Modeling Heat Recovery Plants:
A/C Chillers with HR Condensers

Introduction

This eHelp explains how to model a heat recovery plant using Air-Cooled Chillers with Heat Recovery Condensers. This modeling feature is offered in HAP v4.9 and later versions. In the "System Overview" section below the configuration and operation of equipment in this plant is described. In the second section, a tutorial explains how to model this type of plant in HAP.

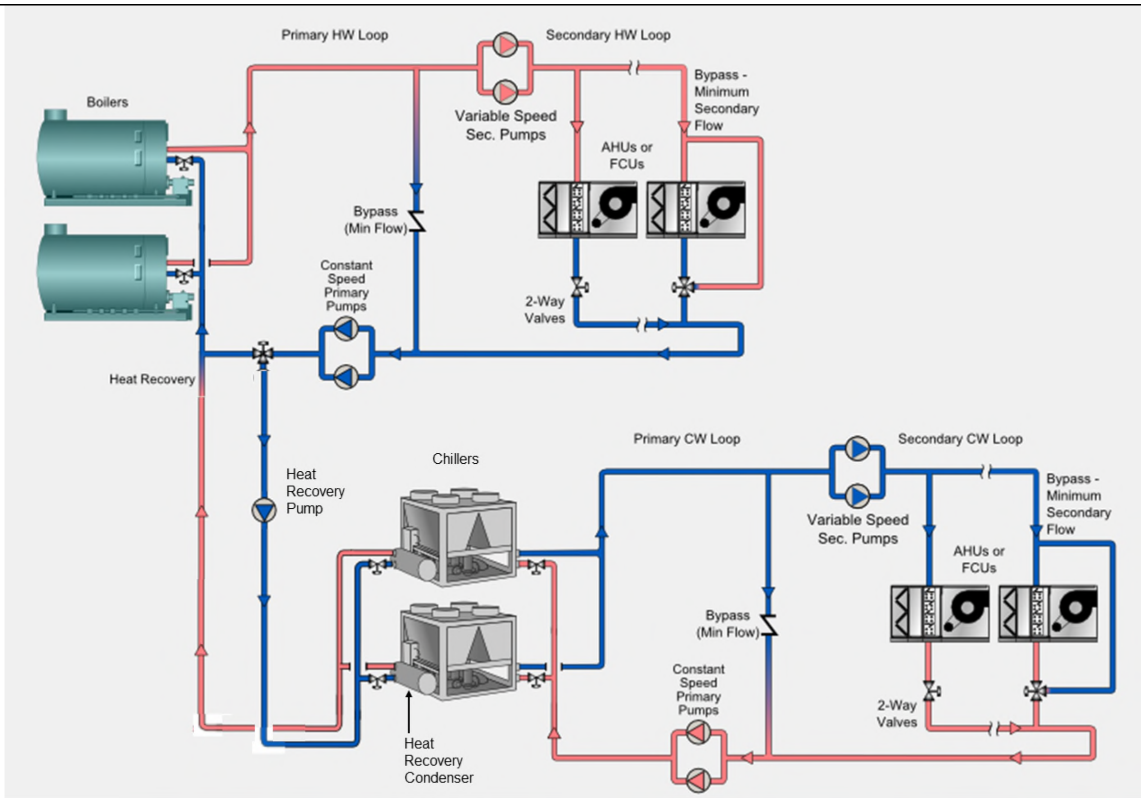

Figure 1. Diagram of Heat Recovery Plant with Air-Cooled Chillers with Heat Recovery Condensers

(*Note: This is a simplified diagram only intended to show the basic arrangement of components*)

System Overview

Basics of Equipment Configuration and Operation

Figure 1 contains a simple diagram of a heat recovery plant using air-cooled chillers with heat recovery condensers:

- The upper half of the diagram shows a hot water plant with two hot water boilers in parallel and a primary/secondary water loop providing hot water to heating coils in air handlers or fan coil units. Note that there can be different types of of heat recovery systems. Some will supply heat to a service hot water (SHW) system instead of or in addition to serving space heating loads.

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- The lower half of the diagram shows a chilled water plant with two air-cooled chillers in parallel and a primary/secondary water loop providing chilled water to cooling coils in air handlers or fan coil units.
- In this diagram the air handler icons are shown separately for the cooling and heating loops, but typically these will be single equipment units containing both cooling and heating coils. The air handlers are shown separately to make the diagram more readable.
- The air-cooled chillers are equipped with dual condensers. One is a refrigerant-to-air condenser which rejects heat to the atmosphere. The other is a refrigerant-to-water condenser which recovers heat to the hot water loop. The diagram shows both chillers as equipped with heat recovery condensers. However, in many cases only one chiller or a subset of chillers in the plant will be equipped with heat recovery condensers. The decision of how many chillers to equip with heat recovery condensers depends on the relative sizes of simultaneous cooling and heating loads, and the relative added first cost of the heat recovery condensers versus the energy cost savings yielded by the heat recovery.
- When simultaneous cooling and heating loads exist in the building, the valve in the hot water return pipe (middle left in the diagram) diverts some or all of the return water flow into the heat recovery pipe. The heat recovery pump is activated and circulates return water to the heat recovery condenser. The air-cooled chiller(s) switch from using the air-cooled condenser for heat rejection to using the water-cooled heat recovery condenser. Return water passes through the heat recovery condenser and absorbs the heat rejected by the chiller. The heated water then returns to the hot water loop just upstream of the boilers.
- If the heat added to the return water is sufficient to meet the heating plant load, then the hot return water bypasses the boilers (bypass leg not shown in diagram), the boilers remain off, and 100% of the demand is supplied by recovered heat. On the other hand, if the recovered heat is not sufficient to meet the full heating plant load, then one or more of the boilers operate to satisfy the remainder of the heating demand, and heat recovery satisfies only part of the demand.

<u>Survey of Advantages and Disadvantages</u>

As with most heat recovery schemes, this scheme causes some costs to increase and other costs to decrease. When applied to a building with good heat recovery potential, the net result can be an overall savings which justifies the system. Key issues for consideration:

- **Heating energy cost decreases.** Use of heat recovered from the chillers reduces the load on boilers in the heating plant and therefore reduces boiler energy consumption and boiler energy cost. In this type of system it makes most sense to view heat recovery as providing “free heat” to the heating system because the recovered heat is a by product of chiller operation.
- **Cooling energy cost may increase.** For some, and possibly many, operating hours the chiller will be less efficient when operating in heat recovery condenser mode than it would be operating in heat rejection condenser mode.

  Example: Suppose the outdoor air dry-bulb temperature (OADB) is 65 F (18.3 C) for a given hour. A typical air-cooled chiller running in heat rejection mode, rejecting heat via the air-cooled condenser to the atmosphere might run at about 0.80 kW/Ton (4.4 COP). If instead the chiller is running in heat recovery mode, it may be receiving entering condenser water at 120 F and therefore be running at about 1.10 kW/Ton (3.2 COP). The elevated condenser water temperature requires the compressors to raise the refrigerant to a higher discharge pressure, and results in greater energy consumption by the compressors in heat recovery mode. Therefore, per unit of cooling delivered for these operating hours, it takes more energy running in heat recovery mode than in heat rejection mode.

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- **Overall energy savings** will depend on the sizes of the heating energy cost savings and additional cooling energy cost. In a building with good heat recovery potential and with a well designed heat recovery system, heating savings will be larger resulting in a net energy cost savings.
- **First cost will typically increase.** High performance HVAC systems often involve a trade off between increased first cost for additional components and controls in exchange for lower energy costs. The lower energy costs ultimately pays back the increased first cost and deliver net savings over the life of the system. This heat recovery system is no exception. The air-cooled chiller requires an added component – the heat recovery condenser – and the system requires additional pumps, piping and controls that a conventional system would not require. Therefore, the purchase and installation cost for the heat recovery plant will be higher than for a conventional plant.
- **Lifecycle cost can decrease.** While first cost will be higher for heat recovery, in a building with good heat recovery potential and a well designed system, energy costs will be lower. This will deliver payback and net savings over the life of the system.

<u>Keys to Successful Application</u>

Successful application of a heat recovery plant first requires a building with simultaneous cooling and heating loads for a significant number of hours per year. Examples of buildings that may have good heat recovery potential include hotels, dormitories and hospitals. Each of these building types tend to have large persistent service hot water (SHW) loads all year long. Therefore heating demands exist during the cooling season when recoverable heat is available from cooling equipment. In moderate to warm climates cooling demands may exist most of the year, further increasing the number of hours with simultaneous demands. Figure 2 shows the full-year hour-by-hour cooling and heating load profiles for a sample hotel in a warm climate in the northern hemisphere. This example demonstrates good heat recovery potential.

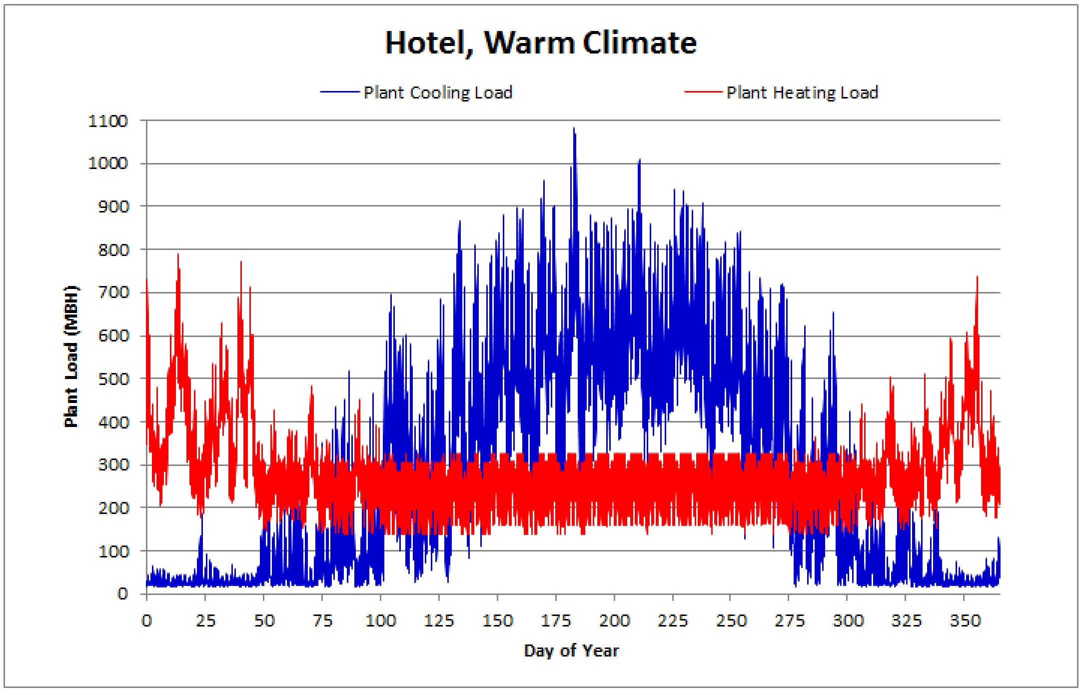

Figure 2. Building with Good Heat Recovery Potential

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On the other hand, the building whose cooling and heating profiles are shown in Figure 3 might not be a good candidate for heat recovery. This is an office building in a cool climate in the northern hemisphere. Cooling is dominant in the summer while heating is dominant in the winter, and SHW demands are relatively small. Some hours with simultaneous cooling and heating demands exist in the shoulder seasons and when SHW demands exist in the summer, but the size of the demands and the number of potential heat recovery hours tend to be small. There could be small net energy cost savings, but it becomes more difficult for this savings to offset the additional first costs of the heat recovery system to achieve project payback objectives.

Note: Figure 3 is not meant to imply that all office buildings in cool climates are poor heat recovery candidates. It is only meant to demonstrate that any building lacking hours with simultaneous cooling and heating demands is a poor candidate for heat recovery. Each building application is different and should be evaluated for heat recovery potential. See “Avoiding Simulation Pitfalls” at the end of this article for further details.

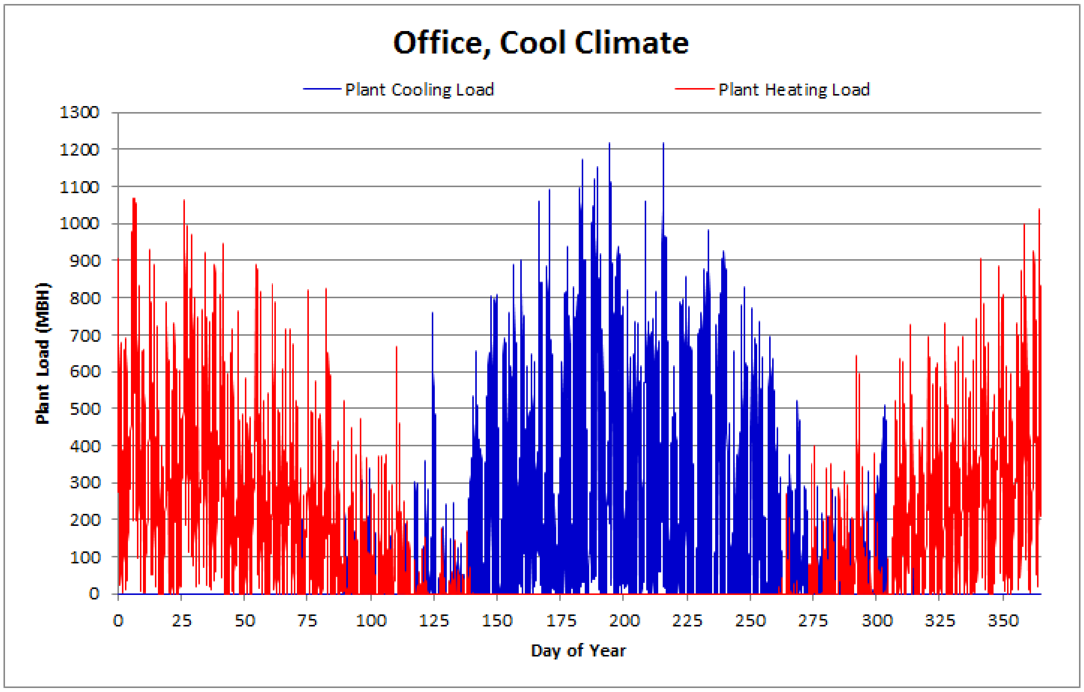

Figure 3. Building with Poor Het Recovery Potential

In addition to building cooling and heating load profiles, viability of a heat recovery system solution will also depend on equipment efficiencies at full and part-load, heating energy sources (electric vs gas for example), relative electric and gas energy prices, and equipment costs. Because many factors are involved, it is often not obvious whether heat recovery makes sense for a given application. Modeling heat recovery versus a conventional plant in an energy modeling tool such as Carrier HAP is a good place to start making the case for heat recovery. The following section provides a tutorial on using HAP to compare energy performance of conventional versus air-cooled chiller with heat recovery condenser plants.

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HAP Tutorial

A typical application with HAP is to compare the energy costs of conventional cooling and heating plants versus a heat recovery plant. The following tutorial summarizes the steps for conducting this analysis with a plant using air-cooled chillers with heat recovery condensers.

Step 1 – Model the Common Elements

Use standard HAP procedures to model the common elements of the building: weather, wall, roof, and window assemblies, schedules, spaces, air systems, and electric and fuel rates.

Step 2 – Model the Conventional Plants

To represent the baseline case – conventional cooling and heating plants – create one chiller plant and one hot water plant using standard HAP procedures.

Step 3 – Input Chiller and Boiler Data for Heat Recovery

Create one or more air-cooled chillers and one or more hot water boilers to use in the heat recovery plant. Chillers and boilers could be created "on-the-fly" while inputting the plant, but are described here as a separate set-up task for simplicity and greater clarity.

1. If the heat recovery plant will include cooling-only chillers, create those first using standard HAP procedures.
2. Then create the air-cooled chillers which are equipped with heat recovery condensers.
   - On the General Tab (Figure 4), first select Equipment Function as "Chiller (chilled water only)". The "chilled water only" note refers to the primary function of the machine, but as we'll see in a moment it does not prevent you from specifying heat recovery features to produce hot water at the same time. Also select an air-cooled chiller type. The example in Figure 4 uses an air-cooled packaged scroll chiller.
   - On the Design Inputs tab (Figure 5) select the "W/C Heat Recovery Condenser" option (see 1 in figure). When "W/C Heat Recovery Condenser" is selected additional inputs will appear on this tab.
   - There are separate inputs for Full Load OAT and Full Load ECWT (see 2). Full Load OAT defines the full load rating temperature for operation using the air-cooled heat rejection condenser and is typically set using the design outdoor air temperature or a standard rating point like 95 F (35 C). Full Load ECWT defines the full load entering condenser water temperature for heat recovery condenser operation. This value will depend on the design of your hot water system and the hot water return temperature that is flowing to the chiller's heat recovery condenser. This temperature is often in the range from 100 F to 120 F (37.8 C to 48.9 C).
   - If chiller capacity is being directly specified (not "autosized"), there are separate capacity inputs for air-cooled and water-cooled operation (see 3). The air-cooled capacity defines the cooling capacity at the Full Load OAT specified earlier. The water-cooled capacity defines the cooling capacity when running at the Full Load ECWT. This data should be obtained from manufacturer's ratings.
   - Separate inputs are provided for chiller full load input power when operating in air-cooled heat rejection condenser mode and when operating in water-cooled heat recovery condenser mode (see 4). This data should be obtained from manufacturer's ratings.

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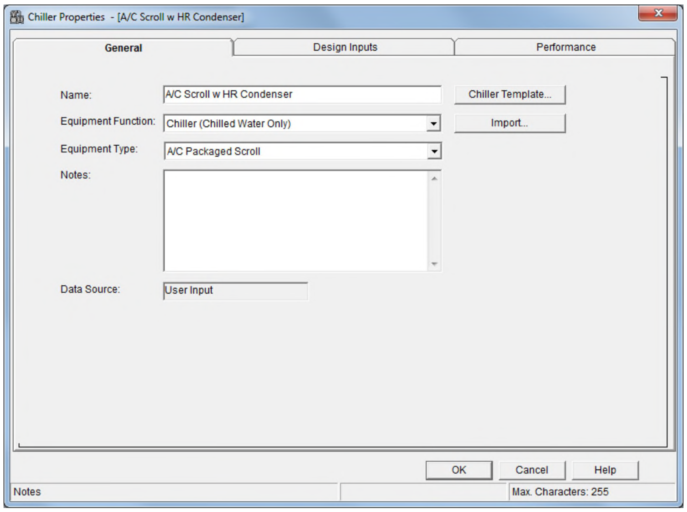

Figure 4.

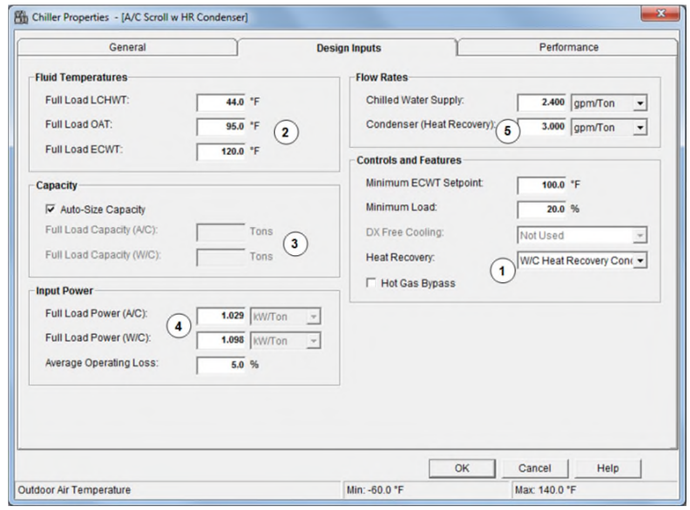

Figure 5.

- Specify the condenser water flow rate, the required flow delta-T or flow per unit capacity for heat recovery mode (see 5). This will depend on the system design.
- Specify the minimum entering condenser water temperature for heat recovery mode (see 6).
- On the Performance tab specify the chiller performance map for air-cooled condenser (heat rejection) operation (Figure 6) and water-cooled condenser (heat recovery) operation (Figure 7). If off-design and part-load performance data is available from the manufacturer, it should be entered here. Because this data is sometimes not available, a common practice is to use the default maps supplied by HAP, which are automatically adjusted based on your full load capacity and full load input power specifications on the Design Tab.
- Make sure the data in the performance maps spans the range of entering condenser temperature conditions expected for this building.

  Air-Cooled Heat Rejection Mode: Suppose the chiller is expected to operate during times of year when the outdoor air dry-bulb temperature is between 95 F (35 C) and 40 F (4.4 C). Therefore the air-cooled performance map (Figure 6) must have rows which span at least this range of outdoor air temperatures. If operating conditions fall outside the range of conditions specified in the map, HAP uses the closest data in the map, but this introduces error. The most accurate results will be obtained when the performance map spans the expected range of operating conditions.

  Water-Cooled Heat Recovery Mode: Suppose the entering water temperature for the heat recovery condenser is expected to range between 100 F (37.8 C) and 120 F (43.3 C). Therefore the water-cooled performance map (Figure 6) must have rows that span at least this range of conditions. As explained for the air-cooled map above, if operating conditions fall outside the range defined, HAP uses the closest data in the map. For example, if the entering condenser temperature rises to 120 F and the map only contains data to 110 F, HAP will use data from the 110 F row since that is the closest available. This will underestimate chiller energy use operating at 120 F entering water temperature and therefore introduce error in the results.
- After data on all the tabs has been entered, save the chiller.

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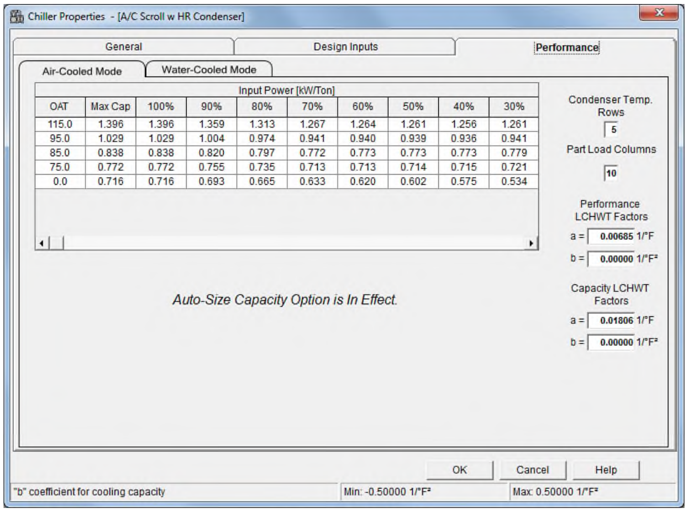

Figure 6.

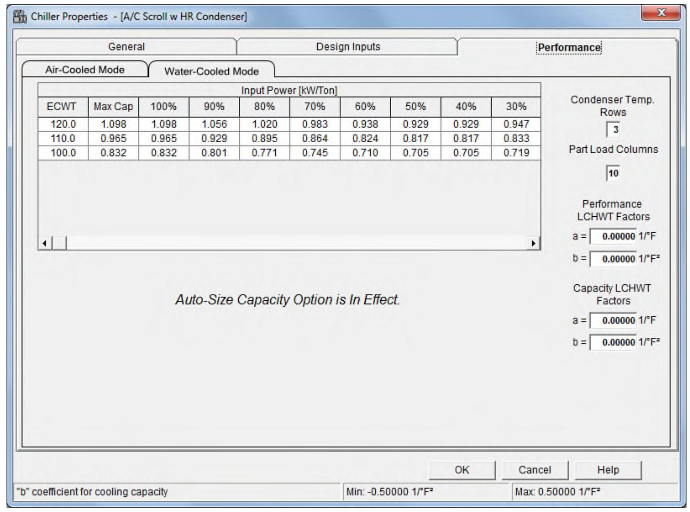

Figure 7.

3. If necessary, create and save the boilers for the heat recovery plant. In many applications the same boiler equipment is used for both conventional and heat recovery plants. This is because common practice is to size the boilers to meet the full heating plant demand in the heat recovery plant as if no heat recovery is available. If this is the case, then the boilers entered previously for the conventional plant can be reused in the heat recovery plant. No additional boiler inputs are required.

Step 4 – Define the Heat Recovery Plant

Next create and configure the heat recovery plant. The following subsections describe inputs on each of the six relevant tabs in the Plant Properties window.

Step 4a – General Tab

On the General Tab select "Heat Recovery Plant" as the plant type (Figure 7). This is a special type of plant which combines the components from one chilled water system, one hot water boiler system and the additional heat recovery equipment, piping and controls. Therefore we will define all of the interconnected cooling and heating equipment as one "plant".

Step 4b – Systems Tab

On the Systems tab link one or more air systems to the plant (Figure 8). Among these systems at least one must have chilled water cooling coils. Typically one or more will also have hot water heating coils.

In warm climates where space heating is not required, all of the air systems might be chilled water cooling-only. In that case the heating load for the plant would come from the service hot water (SHW) system (see Step 4c).

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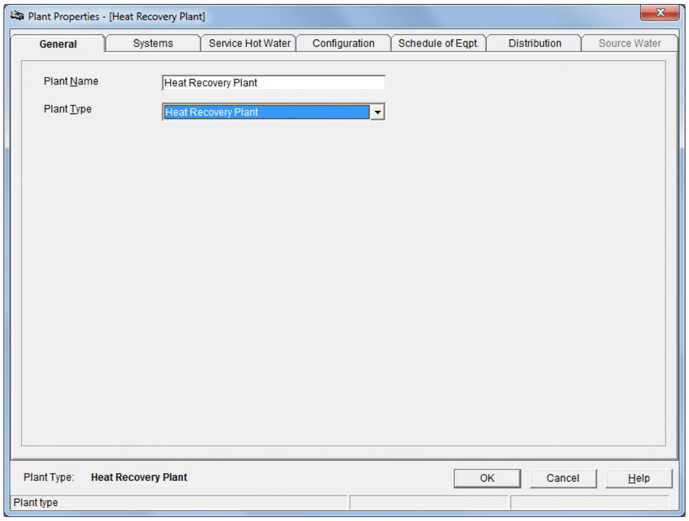

Figure 7.

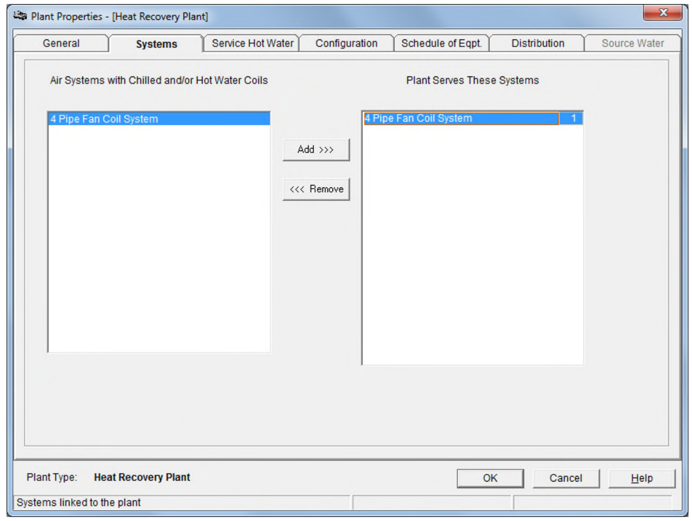

Figure 8.

Step 4c – Service Hot Water Tab

If the heat recovery system serves service hot water (SHW) loads, define those loads and the associated equipment components and controls on the Service Hot Water tab (Figure 9).

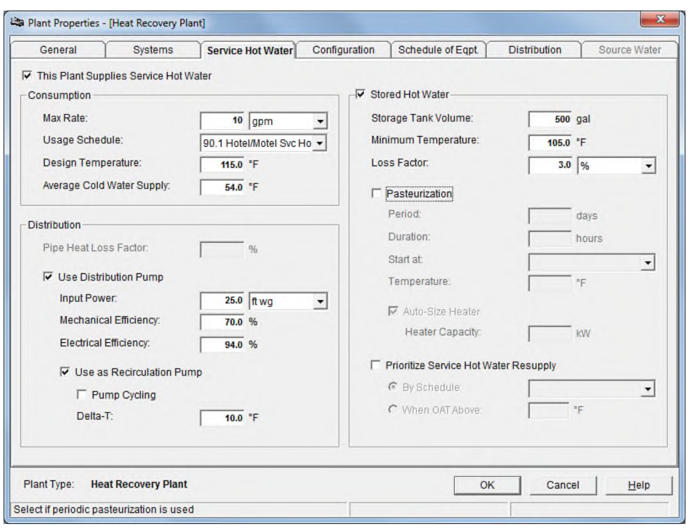

Figure 9.

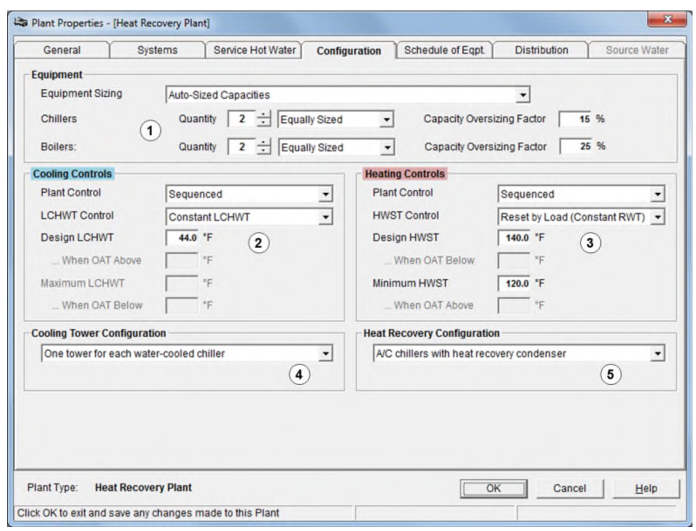

Figure 10.

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Step 4d – Configuration Tab

The Configuration Tab (Figure 10) is divided into five sections containing important information about the configuration and control of the cooling and heating portions of the plant:

- **Equipment** (see 1 in figure) - Specify whether chillers and boilers will be "autosized" or whether you'll use equipment with directly specified capacities. "Autosizing" is typically used for preliminary screening studies. User defined sizing is used for studies where you've designed the system and chosen specific equipment capacities. This section also defines the quantity of chillers and boilers in the plant.
- **Cooling Controls** (2) – Specify how chillers are staged (e.g., sequenced or equally unloaded) and any chilled water reset controls.

  For a heat recovery plant it may be beneficial to sequence the chillers – progressively turn more chillers on as load increases, and progressively turn chillers off as load decreases. For example in a plant with two chillers, only one of which has a heat recovery condenser, the heat recovery chiller would operate as the lead chiller – the first turned on and the last turned off. The cooling-only chiller would be the lag chiller – last on and first off. This would ensure the heat recovery chiller runs whenever a cooling load exists, increasing its availability for providing heat recovery, and that the heat recovery chiller is loaded as heavily as possible, thereby increasing its heat recovery potential. If you use "equal unloading" control, the heat recovery chiller will be on for all cooling hours, but will be more lightly loaded for many operating hours, decreasing its heat recovery potential and, for some types of equipment, reducing its cooling efficiency.
- **Heating Controls** (3) – Specify how the boilers are staged (e.g., sequenced or equally unloaded and any hot water supply reset controls.

  For a heat recovery plant it may be beneficial to use hot water supply temperature reset, if heat recovery is used for space heating and if it's feasible. Hot water reset reduces the hot water supply temperature either as outdoor temperatures warm, or as heating loads decrease. Reduced hot water supply temperatures can result is cooler return water temperatures in the hot water loop. Those cooler return temperatures can allow the air-cooled chiller to operate more efficiently in heat recovery mode and/or increase the number of hours when the air cooled chiller can operate to provide heat recovery.
- **Cooling Tower Configuration** (4) – For a heat recovery plant using air-cooled chillers this section is not relevant. Simply accept the default and skip to the next section.
- **Heat Recovery Configuration** (5) – Select the "A/C chillers with heat recovery condenser" option in this drop-down list.

Step 4e – Schedule of Equipment Tab

The Schedule of Equipment Tab (Figure 12) is used to select the individual chillers and boilers used in the plant:

- The **Equipment Table** (see 1 in figure) contains one row for each chiller or boiler in the plant. In the example in Figure 12 there are two chillers, color coded as blue, and designated as CH-1 and CH-2. There are also two boilers, color coded as red, and designated as BLR-1 and BLR-2. If you've previously defined the chiller and boiler equipment (as in Step 3 above), these items will appear on the drop-down list and can be selected. If the equipment has not yet been defined, you can select the "create new chiller" or "create new boiler" option in the list to create and link the equipment.

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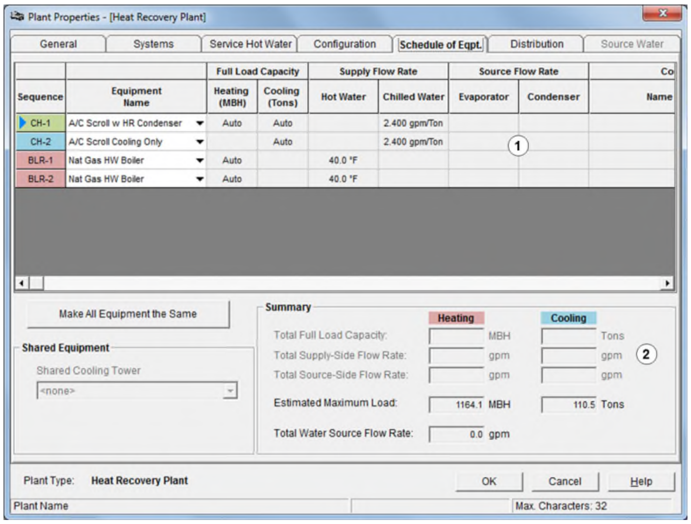

Figure 12.

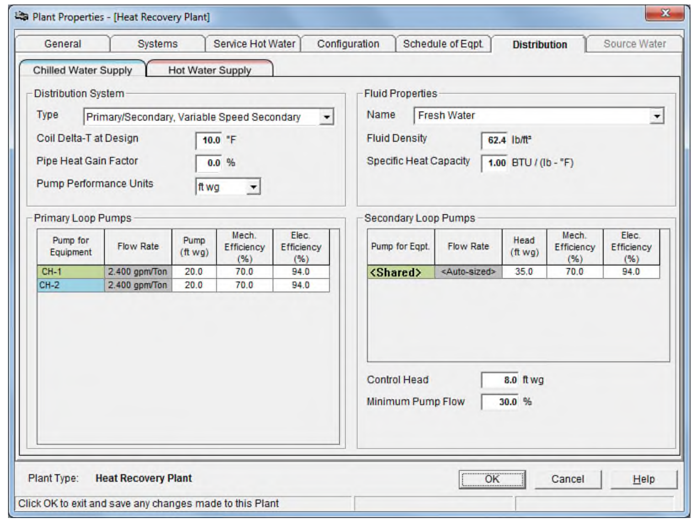

Figure 13.

If only a subset of chillers is equipped for heat recovery and the chillers are sequenced, make sure to properly position the heat recovery chillers in the sequence. As noted earlier, positioning the heat recovery chiller as CH-1 is likely to maximize heat recovery potential for the plant.

- The remaining items on this tab (2) are display only and provide reference information about equipment flow rates and capacities (if available).

Step 4f – Distribution Tab

The Distribution Tab (Figures 13 and 14) is used to define the performance of the chilled water and hot water distribution loops. The tab contains two sub-tabs: one for the chilled water supply loop, color coded blue, (Figure 13) and one for the hot water supply, color coded red (Figure 14).

- Inputs on the **Chilled Water Supply** sub-tab function the same as for a conventional chiller plant. You can select from a list of different system types (primary-only, primary/secondary) and then define the fluid properties and pump performance characteristics.
- Inputs on the **Hot Water Supply** sub-tab are similar to those for a conventional hot water plant. You select the distribution system type, specify fluid properties and pump performance. However, for this type of heat recovery system there is an additional line item in the Primary Loop Pump table for the heat recovery pump. This line is color coded green. In Figure 1 this is the pump in the heat recovery leg of the system (middle left in Figure 1) that circulates water from the hot water return pipe to the chiller heat recovery condensers.

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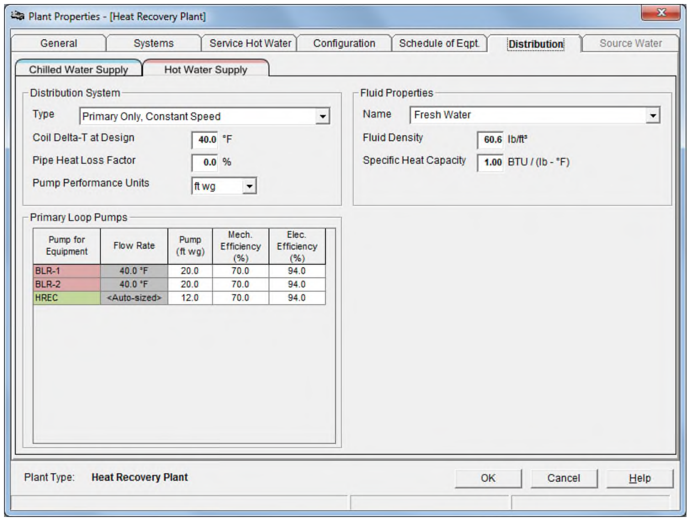

Figure 14.

<u>Step 4g – Source Water Tab</u>

For a heat recovery plant using air-cooled chillers with heat recovery condensers, the Source Water tab is disabled as it is not relevant. In other types of heat recovery systems this tab defines performance of condenser water and in some cases heat recovery pumps.

<u>Step 5 – Run the Simulations</u>

Once both the conventional and heat recovery plants have been defined, create two “buildings”, one to represent the conventional scenario and one to represent the heat recovery scenario. Then run the energy simulations and evaluate the results.

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Avoiding Simulation Pitfalls

Heat recovery plants are complex engineered systems. Energy models of these plants are complex as well. When modeling the "air-cooled chillers with heat recovery condenser" plant in HAP there are several key details to consider to ensure high quality, accurate results.

1. **Lack of Heat Recovery Savings** – The most common questions arising from heat recovery energy simulations are "Why didn't heat recovery provide any savings?" or "Why are the heat recovery savings so small?". In many cases the answer is the building lacks heat recovery potential because of the small number of hours with simultaneous cooling and heating loads.

   Figure 3, shown earlier, contains an example of a building which is not a good candidate for heat recovery. Cooling (blue) is predominant in summer. Heating (red) is predominant in winter. There are very few hours where simultaneous cooling and heating demands occur. This example is for an office building in a cool climate. The building uses floor-by-floor VAV AHUs with an outdoor air economizer. The economizer provides partial free cooling when the outdoor air dry-bulb (OADB) is between 55 F (12.8 C) and 75 F (23.9 C), and provides full free cooling when the OADB is less than 55 F. While an outdoor air economizer is a useful device for reducing cooling energy use, and may be required by prescriptive codes, it reduces heat recovery potential because it reduces the number of hours when simultaneous cooling and heating loads exist.

   Figure 2, shown earlier, shows an example of a building which is a good candidate for heat recovery. Again cooling coil loads are shown in blue and heating coil loads are shown in red. This is a hotel building in a warm climate. It uses 4-pipe fan coils to cool and heat guest rooms, with a dedicated outdoor air system (DOAS) for ventilation, and it has significant service hot water (SHW) loads throughout the year. These characteristics result in cooling loads for much of the year and persistent heating plant demands all year long. As a result there are many hours throughout the year with simultaneous cooling and heating demands where heat recovery can operate.

   You can assess the heat recovery potential of your building using HAP as follows:

   a. Create the conventional chiller plant and hot water plant using standard HAP procedures.
   b. Run the plant simulations for these two plants.
   c. For the chiller plant request a graph of hourly simulation results for January 1 thru December 31. Choose the "Plant Cooling Load" item as the data to be graphed (Figure 15). This will plot the total hourly cooling load imposed on the plant for the full year.
   d. For the hot water plant request a graph of hourly simulation results for January 1 thru December 31. choose the "Boiler Output" item as the data to graphed (Figure 16). This will plot the total hourly heating load imposed on the plant, including space heating and SHW loads.
   e. Place the graphs side by side to visually evaluate whether simultaneous cooling and heating demands exist during the year.

2. **Plant Cooling Control – Sequenced or Equal Unloading** – As noted in Step 4d of the Tutorial, it is usually beneficial to use "sequenced" control for the air-cooled chillers and to place the chiller with heat recovery condenser in the lead (CH-1) position in the equipment schedule. Because CH-1 is the first on and last off, the plant will be able to delivered recovered heat to the heating system any hour when cooling and heating demands exist simultaneously. Using sequenced control will tend to maximize loading of CH-1, particularly at off-design and lower part-load conditions. This increases the chiller heat rejection and provides greater heat rejection potential.

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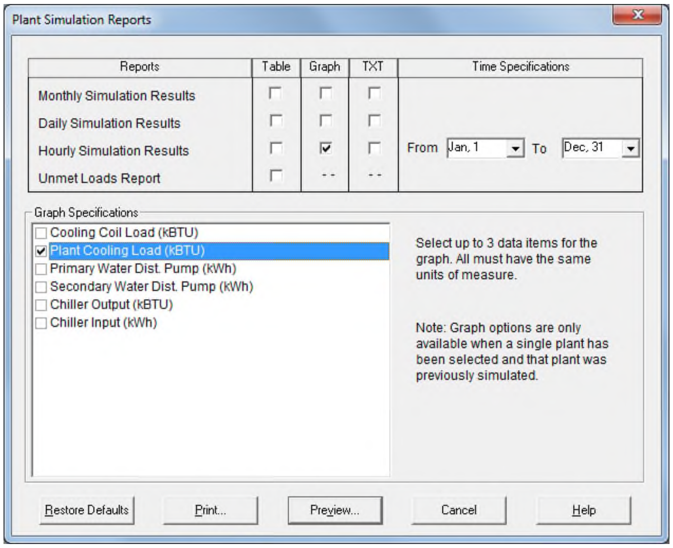

Figure 15.

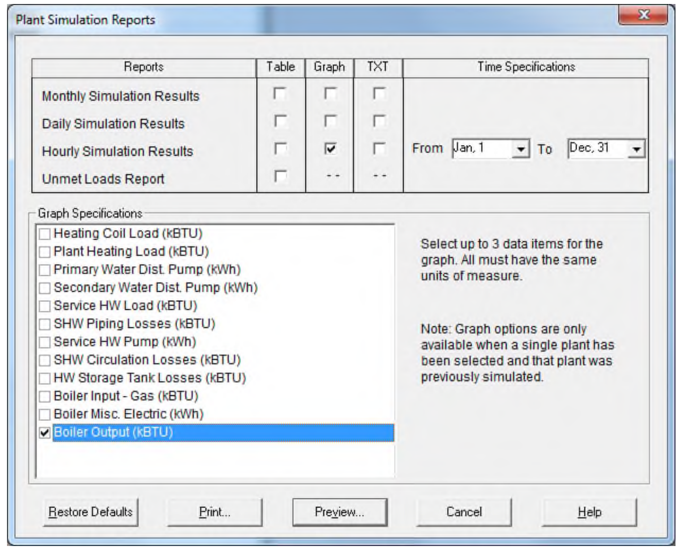

Figure 16.

3. **Plant Heating Control – Design HWST** – As a design issue, the design hot water supply temperature (HWST) for the heating plant should be carefully coordinated with heat recovery chiller capabilities.

   Example: The Design HWST is set to 160 F (71.1 C). The hot water system delta-T is set to 40 F (22.2 K). At full load this means the return water temperature will be 120 F (48.9 C), at 75% load the return water temperature will be 130 F (54.4 C), and at 50% load the return water temperature will be 140 C (60 C). These are the entering water temperatures for the air-cooled chiller heat recovery condenser. If the chiller's heat recovery condenser is rated for 130 F HWST, the chiller will only be able to provide heat recovery between when the heating system is between 100% and 75% load. At 75% load and lower, the return water temperature will be 130 F or higher and the heat recovery condenser will be unable to recover heat to the heating system. Therefore the design HWST of the hot water plant must be set so it is compatible with the operating limits of the air-cooled chiller with heat recovery condenser (as defined via the Full Load ECWT and W/C Mode performance map ECWT values of the chiller), and so it allows heat recovery over the widest range of part-load conditions possible.

4. **Plant Heating Control – HWST Reset** – As noted in Step 4d of the Tutorial it can be beneficial to use hot water supply temperature reset, if heat recovery is used for space heating and if reset is feasible. Hot water reset reduces the hot water supply temperature either as outdoor temperatures warm, or as heating loads decrease. Reduced hot water supply temperatures can result in cooler return water temperatures in the hot water loop. Those cooler return temperatures can allow the air-cooled chiller to operate more efficiently in heat recovery mode and/or increase the number of hours when the air cooled chiller can operate to provide heat recovery.

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Further Information

If you have further questions about modeling air-cooled chiller with heat recovery condenser plants and you are located in the US or Canada, please contact Carrier software support at **software.systems@carrier.utc.com**. Otherwise, please contact your local Carrier sales office for assistance.

HAP also offers simulation models for the following five additional heat recovery schemes:

- Dedicated heat recovery chiller (DHRC) in parallel with cooling only chillers.
- Heat exchanger in the condenser water loop
- Dedicated heat recovery chiller (DHRC) in the condenser water loop
- Chiller with double-bundle condenser
- Chiller with desuperheater.

For separate e-Helps explaining how to model these other heat recovery schemes, please visit the **Carrier software application support** web page.