

HEAT RECOVERY FROM AIR-COOLED CHILLERS

Applications for Heat Reclaim Chillers



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INTRODUCTION

Why is heat recovery important?

Buildings are responsible for 40% of the total U.S.A. primary energy consumption [1] and 43% of the energy consumed in commercial buildings is used for space and water heating [2] as illustrated in Fig. 1. If a more efficient means of providing heat could be implemented it would represent a tremendous

opportunity to reduce energy consumption in buildings and thus reduce total energy consumption in the U.S.A. This white paper explores a more efficient means of generating hot water through the application of air-cooled chiller systems with heat reclaim capabilities to reduce the energy consumption in buildings.

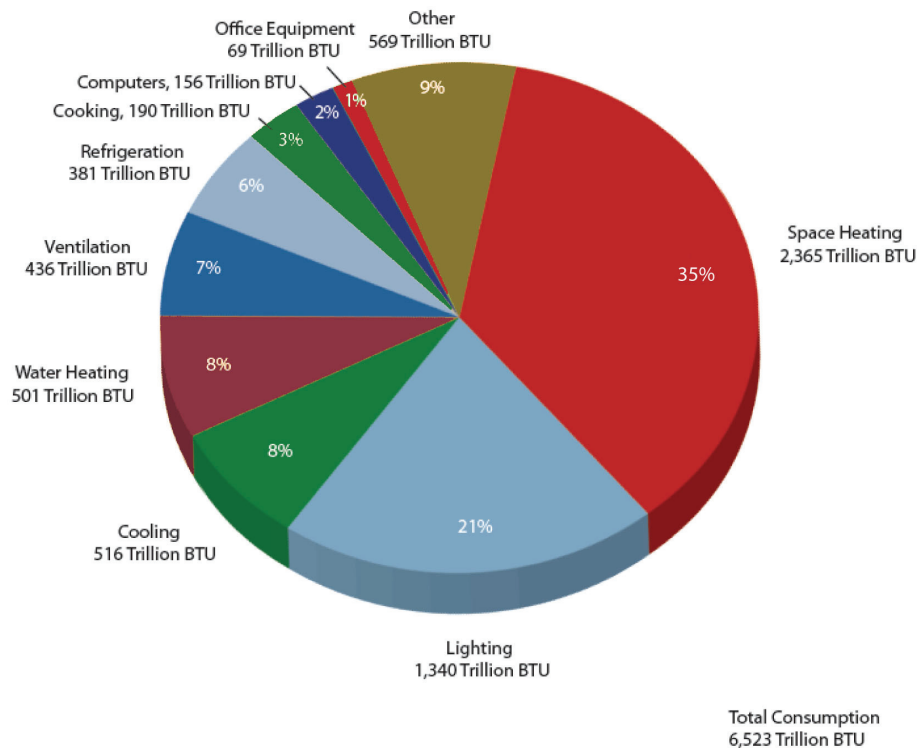


Fig. 1. 2003 Commercial Buildings Energy Consumption Survey - Major Fuel Consumption by End Use for All Buildings

MAXIMIZING THE EFFICIENCY OF GENERATING HOT WATER

Hot water has been created in very much the same way for many years. Fossil fuels are combusted around a metal vessel filled with water. More recently, electric elements have been immersed in a water vessel to heat the water. When heating with fossil fuels, efficiencies can reach more than 90% [3] in a condensing-type boiler and upwards of 100% with electric immersion water heaters. These efficiencies represent a coefficient of performance (COP) of 0.90 and 1.0 respectively. Is it possible to generate hot water at a COP greater than 1.0? The answer is yes.

Heat recovery captures energy that would otherwise be wasted to the atmosphere and converts this energy into useful heat. As shown in Fig. 2, it is possible to capture this “Heat Out” from the condenser and use it to generate hot water. By capturing this heat that would otherwise be wasted, overall system efficiencies can be significantly increased.

Unlike the process of generating heat from combustion or electrically driven water heaters, capturing waste heat from the condenser can result in efficiencies greater than 100%. This achievement is the result of using the heat captured from the condenser plus the cooling effect from the evaporator. When both sources of heat are captured, efficiencies greater than 100% can be realized. In fact, the total COP for heat reclaim from a chiller system for both water heating and cooling purposes can reach over 5.0.

$$\text{COP}_{\text{total}} = \frac{\text{Heat}_{\text{out}}}{\text{Work}_{\text{in}}} + \frac{\text{Heat}_{\text{in}}}{\text{Work}_{\text{in}}}$$

Equation 1

Total COP for Heat Recovery + Chilled Water

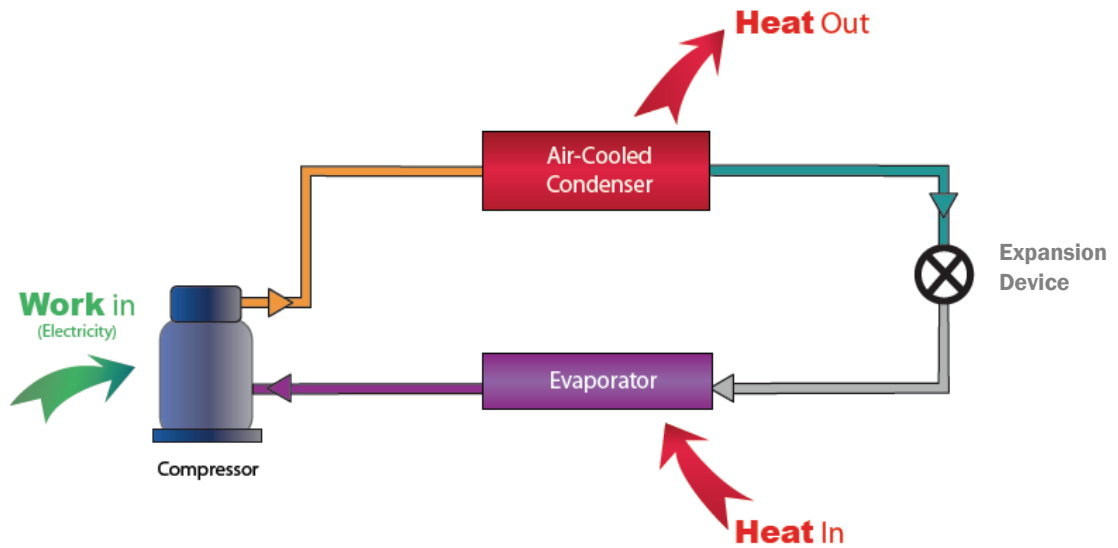


Fig. 2. Heat and Work Relationship in an Air-Conditioning System

If we look at the performance of a nominal 120-ton air-cooled chiller with heat reclaim we can see the energy advantages based on the total COP.

Chiller performance at 44 F leaving chilled water temperature, 2.5 gpm/ton evaporator flow with heat reclaim in operation to produce 121 F entering heat reclaim water temperature and 131 F leaving heat reclaim water temperature:

Cooling Capacity 93.7 tons (329.6 kW)
Input Power 159.9 kW
Heating Output 1,642 MBH (480.7 kW)

$$\text{COP}_{\text{total}} = \frac{480.7 \text{ kW} + 329.6 \text{ kW}}{159.9 \text{ kW}} = 5.07$$

Equation 2
Total COP for Heat Recovery + Chilled Water for Heat Reclaim Chiller

THE AIR-COOLED CHILLER WITH HEAT RECLAIM CAPABILITY

An air-cooled chiller produces chilled water while simultaneously transferring significant quantities of heat to the outdoors through its air-cooled condenser. If this heat could be captured and re-directed to a water-cooled condenser, the system could produce not only a controlled source of chilled water but also a significant amount of useful heat to generate hot water. Carrier's air-cooled chillers with heat reclaim capabilities can do just that – produce chilled water controlled to the necessary temperature while generating hot water as a by-product of the chilled water system.

How does it work?

Under the normal Cooling Only mode, the chiller produces a controlled source of chilled water using its air-cooled condenser. In this mode, the system performs as a typical air-cooled chiller to produce a controlled source of leaving chilled water according to its set point temperature while rejecting heat to the environment through its air-cooled condenser (Fig. 3).

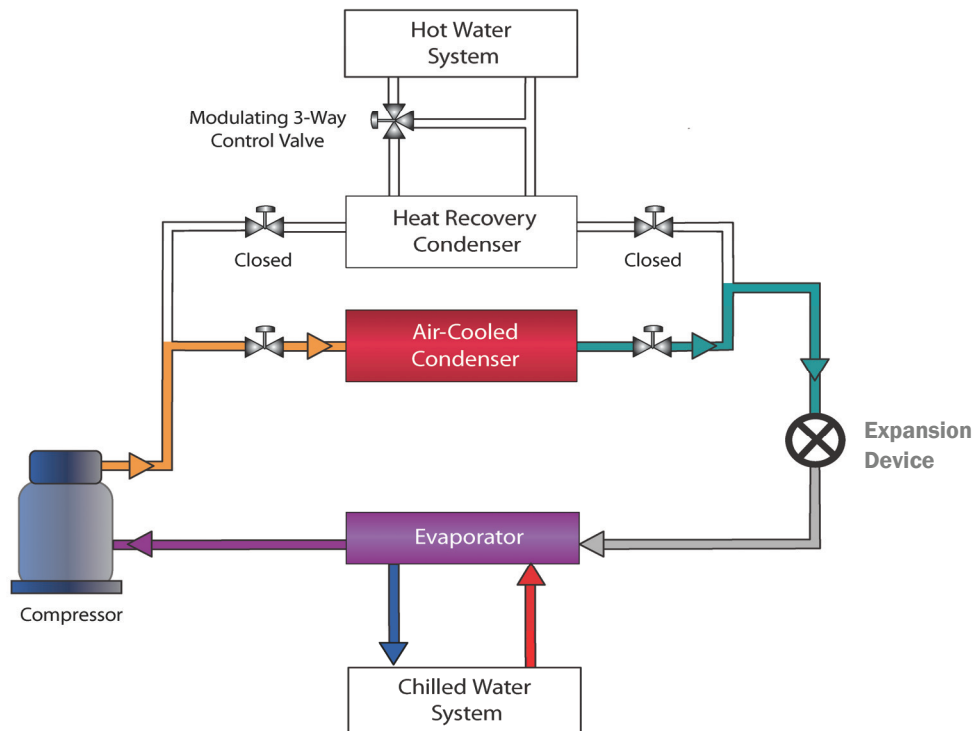


Fig. 3. Air-Cooled Chiller with Heat Reclaim Capabilities: Cooling-Only Mode

When an air-cooled chiller is operating in the Heat Recovery mode, there must be a simultaneous need for chilled water and tempered hot water. It is important to note that this chiller will always maintain the leaving chilled water temperature. As a result, the chiller will produce as much hot water as possible while controlling the leaving chilled water temperature. The leaving hot water temperature is a by-product of the cooling cycle. To generate hot water, the entering hot water temperature is compared to the hot water set point, also known as the heat reclaim set point, to determine the number of circuits necessary to maintain entering hot water temperatures. If the entering hot water temperature is below the customer adjustable set point, one refrigeration circuit will automatically change over to Heat Recovery mode

as shown in Fig. 4. The chiller is now operating much like a water-cooled chiller with one circuit and as an air-cooled chiller with the other circuit. Depending on the entering hot water temperature and deviation from set point, the second circuit may also be switched to Heat Recovery mode through the integrated controls. The entering hot water temperature is controlled by the cycling of each refrigerant circuit from the Cooling to the Heat Recovery modes. When the hot water set point is satisfied, the chiller will then transition back to the Cooling Only mode to operate as a conventional air-cooled chiller. The leaving hot water temperature is a function of the entering hot water temperature, hot water flow, and chiller capacity.

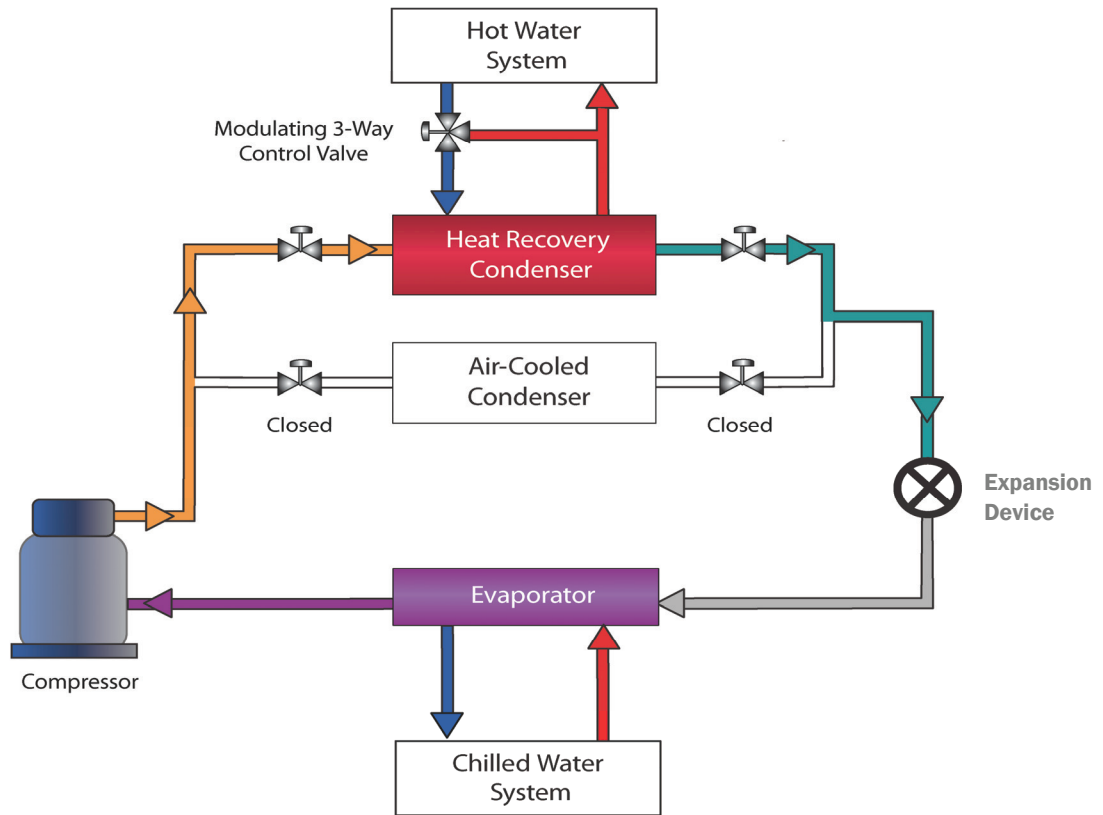


Fig. 4. Air-Cooled Chiller with Heat Reclaim Capabilities: Heat Recovery Mode

APPLICATION CONSIDERATION

The heat recovery condenser can transfer 100% of the chiller's total heat of rejection to the hot water loop. The leaving water temperature can reach a maximum temperature of 131 F under steady state and constant hot water flow conditions. The allowable leaving hot water temperature range is 68 to 131 F. Since the hot water loop is used to condense refrigerant into a sub-cooled liquid, head pressure control may be necessary to ensure stable chiller operation when entering-water temperatures are between 59 and 104 F. A modulating 3-way control valve will be necessary when the entering-water temperature (EWT) is within this range. Piping configurations for these applications are shown in Fig. 5.

Since the 3-way valve must respond to chiller head pressure control needs, the distance between the 3-way valve and the chiller should be minimized to ensure a sufficient response time for stable chiller operation. As a result, this distance and minimum loop volume should be confirmed with the manufacturer's recommendations.

HOT WATER APPLICATIONS IN BUILDINGS

It is important to understand the type of building or process and how this captured heat will be used for a given application. Hot water can be used to heat a building or pre-heat ventilation air, for zone reheat

coils, to maintain pool conditions, pre-heat make-up domestic water, or to heat a process. Each of these applications requires thorough consideration of the simultaneous need for chilled water and hot water. This requirement 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.

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

Athletics Facilities (College, High School, Community) – Shower and washroom make-up water and swimming pool heating

College Residence Halls – Hot water make-up for showers, laundry, kitchen, and dining facilities

Commercial Laundries – Hot water make-up

Hospitals and Elderly Care Facilities – Patient room make-up hot water, laundry, and kitchen facilities

Condominiums and Residential Buildings – Hot water make-up for showers, laundry, kitchen, and dining facilities

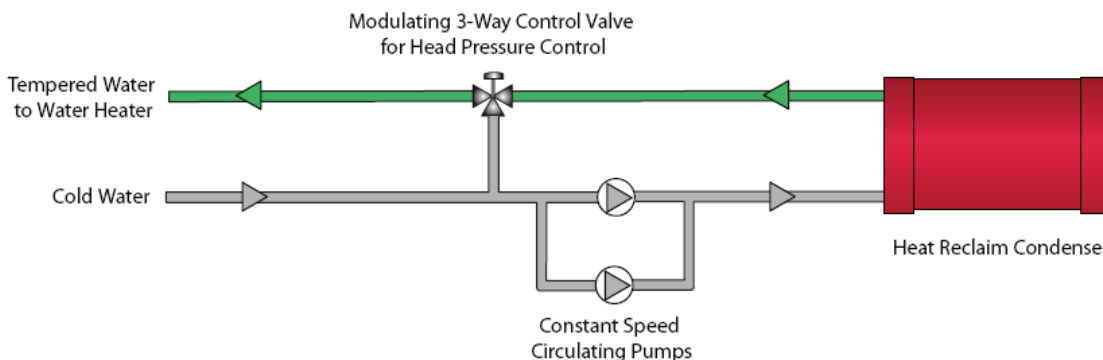


Fig. 5. Modulating 3-Way Valve for Head Pressure Control

Specific Applications

Reheat Coils

ASHRAE 90.1-2007 states that simultaneous heating and cooling is prohibited.[4] However, the standard also states several exceptions to this limitation, one of which opens the possibility of heat reclaim from chilled water systems: "Zones where at least 75% of the energy for reheating or for providing warm air in mixing systems is provided from a site recovered energy source (including condenser heat) or site-solar energy source." Therefore, it is entirely possible to design a heat reclaim system for at least 75% of the reheating load while meeting the intent of the standard. Also, the leaving hot water temperatures available from heat reclaim are within the reheat coil performance capabilities.

In many VAV (variable air volume) reheat applications, 105 to 131 F hot water can be used very effectively by simply specifying a 2-row reheat coil instead of a 1-row coil. For these applications, using the reclaimed heat is possible with appropriate design consideration and a suitable quantity of site recovered energy. If higher hot water temperatures are necessary, an auxiliary heating apparatus such as a hot water boiler can be added to the heat reclaim water loop as shown in Fig. 6.

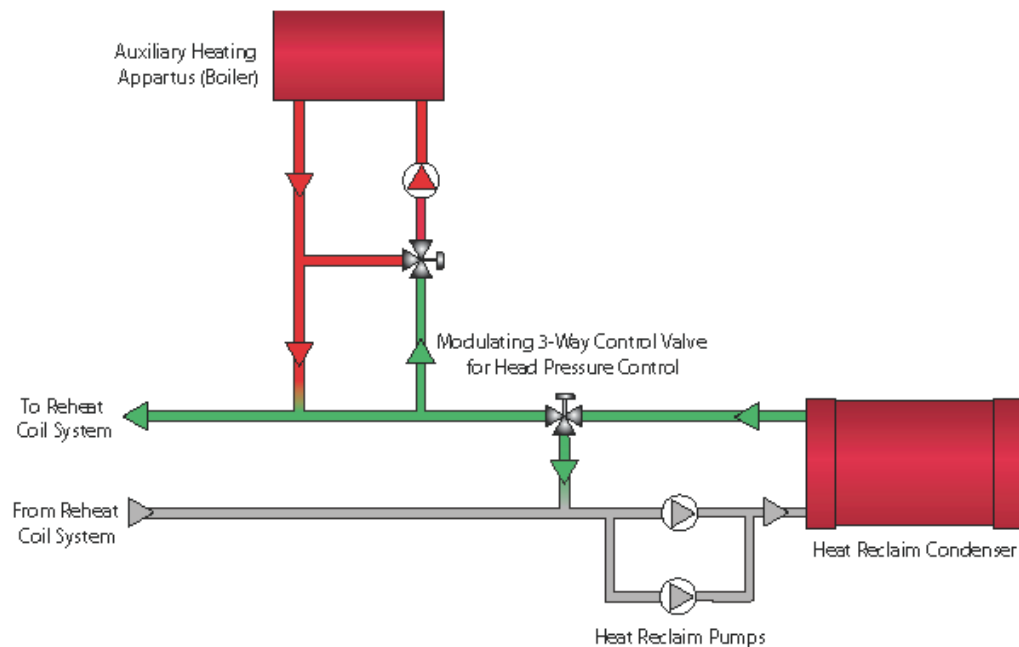


Fig. 6. Auxiliary Heating Apparatus to Boost Heat Reclaim Water Temperatures

Potable Domestic Hot Water Make-Up

Reclaimed heat may be used to pre-heat the domestic (potable) hot water make-up. However, many building codes require the protection of the potable water supply from contamination from toxic heat transfer fluids. For example, the New York State Plumbing Code states, “Heat exchangers utilizing an essentially toxic transfer fluid shall be separated from the potable water by double-wall construction. An air gap open to the atmosphere shall be provided between the two walls.”[5] Compliance with local codes is the responsibility of the design professional.

Specifying a double-wall vented heat exchanger is one way to meet the intent of the code. These heat exchangers are available on some heat reclaim chillers.

However, another method that can meet the intent of separating the heat transfer fluids from the potable water source is to use an intermediate heat exchanger located between the potable water source and the reclaimed hot water as shown in Fig. 7.

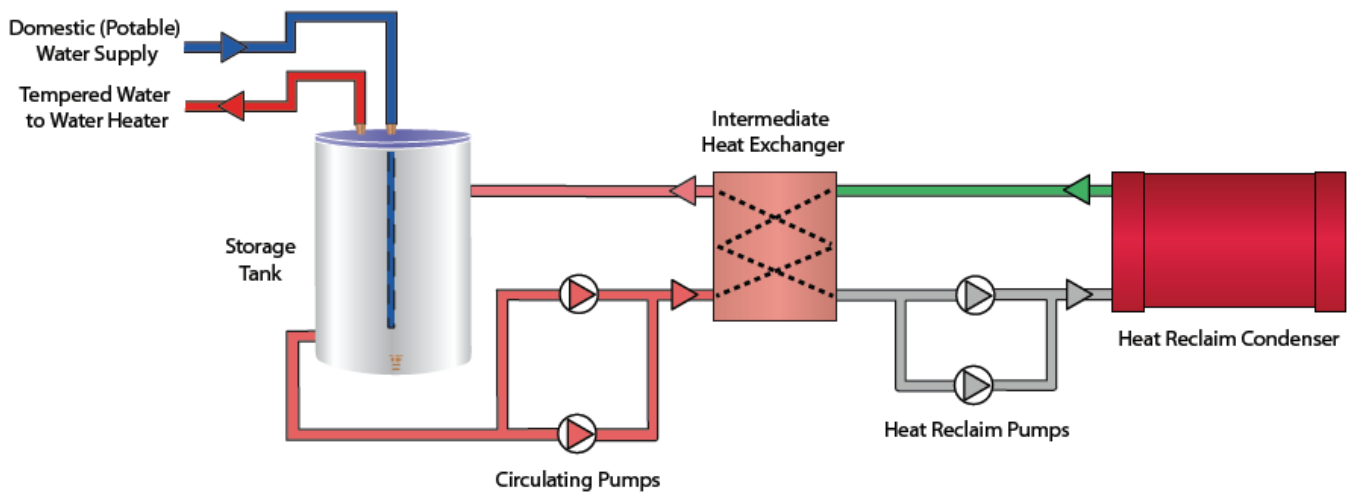


Fig. 7. Intermediate Heat Exchanger between Potable Water and the Heat Reclaim Condenser

Swimming Pool and Spa Heating

Spa water temperatures must be limited to 104 F according to some codes [6] and the desired temperature for swimming pools is 80 F. These temperatures are well within the operating range of many heat reclaim systems. One of the unique design challenges for this application is protecting the heat reclaim condenser from the corrosive effects of the pool or spa water. High concentrations of chlorine, bromine, and sodium chloride disinfectants can cause corrosion damage to the metallic components of the heat reclaim condenser. The use of an intermediate heat exchanger with suitable corrosion resistant construction can help overcome this design issue as shown in Fig. 8.

Laundry Water Heating

Commercial laundries, also known as “on premise laundries,” or industrial laundries, use significant quantities of water for washing and rinsing purposes. [7] There are many facilities in which laundries are found, including motels, hotels, nursing homes, prisons, universities, and hospitals. Tremendous

energy savings can be realized by pre-heating the vast quantities of make-up water used by these facilities.

NOTE: Many packaged laundry systems have self contained heat recovery, since the waste water discharge can be sufficiently warm enough to preheat the make-up water. Application of the heat reclaim chiller may be limited when the packaged laundry system has an integral heat recovery system.

Be sure to confirm the manufacturer’s recommended operating limits of the chiller EWT for the application served. Carrier’s 30RB air-cooled chiller with heat reclaim capabilities is limited to a continuous EWT of 59 F when head pressure control is used. The make-up water coming from the street water main or water well can be as cold as 50 F, or even lower in some climates. This is colder than the minimum entering-water temperature (EWT) limitations for the heat reclaim chiller.

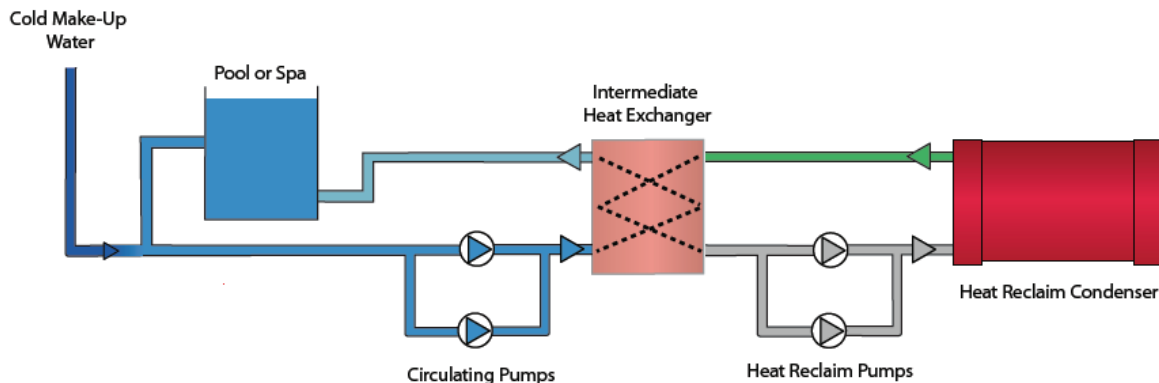


Fig. 8. Intermediate Heat Exchanger between Pool/Spa and the Heat Reclaim Condenser

Not only does the heat reclaim condenser provide an abundant quantity of useful heat, it also serves a vital role in the refrigeration process. The condenser EWT influences the head pressure control system of the chiller. If the EWT is too cold, the resulting refrigeration system head pressure can affect proper chiller operation. If the EWT is expected to be between 59 and 104 F, the chiller must take control of the condenser water flow rate to maintain proper head pressure. A modulating 3-way control valve must be provided as shown in Fig 9. When the EWT is between 59 and 104 F, the chiller's head pressure control system will initiate an analog control signal to modulate the 3-way valve position between 20 to 100% open to regulate the condenser water flow rate and maintain proper head pressure. At no time should the valve allow flow less than 20% of full flow.

Snow Melting

In mildly cold climates with low to moderate snow fall rates, building processes that require year-round chilled water for cooling purposes can take advantage of the hot water generated by the heat reclaim chiller and use it for snow melting purposes.[8] The greatest

challenge with this application is to ensure that the EWT does not fall below 59 F. Fluid temperatures below this limit can be present when the snow melting system is first activated. As a result, snow melting fluid temperature controls will be necessary to ensure that the EWT is maintained within acceptable limits for the chiller. The modulating 3-way valve head pressure control as described above (see Fig. 9) must be used when the EWT is below 59 F.

For a system exposed to cold outdoor conditions in applications where fluid temperatures can be below 32 F an appropriate antifreeze solution must be used.

In colder climates, winter soil temperatures can fall well below 59 F which is outside the required operating limits of the heat reclaim chiller. These applications will require an auxiliary heating apparatus, such as a boiler, to ensure that the required operating limits are satisfied. Figure 10 shows the location of the auxiliary heating apparatus to ensure the EWT is sufficiently warm to allow the heat reclaim chiller to operate.

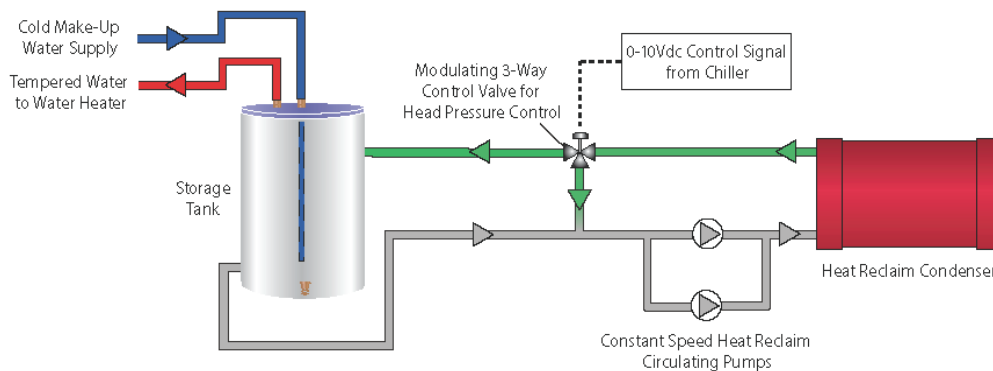


Fig. 9. Make-up Water System with Modulating 3-Way Valve for Head Pressure Control

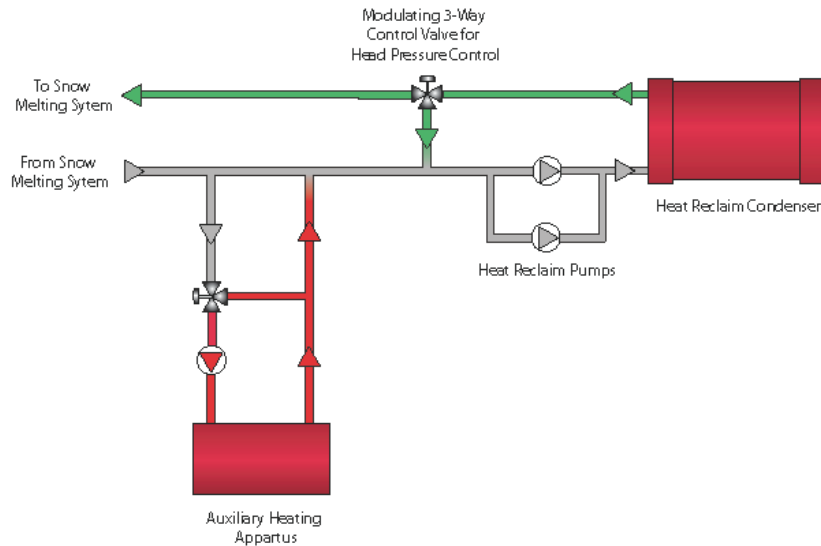


Fig. 10. Auxiliary Heating Apparatus for Snow Melting System

Process Heating

It is important to fully understand the cycle rate and temperature needs of the process served by the heat reclaim chiller. Process heating is usually associated with non-potable water applications. However, appropriate measures must be taken if the process water is for potable purposes. This application requires a separation between the heat reclaim condenser and the potable water source by means of an intermediate heat exchanger as previously described.

The cyclical nature of many process heating loads can create a challenge for stable heat reclaim chiller operation if not properly addressed. The heat reclaim loop volume, defined as the gallons of fluid in the heat reclaim loop, becomes more important as the process heating loads fluctuate. To overcome these fluctuations, the manufacturer's minimum loop volume recommendations must be followed. The storage tank, as shown in Fig. 9, can add effective loop volume to the system and help stabilize the leaving water temperature.

Kitchen Water/Dishwashing

These are potable water applications that will require suitable separation between the heat reclaim condenser and the potable water source by an intermediate heat exchanger. Commercial dish washing can require elevated hot water temperatures above 150 F [9] to meet local plumbing and health codes. As a result, the heat reclaim chiller is best suited for make-up water preheating as previously shown in Fig. 7.

Evaluation of Potential Application

The following should be used as a guide to determine if your project is a candidate for Carrier's heat reclaim solution. This initial evaluation can assess the likelihood of a suitable project given the application criteria for heat reclaim.

Simultaneous need for chilled water and hot water? YES NO

Hot water temperatures from the heating system between 59 and 131 F? YES NO

Chilled water load between 60 and 190 tons? YES NO

Hot water load between 770 and 2650 MBH? (for single chiller applications) YES NO

Space for an outdoor chiller YES NO

If the answer is YES to all of the above questions, Carrier's heat reclaim chiller is a likely candidate for the application. If the cooling or heating loads are greater than those shown above, multiple heat reclaim chillers can be used.

ENERGY SAVINGS ANALYSIS

There are numerous uses for the recovered heat from the 30RB chiller with heat reclaim. However, an economic assessment should be conducted to determine the financial viability of the system. A simple way to determine the viability of a heat reclaim system is to compare the potential energy cost savings between a conventional hot water boiler and the heat reclaim chiller. The basis of this comparison should include the amount of heat generated, the fuel cost, and operating efficiency of the alternatives. To simplify the analysis, consider the energy cost savings of creating 1,000,000 Btu of heat output between the heat reclaim chiller and several alternative hot water boiler systems. Figure 11 shows a simple analysis to determine the potential energy cost savings comparing these systems.

The example in Fig. 11 provides a simple estimate of the potential energy cost savings. A more refined approach in assessing the potential energy costs savings should include the part load performance of the heat machine while operating under the intended

conditions when producing chilled and hot water. Energy analysis programs such as Carrier’s Hourly Analysis Program (HAP v4.4 or later) can help with annual energy cost assessments and also provided information suitable for submission to the USGBC (U.S. Green Building Council) for Leadership in Energy and Environmental Design (LEED®) certification. Carrier’s HAP software (v4.4 or later) has the ability to generate the all important LEED Energy and Atmosphere Credit 1 (EAc1) template data formatted to USGBC’s on-line credit template form. This feature can save substantial time when developing the LEED (v3.0) EAc1 credit forms.

EQUIPMENT SELECTION GUIDELINES

When choosing a heat reclaim chiller, always follow the manufacturer’s procedure outlined with their selection tools. Carrier’s Packaged Chiller Builder Program (version 3.29h or later) can help make chiller and heat reclaim selections easier.

		Heating System					
		Electric Boiler	#2 Fuel Oil Boiler	Natural Gas Boiler	Heat Recovery		
Heat Output	(MBH)	1,000	1,000	1,000	1,000	1,000	1,000
Fuel Costs							
Electricity	(\$/kWh)	\$ 0.10					\$ 0.10
#2 Fuel Oil	(\$/gal)		\$ 3.00	\$ 3.00			
Natural Gas	(\$/1000 ft ³)				\$ 12.00	\$ 12.00	
Energy Conversion Factor							
Electricity	kWh/MBH	0.2928					0.2928
#2 Fuel Oil	MBH/gal		140	140			
Natural Gas	MBH/1000 ft ³				1,030	1,030	
Efficiency							
	Heating COP						3.5
	Efficiency	100%	65%	80%	70%	95%	
Energy Costs for 1,000 MBH		\$ 29.28	\$ 32.97	\$ 26.79	\$ 16.64	\$ 12.26	\$ 8.37
Savings vs. Boilers		71%	75%	69%	50%	32%	-

Fig. 11. Savings Analysis: Heat Reclaim Chiller vs Hot Water Boiler

SYSTEM DESIGN CONSIDERATION

Multiple Chiller System with Heat Reclaim for Building Heating

Integrated building cooling and heating systems can be achieved with proper attention to the application limits and control requirements of the system components. When seeking to capture heat from the heat reclaim loop, there must be the need for simultaneous cooling and heating. However, the system illustrated in Fig. 12 can operate in the Cooling-Only, Heat Reclaim, or Heating modes to satisfy the building's HVAC loads. This system is one of many potential ways to capture heat from the heat reclaim chiller for useful purposes. A variable primary flow chilled water system is described below. However, alternative systems such as a primary-secondary chilled water system would also be possible. For either system, the heat reclaim pumps must be enabled by the lead heat reclaim chiller. Also,

the return hot water temperature from the building heating system must be lower than the heat reclaim set point in order for reclaimed heat to be effective. If the storage tank mixed water temperature is between 59 and 104 F, head pressure control from the chiller will be necessary. A modulating 2-way control valve located downstream of each chiller must be controlled by the chiller head pressure control signal. The VFD (variable frequency drive) heat reclaim pump is controlled by system differential pressure. The 2-way valve and VFD pump system is the best way to provide the necessary head pressure control while reducing pump energy. Three-way valves applied to each chiller could be used, but pump energy consumption would be higher.

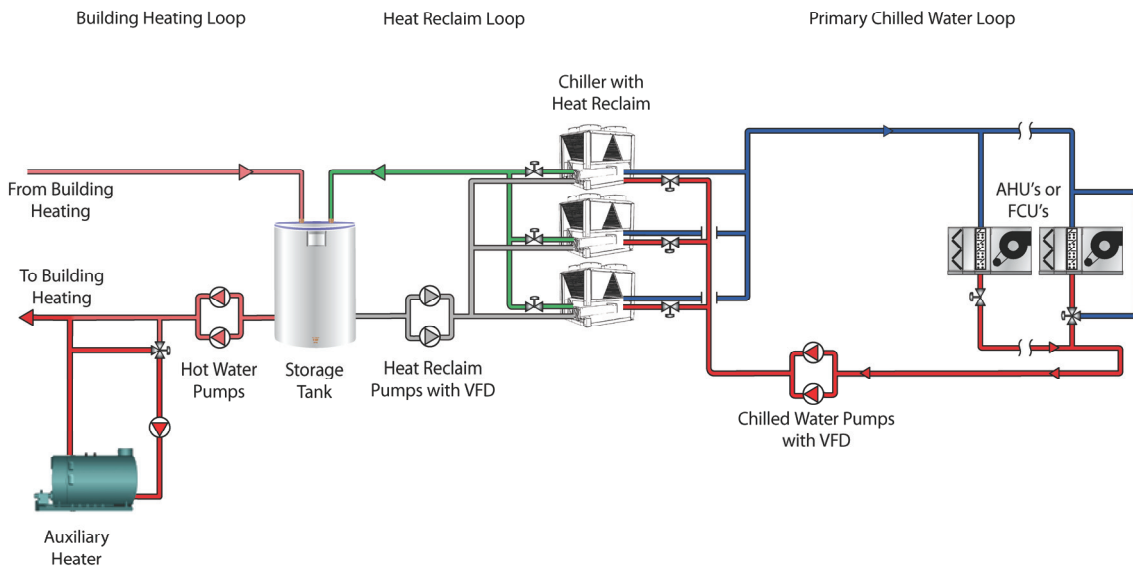


Fig. 12. Multiple Chiller System with Heat Reclaim for Building Heating

The following sequence describes the function of various system components during different operating modes. This system is intended to produce chilled water for building cooling purposes, reclaimed heat to temper the mixed water in the storage tank, and hot water for building heating purposes.

Cooling-Only Mode

On a call for cooling, the 2-way chilled water valve serving the lead chiller will open and the chilled water pump will provide flow. Variable primary chilled water flow is then provided by the VFD driven chilled water pump controlled in response to a differential pressure signal from the chilled water loop piping. The chiller will control the leaving chilled water temperature based on its set point conditions. The chiller's air-cooled condensers will condense the refrigerant and the heat reclaim condensers will remain off. As a result, no heat is added to the heat reclaim loop. Building heating is not energized in this mode. If the primary chilled water temperature cannot be maintained by one chiller, the 2-way chilled water valve on the second chiller will open to allow chilled water flow to the second chiller. The second chiller will then be energized to provide a controlled source of chilled water. The third 2-way valve will open and its chiller will provide chilled water when necessary to maintain the primary chilled water loop temperature.

Heat Recovery Mode

On a call for cooling, the 2-way chilled water valve control, chilled water pump VFD control, and chilled water temperature control will function as described in the "Cooling-Only" mode above. At the same time, the lead chiller will open its heat reclaim modulating 2-way valve to its minimum position and enable the heat reclaim pump to monitor the entering heat reclaim water temperature to determine if heat should be added to the heat reclaim loop. Heat reclaim water flow is provided by the VFD driven pump controlled by a differential pressure signal from the heat reclaim loop piping. The chiller will determine how much heat should be added to the heat reclaim loop based on the deviation from the entering heat reclaim set point temperature. The chiller will reduce the amount of heat added to the heat reclaim loop once the entering water temperature set point conditions have been satisfied. As other chillers are energized in response to increased cooling loads, the heat reclaim 2-way valves will be opened to allow additional heat to be added to the heat reclaim loop. If the entering heat reclaim water temperature is between 59 and 104 F, the heat reclaim

modulating 2-way valve will receive an analog signal from the chiller to regulate the valve position to maintain proper head pressure control. At the same time, the VFD driven heat reclaim pumps will regulate water flow to maintain the system differential pressure. The building heating control system will energize the hot water pumps and auxiliary heater as necessary to maintain the building heating loop temperature.

Heating Mode

The building heating control system and auxiliary heater, typically a boiler system, will provide all building heating needs. Since no chilled water is needed, the heat reclaim chiller remains off in this mode and no heat is added to the heat reclaim loop.

CONCLUSION

With the ever growing concerns over escalating energy costs, increased energy consumption, and the resulting impact on the economy and the environment, heat recovery from the chilled water system offers an excellent solution to all of these issues. Capturing heat that would otherwise be wasted and converting it into useful energy can minimize operating cost, reduce energy consumption, and advance the movement toward sustainability. The design professional should fully understand the application needs, system requirements and component capabilities to develop a system to meet the intended goals. Once these needs are fully understood and properly implemented, the energy efficiency and operating benefits can be fully realized. Heat recovery using Carrier's heat reclaim chiller is an excellent choice when looking for 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. The heat reclaim chiller is a wonderful supplement to fossil fueled water heating systems to maximize LEED-NC Energy and Atmosphere credit 1 points and meet or exceed the requirements of ASHRAE 90.1-2007. 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 with Carrier's 30RB heat reclaim chiller.

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9. 2007 ASHRAE Handbook – HVAC Applications, Chapter 49, Service Water Heating, Table 3, Representative Hot-Water Temperatures, page 49.10



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