

Heat Recovery in Data Centers

Reuse the BTUs

Whitepaper

The Challenge

Data centers have transformed the digital world, processing vast amounts of information at high speeds. However, this data processing generates significant heat. Nearly 100 percent of the electrical energy consumed by data centers is converted to heat, which must be removed from the space to prevent the data center's IT equipment (ITE) from overheating.



In many cases, the heat is treated as a waste byproduct and is rejected to the outside air. This is not a small amount of heat, considering the energy data centers use. The International Energy Agency found that data centers used 1.5% of the world's electricity consumption in 2024, with predictions expecting this number to more than double by 2030[1].

As power needs escalate, the motivation for onsite power generation grows, leading to the production of additional heat. In the cooling process, however, there are significant opportunities to recover this thermal energy and apply it to commercial comfort and district heating, as well as manufacturing, process, and industrial heat applications.

Cooling Methods & Temperature Considerations

The primary methods of ITE cooling include air cooling and liquid cooling. In air cooling, computer room air handlers (CRAH) or direct expansion (DX) units absorb heat from hot aisle return air and provide conditioned air to cold aisles. Air cooling supply temperatures are typically 50-68°F. Liquid Cooling uses fluid to absorb heat, either by direct-to-chip (D2C), where plates are directly attached to chips, or by immersion, where ITE is submerged in a dielectric fluid. Compared to air cooling, heat is transferred closer to the source, resulting in warmer supply temperatures for liquid cooling, typically ranging from 68°F to 104°F. Due to the range of cooling temperatures, there are various ways to utilize recovered heat, many of which involve using chillers.

Heat Recovery Fundamentals & Efficiency Benefits

Heat recovery is not a new topic; water-cooled chillers have been used to recover heat for over 80 years[2]. Applying this concept to data centers is not novel, either. In 2017, a 5MW data center in Sweden was designed to provide enough recovered heat to satisfy the heating needs over 10,000 apartment buildings through Stockholm's Open District Heating[3]. Similarly, in Germany in 2019, one data center's waste heat was used to heat both the commercial office space on site and an additional 400 apartment buildings, all while maintaining an annual average full load Power Usage Effectiveness (PUE) below 1.3[4]. Recovering heat increases overall chiller efficiency and reduces total energy consumption and emissions by replacing less efficient equipment that would otherwise be required to provide heat.

Chiller efficiency is measured by either kW/ton or a Coefficient of Performance (COP). COP is equal to useful work output divided by electrical kW input. When cooling only, a chiller's COP is equal to the cooling kW output divided by the electrical kW input. For a chiller that simultaneously provides cooling and utilizes recovered heat, the COP_{SHC} is calculated as the sum of heating kW output and cooling kW output, divided by the electrical kW input. Instead of rejecting heat to the atmosphere, this heat satisfies a heating load and is therefore considered useful work output. Since the heat rejection capacity is equal to the cooling capacity plus the heat of compression, the full heat recovery COP_{SHC} is more than twice the cooling-only COP. Heat recovery chiller COP_{SHC} is higher than the heating COP of natural gas boilers or electric heat, which have heating COPs ≤ 1.

Best Practices for Data Center Heat Recovery

Typical best practices for condenser water heat recovery apply to data center applications.

- Control the data center facility cooling loop to the warmest possible fluid temperature while still meeting data center uptime requirements.
- Position heat recovery to have access to the warmest fluid sourced from the data center chiller.
- Use warm fluid directly if a low-grade, or low temperature, fluid is needed.
- Consider using booster heat pumps if a higher fluid temperature is required.

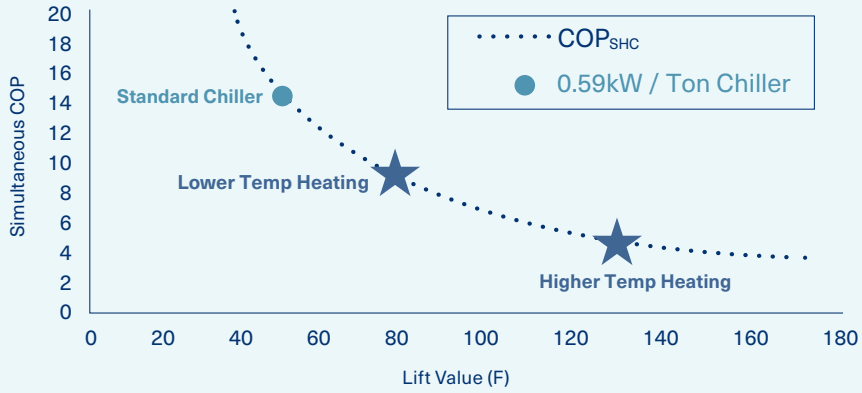
Optimizing System Performance

A warm fluid used directly typically uses less energy than if the application requires additional energy to raise the fluid's temperature or lower it. In some cases, such as when ITE is paired with heat users like greenhouse farms and indoor horticulture, a heat pump may not be needed at all. However, in many cases, at least one heat pump stage is required to reach the required hot water temperature. By keeping the cooling loop at the highest possible fluid temperature and lowering the hot water temperature produced by the chiller, the lift the chiller must maintain is reduced.

Because the power a chiller consumes is proportional to the load times the lift, lower lift results in a higher COP_{SHC}. A chiller supplying chilled water to an immersion cooling station while supplying hot water to an office building with heating coils designed for a 105°F supply fluid would result in significantly less lift than if that chiller were supplying chilled water to a CRAH and hot water to coils designed for a 140°F supply.

Impact of Lift on Chiller Efficiency

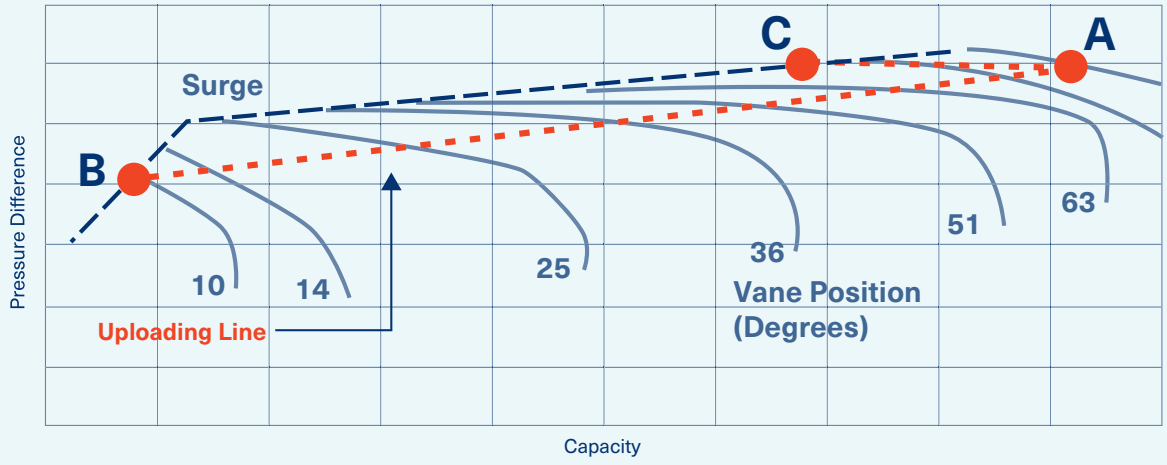
Figure 1: COP_{SHC} Versus Leaving Condenser Temperature



Additionally, the turndown of a chiller or heat pump will vary depending on the equipment's technology and sizing. Maintaining higher lift conditions results in reduced turndown capability, as the machine will encounter operational limits at a higher part-load ratio than if the lift were decreased. In Figure 2, line A to B represents a centrifugal machine controlling to a chilled water setpoint and letting the hot water temperature vary. This line runs into the surge line at a low part-load ratio. Line A to C represents a centrifugal machine controlled to a chilled water setpoint while also maintaining a hot water setpoint, which experiences surge at a higher part-load ratio.

Equipment Operational Limitations

Figure 2: Centrifugal Unloading

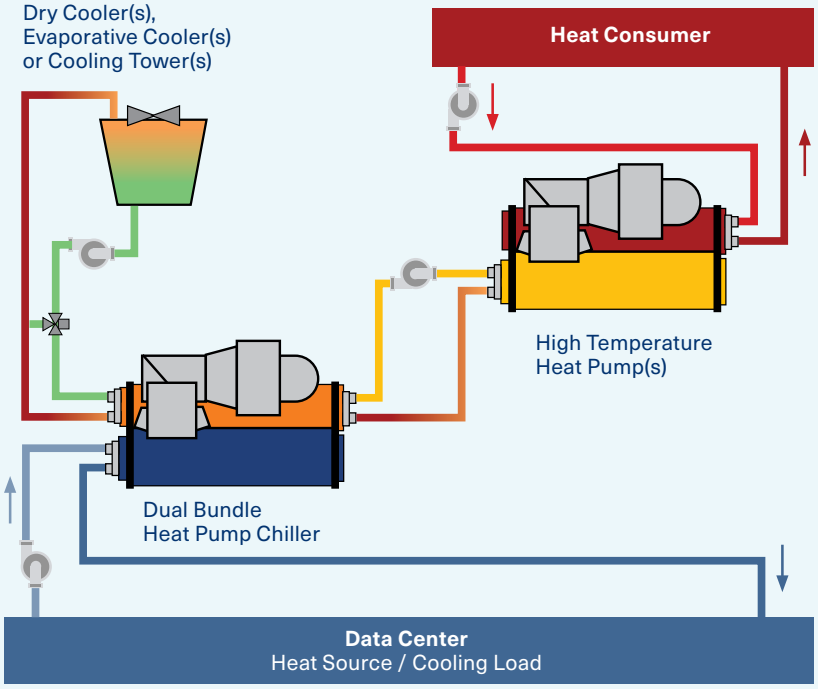


The heat a water-cooled chiller can provide is limited by the heat extracted by the evaporator plus the heat of compression. While it is unlikely, if the data center cooling load is insufficient to meet the heat recovery users' heating load, additional heat sources will be needed.

If the fluid needs to be supplied at a higher temperature than the data center can provide reliably via heat recovery, consider using booster heat pumps. An example of this is shown in Figure 3. The data center chiller's leaving condenser fluid runs through the evaporator of the booster heat pump, cooling the chiller's condenser fluid while producing higher temperature booster condenser fluid for heat consumption.

Managing Excess Heat & System Balance

Figure 3: Example Waste Heat Recovery Layout for Data Centers



Each component shown represents a plant consisting of many units operating as a team. Redundancy in equipment and piping is not shown for simplicity.

If the data center cooling load generates more heat than the heat recovery users' heating load, the excess heat must be removed to achieve an acceptable condenser return temperature. Dry coolers, evaporative coolers, or cooling towers could reject this.

It is essential to carefully consider the data center's load range, daily load swings, and uptime expectations to determine the best mix of systems and required redundancy. Likewise, the load range of downstream heat recovery users, their daily load swings, and the uptime expectations must be considered. Regardless of end use, recovering heat becomes practical and more efficient when the heat source and heat consumer are close to each other, have compatible load profiles, temperature ranges, and uptime requirements.

About the Author



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Michelle Hull serves as an Applications Engineer for Trane, specializing in hydronic systems, heat recovery, and energy modeling. In this role, Michelle supports a variety of applications, from high schools to data centers. Her background includes equipment testing and developing Trane's building performance simulation tools.

For more information, join us at trane.com

1. Executive summary – Energy and AI – Analysis - IEA
2. "Heat Recovery Chillers: State of the Art", Bill Landman, April 17th, 1978
3. New data center in Stockholm heats 10,000 apartments - Stockholm Data Parks
4. Data center waste heat supplies 400 apartments

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