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Converting Waste Heat to Useful Energy in Heating, Ventilating and Air-Conditioning Systems

Careful management of waste heat produced in the chilled water process of a Heating, Ventilation, and Air Conditioning (HVAC) system can yield significant savings in the energy cost of the building. With constantly increasing energy costs, increased energy consumption, and the resulting impact on the economy and the environment, heat recovery from a chilled water system offers an excellent low-cost, value-added component of an HVAC installation. There are many options on how to use this heat and on how to process it. This newsletter gives clear and simple instructions on how to maximize efficiency and demonstrates ongoing savings in your facility.

What Is Heat Recovery?

Heat recovery is capturing heat that would otherwise be wasted and converting it into useful energy which can then minimize operating cost, reduce energy consumption, and advance the concept of sustainable design.

Hot water can be used to heat a building, heat a process, pre-heat make up domestic water, pre-heat ventilation air or supply heat to reheat coils. Typical applications are hospitals, colleges/universities, resorts/hotels and data centers.

Each of these applications requires thorough consideration of the simultaneous need for chilled water and hot water.

Is Heat Recovery Required?

The current American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1 Energy Standard Section § 6.5.6.2 Heat Recovery for Service Water Heating requires heat recovery from the condenser side of water-cooled systems for preheating service hot water in large 24-hour facilities [1]. There are a few exceptions identified in this standard; the design engineer is encouraged to closely examine this standard and other codes associated with the project to completely understand the content and intent. With this in mind, projects seeking to maximize Leadership in Energy & Environmental Design (LEED®)-New Construction, Energy & Atmosphere, credit one (NC EAc1) certification points may choose to apply heat recovery using a method that minimizes building energy consumption. To do so, the designer must determine the best means to capture sufficient heat and apply it to useful purposes without decreasing the chiller plant efficiency.

*Carrier provides a library of white papers with detailed information about a host of topics including Heat Recovery at **commercial.carrier.com**. The following links go directly to the white paper noted:*

- Heat Recovery from Chilled Water Systems/Applications for Heat Reclaim Chillers
- Heat Recovery from Air Cooled Chillers/Applications for Heat Reclaim Chillers

How Does Heat Recovery Work?

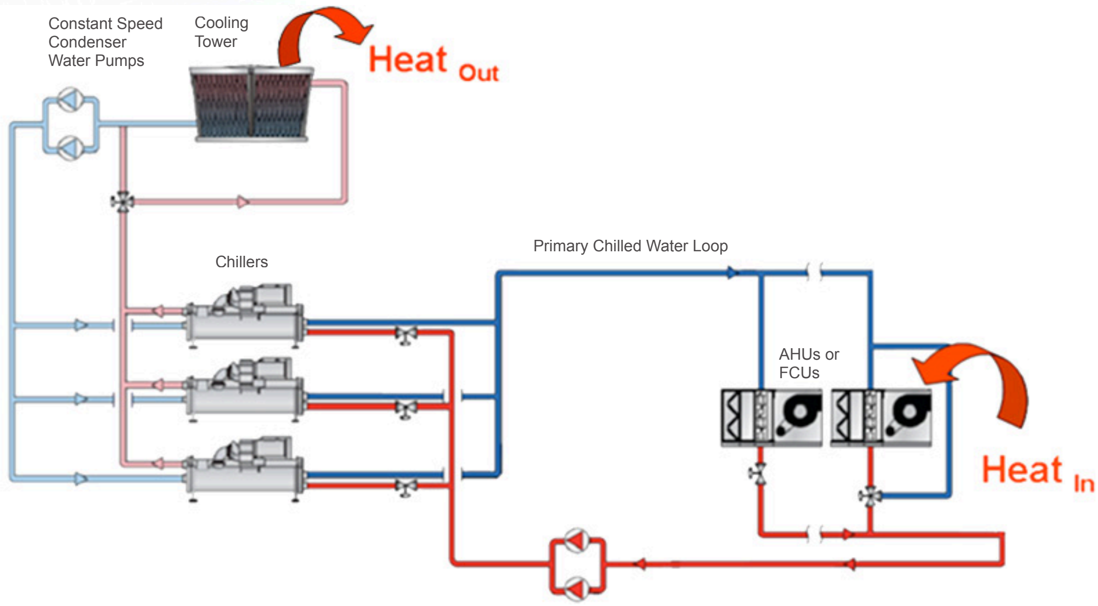

Figure 1: Typical Chiller HVAC System

In a typical chiller HVAC system, unwanted heat is drawn in from the spaces or process and is released to the atmosphere through the cooling tower.

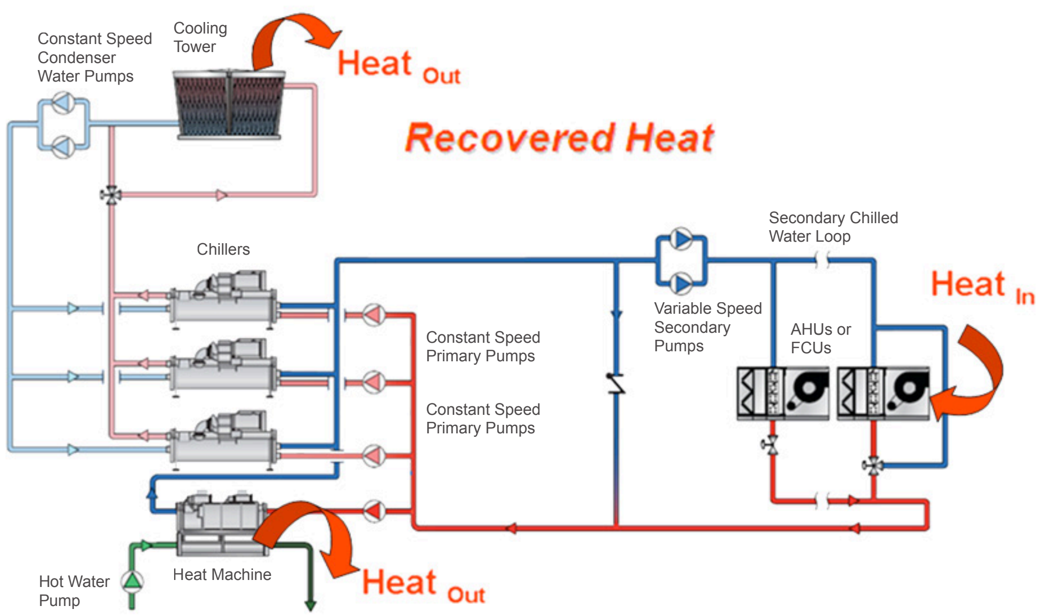

Figure 2: Heat Recovery System

In a heat recovery system, some of the waste heat is captured through the heat machine and the surplus is released through the cooling tower.

The useful heating output of these units can vary from zero (all heat to the tower) to all of the heat (cooling load plus the compressor work), converted to useful heat. These units are optimized economically when the majority of the total heat rejection is used for heating, most of the time. The electric cost of the heat is all the incremental compressor input power required to make the hot water; i.e., the power at the high water temperature, minus the power that would be required for a conventional chiller operating at a lower, optimized tower water temperature.

Specifying the appropriate equipment to serve these needs is important when a controlled source of hot water is desired. There are several chiller plant configurations that will accomplish this goal. Equipment must be specified that can provide a controlled source of recovered heat for hot water. On-board chiller controls can maintain the hot water set point temperatures without sacrificing efficiencies of the entire chilled water plant. The combination of captured heat with optimum chiller plant efficiency will minimize energy consumption.

Why Is This Important?

Recovering heat by using heat reclaim chillers leads to reduced fossil fuel use. In addition to the environmental benefits, this has advantages for building management in the form of lower operating costs. In a typical building. approximately 43% of the energy consumed is used for space and water heating [2].

If there are simultaneous heating and cooling loads available, then heat recovery should be considered.

Typical operating costs can be decreased significantly by implementing heat recovery in a building. To compare the total savings, we need to compare both the cooling and heating cost of operation. This can be easily compared by calculating the coefficient of performance (COP). COP is the ratio of heating or cooling provided to energy consumed.

$$COP_{Heat} = \frac{Heat_{Out}}{Work_{In}}$$

Equation 1: Coefficient of Performance for Heating

Typical natural gas boiler efficiency from the latest version of ASHRAE 90.1 is 80% Annual Fuel Utilization Efficiency (AFUE). This translates to 0.8 COP. For a corresponding heat recovery chiller the COP heating portion is between 3.4 and 3.9*. Utilizing a dedicated heat recovery chiller for heating is between 300 - 400% more efficient than a traditional boiler.

**NOTE: 3.4 to 3.9 is a range based on AHRI IPLV chiller evaporator conditions (44 leaving evaporator, and 140F and 130F at 3 gpm/ton leaving the condenser, respectively.)*

Energy Saving Analysis

The table below is an example of how COP is compared utilizing a chiller for heat recovery versus a boiler.

		Heating System					
		Electric Boiler	#2 Fuel Boiler		Natural Gas Boiler		Heat Recovery Chiller
Heat Output	**(MBH)**	**1,000**	**1,000**		**1,000**		**1,000**
Fuel Costs**							
Electricity	($/kWh)	$0.103					$0.103
#2 Fuel Oil	($/gal)		$3.08				
Natural Gas	($/1,000 ft³)				$8.43		
Energy Conversion Factor							
Electricity	kWh/MBH	0.2928					0.2928
#2 Fuel Oil	MBH/gal		140				
Natural Gas	MBH/1,000 ft³				1,030		
Energy Costs for 1,000 MBH		$30.22	$33.85	$27.50	$10.23	$8.62	$8.63
Savings vs. Boilers		71%	74%	69%	16%	0%	
Efficiency							
Boiler	Efficiency	100%	65%	80%	80%	95%	
Chiller	Heating COP						350%

Figure 3: Conventional Hot Water Boiler vs. Heat Reclaim Chiller

** Fuel costs noted are as of 3/18/14 per the following sources:

Fuel Oil #2 for US overall (price of 3/4/2014 was 3.08 / gal) http://www.eia.gov/todayinenergy/prices.cfm
Electric price for US overall (used US average - $10.32) http://www.eia.gov/electricity/data.cfm#sales
Natural Gas for the US overall (average from 2013 is $8.43) http://www.eia.gov/dnav/ng/hist/n3020us3m.htm
Natural Gas by state http://www.eia.gov/dnav/ng/NG_PRI_SUM_A_EPG0_PCS_DMCF_M.htm

Applications

The requirement for chilled and hot water can be present in each of the building types listed below. In all cases, chilled water can be used for space cooling and air conditioning purposes.

Colleges/Universities

- Dining & Residence Halls – Hot water make-up for showers, laundry, kitchen & dining facilities
- Athletic Facilities – Shower and washroom make-up water and swimming pool heating

Resorts/Hotels

- Hot water make-up for potable and non-potable purposes such as laundry, kitchen washroom and swimming pool heating

Hospitals and Elder Care Facilities

- Hot water make-up for laundry, kitchen facilities and reheat systems
- Operating Rooms

Data Centers

- Heat recovery for centers requiring dehumidified air and have a year-round requirement for simultaneous cooling and heating

In many chilled water installations, there is redundant or "backup" capacity in the design. These chillers are intended to operate when the primary chillers are not working. Since the backup chillers run only when there is a mechanical breakdown or required maintenance on the primary chillers, there are few run hours for the backup machines. Therefore, there is no efficiency benefit for the backup chiller. If a heat recovery chiller were utilized as the redundant capacity, this machine could operate when there was a simultaneous need for heating and cooling. Otherwise it would remain on standby. If this chiller is required to run due to any issue with the primary chiller, it will function as a cooling only chiller rejecting the heat to the cooling tower. With the understanding that the hydronic system must be designed to handle both heat rejection arrangements, the heat recovery chiller can be used as a cooling only chiller as well.

It is recommended that the control of this type of heat recovery machine be provided by the manufacturer and integrated into the main control board of the chiller. When designed properly, the controls can simply alternate between cooling only to heat machine with a discrete input from the control communications (remote).

Using an air-cooled chiller is another option when considering heat recovery systems. It operates in one of two modes, either cooling only or heat recovery. While operating in cooling only mode the condenser heat is rejected to the atmosphere via the air cooled coils. When the heat recovery mode is enabled and if the return hot water temperature is below the customer adjustable set point, one refrigerant circuit is automatically changed over to heat recovery mode using the solenoid valves and the integrated water cooled condenser. The chiller is now operating as a water cooled chiller with one circuit and an air cooled chiller with the other. Depending on the hot water requirements the second circuit may also be switched to heat recovery mode through the integrated controls. The hot water temperature is controlled by the cycling of each refrigerant circuit from the cooling only to the heat recovery modes. When the hot water set point is satisfied, the chiller will then transition back to cooling only mode or return to operation as an air-cooled chiller.

Conclusion

Whether striving to minimize the operating costs of a facility or reducing the building's carbon footprint, heat recovery from the chilled water system is entirely possible and practical. Heat recovery using a heat reclaim chiller is an excellent choice when looking for economic and environmentally responsible energy saving solutions. In applications from hotels to hospitals, casinos or universities, for service water heating to building heating, pool heating or preheating domestic water sources, heat reclaim is not only possible but also potentially a very efficient means to reduce energy costs and consumption.

1. 90.1 User's Manual, ANSI/ASHRAE/IESNA Standard 90.1-2013, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA USA

2. Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Table E1A. Major Fuel Consumption (Btu) by End Use for All Buildings, 2003 http://www.eia.doe.gov/emeu/cbecs2003/overview1.html