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Heat Recovery Chillers In Campus Chilled Water Distribution Systems

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Designers are sometimes faced with the challenge of interfacing remote heat recovery chillers (HRCs) in buildings that are connected to large campus chilled water systems. This month, I provide some design tips on how these remote chillers can provide local heating while supplying both local cooling and chilled water back into the campus chilled water distribution system.

Understanding the Issues

When faced with a new challenge in hydronic systems, it is important to break down the problem into smaller objectives that need to be accomplished with the design alternative. These objectives can be hydraulic issues, control issues, life-cycle cost issues, and more. The author has seen an increase in remote HRCs in large campus distribution systems in recent years. These can be in many forms when they are connected to a chilled water distribution system. HRCs can be used to meet or supplement the local building heating requirements while utilizing the benefit of the simultaneous cooling to cool the building or export this by-product to the campus chilled water distribution loop. Single or multiple chillers can be installed in a building to provide additional redundancy if the main system is not reliable for critical loads. Whatever the situation, it is always critical to understand the various modes of intended operation to determine the optimum piping arrangement and control schemes.

Heat Recovery Chiller Considerations

Heat recovery chillers provide roughly 13 MBH of heating per ton of cooling. The coefficient of performance for heating (COP_H) is the ratio of the useful heating energy divided by the energy input. The coefficient of performance for cooling (COP_C) is the ratio of the useful cooling energy divided by the energy input. For heat recovery chillers, if the energy rejected is useful for heating and the energy absorbed is useful for cooling, the unit will have a combined, $COP_{combined}$, that is the ratio of the sum of heating energy and cooling energy to the energy input. Higher COPs equate to lower operating costs. The efficiency of the HRC will be impacted by the overall compressor lift required. A higher compressor lift will increase the compressor energy and lower the COP. The compressor lift can be minimized by selecting lower hot water temperatures, where possible. As an example, an HRC selection of 44°F (7°C) chilled

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water supply (CHWS) temperature with 110°F (43°C) heating hot water supply (HHWS) temperature might result in a $COP_{combined}$ of 8.4. The same model selected for 44°F (7°C) CHWS with 140°F (60°C) HHW might result in a combined COP of 5.6.

Heat recovery chillers can be provided in many different configurations. A modular HRC consists of multiple modules connected to a single header with compressors in each module. Modules and compressors can be staged to meet the load while internal automatic isolation valves can isolate non-operating modules in variable flow applications. These types of chillers use plate-and-frame heat exchangers for the evaporators and condensers and require a good water treatment program with fine mesh strainers to ensure the reliability of the heat exchangers. Modular HRCs also have the option of providing an air-source/air-cooled heat exchanger when heating and cooling loads do not match.

Non-modular HRCs have the benefit of conventional evaporator and condenser barrels with copper tubes to allow for tube cleaning but will generally not provide the low load operating efficiency of modular heat recovery chillers, especially centrifugal chillers where high lift at low load can lead to surge conditions solved, inefficiently, by use of hot-gas-bypass. These can sometimes be the best option if the project owner cannot maintain the water treatment program required for the modular HRCs.

The reasons for using heat recovery chillers can vary. A project may desire to eliminate combustion sources for heating and therefore use all-electric, 100% heating from HRCs, perhaps driven by California's electrification goals[1] where heating generated by electrical sources is preferred environmentally to fossil fuel sources. New buildings and major renovations can select the building hot water heating coils for lower heating hot water supply temperatures to optimize efficiency.

Another project may desire to provide most of the annual heating with HRCs for low-load, low-temperature heating hot water on older buildings that were designed with higher heating hot water temperatures to reduce carbon emissions from gas-fired boilers. Retrofit projects in existing buildings may still need the capability of the gas-fired heating hot water systems to provide the original design hot water supply temperatures at peak loads with existing one-row heating coils. In the author's experience, HHWS temperature setpoint reset controls can substantially reduce annual heating energy losses. Generally, one-row heating coils selected at 180°F (82°C) can provide roughly 30% to 40% of the peak capacity when the supply temperature is reduced to 110°F (43°C). The existing coils can be modeled at the lower temperatures to determine their heating capacity when using lower hot water supply temperatures.

It is critical to understand the cooling and heating load profiles for the project when deciding how to size and select heat recovery chillers. Standalone building chilled water systems do not have a means of energy storage in a campus system and will require an understanding of the simultaneous building cooling and heating load profiles throughout the year to select the best HRS size to optimize life-cycle cost and to minimize dumping heat when it is not needed. Clearly, if there are few hours where simultaneous heating and cooling occur, as might be the case with well-designed HVAC systems, HRCs will not be cost effective and should not be considered. However, if the HRC is connected to a continuously operated chilled water plant, then simultaneous heating and cooling need not occur within the building itself; heating can be provided to the building while cooling is provided to other buildings served by the central plant.

Heat recovery chillers that provide only simultaneous heating and cooling are the lowest cost per ton (kW) while HRCs with auxiliary air-source/air-cooled heat exchanger can be twice the cost per ton (kW). The projected electrical and gas rates, including demand charges (where applicable), for the project location can have a substantial impact on the life-cycle cost of individual projects.

The Art of Piping Diagrams

The integration of HRCs into the design can add new complexity into the piping, controls, and operation of the system. Easy to understand logical piping diagrams can be a useful tool for evaluating and communicating different piping arrangements and control options. The goal of the piping diagram is to convey the flow logic of the connected components. It should be easy for the operator to determine what equipment is piped in series and what equipment is piped in parallel. Piping diagrams with multiple pipes crossing each other can be difficult for others to understand the flow logic.

The author uses the following simple rules for generating piping diagrams that are easy to understand:

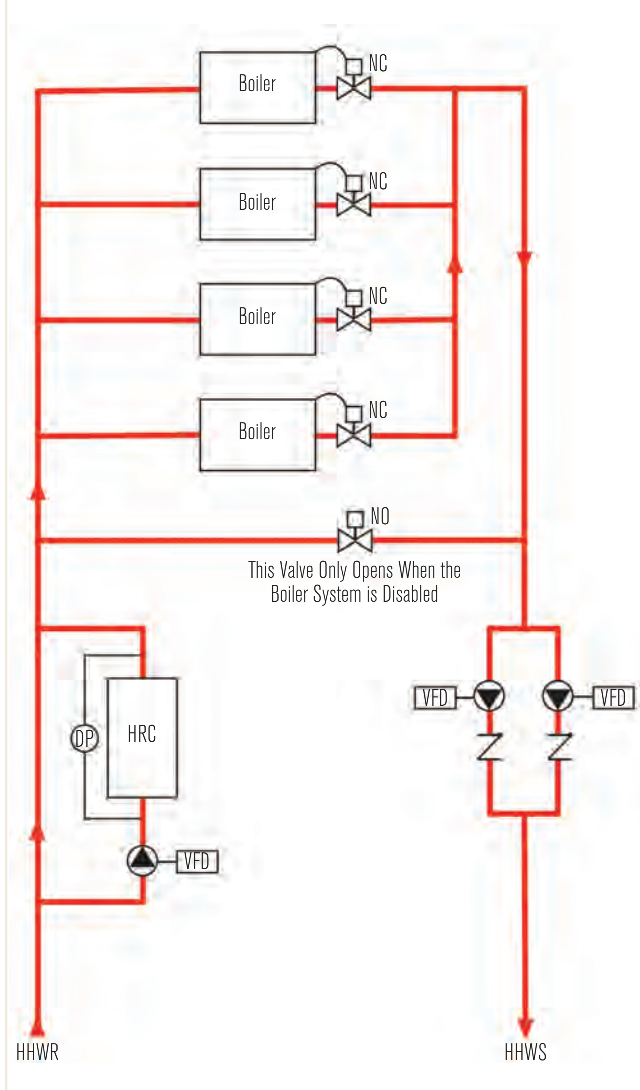
- Diagrams that can be followed from one side to the other are simplest for others to understand.
- Avoid drawing piping that crosses over other pipes whenever possible.
- Avoid aligning all the equipment on the bottom or side of the diagram and connecting all the piping on the other side. This will almost always result in pipes crossing over each other.
- When evaluating alternatives, start with a base diagram of the known piping system without the considered design alternative. This can be used to evaluate different piping arrangements for the considered alternative equipment.
- Avoid placing multiple systems (chilled water, condenser water, heating hot water) on the same piping diagram.

To illustrate this concept, the following simplified heating hot water piping diagram in *Figure 1* shows a modular heat recovery chiller piped in series with a variable flow, gas-fired, condensing boiler plant to provide preferential loading of the HRC. This project was located in a mild climate where 80% of the annual heating energy used occurs when the heating load is less than 20% of the peak load. The project goal was to improve efficiency, reduce annual natural gas consumption, and reduce greenhouse gas emissions.

The hot water reheat coils in the existing buildings served by this plant were all originally selected at 180°F (82°C). The HRC was sized to provide 20% of the plant's peak capacity at 110°F (43°C). The HRC is used to handle most of the annual heating requirements at the lower HHWS temperature while simultaneously supplementing the chilled water capacity from the campus distribution system. The modular HRC requires a constant differential pressure setpoint across the evaporator and condenser while each of the medium thermal mass condensing boilers allows variable flow.

The objective was to develop a heating hot water piping diagram that would allow the HRC to preferentially provide as much heat as possible before the gas-fired boilers are engaged, even when both systems are enabled at the HRC HHWS temperature setpoint. The boiler system will not be enabled until the HRC controls indicated the HRC was at full load or if the HHWS temperature setpoint increased above the HRC HHWS temperature

FIGURE 1 Sample preferential loading HRC HHW piping diagram.



setpoint. The bypass valve needs to be opened when the boiler system is disabled and closed when the boiler system is enabled.

Connecting to Campus CHW Distribution Systems

As with most mechanical systems, there are several ways to connect a heat recovery chiller into a building chilled water system when it is connected to a central chilled water distribution system.

It is useful to start with a base diagram of the known piping system without the HRC alternative. As discussed in a previous Engineer's Notebook column,[2] it is critical to understand the chilled water distribution system pumping control scheme before designing the chilled water building connection. This includes understanding the potential range of differential pressure the building connection would encounter throughout the year. The most common building connection in campus-type chilled water systems is a direct connection since the same entity owns the central plant, distribution, and buildings. Direct connections are suitable in a system with low-rise buildings where the static head in the distribution system can be kept low.

FIGURE 2 Non-Decoupled CHW direct building connection.

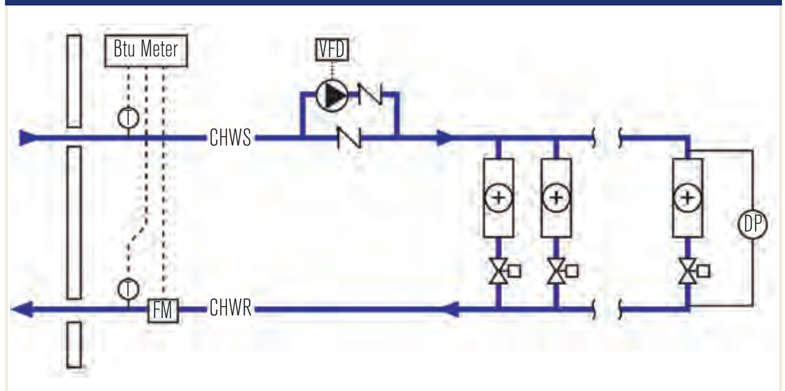


FIGURE 3 Non-Decoupled CHW direct building connection with HRC.

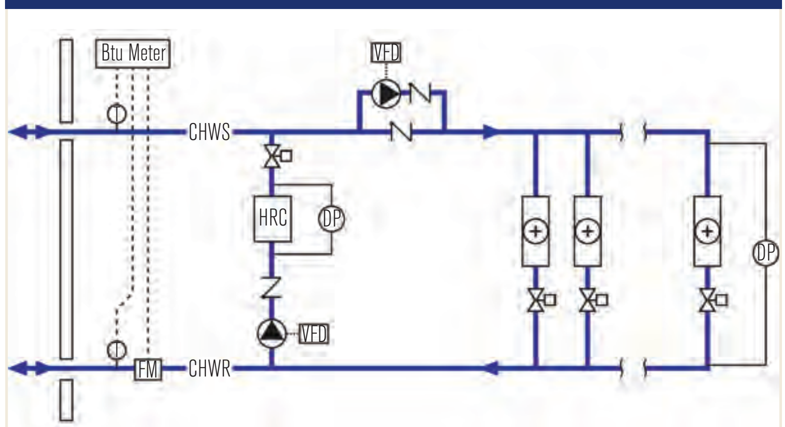


Figure 2 shows a non-decoupled (series pumping) approach where the distribution system differential pressure at the building connection may not be adequate during peak loads by adding a building booster pump that is installed with a parallel bypass and check valve so the pump is only operated when it is required to increase differential pressure for the building.

The primary purpose is for the HRC to provide the building heating hot water while providing chilled water as the secondary benefit. The objective of the piping configuration with the HRC example is to allow the HRC to provide chilled water to either the building load or the campus chilled water distribution system when the building heating load requires the HRC to operate. In the author's experience, system operators always prefer simplicity over complexity to ensure more reliable operation. *Figure 3* shows a simple means to connect the HRC into the previous diagram shown in *Figure 1*.

Figure 3 shows a dedicated variable speed CHW pump for the HRC to provide the required differential pressure setpoint across the HRC evaporator. The pump is required to be sized to overcome the highest anticipated chilled water distribution system differential pressure at the building connection. Most large campus systems maintain minimal distribution differential pressure by including building booster pumps to minimize pumping energy. In this piping configuration, the building will use the HRC chilled water and any additional chilled water will supply the campus chilled water distribution system. The automatic isolation valve is required if the main distribution pumps maintain neutral differential pressure at the building connection to prevent the building booster pumps from causing bypass flow through the HRC.

Concluding Remarks

Heat recovery chiller performance and operation are a function of both good HRC selection and good system design and controls for both the chilled water and heating hot water system. Simplifying these piping diagrams while using variable speed pumps can simplify controls to meet the project objectives. Hopefully, these tips can help designers when faced with the challenge of interfacing remote heat recovery chillers (HRCs) in buildings that are connected to large campus chilled water systems.

References

1. California Senate. 2018. California SB-100, California Renewables Portfolio Standard Program: Emissions of Greenhouse Gases.

2. Peterson, K. 2014. "Improving performance of large chilled water plants." *ASHRAE Journal* 56(1). ■