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Carrier Engineering Newsletter Volume 4, Issue 1

How to Model a Waterside Economizer Application

An underlying theme common to most successful energy-use reduction strategies is the utilization of ambient conditions. One approach to reducing energy consumption, the use of a waterside economizer, has recently gained importance with the adoption of the requirements of ASHRAE Standard 90.1 2013 by several state building codes. These requirements call for a very aggressive reduction of mechanical cooling by eliminating it during ambient conditions at or below 50 F dry bulb/45 F wet bulb. During these conditions, if an airside economizer is not satisfying the total cooling load, 100% of the chiller plant cooling load must be met by an integrated waterside economizer. In addition, even when not required by code, use of an integrated waterside economizer can provide an advantage by pre-cooling the return chilled water and enabling part load operation, thereby reducing energy costs and securing utility incentives or rebates. This newsletter will describe how to incorporate an integrated waterside economizer into a chilled water system and demonstrate why use of a modeling tool is essential for proper application of the economizer and optimization of the chiller plant.

Reducing Chilled Water System Energy Usage

As noted above, ASHRAE 90.1 2013[1] requires that a chilled water plant switch to 100% free cooling when ambient conditions are at or below 50 F dry bulb/45 F wet bulb. This requirement is intended to advance ASHRAE's published goal[2] of reaching net zero energy usage for buildings by 2030.

Although the realization of net zero energy usage may be well in the future, use of a waterside economizer to handle the cooling load is one way of achieving "free cooling" today.

Beyond the requirements of ASHRAE 90.1 2013, there are several advantages to including an integrated waterside economizer in a chilled water plant system.

One benefit is the ability to pre-cool the return chilled water from the system before the water enters the cooler. When climate conditions do not allow for the waterside economizer to carry the entire cooling load, the waterside economizer will act in series with the part loading chiller, reducing the delta T between the leaving chilled water and the entering chilled water. The reduced temperature difference between the return and supply water temperatures will reduce the mechanical cooling load on the chillers.

This part loading allows for the reduction in work effort of other chilled water plant equipment, Note that variable frequency drive (VFD) motors associated with the condenser pumps could reduce their speed (rpm) and water flow rates (gpm) as long as the minimum flow rate to the chiller condenser barrel and then to the heat exchanger are maintained.

Another benefit is that the chiller can remain off longer while running the tower to maintain chilled water between load reset and leaving chilled water temperature. System part loading kW/ton will decrease significantly since the chiller motor is off.

The pre-cooling function of the integrated waterside economizer may also be used in a system that is equipped with an airside economizer that does not serve all areas of the system.

When implemented with part loading performance and condenser water reset, use of a waterside economizer may reduce the need to reconfigure a chiller plant to serve a single building rather than multiple buildings for energy management (reduction of master to sub metered chiller plants).

[1]ANSI/ASHRAE/IES Standard 90.1.2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, Section 6.5.1.2.1

[2]ASHRAE Vision 2020, Producing Net Zero Energy Buildings, January 2008

UTILITY INCENTIVES

Utilities offer incentives for energy efficiency, which can be based on reducing peak demand of equipment (kW) and/or consumption (kWh).

A waterside economizer may contribute to reduced energy use in the following ways:

- *Reducing the mechanical cooling load on chillers by precooling return water*
- *Reducing energy use of the plant by allowing chillers to turn off at times of free cooling*

Energy efficiency of replacement equipment is incentivized per kWh saved.

Consumption (kWh) may decrease with the use of a waterside economizer because the leaving chilled water temperature can be reduced based on the wet bulb temperature. With this control strategy, the effect will be a reduction in motor speed (rpms) of the compressor as well as the pre-cooling of the chilled water return through the waterside economizer. Utility companies incentivize this reduction in kWh compared to mechanical cooling only.

Incorporating the Integrated Waterside Economizer into the Chiller Plant

When to Use a Waterside Economizer

Does a waterside economizer make sense for a particular system?

Following are some questions to begin the load analysis that will help determine whether or not a system will benefit from a waterside economizer.

Is chilled water required all year round?

The most important question, other than if cooling is required all year round, is whether or not chilled water is required. Is there an internal cooling load that is not based on envelope load or ventilation load? If yes, will the forced air system satisfy the internal cooling load using airside economizer? It is important to note that not all cooling can be satisfied by an outdoor air economizer in the non-cooling season; in those cases, the remaining cooling capacity will need to be satisfied by chilled water.

Is an airside economizer used?

The airside economizer can achieve free cooling before the waterside economizer, because the airside economizer uses the ambient dry bulb temperature, while the waterside economizer must use wet bulb temperatures. For example, assume the leaving discharge air temperature from the chilled water coil is 55 F. In order to achieve free cooling through a waterside economizer, which is based on the wet bulb temperature, the required wet bulb temperature would be 38 F, which is much lower than the dry bulb temperature.

As noted above, even if an airside economizer is being used, further analysis is required to be sure that airside economizer system provides 100% cooling to spaces. It is possible that the airside economizer system only provides a percentage of the cooling load, such as ventilation load or a combination envelope load.

Does the chiller operating system support waterside economizer application?

Does the existing or new chiller have head pressure control and to what degree will a reduction in entering condenser water temperatures be acceptable? In order to determine the energy strategy to be used, chiller selection data is required to provide data on parameters related to minimum cooling capacities and entering condenser water temperatures.

Do weather conditions support use of a waterside economizer?

It is important to know whether local weather conditions will achieve the wet bulb temperatures required to enable pre-cooling to 100% waterside economizer operation, as well as the hours at which these temperatures will occur. The wet bulb temperatures must be at a level where the combined approaches of the cooling tower and heat exchanger are below return chilled water temperatures. For example, the combined heat exchanger approach and cooling tower approach must be 2ºF below the return chilled water temperature to start the process of pre-cooling, and at the supply chilled water temperature for 100% waterside economizer operation.

Defining the Cooling Load for the Waterside Economizer

A strong modeling tool can assist with this process as well as help determine the effects of a waterside economizer using multiple variables within a complex set of matrix equations. A step-by-step example will be provided later using Carrier's Chiller System Optimizer tool.

The cooling load is derived from the sensible and latent loads, the building climate zone, the schedule of operation, and whether an outdoor air economizer is serving any of the spaces.

A modeling tool like Carrier's HAP software, which can perform an 8760 analysis, can use a given load profile to define the building cooling load at the conditions of 50 F dry bulb/ 45 F wet bulb and determine whether this load is being met by an outdoor air economizer. If there is no 100% airside economizer serving the mechanical cooling, the calculated loads will be used to define the waterside economizer cooling load.

A parameter that can influence the application of the waterside economizer is the leaving chilled water temperature and whether or not this temperature can be allowed to rise from design day conditions, referred to as "chilled water reset." To make this determination, we must consider the make-up of the cooling load, specifically whether or not it is comprised of a high latent load that may require dehumidification and/or a process load.

Dehumidification

One of the factors that may restrict the design day leaving chilled water temperature is the requirement regarding removal of moisture. If the moisture content is coming from ventilation air, then chilled water reset operation must be a function of ambient wet bulb temperature, e.g., a decrease in the ambient wet bulb temperature will correspond to a proportional increase in leaving chilled water temperature.

Process Load

If a chilled water capacity requirement is based on process load, it may not be possible to increase the chilled water reset due to the restriction placed on the leaving chilled water temperature. The waterside economizer can still be implemented, but hours of use may be sharply reduced. The operation of the non-integrated economizer may be limited to the period when the ambient wet bulb temperature is lower than the combined approaches of the cooling tower and heat exchanger. This is known as 100% waterside economizer operation.

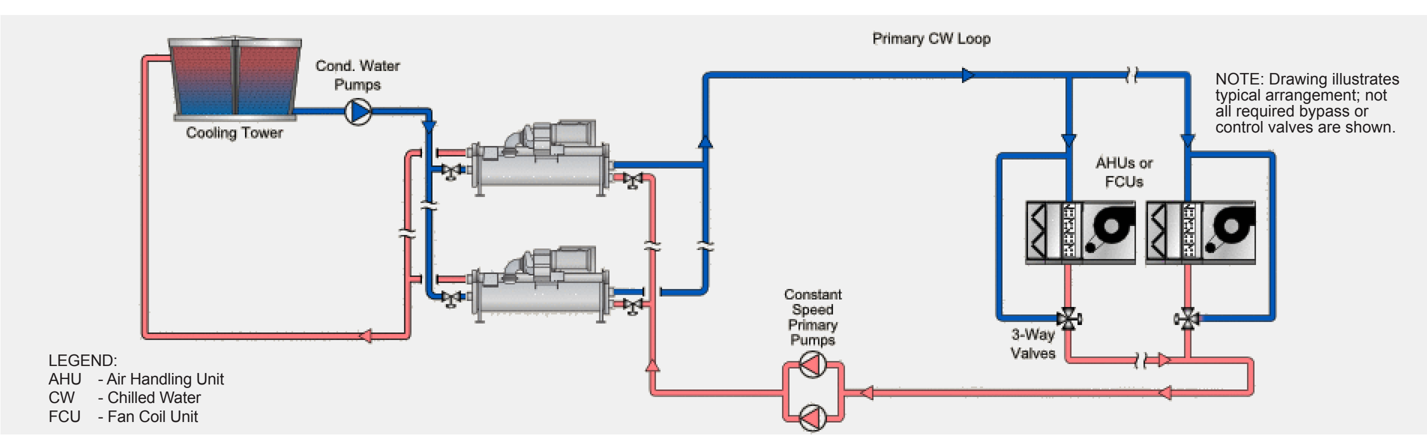
If there are no dehumidification or process load requirements from the building load, then the chilled water outdoor air reset schedule can be more aggressive. The ambient dry bulb temperature will be used to determine chilled water reset.

Integrated Waterside Economizer Operation

Waterside Economizer Plant Components

There are several components required to achieve waterside economizer operation. The previous section described the importance of leaving chilled water temperature to a particular building load environment. The acceptable value for the leaving chilled water temperature must be established before the control strategy can be developed to reset chilled water temperature. The next section will outline how to lower the condenser water from the cooling tower with head pressure control for the chiller. The pumping/piping system used to implement the cooling chilled water system must also be considered. A typical water-cooled system is shown in Figure 1.

Figure 1 – Typical Water-Cooled Chiller Plant and Three-Way Control Valve Piping System Supported by a Primary Constant Speed Pumping System



Carrier's Chiller System Optimizer modeling tool can be used to predict the effects of a waterside economizer (WSE) by managing multiple variables within the complex settings outlined in the energy strategy described below. The modeling process will show:

- Reduction in chilled water return temperatures
- Reduction of the delta T between return and supply water temperatures by pre-cooling through the waterside economizer heat exchanger
- 100% waterside economizer breakpoint related to chilled water reset

Sizing of chiller plant equipment is important in order to evaluate the potential benefits of the waterside economizer. Chiller System Optimizer will demonstrate the importance of chiller plant equipment sizing by analyzing the following equipment.

Chillers

The minimum percent turndown of a chiller, related to the period from shoulder months through to minimum cooling capacity, is an important aspect of waterside economizer operation. The performance of the other components (i.e. cooling tower, waterside heat exchanger, and condenser and chilled water pumps) is essential to maximize the chiller performance outside of waterside economizer conditions. Establishing minimum cooling capacity will result in accurate selection of the other components within the system in order to achieve their best performance as detailed below:

- Lowest temperature condenser water through the cooling tower
- Approach from the waterside economizer heat exchanger
- Condenser and chilled water pump flow reduction

Cooling Tower

The science behind removing heat from entering condenser water will not be discussed here, but we will define the factors required for setting the leaving condenser water, i.e., approach and wet bulb temperature.

The following factors are key to obtaining the best performance of the cooling tower:

- Using lowest leaving condenser water temperature that is possible without causing the tower water to freeze
- Decreasing the approach from the ambient wet bulb temperature
- Maximizing the percent fan performance from pre-cool to 100% waterside economizer

Waterside Heat Exchanger

An important factor to consider regarding the waterside heat exchanger is to weigh the efficiency of load shedding, from pre-cooling to 100% free cooling, with the incremental cost increase of the associated approach. Achieving the correct balance here, combined with the energy strategy of chilled water reset, can be an effective way to reduce the performance-to-upfront cost ratio.

A system strategy can be used to quickly enable the waterside economizer to supplement the outdoor air economizer during the period when the shoulder season ambient temperature increases the latent load.

Note: The minimum water flow through the chiller's condenser barrel would be maintained through the waterside heat exchanger through the three-way bypass valve to the cooling tower. The chiller condenser barrel water flow rate must be within the minimum water flow rate required by the condenser water system, which must maintain minimum flow for cooling tower nozzle and fill effectiveness in order to achieve proper approach from the wet bulb temperature.

Condenser and Chilled Water Pumps

A reduction in condenser water flow and/or chilled water flow can be an additional energy strategy available to enhance the waterside economizer benefit. Condenser water flow can be reduced during periods of low load, when full condenser flow to the waterside economizer is not required. Attention should be paid to the minimum flow rates of each piece of equipment in the system. During integrated waterside economizer operation, the chiller will typically require a significantly lower flow rate through the condenser barrel in order to maintain head pressure control. However, the cooling tower flow rates should not be reduced below the cooling tower manufacturer's minimum water flow rate per individual fan cell. The use of a bypass around the chiller's condenser will allow flow to be modulated in the chiller's condenser without limiting flow in the rest of the system and cooling tower. The modulation between the two different flow rates will determine the best pump selection and efficiencies. Defining the operating minimum and maximum flow rates will properly allow for modulating the turndown to maintain the required condenser water temperature delta T.

COOLING TOWER AND WATERSIDE ECONOMIZER
When implementing WSE it is important to consider the following factors:

- *Design day return temperatures of 56 F or greater*
- *Chilled water reset to leaving chilled water temperatures at or above 50 F*
- *Wet bulb profile of site weather data to determine lowest leaving condenser water temperatures*
- *Cold weather operating requirements for the cooling tower*
- *Changes to maintenance requirements due to water side economizer operation*
  - *Chiller tube cleaning intervals (fouling)*
  - *Plate frame cleaning (fouling)*
  - *Cooling tower observation intervals during cold weather operation (icing)*

Controls

A well-designed chiller plant will incorporate all the parts described above with a control system that can balance performance. The required operating sequences are outlined below:

- Integrated waterside economizer with no chilled water reset. This method achieves unloading of the chiller by reducing the incoming return water temperature while no chilled water reset schedule is applied.
- Integrated waterside economizer with chilled water reset. This method achieves unloading of the chiller by reducing the incoming return water temperature as seen above but with the increase in pre-cooling hours resulting from by raising the return water temperature The combined energy strategy will be enhanced when there is an incremental increase in ambient conditions and the chilled water temperature rises at the same time.

AIRSIDE ECONOMIZER

An economizer should be used in an HVAC system that uses a fan for any cooling process. Either an airside economizer or waterside economizer should be used based on the most efficient free cooling that can be achieved and the ambient conditions of the climate zone in which the system is located. There are two ways in which to use the power of "free cooling." This article focuses on the use of the waterside economizer, but another powerful method of "free cooling" is through an airside enthalpy or dry bulb type economizer. This free cooling application is possible when the ambient dry bulb temperature meets the required discharge air temperature leaving the cooling coil. In this practice, just as with waterside economizer, there is a pre-cooling effect from the modulation of the outdoor air damper from ventilation position to 100% open, along with the reduction in return air percentage of the mixed air temperatures. An airside economizer may achieve a significant increase in free cooling hours compared to a waterside economizer, since the airside economizer is based on dry bulb vs wet bulb temperature. Also, the airside economizer does not have to overcome any derating as seen in the approaches on the waterside economizer from the cooling tower plus the plate and frame heat exchanger. The ratio for the airside economizer is 1:1 dry bulb to discharge cooling air temperature.

A drawback to the use of an airside economizer, unless it is an integrated economizer, may occur in correlation to the relative humidity remaining in the space. Exhausting of all return air does eliminate the increase in mixed air temperature. However, this effect on the temperature results in the removal of moisture from the air stream that will require maintaining a relative humidity in the environment. A humidifier must be placed into the system to provide the moisture make-up for the return air, plus the additional humidification required by the ventilation air.

To fully evaluate the "pros" and "cons" of an airside economizer for an all-encompassing picture of an energy strategy, the following factors should be considered:

Pros:

- *Increased free cooling hours*
- *Pre-cooling application through integrated dry bulb or enthalpy control*
- *Potential fan energy saved from return fan modulation to off*
- *Discharge air temperature reset*

Cons:

- *Addition of humidifier (size and run time)*
- *Increased water consumption from moisture make up due to elimination of return air*
- *Electrical to steam consumption of humidifier*

Modeling Example Using Chiller System Optimizer Tool

Here is a breakdown of the modeling parameters that will be carried throughout the Chiller System Optimizer model to show the effects of waterside economizer as well as other combined energy strategies.

Four different paths are used to show the significance of waterside economizer: 1) Baseline (no waterside economizer); 2) Non-integrated waterside economizer; 3) Integrated waterside economizer with no chilled water reset; and 4) Integrated waterside economizer with chilled water reset. Note: Heat exchanger approach may range from 1º to 6º; for this example, an approach of 4º is used.

General Conditions

- Building type is a hospital
- All hours on, with minimum cooling capacity of 150 tons during heating season
- Location is New York, NY — Weather conditions are design day 92 F dry bulb / 74 F wet bulb
- Cross flow cooling tower with a 6ºF approach — variable speed fans
- Centrifugal chiller with head pressure control down to 55 F entering condenser water flow
- Primary / secondary with variable flow secondary chilled water pumps

Possible Energy Strategies

Baseline-No Waterside Economizer

Non-Integrated Waterside Economizer

- No chilled water reset, 44 F leaving chilled water all year round
- Heat exchanger approach is 4ºF

Integrated Waterside Economizer with No Chilled Water Reset

- No chilled water reset, 44 F leaving chilled water all year round
- Heat exchanger approach is 4ºF

Integrated Waterside Economizer with Chilled Water Reset

- Chilled water condition of 44 F, return water of 54 F
- Chilled water reset up to 48 F
- Waterside economizer heat exchanger sized with 4ºF approach

Other energy strategies to consider would include reducing condenser water flow through the chiller's condenser (while maintaining adequate flow for tower protection) to match reduction in chilled water capacity required, using chilled water reset to increase chilled water delta T from 10º to 12º or higher, and increasing leaving air discharge temperatures from the chilled water coils.

Note: When no chilled water reset is used, the integrated economizer would start when the outdoor air wet bulb temperature is 40 F or lower. Integrated waterside economizer operation can start earlier if the chilled water temperature is allowed to rise. If the chilled water temperatures can be reset to 48 F with delta of 10º (58 F return chilled water temperature), waterside economizer operation can start at an ambient wet bulb temperature of 44 F. The next important condition to consider is to keep a 6ºF approach on the cooling tower approach and a 4ºF heat exchanger approach. When chilled water reset is used with the above leaving chilled water conditions of 48 F, while maintaining a 10º delta temperature, the best approach is an integrated waterside economizer.

OVERVIEW OF MODELING TOOLS

As utility incentive programs become increasingly important considerations in equipment investment decisions, the value of modeling tools also increases. Carrier offers several system analysis tools that together provide a clear picture of strategies that can lead to energy savings.

***Chiller System Optimizer**, as described in detail in this article, is a schematic design "screening tool" that helps lay the groundwork for system design, using basic inputs to quickly evaluate overall chiller plant energy strategies.*

***Building System Optimizer** is another schematic design screening tool whose scope extends beyond chiller plants to all HVAC system and equipment types. It provides a quick way to compare energy costs of HVAC design alternatives. Inputs for location, building, HVAC equipment, and utility prices are used to generate a detailed model of the building and its HVAC systems. An 8760 hour-by-hour load simulation analysis results in accurate comparisons of alternatives.*

*The **Hourly Analysis Program (HAP)** offers features that support peak load calculation, system sizing, and energy analysis. This software is primarily intended for use in the detailed design phase of projects, but also supports schematic design evaluation of systems. Detailed schedules and reports enable the user to fine-tune energy savings.*

Step 1 – Define the weather climate and schedule.

The Weather Properties screen is shown in Figure 2.

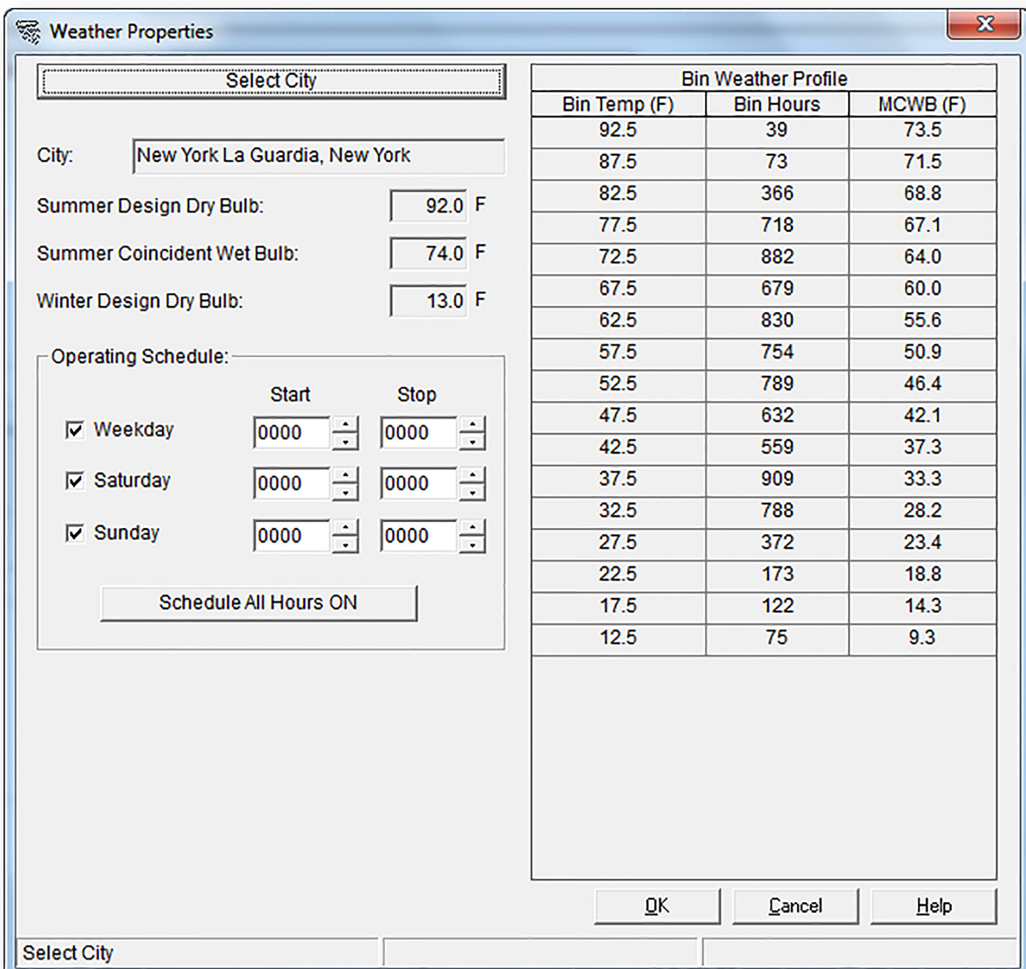
Schedule

Determining the schedule of the building environment will provide the amount of hours of system occupied time. As described above, for this example the building type is a hospital with no unoccupied times.

Weather

It is important to define the weather conditions in order to calculate the length of time for which it will be possible to use free cooling from the cooling tower.

Figure 2 – Weather Properties Screen



Step 2 – Create the building load profile and define airside economizer usage

For this example, we will assume that there is no airside economizer. Refer to Figure 3.

Load Profile

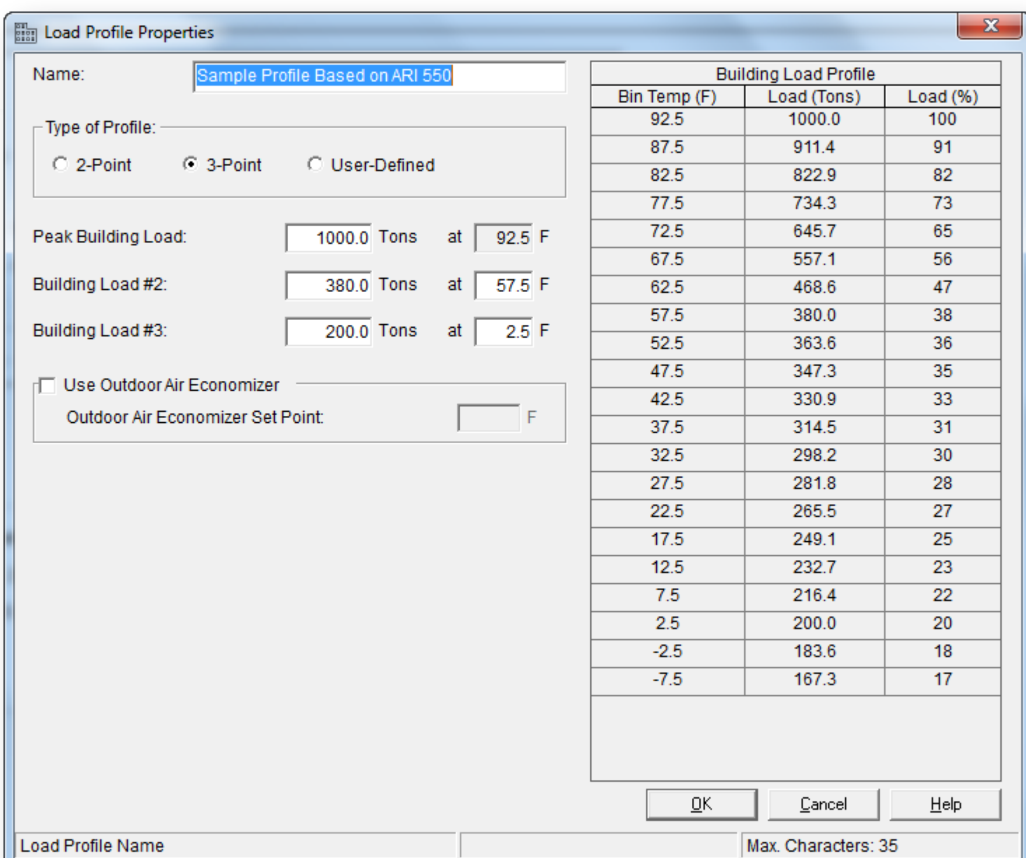
Determining the load profile will show the minimum cooling capacity required for a range of temperatures for pre-cooling to 100% waterside economizer. This will only partially define the energy savings. The other two factors are:

- The schedule for run hours (defined in Step 1)
- The implementation of chilled water reset, which will be determined later

Airside Economizer

Free cooling can be accomplished by two methods: waterside economizer or airside economizer. It is important to clearly define the extent to which each will be used in order to properly choose the most effective free cooling strategy. If the building has a forced air system that can use an airside economizer, you will be able to increase free cooling capabilities above those of the waterside economizer due to dry bulb and reduction of approach on the waterside economizer. It is also possible that the airside economizer does not provide cooling for all required spaces/zones.

Figure 3 – Load Profile Properties Screen



Building Load Profile		
Bin Temp (F)	Load (Tons)	Load (%)
92.5	1000.0	100
87.5	911.4	91
82.5	822.9	82
77.5	734.3	73
72.5	645.7	65
67.5	557.1	56
62.5	468.6	47
57.5	380.0	38
52.5	363.6	36
47.5	347.3	35
42.5	330.9	33
37.5	314.5	31
32.5	298.2	30
27.5	281.8	28
22.5	265.5	27
17.5	249.1	25
12.5	232.7	23
7.5	216.4	22
2.5	200.0	20
-2.5	183.6	18
-7.5	167.3	17

Step 3 – Define chiller efficiency matrix: condenser water-lift vs load profile

Chiller Efficiency Matrix

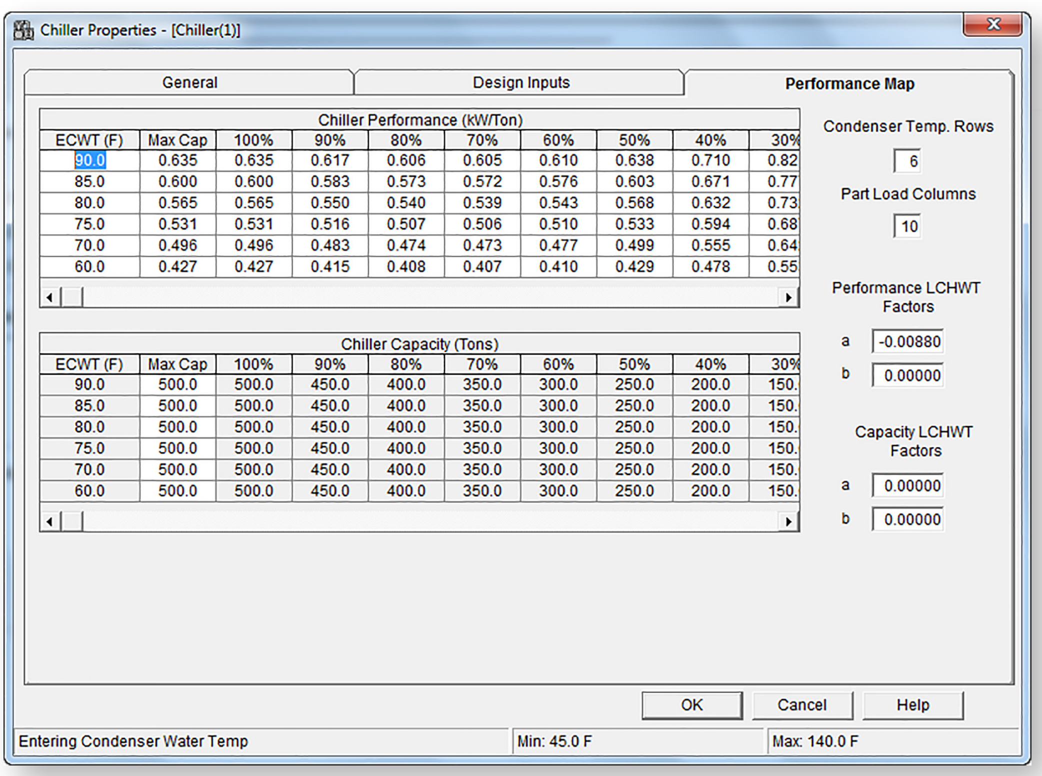
The matrix shown in Figure 4 is important data for every chiller in the facility. This matrix provides the ability to see the changes in kW/ton based on strategies of part loading to reduction in entering condenser water temperatures. This is particularly important when trying to decide the payback on the pre-cooling effect from the integrated waterside economizer.

NOTE: Free cooling, by definition, is the reduction of mechanical cooling run hours from part loading to off, while using ambient conditions.

Step 4 – Determine heat of rejection selection parameters to emphasize waterside economizer operation and efficiencies

To maximize the benefit of a waterside economizer, the heat of rejection must be sized to allow as many free cooling hours as possible. As discussed above, it is important to correctly define the wet bulb temperature for the building location, the range, and the approach. All three of these factors contribute a particular energy percentage to waterside economizer effectiveness.

Figure 4 – Chiller Properties – Entering Condenser Water Temperature Screen



Chiller Performance (kW/Ton)

ECWT (F)	Max Cap	100%	90%	80%	70%	60%	50%	40%	30%
90.0	0.635	0.635	0.617	0.606	0.605	0.610	0.638	0.710	0.82
85.0	0.600	0.600	0.583	0.573	0.572	0.576	0.603	0.671	0.77
80.0	0.565	0.565	0.550	0.540	0.539	0.543	0.568	0.632	0.73
75.0	0.531	0.531	0.516	0.507	0.506	0.510	0.533	0.594	0.68
70.0	0.496	0.496	0.483	0.474	0.473	0.477	0.499	0.555	0.64
60.0	0.427	0.427	0.415	0.408	0.407	0.410	0.429	0.478	0.55

Chiller Capacity (Tons)

ECWT (F)	Max Cap	100%	90%	80%	70%	60%	50%	40%	30%
90.0	500.0	500.0	450.0	400.0	350.0	300.0	250.0	200.0	150.
85.0	500.0	500.0	450.0	400.0	350.0	300.0	250.0	200.0	150.
80.0	500.0	500.0	450.0	400.0	350.0	300.0	250.0	200.0	150.
75.0	500.0	500.0	450.0	400.0	350.0	300.0	250.0	200.0	150.
70.0	500.0	500.0	450.0	400.0	350.0	300.0	250.0	200.0	150.
60.0	500.0	500.0	450.0	400.0	350.0	300.0	250.0	200.0	150.

Cooling Tower Parameters

Refer to Figure 5.

Wet bulb temperature is the first step in correctly sizing a cooling tower. During the modeling process, using a higher wet bulb temperature for design day will greatly decrease the ability of the cooling tower fan to turn down most efficiently in order to achieve required lower condenser water temperatures and water flow. If the cooling tower is oversized, the kWh will increase during pre-cooling to 100% waterside economizer operation and will sharply offset the pre-cooling to 100% economizer operation kWh story.

Approach will be the defining factor in correctly sizing the cooling tower and will determine how many hours of “free cooling” will be captured, from pre-cooling to 100% economizer operation. To maximize the cooling towers approach, the delta T between the condenser water and wet bulb temperatures should be within 5 to 6 degrees.

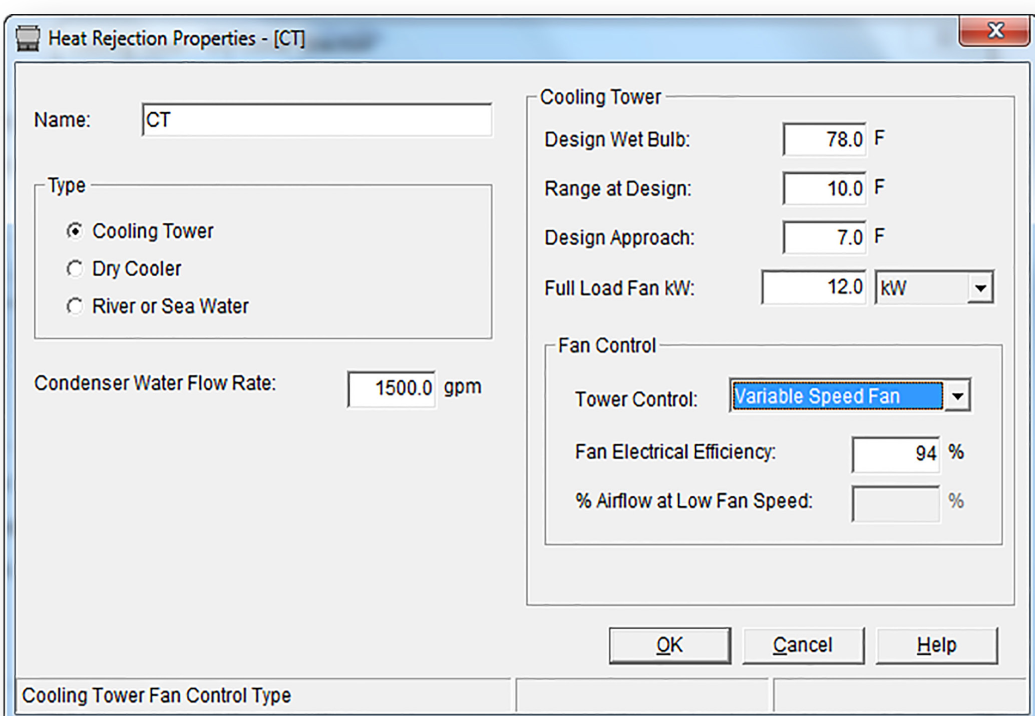
Range – Maintaining a 10º delta from the leaving to return condenser water temperatures will directly affect the lift and therefore increase the part lift benefits of condenser water reset strategies.

Note: a small approach will also allow for the chiller’s compressor to be resized to a smaller size to directly increase the part lifting effect on chiller efficiency.

Fan Sizing and Controls are two critical balancing points to be considered in a waterside economizer application. During the modeling process, if the cooling tower fan is oversized based on improper approach to range, the fan curve for reduction in speed (rpms) might show a kWh spike, thereby reducing the energy saving to be obtained from pre-cooling to 100% waterside economizer operating times. Under-sizing the fan will cause a limiting turndown of condenser water temperature, potentially eliminating waterside economizer kWh reduction.

In addition to incorrect fan sizing for a cooling tower being used in a waterside economizer application, a potential problem is the limiting of controls for variable fan modulation. Again, this will severely hinder the waterside economizer plant kWh effects, and possibly eliminate the energy strategy benefits altogether. Note: During the modeling process, in either new or renovated chiller plants, the diversity of the percentage of waterside economizer cooling load to design day capacity might suggest different sizing of towers; if the pre-cooling to 100% free cooling capacity is large enough, corresponding to a better energy performance at a smaller horsepower fan, it would be beneficial for a cooling tower to be sized using waterside economizer parameters.

Figure 5 – Heat Rejection Properties – Cooling Tower Screen



Step 5 – Chiller Plant System Integration – Defining the Waterside Economizer Type and Approach

Refer to Figures 6 and 7.

Understanding all of the system components and sizing them to provide the best performance in a waterside economizer application is only the beginning. The integration of all chiller plant equipment described above is necessary in order to achieve the greatest energy savings, which is why each component sizing factor was based on interaction with the other components, and not based on standalone application.

Chilled Water Configuration

Constructing a chiller plant model starts with identifying how many chillers will be operating in the system. Defining the quantity of chillers also establishes the pumping and piping arrangements, which are critical pieces of information required to determine piping recommendations for the waterside economizer heat exchanger.

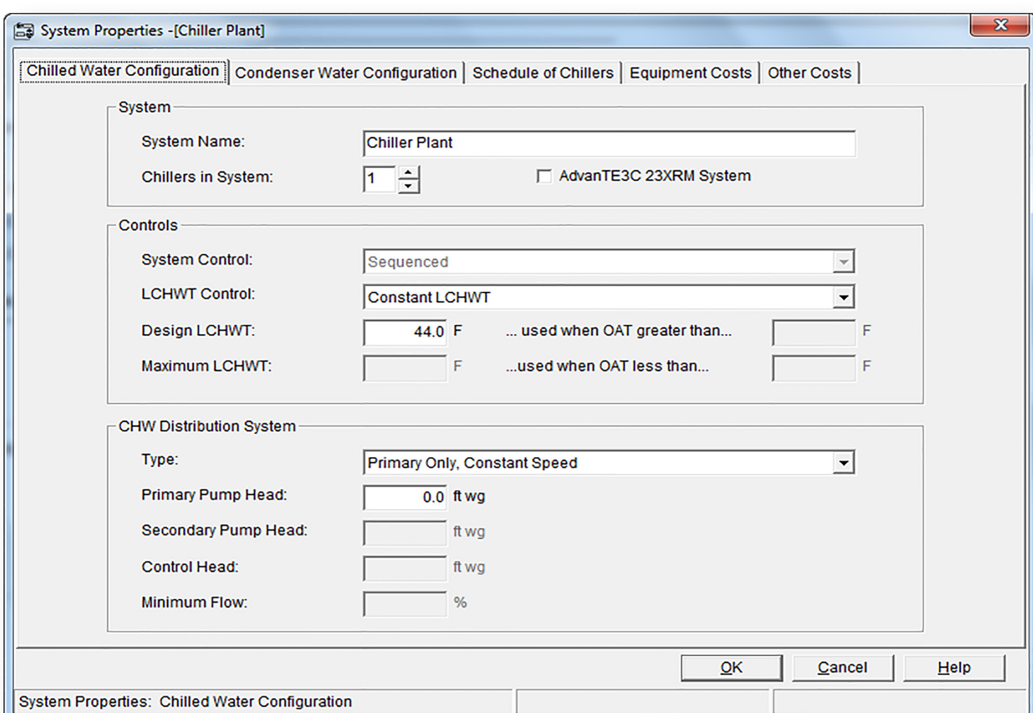
Determining how the chillers will interact within a chilled water system is important, not only in relation to sizing of the chillers, but also with respect to one of the most important energy strategies beyond waterside economizer: chilled water reset. When there are multiple chillers in a chilled water plant, the primary chiller will be the one that has the best potential for part loading. That part loading performance will also be based on chilled water reset parameters. If chilled water reset application can be implemented, it is here where the increase in the leaving chilled water temperature can show effects based on the corresponding ambient dry bulb conditions.

The chilled water pumping system (CHW Distribution System) describes how water moves from the chiller plant through to the required equipment coils and back to be cooled. In the case of waterside economizer, whether integrated or non-integrated, the heat exchanger placement into a chilled water distribution system depends on which type of system is being used. The three main hydronic systems are: variable primary; primary with variable secondary; and constant primary.

A brief breakdown of each system is given below.

Variable Primary is a commonly implemented distribution system for chilled water in which one set of pumps is used for the entire system. In this system, the minimum flow (gpm) of the chiller that is necessary for freeze protection must be equal to or less than the minimum water flow of the system. This is accomplished either by using two-way valves with a

Figure 6 – System Properties – Chilled Water Configuration Screen



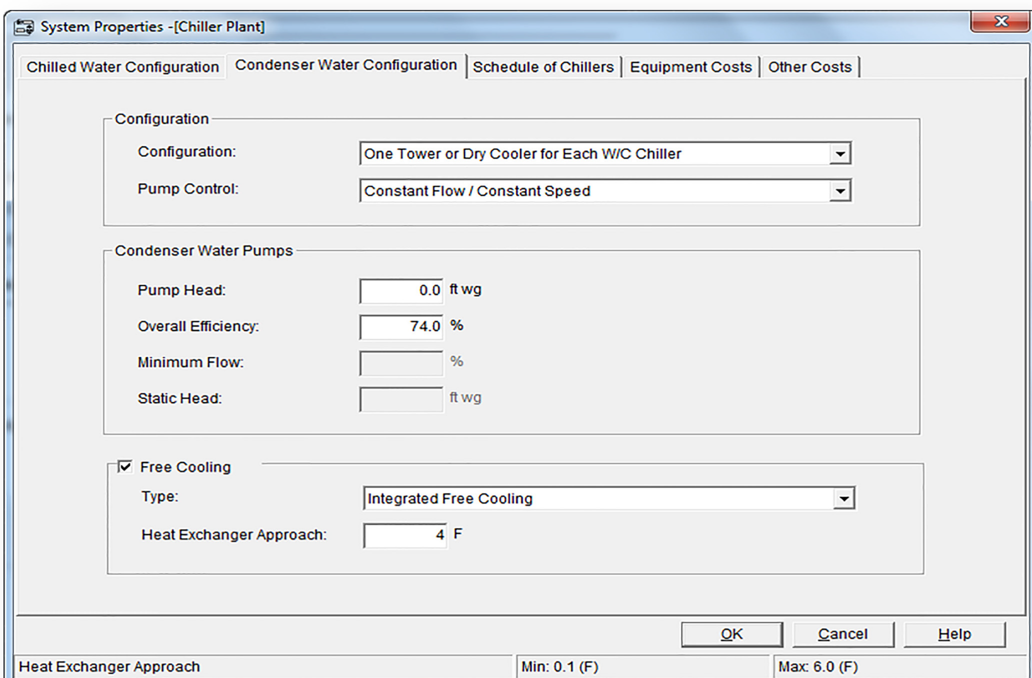
bypass to control minimum flow or using a combination of three-way valve(s) to bypass the lowest flow.

Primary with a Variable Secondary is a distribution system separated by two pumping loops, one for the chiller plant and the other for the building system, with each loop connected through a decoupler. Each of the loops is served by its own pump.

Constant Primary provides for the pump to be locked in at one flow rate throughout all loading calculations. In order to ensure that water flows without "dead heading" the pump, each piece of equipment is piped with a three-way control valve.

The way in which the cooling towers are matched to chiller quantity is another variable that will influence the type of waterside economizer implemented and determine the best way to efficiently operate condenser water reset. The chiller sequencing used for shoulder to winter cooling load will be a driving force in determining tower setup.

Figure 7 – System Properties – Heat Exchanger Approach Screen



Waterside Economizer Types:

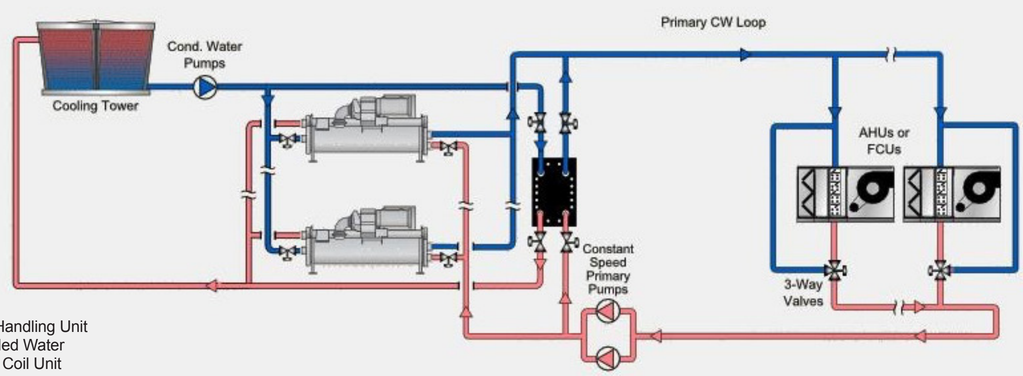
Non-integrated waterside economizer is an “on-off” strategy whereby the mechanical cooling to the leaving chilled water temperature can be met from the cooling tower condenser water. The heat exchanger, operating in parallel with the other chiller, will provide the required cooling capacity in place of a chiller. When evaluating the condenser water temperature delta between the minimum required to maintain chiller operation and what is need to achieve 100% waterside economizer operation, the following questions must be considered:

- What is the time required to lower the condenser water temperature delta T in order for the switch to 100% waterside economizer operation to occur?
- For the greatest benefit, consider how to supplement the cooling time loss between the switch from mechanical cooling to free cooling.

Integrated waterside economizer optimizes the approach of the cooling tower to achieve pre-cooling operation. The method by which this is accomplished depends on whether or not chilled water reset can be implemented. If there is no chilled water reset strategy, a smaller approach of 4º is recommended to ensure the most optimal pre-cooling hours. If chilled water reset is in place, start with an approach of 4º and evaluate the difference as the approach is increased by one degree vs chilled water return temperature to determine the most economical upfront cost.

Figures 8 and 9 show examples of piping diagrams showing the implementation of non-integrated and integrated waterside economizer.

Figure 8 – Non-Integrated Waterside Economizer

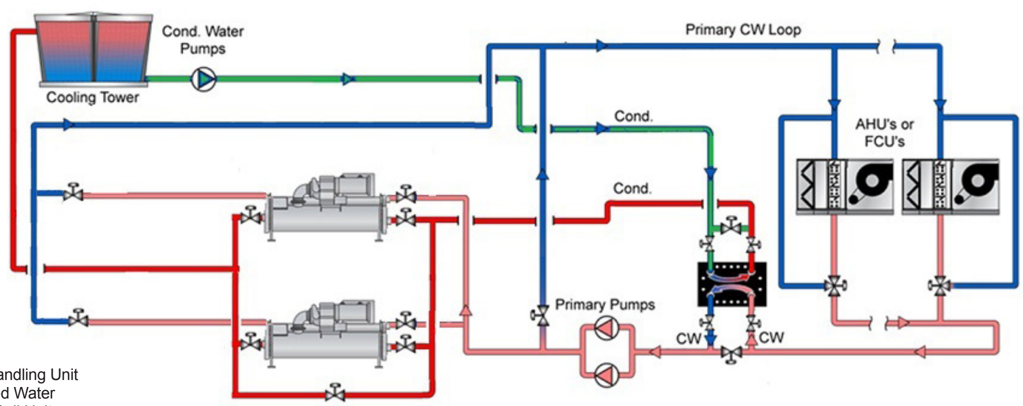


LEGEND:
AHU - Air Handling Unit
CW - Chilled Water
FCU - Fan Coil Unit

Non-Integrated Waterside Economizer in a Water-Cooled Chilled Water Plant with Three-Way Control Valve Piping System and Constant Speed Arrangement

NOTE: Drawing illustrates typical arrangement; not all required bypass or control valves are shown, some field programming may be required.

Figure 9 – Integrated Waterside Economizer



LEGEND:
AHU - Air Handling Unit
CW - Chilled Water
FCU - Fan Coil Unit

Integrated Waterside Economizer in a Water-Cooled Chilled Water Plant with Three-Way Control Valve Piping System and Constant Speed Pumping Arrangement

NOTE: Drawing illustrates typical arrangement; not all required bypass or control valves are shown, some field programming may be required.

Results from Chiller System Optimizer

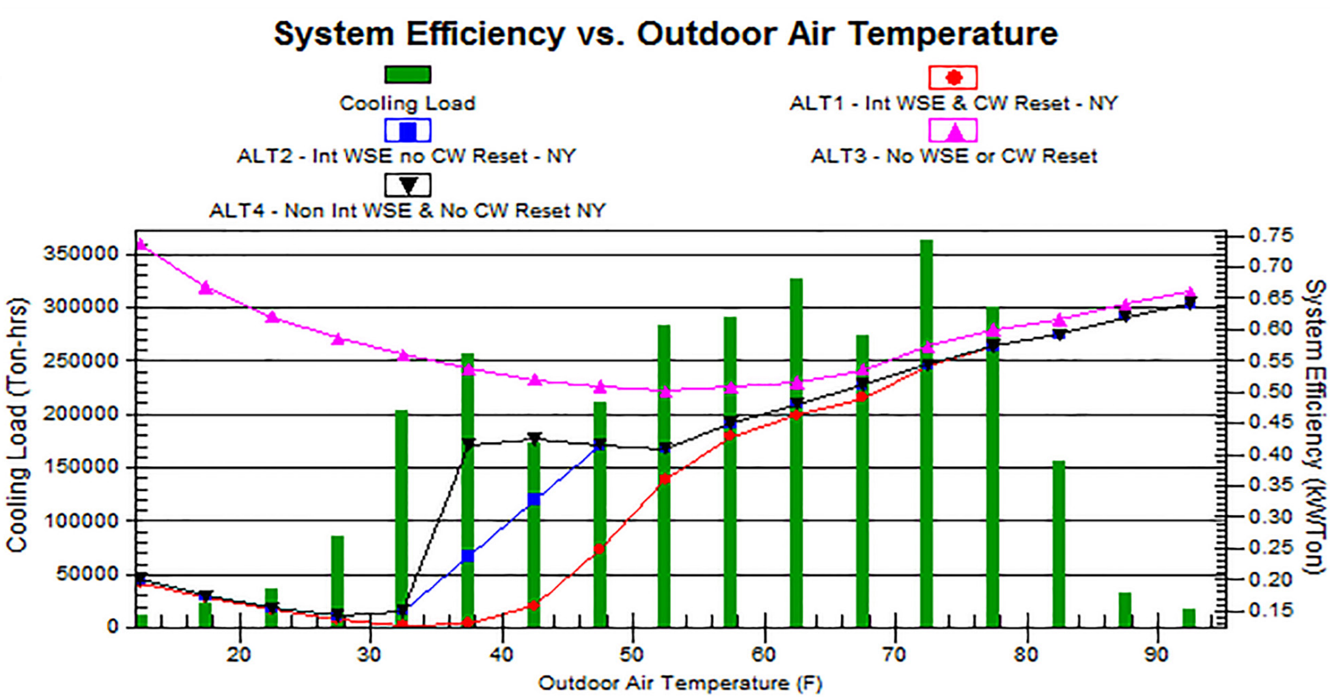
Here is the breakdown of the results from modeling the effects of waterside economizer through Chiller System Optimizer.

System Efficiency vs Outdoor Air Temperature Graph (Figure 10)

This graph shows how the electrical power usage of the chiller plant changes with the implementation of the energy strategies described earlier.

- There is only a subtle difference between the baseline (ALT3) and the use of non-integrated waterside economizer (ALT4) based on temperatures above 55 F. The difference starts to widen beyond until 100% WSE operation is achieved at 38 F.
- Above 55 F, waterside economizer without chilled water reset shows no difference whether it is integrated (ALT2) or non-integrated (ALT4).
- Two effects of chilled water reset (ALT1) are emphasized in the chart: One shows the effects of pre-cooling starting as early as 72 F outside air. The second shows the significant difference in kW/ton from 58 F to 30 F.
- The baseline of no waterside economizer (ALT3) compared to non-integrated waterside economizer (ALT4) show the energy saved with free cooling. The increase in energy saved by using the integrated waterside economizer combined with the additional energy strategy of chilled water reset (ALT1) shows the power saved in pre-cooling hours of a chilled water system.

Figure 10 – Comparison of Waterside Economizer Energy Strategies



LEGEND:
ALT1 – Integrated Waterside Economizer and Chilled Water Reset
ATL2 – Integrated Waterside Economizer, no Chilled Water Reset
ATL3 – No Waterside Economizer or Chilled Water Reset
ATL4 – Non-integrated Waterside Economizer, no Chilled Water Reset
NY – New York

Annual System Efficiency (kW/ton), better known as System Part Loading Value (Figure 11)

The chart in Figure 11 shows the increase in efficiency of systems using a waterside economizer.

- When cooling is required year-round, the use of ambient conditions results in an overall system efficiency benefit of a 30% reduction in kW/ton compared to mechanical cooling (from 0.547 for ALT3 to .0383 for ALT1).
- The reduction from 0.426 for ALT2 to 0.383 for ALT1 shows that 10% of the overall energy reduction can be attributed to the addition of chilled water reset to the integrated waterside economizer strategy.
- Evaluating energy strategies, whether mutually independent or combined can provide a significant decrease in electrical consumption as well as demand.

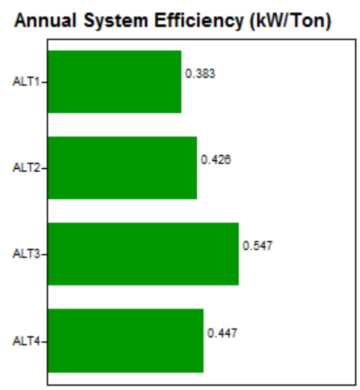
Cost and Energy Use Details

The table below clearly shows the overall increase in system efficiency, seen in the comparison of the baseline (no waterside economizer or chilled water reset) to the results shown by utilization of the waterside economizer energy strategies.

Heat of rejection does increase with waterside economizer application due to fan performance at lower leaving condenser water temperatures. This factor shows the importance of fan energy and the trade-offs of energy strategies.

Note: To reduce the effect of the increase in kWh of the cooling tower as a result of waterside economizer conditions, consider evaluating fan operating conditions.

Figure 11 – Evaluation of Waterside Economizer Energy Strategies



LEGEND:
ALT1 – Integrated Waterside Economizer and Chilled Water Reset
ATL2 – Integrated Waterside Economizer, no Chilled Water Reset
ATL3 – No Waterside Economizer or Chilled Water Reset
ATL4 – Non-integrated Waterside Economizer, no Chilled Water Reset

*Figure 12 – Annual Energy Cost and Energy Use Details**

1. Executive Summary

Economic Criteria	Best System Design for Each Criteria	Value
Lowest Annual Energy Cost	(A) Int WSE & CW Reset - NY	$116,450

2. Cost and Energy Use Details

	(A) Int WSE & CW Reset - NY	(B) Int WSE no CW Reset - NY	(C) No WSE or CW Reset	(D) Non Int WSE & No CW Reset NY
Annual Energy Cost Details				
Chiller Electric Cost ($)	$74,084	$84,696	$127,084	$90,986
Chiller Fuel Cost ($)	$0	$0	$0	$0
Heat Rejection Fans ($)	$17,929	$20,210	$9,602	$20,208
Chilled Water Pump ($)	$16,080	$16,080	$16,080	$16,080
Condenser Water Pump ($)	$8,357	$8,529	$13,539	$8,529
Total Energy Cost ($)	$116,450	$129,515	$166,305	$135,803
Annual Energy Use Details				
Chillers (kWh/yr)	740,836	846,958	1,270,838	909,860
Heat Rejection Fans (kWh/yr)	179,287	202,103	96,020	202,077
Chiller Water Pumps (kWh/yr)	160,801	160,801	160,801	160,801
Condenser Water Pumps (kWh/yr)	83,575	85,291	135,394	85,291
Total Electric (kWh/yr)	1,164,498	1,295,154	1,663,053	1,358,029
Natural Gas Use (THM)	0	0	0	0
Steam Use (MMBTU)	0	0	0	0

LEGEND:
ALT1 – Integrated Waterside Economizer and Chilled Water Reset
ATL2 – Integrated Waterside Economizer, no Chilled Water Reset
ATL3 – No Waterside Economizer or Chilled Water Reset
ATL4 – Non-integrated Waterside Economizer, no Chilled Water Reset
NY – New York

*For modeling purposes, data is based on $ 0.12 kWh. Actual savings will vary depending on the rate at the time of use.

Summary

As described in the opening paragraph of this article, use of a waterside economizer may provide reductions in consumption (kWh) as part of an energy strategy for chilled water plant operation. Even when not required by code, application of a waterside economizer should be considered for its contribution to energy savings. The analysis provided in this article shows that the different types of waterside economizer, i.e. non-integrated or integrated, will increase or decrease the significance of the electrical savings based on the weather and building environment being served. Particularly, an integrated waterside economizer can be paired with additional energy strategies, such as chilled water reset, in order to enhance the pre-cooling to 100% WSE operation.

These applied energy strategies were solidified through the featured modeling tool, Chiller System Optimizer (CSO). The ability of the CSO to quantify each of these strategies brought to light the possible benefits and drawbacks of implementing each strategy. The potential to optimize incentives available from the utility companies was demonstrated by the kWh reductions shown.

In any system, the performance of each piece of equipment is dependent on the overall chiller plant efficiency. This analysis of the implementation of waterside economizer shows the critical importance of the breakdown of the chiller plant components as well as the economic impact of optimizing an application for local weather conditions.