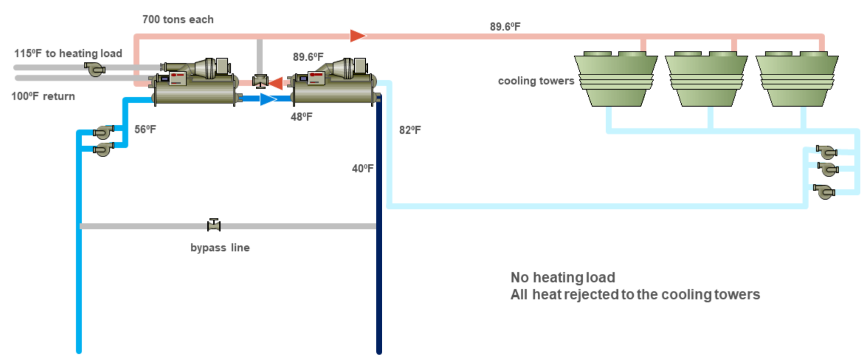
- Variable-primary flow chilled-water system.
- Two equally sized chillers with respect to cooling capacity.
- In the chilled-water stream, a double-bundle heat recovery chiller upstream of the cooling only chiller.
- Series-counterflow condenser water flow for heat rejection. (Parallel condensers are addressed in a later section.)
- A condenser bypass line used to control the amount of heat recovered.
- When all available heat is being recovered, no cooling tower water flows through the standard condenser. Since less heat is rejected, the cooling tower provides cooler condenser water to the cooling-only chiller.

Series heat recovery chiller selection
The amount of heat available for recovery is dependent on the chilled-water flow rate (variable in this example) and chilled-water ΔT. Therefore, at a constant return chilled-water temperature, the heat recovery chiller's cooling load is determined by its leaving chilled-water setpoint. Significant time and thought should be expended on the heat recovery chiller selection with respect to minimum operating percentage and minimum chilled-water leaving temperature. Work closely with the chiller provider to determine the load and leaving evaporator temperature limits.

No Heating Load

When there is no heating load, all heat is rejected to the cooling tower loop and there is no flow through the heat-recovery condenser (Figure 8). If chillers are properly selected, either chiller can be sequenced on first. When both operate, the leaving chilled-water temperature for the upstream chiller is usually controlled at its design setpoint.

Figure 8. Series chillers with heat recovery, no heating load



Operating to provide heat

When the heat recovery chiller operates in heating mode, its leaving chilled-water temperature varies. The chilled-water plant control system must monitor the heat-recovery chiller's load and leaving chilled-water temperature, then respond if the leaving chilled-water temperature approaches its minimum limit.

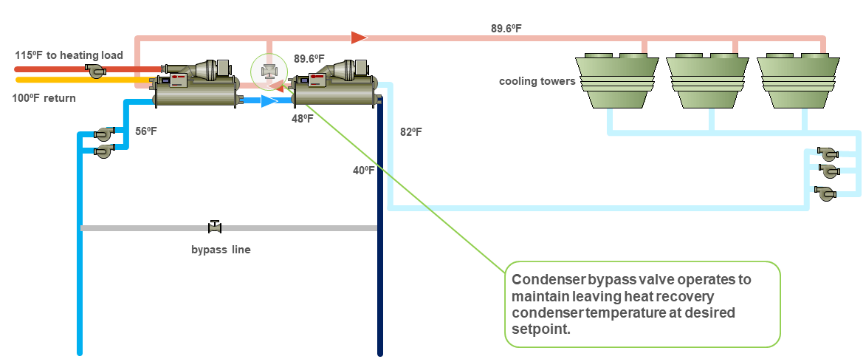
Operating the heat-recovery chiller in cooling mode at its design leaving chilled-water temperature is more likely to keep the unit within its operating envelope, but may not satisfy the heating load.

In this operating mode the cooling-only chiller maintains the system chilled-water temperature and satisfies the remainder of the cooling load.

Reject Excess Heat

When controlled in cooling mode the heat from the heat-recovery chiller may be more than needed to satisfy the heating load. In this case heat must be rejected from its standard condenser. This is controlled by modulating the water flow through the standard condenser using the bypass valve to maintain the heat-recovery condenser leaving water temperature (115°F in Figure 9).

Figure 9. Series chillers with heat recovery, reject excess heat



Modulating flow rate through chiller evaporators to load heat recovery chillers
A few, very sophisticated chilled water plant users have successfully used modulating valves on all chiller evaporators to vary water flow (and therefore load) of each chiller. This is very complex, requires significant engineering design time and thought as well as long-term operator training and system tweaking. It is a subject beyond the scope of this *Engineers Newsletter*.

Rather than the series counterflow configuration shown, piping the cooling-only and heat-recovery chiller condensers in parallel provides the following advantages:

- Reduced condenser water flow rate per chiller as well as pressure drop.
- Independent operation of each chiller.
- Smaller bypass and valve for the heat-recovery chiller. Also reduced cost and space for the bypass and valve.
- The ability to use a throttling valve for the heat recovery chiller's standard condenser. A drawback is that the cooling tower water flow rate varies—which could affect cooling tower operation and flow limits.

Summary

Heat recovery is more prevalent today than in the past and more customers are requesting or requiring its use. Advantages include reduced energy use, energy cost, emissions, as well as heat rejection water cost and treatment. Attempt to keep the plant design and operation as simple as possible, but not simpler.

Chiller selection: Spend the up-front time to understand the operating map of the specific heat recovery chiller. Work closely with the provider and determine minimum unloading, as well as heating (condenser) water and chilled water limits.

Sidestream: Consider this configuration first. In cases where the heat-recovery chiller cooling capacity is not large it's simple to design, install, control, operate and understand.

Preferential loading in primary-secondary system: In primary-secondary systems with significant heat recovery loads, this system should receive significant consideration. System design and operation are understandable and controls are fairly simple. However, with the advent of more variable primary flow systems this option is not as applicable today as it was 30 years ago.

Series: Consider this configuration when the cooling capacity of the heat-recovery chillers is significant. While more design thought is necessary, the series configuration offers significant flexibility of heat recovery operation with a modest increase in control complexity.

By Mick Schwedler, Trane. To subscribe or view previous issues of the Engineers Newsletter visit trane.com. Send comments to ENL@trane.com.

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- Thermal Battery™ Storage Source Heat Pump Systems application guide (APP-APG022*-EN)
- Modular Air-to-Water Heat Pumps application guide (APP-APG021*-EN)
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