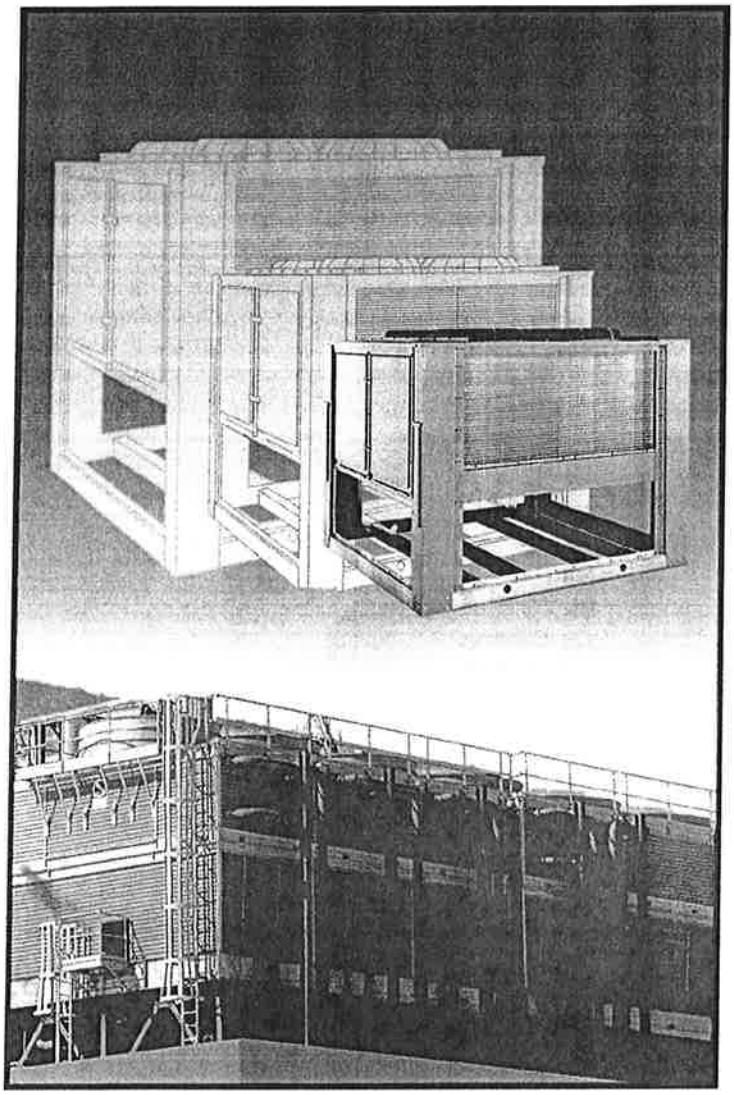
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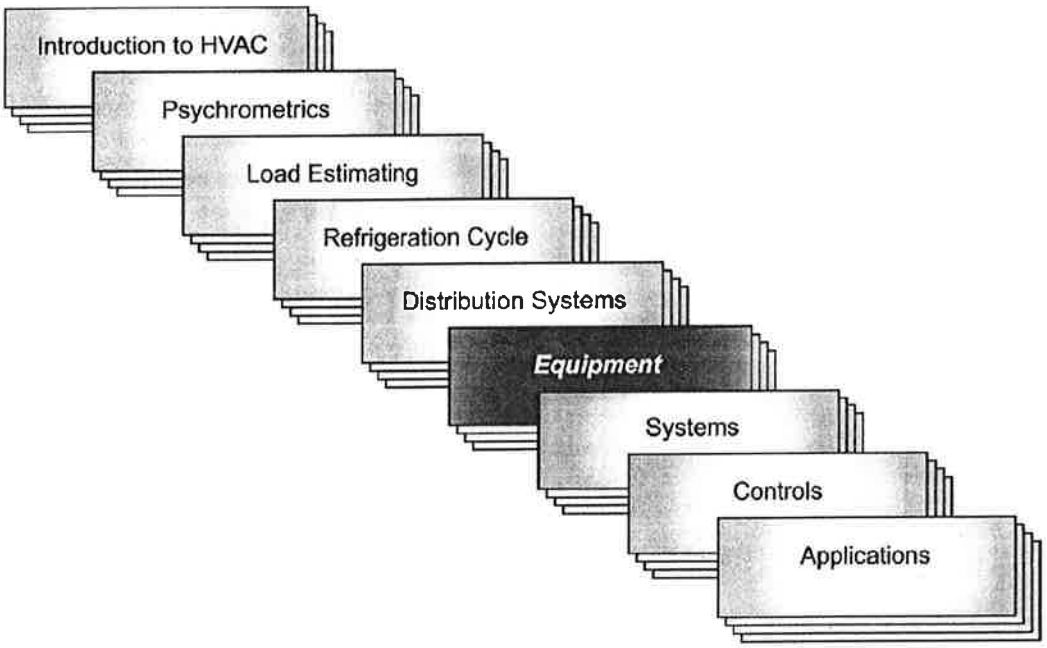
COMMERCIAL
HVAC EQUIPMENT

Condensers and Cooling Towers

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



This TDP module discusses the most common heat rejection equipment: condensers and cooling towers. Heat rejection is a process that is an integral part of the air conditioning cycle. The heat is rejected to the environment using air or water as the medium. In order to properly apply system concepts to a design, HVAC designers must be aware of the different heat rejection methods. Also presented is the concept of total heat of rejection, it's derivation, and how it applies to the process of air conditioning, as well as the controls that are used to regulate each type of heat rejection unit.

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The information in this manual is offered as a general guide for the use of industry and consulting engineers in designing systems. Judgment is required for application of this information to specific installations and design applications. Carrier is not responsible for any uses made of this information and assumes no responsibility for the performance or desirability of any resulting system design.

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Introduction

Condensers and cooling towers are the most common kinds of heat rejection equipment. There are three types of condensers: water-cooled, air-cooled, and evaporative. Water-cooled and air-cooled condensers use a sensible-only cooling process to reject heat. Evaporative condensers use both sensible and latent heat principles to reject heat.

Cooling towers are similar to evaporative condensers because they also utilize latent cooling through the process of evaporation. We will discuss three kinds of cooling towers in this TDP: natural, mechanical, and closed-circuit.

We will discuss total heat of rejection, its derivation, and how it applies to the process of air conditioning. Applications for condensers and cooling towers, as well as the controls that may be used to maintain proper refrigerant and water temperatures will also be covered.

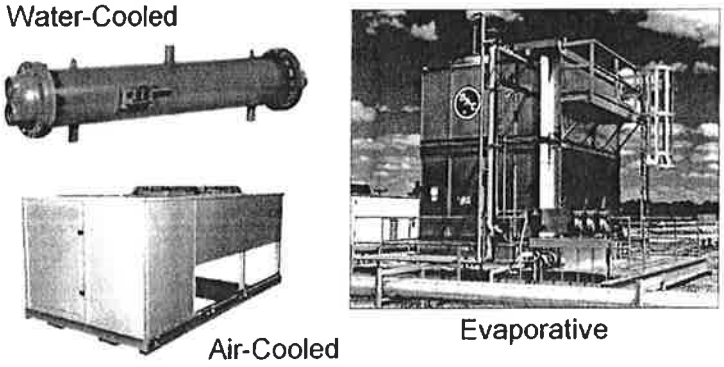


Figure 1

Three Types of Condensers
Photos: Water-cooled: Courtesy of Standard Refrigeration; Evaporative: Courtesy of Baltimore Aircoil Company

Cooling towers are heat rejecters. They do not condense refrigerant so they are not considered condensers.

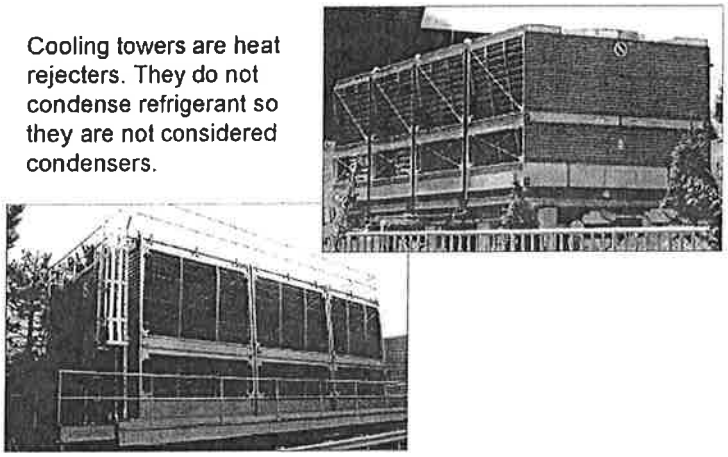


Figure 2

Cooling Towers
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Condenser Total Heat of Rejection

The heat to be rejected by the condenser in condensing the refrigerant is equal to the sum of the refrigeration effect (RE) of the evaporator plus the heat equivalent of the work of the compression.

RE + Compressor work = THR (Total Heat Rejection)

Heat rejection in the condenser may be illustrated on the P-H (pressure-enthalpy) diagram. A pressure-enthalpy diagram is used because condensing takes place at constant pressure, or nearly constant pressure when blended refrigerants are used, (line F-G). This diagram may also be used to show the pressure rise of the condensing medium as it absorbs heat from the refrigerant (curved line).

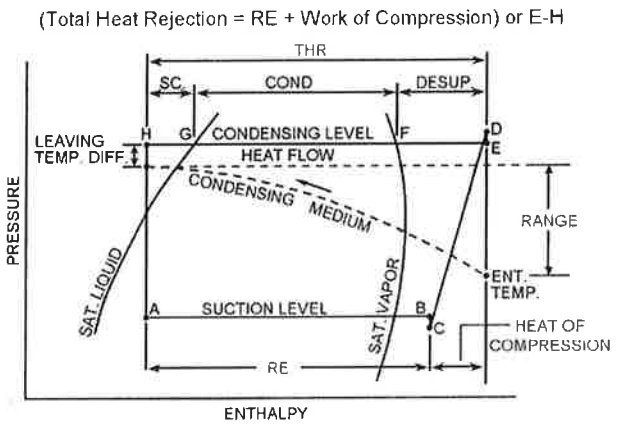


Figure 3

Condenser Total Heat of Rejection (shown on p-h diagram)

The THR of the condenser is defined by line E-H, which is the sum of the refrigeration effect (line A-B) and the heat of compression (line C-D). As the ratio between compressor discharge and suction pressures increase, the refrigeration effect decreases and the heat of compression increases. This is because the work done by the compressor has increased.

These are the equations to calculate the THR in units of Btuh:

In cases where the brake horsepower (bhp) of the compressor(s) is known:

$$THR = RE + (bhp * 2545)$$

2545 is a constant; it is the Btuh equivalent of one bhp. Brake horsepower is the application rating for the compressor.

In cases where the compressor kW is known:

$$THR = RE + (kW * 3414)$$

3414 Btuh is equivalent to one kW.

If you know the compressor bhp or kW:

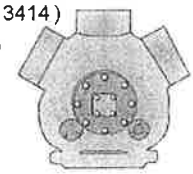
1. Total Heat Rejection = RE + (bhp * 2545)

   or

2. Total Heat Rejection = RE + (kW * 3414)

   2545 is the Btuh equivalent of one bhp

   3414 is the Btuh equivalent of one kW



If you don't know the compressor energy consumption:

3. Total Heat Rejection = RE * (Heat Rejection Factor)

What is the heat rejection factor?

Figure 4

Total Heat of Rejection Formulas

Kilowatts

(1000 watts) is the term used to describe compressor power. The kW unit is used more often than brake horsepower because most manufacturers' product ratings are now expressed in kW.

THR reflects the work done by the compressor as well as the evaporator. THR can be expressed in Btuh tons, or MBtuh. One MBtuh is equal to 1000 Btuh. Where refrigerant is used to cool the motor, such as in a hermetic-type compressor design, added heat (the heat from the motor losses) also becomes part of the THR in the condenser.

Heat Rejection Factors

Heat rejection factor is a multiplier applied to the cooling capacity to find the condenser total heat of rejection.

When a chiller

is said to have a 100-ton capacity we are referring to the refrigeration effect. The condenser, however, should be represented in terms of THR tons. In the case of an air-cooled chiller, for example, the THR would be approximately 1.25 * 100 = 125 tons.

The amount of heat added to the cooling capacity to arrive at the THR for any given application is a function of the compressor efficiency and the condenser cooling method (air, water, or evaporative) cooled. As an example, compressors used in HVAC equipment typically have a full load heat rejection factor in the range of 1.15 to 1.25.

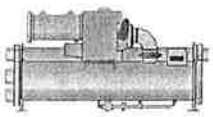
Water-cooled screw and centrifugal compressors are very efficient, so they tend to have heat rejection factors between 1.15 and 1.18. Compressors used in air-cooled applications typically have heat rejection factors closer to 1.25. This efficiency is a function of the saturated condensing temperature, which is lower for water-cooled chiller compressors.

Using a value of 1.17 as an example for a water-cooled chiller, for every ton (12,000 Btuh) refrigeration effect, the load on the water-cooled condenser would be:

12,000 * 1.17 = 14,040 Btuh heat rejection for each ton of cooling capacity

A heat rejection factor of 1.25 results in 15,000 Btuh heat rejection per ton of cooling. (12,000 * 1.25 = 15,000). Consequently, 15,000 Btuh per cooling ton was used for many years as representative of all chillers. For modern water-cooled chillers, however, this value is no longer accurate due to efficiency improvements.

A multiplier that is used to quickly find the condenser total heat of rejection



Typical Water-Cooled Condenser Applications = 1.15 to 1.18 * Cooling Tons

Typical Air-Cooled Condenser Applications = 1.25 * Cooling Tons

Example:

100-ton water-cooled chiller has a condenser total heat of rejection of

1.17 * 100 tons = 117 tons

Figure 5

Typical Heat Rejection Factors

Condensers

Condensers remove heat from the refrigeration system. Like the evaporator, the condenser is a heat transfer device. Heat from the high-temperature, high-pressure refrigerant vapor is transferred to a heat-absorbing medium (air or water) that passes over or through the condenser. Condensers do three things: desuperheat the refrigerant gas, condense the hot refrigerant gas into a liquid, and subcool the liquid refrigerant.

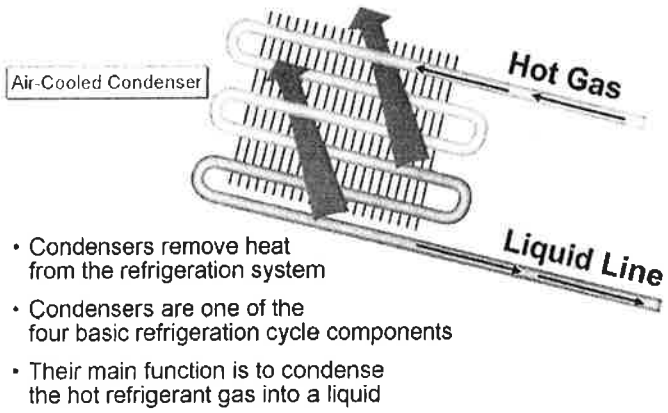


Figure 6

Condenser Definition

Condensers are one of the four basic refrigeration components. The other three are the evaporator, compressor, and metering device. The metering device shown in Figure 7 is a thermostatic expansion valve.

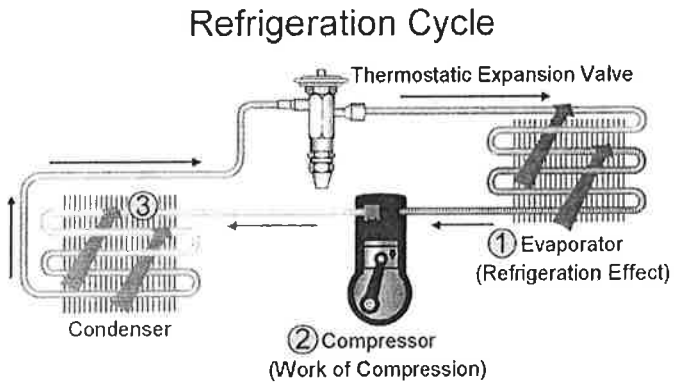


Figure 7

Condensers reject the heat from the evaporator and the compressor.

Water-Cooled Condensers

Water-cooled condensers employ water as the condensing medium. Most water-cooled condenser systems recirculate the water through the condenser then out to a cooling tower, which then rejects the heat to the atmosphere.

Once-Thru versus Recirculating

Systems employing water-cooled condensers may be classified as once-thru or "waste" water systems or recirculating water systems.

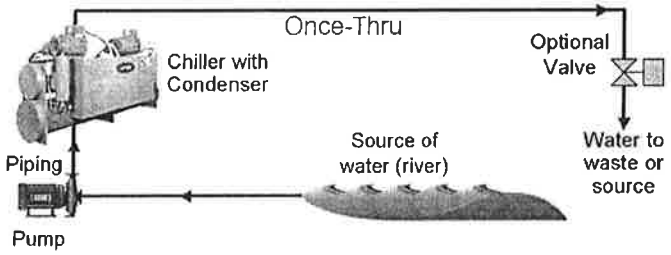
In the past, there were many water-cooled condenser applications that utilized water supplied from city water mains or from natural sources such as rivers, lakes, or wells. These did not recirculate the water. The condenser water in these systems passed through the condenser only once, and was wasted to a sewer or returned to the source.

Once-thru systems

must be evaluated for environmental acceptability before use. Water consumption is large and the rejection of the heat to a well or lake is thermal pollution.

This resulted in unnecessary water costs and thermal pollution. Today, this application is not used nearly as often as a recirculating system.

With the ever increasing quantity of installations, the demands on water distribution and treatment systems became unreasonable and virtually all municipalities now have ordinances controlling the use of city water for condensing purposes. These ordinances typically require a water conservation device, such as a cooling tower, so water may be recirculated through the condenser and used repeatedly.



- Much less common due to environmental concerns
- Water is sent to waste or returned back to source
- Large consumption of water
- Source example: river, lake, well

Figure 8

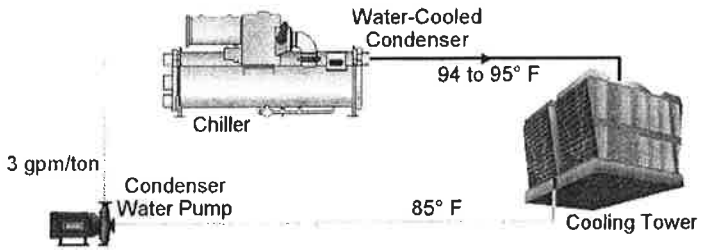
Once-Thru Water-Cooled Condenser System

Water Requirement Calculation for Recirculating Systems

In order to explain some concepts involving recirculating water-cooled condenser systems, we should now discuss some basic information on cooling towers since they are almost always part of the water-cooled condenser system.

A separate section of this TDP is dedicated to cooling towers where they will be covered in detail.

When a water-cooled condenser uses recirculating water from a cooling tower, the temperature of the water leaving the tower on a "design" day is typically 85° F in much of North America. This is because much of North America has a design wb (wet bulb) temperature of 78° F. Cooling towers are often sized for a 7° F approach (difference in leaving tower water and entering wb). A 7° F approach results in an efficient tower selection at a reasonable first cost.



- The water-cooled condenser is typically part of a water-cooled chiller
- A cooling tower rejects the condenser heat to the atmosphere
- Flow rates and temperatures are industry standards for North America
- Piping and pumps circulate water
- Water is reused

Figure 9

Typical Recirculating Water-Cooled Condenser System

If we use 14,040 Btuh as our total heat of rejection (12,000 * 1.17) for a typical water-cooled condenser per one ton (12,000 Btuh) refrigeration effect, we can solve for gpm and it will reflect the gpm per one ton of cooling for a recirculating water-cooled condenser system.

Capacity or load (Btuh) = 500 * gpm * rise

The constant 500 = 60 minutes per hour * 8.33 pounds per gallon of water at 60° F.

In this example, there is a 2.6° F approach. Approach, as it pertains to water-cooled condensers, is the difference between water leaving the condenser and the condensing temperature of the refrigerant. It is not the same approach as described above for cooling towers. This approach is representative of a high quality shell and tube-type condenser as used on larger water-cooled chillers.

• Typical water-cooled condensing temperature	97.0° F
• Typical water leaving the condenser	94.4° F
• Typical difference between water leaving the condenser and condensing temperature	2.6° F
• Typical entering condenser water from tower	85.0° F
• Water rise in the condenser	9.4° F

$$\text{gpm/ton} = \frac{14{,}040 \text{ Btuh}}{9.4 * 8.33 * 60}$$

14,040 (1.17 * 12,000) is the THR for 12,000 Btuh (1 ton) for typical water-cooled chillers

$$\frac{14{,}040}{9.4 * 500}$$

3.0 gpm/ton

Figure 10

Recirculating Water-Cooled Condenser Flow Rate Calculation

Solving for gpm, we arrive at three gpm per ton of cooling for a recirculating (cooling tower) system. This is the ARI (Air Conditioning and Refrigeration Institute) standard gpm for a water-cooled condenser on a chiller.

On once-thru systems, the gpm in circulation is typically less than with recirculating systems. This is because the entering condenser water temperature from the lake or river is lower than 85° F. As an example, with 75° F entering condenser water temperature, the flow rate works out to be 1.45 gpm/ton, but most municipal codes still find this unacceptable water usage.

The 85° F temperature of the water exiting a cooling tower is a function of the entering wet bulb temperature of the air. This "design" wet bulb varies based on local climate. Cities like Houston in humid North American areas may use 86° F or even 87° F as their tower water temperature for condenser selection.

In some Asian cities, due to even higher design wet bulb temperatures, as high as 90° F has been used as the tower water temperature entering the condenser. This is often referred to as ecwt (entering condenser water temperature).

If in doubt as to your local design wet bulb, consult with your local cooling tower supplier. Wet bulb temperatures for various locations are also shown in the Carrier Load Estimating System Design Manual and in the AHSRAE Fundamentals Handbook.

Good Tower Climates

Cities with a lower design wet bulb temperature, such as San Diego, can design their systems with entering condenser water temperatures less than 85°F.

ARI Conditions

The 3.0 gpm/ton just derived is a traditional condenser flow rate and is utilized by ARI as the basis for standardization for water-cooled chillers.

ARI incorporates chiller certification programs, develops standards, and certifies manufacturers' software and chiller products within specified tolerances of performance. Here are the ARI conditions for rating water-cooled equipment:

- 3.0 gpm/ton in the condenser water loop
- 0.00025 fouling factor in condenser
- 0.0001 fouling factor in evaporator
- 85° F ecwt
- 2.4 gpm/ton in the chilled water loop
- 44° F leaving chilled water temperature
- The units for fouling are: $h * ft^2 * {}^\circ F / Btu$

- 3 gpm/ton in condenser
- 0.00025 fouling factor in condenser
- 0.0001 fouling factor in cooler
- 85° F ECWT (Entering Condenser Water Temperature)
- 2.4 gpm/ton in the chilled-water loop (10° F rise)
- 44° F leaving chilled-water temp

Figure 11

ARI Conditions for Water-Cooled Chillers

The ARI fouling factor

of 0.00025 is for a condenser in an open-circuit cooling tower condenser water system; the fouling factor will be less with a closed-circuit fluid cooler.

Water Consumption and Makeup Quantity

Makeup water requirements for a recirculating system can also vary due to geography. However for purposes of making a comparison, we will approximate 1.5% * 3 gpm/ton = .045 gpm/ton of the recirculated flow rate must be made up.

A once-thru water-cooled condenser uses 1.45 gpm/ton, approximately, while a cooling tower, using the evaporative principle, uses only 0.045 gpm/ton. It is apparent from this comparison that a cooling tower reduces water consumption as much as 97% as compared to condensers using water on a once-thru basis.

That is why cooling towers are used in the vast majority of open water-cooled condenser applications.

Once-thru Condenser System 1.450 gpm/ton

Cooling Tower 0.045 gpm/ton*

$$\% \text{ Water Savings} = \frac{1.450 - 0.045}{1.450} * 100 = 96.9\%$$

* Lost by evaporation and other factors



Figure 12

Water Consumption Comparison: Once-thru versus Cooling Tower

Construction and Types of Water-Cooled Condensers

The majority of water-cooled condensers in use today may be classified as:

- Tube-in-tube
- Shell and coil
- Shell and tube
- Brazed-Plate type

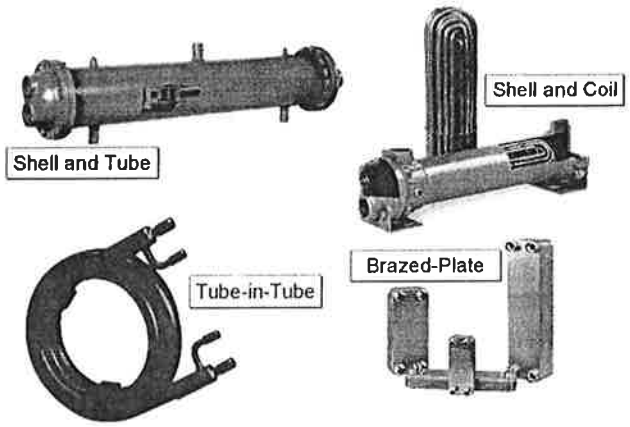


Figure 13

Types of Water-Cooled Condensers
Photos: Shell and Tube: Courtesy of Standard Refrigeration;
Shell and Coil, Tube-in-Tube, and Plate Type: Courtesy of API Heat Transfer

Tube-in-Tube

The tube-in-tube condenser (also called a coaxial condenser when wrapped in a circular fashion) consists of a tube-shaped condenser composed of a series of copper water tubes inside refrigerant tubes. The passages that the refrigerant flows through are small. These condensers tend to be used on packaged products in the smaller tonnage ranges such as water source heat pumps. Tube-in-tube condensers are not mechanically cleanable because of their configuration.

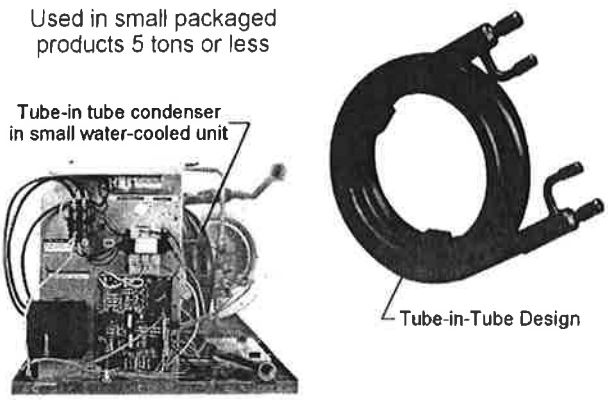


Figure 14

Tube-in-Tube Condenser
Photo: Tube-in-Tube: Courtesy of API Heat Transfer

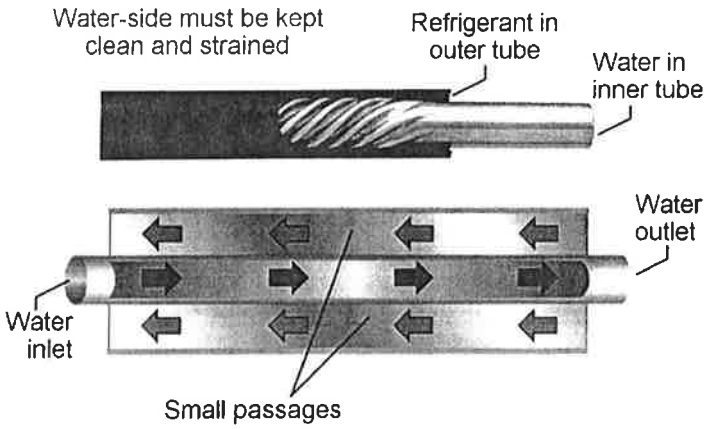


Figure 15

Tube-in-Tube Cross Section

Shell and Coil

The shell and coil condenser consists of a cylindrical steel shell containing one or more coil bundles of finned water tubing. The coil is continuous so intermediate joints are eliminated. Condensers of this type are available for both horizontal or vertical shell arrangement.

The condenser water flows into the tubes, and hot gas from the compressor fills the shell. Condensed refrigerant drops to the bottom of the shell where a liquid sump is provided. This type of condenser is generally limited to systems of about 20 tons or less. Cleaning the tubes is accomplished by chemical means.

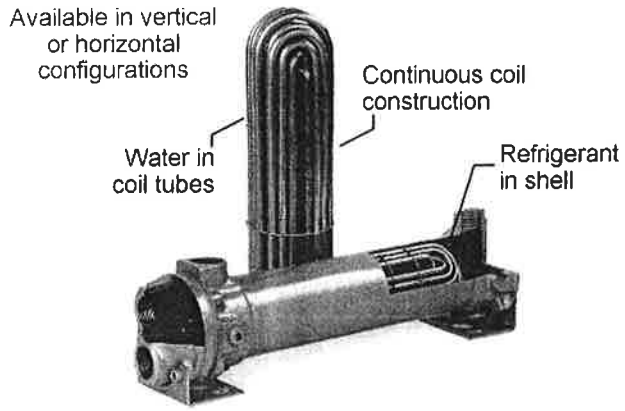


Figure 16

Shell and Coil Condenser
Photo: Courtesy of API Heat Transfer

Shell and Tube

The shell and tube condenser consists of a cylindrical shell containing a number of straight tubes that are supported by tube sheets at each end of the shell, as well as intermediate supports. A waterbox is attached to both end tube sheets. The waterbox is the area at the end of the shell and tube condenser that provides access to the tubes. The field piping connects to the condenser at the waterbox connections. The waterbox may have a bolted removable piece called the waterbox cover or head.

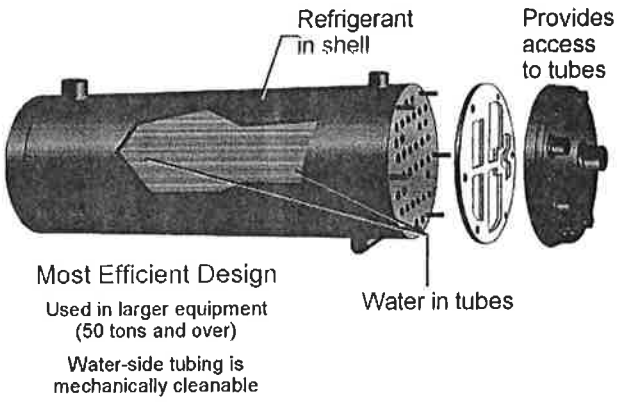
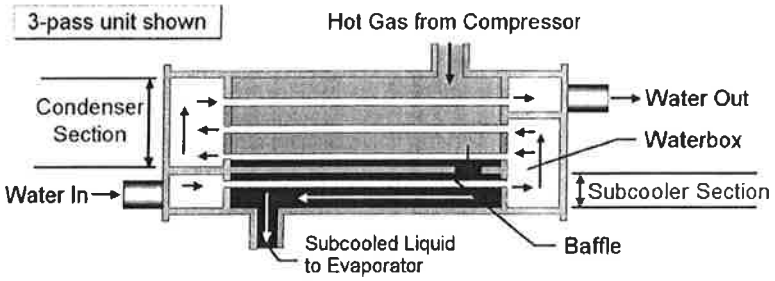


Figure 17

Shell and Tube Condenser
Photo: Courtesy of Standard Refrigeration

Water flows within the tubes and refrigerant vapor fills the space between the shell and the tubes. At the bottom of the shell is a design to collect the condensed refrigerant.

A major advantage of this type of condenser is that the tubes may be cleaned mechanically by removing the waterbox covers or heads on the end. Cleaning by mechanical means reduces fouling and increases efficiency if done regularly.



- Baffle separates bottom of condenser
- Refrigerant gas condenses in top of condenser
- Liquid drains into subcooler section below baffle
- Coldest water enters subcooler and liquid refrigerant is subcooled below saturation

Figure 18

Cross Section of Typical Shell and Tube Condenser

Shell and tube condensers are used on most water chillers above approximately 50 tons. They offer a flexible, maintainable design that allows for tube cleaning and tube replacement on site. These types of condensers are found on the largest centrifugal and screw chillers.

Marine waterbox connections are shown in the figure. These allow for access to the tubes without disturbing the field-installed connection piping. For more information regarding marine waterbox connections, refer to TDP-623, Water-Cooled Chillers.

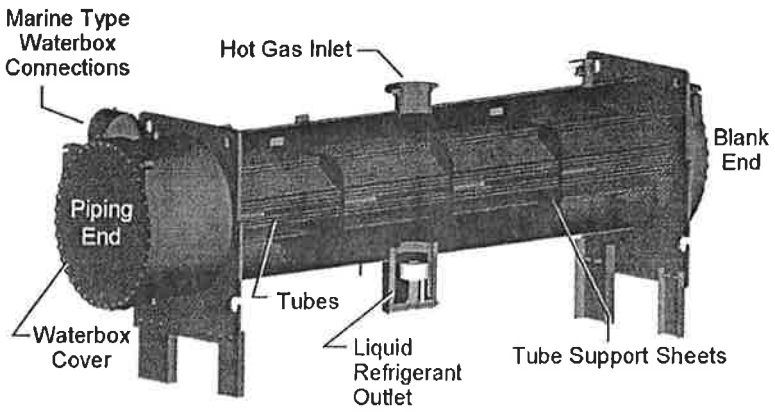
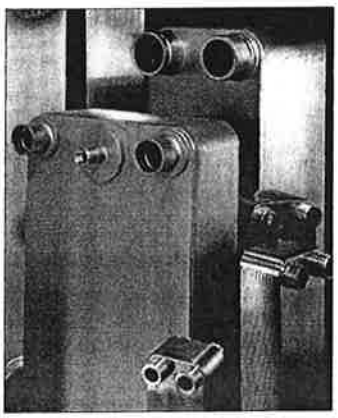


Figure 19

Large Shell and Tube Condenser

Brazed-Plate Heat Exchangers

Brazed-plate heat exchangers are used as condensers on chillers up to approximately 60 tons. Often mechanical cleaning is required in larger sizes so a shell and tube type condenser is used. Brazed-plate condensers consist of a series of plates brazed together with every second plate turned 180 degrees. Some plate heat exchangers are mechanically fastened together instead of brazed.



- Smaller capacity design (up to approximately 60 tons)
- Good efficiency for the cost
- Not mechanically cleanable
- Require clean, strained waterflow
- Also used as evaporators

Figure 20

Brazed-Plate Heat Exchanger Condensers
Photo: Courtesy of API Heat Transfer

Brazed-plate condensers require clean waterflow or else they can be damaged or plugged. They generally require very fine strainers and do not work well if the condenser water system is very dirty. Since they are susceptible to fouling, they are best applied with a closed-circuit condenser water system.

Brazed-plate condensers are much smaller than their shell and tube counterpart is. They may be less than one third the size of an equivalent shell and tube heat exchanger.

Brazed-plate heat exchangers are excellent for jobs requiring compact condensers.

Closed versus open circuit

On tube-in-tube, shell and coil, and brazed-plate condensers, the best application is to use a closed circuit for the condenser water. That is because the internal water passages on these types of condensers are not mechanically cleanable. That means a fluid cooler (not an open cooling tower) is the best application with them.

Fouling Factors

Fouling or scaling on the waterside of condenser tubes is an important factor in water-cooled condenser selection. Fouling, or scaling, is caused by the building up of mineral solids, which precipitate out of the water, or by entrained solids, such as silt, which deposit on the tube surface.

Typically, water-cooled condensers are selected in the range between 3-12 feet per second water velocity in the tubes. At lower velocities, increased fouling is possible as with low cooling tower flow and with once-thru systems. This is because the scrubbing action of more turbulent flow is diminished and sediments can deposit more easily on the tube walls.

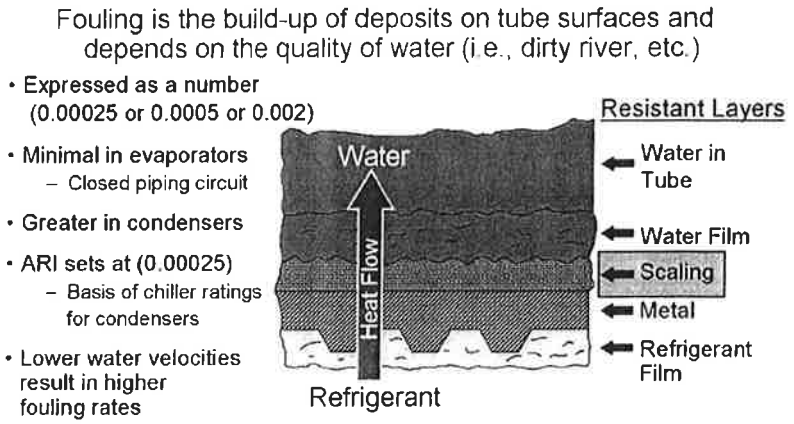


Figure 21

Fouling (Scaling Resistance)

Increased fouling potential must be considered if the condenser water flow is reduced for extended periods of time from traditional flows. An example of this would be a low flow (2 gpm/ton) condenser water system operation. In these systems, the potential exists for greater fouling than ARI standard three gpm/ton systems. In low-flow systems, there is a higher rise so the water exiting the condenser is warmer. Heat also contributes to greater fouling.

The rate of tube fouling is also a function of the quality of condenser water.

Fouling adds resistance

to the flow of heat and restricts waterflow, both of which reduce condenser capacity and system capacity. Excessive fouling in centrifugal chiller condensers can elevate the condenser pressure to the point of causing compressor operational issues. In other types of compressors, like screws, reciprocating, and scrolls, excessive fouling is still detrimental by reducing efficiency. For a complete discussion on this topic, refer to TDP-623, Water-Cooled Chillers.

For cooling tower applications, ARI Standard 550/590 for vapor-compression chillers utilizes a fouling factor of 0.00025 in the condenser as a basis for chiller ratings.

Designers should not arbitrarily assume excessive fouling factors such as 0.001, thinking they have a robust design by doing so. Excessive fouling utilized as a basis of chiller selection may result in additional heat exchanger area with a higher first cost.

Selection of a fouling factor provides for a certain amount of scale buildup, which is then taken into account in the selection of the condenser. If too low a value is selected, frequent cleaning of the condenser tubes may be required.

Fouling

is inversely proportional to the velocity of the water.

Normally, a fouling factor is chosen based on experience for a given area (operating hours, water quality) so that the chemical or mechanical cleaning of tubes is required not more than once a year. A more frequent cleaning schedule may be practical and is dependent on the actual job conditions.

On larger chillers, the control panel may contain a feature that permits display of the difference in leaving water temperature and refrigerant temperature (approach or leaving temperature difference) in the condenser and cooler. This is valuable because the operator can see if the temperature difference has increased from the initial job commissioning, often a result of increased or excessive fouling. The approach is indicative of heat exchanger efficiency.

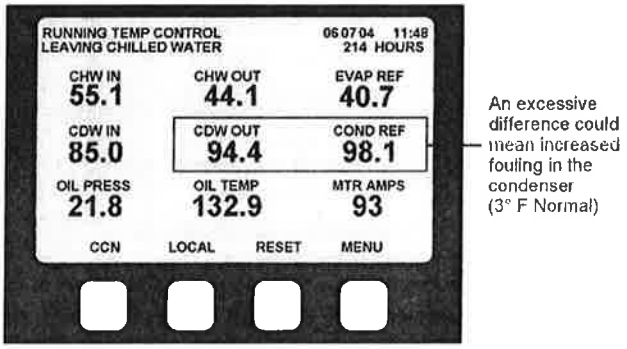


Figure 22

Water-Cooled Chiller Control Panel

On modern centrifugal chillers

with clean tubes in the condenser, an approach of approximately 1 to 3.0° F in the condenser, depending on design, is considered acceptable.

This value will increase as tube fouling increases. If it increases to the point of exceeding the lift capabilities of the compressor, operational problems may occur.

In selecting a water-cooled condenser, a good recommendation for comfort cooling applications is to use the current ARI values for fouling in cooler and condenser. As of this writing, these values are:

$0.0001\ h * ft^2 * °F / Btu$ *cooler fouling factor*

$0.00025\ h * ft^2 * °F / Btu$ *condenser fouling factor*

Regular maintenance and water treatment programs

should be initiated for the cooling towers. This will keep the effects of fouling to predictable levels.

Tubing Materials

When considering efficiency, the manufacturer's standard copper tubing is the best choice in the condenser. Standard tubing for a centrifugal chiller is shown here and is often finned or "enhanced" internally and externally to promote heat transfer.

Enhancing improves the refrigerant coefficient of heat transfer and the waterside heat transfer.

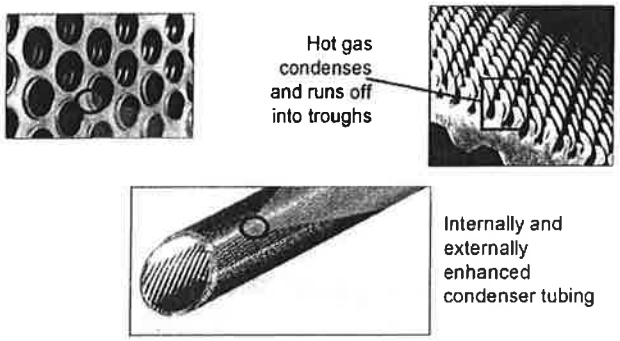


Figure 23

Large Water-Cooled Condenser Tubing

On larger water-cooled centrifugals and screw chillers, there are often various choices for non-standard tubing based on application requirements. On smaller reciprocating and scroll chillers, these tubing choices do not typically exist.

Application	Tubing Material	Cost factor
Fresh Water	Copper	1.0
Glycols	Copper	1.0
Corrosive Water	Cupro nickel	1.3
Special Process	Stainless steel	2-3
Sea Water	Titanium and Cupro nickel	3-4

Figure 24

Water-Cooled Condenser Tubing Cost Factors

Effects of Antifreeze

Antifreeze is sometimes used in the recirculating condenser loop instead of fresh water for purposes of freeze protection. The use of antifreeze versus fresh water will affect the condenser water pressure drop, flow rate, and capacity.

To determine the effects of antifreeze on a particular water-cooled condenser application, the best method is to make an actual selection with and without glycol for comparison.

Figure 25 shows the effects of using propylene glycol in the condenser of a typical water-cooled centrifugal chiller. As the percent of glycol increases, the effect on the efficiency is shown.

The efficiency is not affected that much in this particular example. However, it is important to select the water-cooled chiller to reflect the exact percent of glycol, if any, used in the condenser. If the percent changes, a reselection should be done as the components in the chiller may be affected.

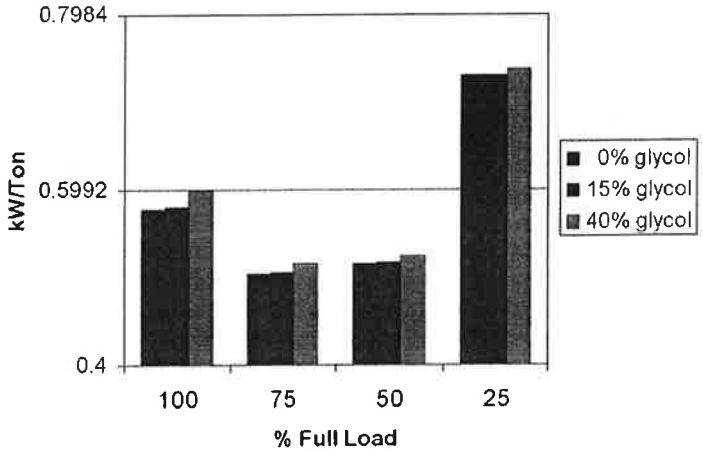


Figure 25

Effects of Glycol in the Condenser

Condenser Pass Arrangements

Passes are defined as the number of times the water traverses the length of the condenser prior to exiting. Water-cooled condensers are often offered in one, two, and three-pass arrangements. The number of passes is normally related to maximum allowable tube velocity or maximum allowable pressure drop requirements. A water-cooled condenser with a two-pass arrangement will be more efficient than the same condenser with one-pass. A three-pass arrangement will be more efficient that the two-pass version of the same condenser. However, the pressure drop may be too high for the higher pass.

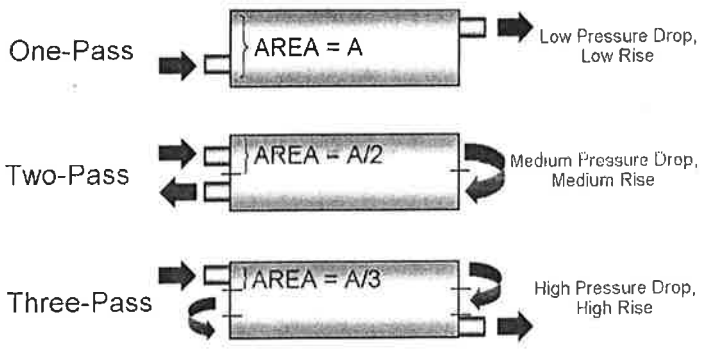


Figure 26

Condenser Pass Arrangements

Selection Inputs

Water-cooled condensers are almost always selected as part of the water-cooled chiller or packaged air conditioner. The following factors must be taken into account because they affect the selection of the unit:

- Entering condenser water temperature
- Fouling factor
- Pressure drop
- gpm
- Total heat of rejection

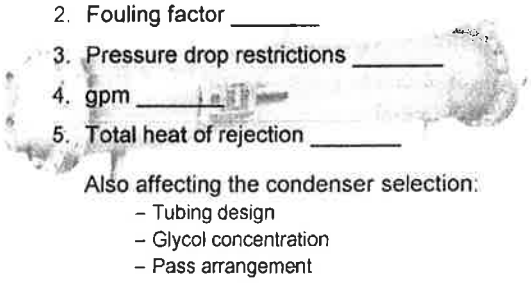


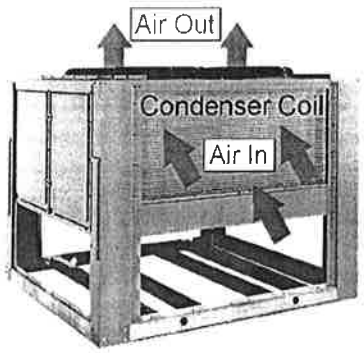
Figure 27

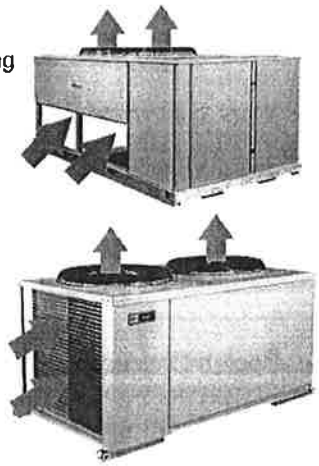
Selection Inputs for Water-Cooled Condenser

Air-Cooled Condensers

Air-cooled condensers are the most commonly used condensers modern HVAC systems. Air-cooled condensers are commonly applied on medium to large commercial jobs. Residential split systems are also a large user of air-cooled equipment. They can be used in multiples to form systems reaching several thousand tons of installed capacity.

- Simplicity due to packaged design
- No condenser water pump and piping
- Ease of maintenance
- Simplified wintertime operation





Condensing pressures and temperatures are higher for air-cooled than water-cooled condensers. This usually translates into a less efficient refrigeration cycle for the same-sized system.

Figure 28

Air-Cooled Condensers

Here are some of the reasons air-cooled condensers are popular:

- Simplicity of installation due to a packaged design
- Condenser water piping and condenser water pump are not required
- Chemical treatment is not required because there is no condenser water loop
- Ease of maintenance
- Winter operation is simplified since there is no water involved so freeze-up concerns do not exist

Many years ago, air-cooled condensers were limited primarily to small commercial refrigeration systems and room air conditioners. Now they are used far more often than water-cooled condensers in the HVAC industry.

Many designers feel that when a project gets larger in size, water-cooled is the better application because of higher efficiency. However, many project designs are not decided solely on efficiency. Shopping malls are a good example of where air-cooled equipment is used very often.

The reliability of air-cooled products for both residential and commercial-sized projects has improved compared to past designs. Even when the condenser or condensing unit is remote from the evaporator as in a split system, components are pre-matched so incompatibilities can be avoided.

Air-Cooled Condenser versus Air-Cooled Condensing Unit

The term air-cooled condenser refers to a heat rejecter (coil and fan) without an integral compressor section. An air-cooled condensing unit refers to the same condenser unit but with a compressor section.

The air-cooled condenser has hot gas inlet and liquid line outlet connections for field piping. The air-cooled condensing unit has suction and liquid line connections because the hot gas line is factory installed between the compressor and condenser coil.

Air-cooled condensers and condensing units are easy to install, requiring only power, controls, and refrigerant connections. Maintenance is simple and they do not have to be winterized in the fall.

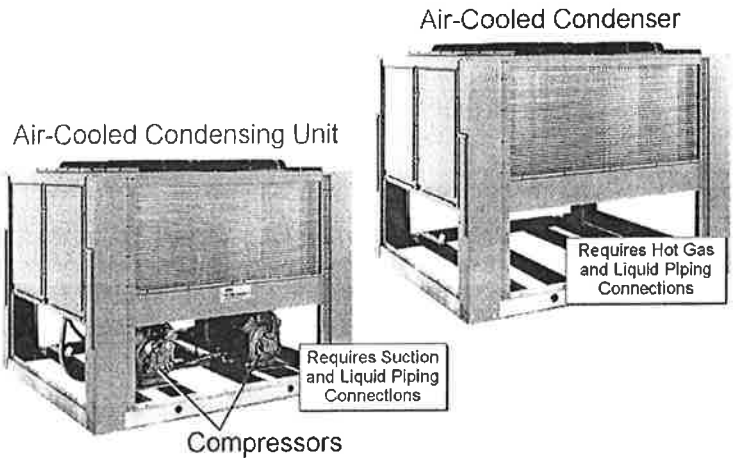


Figure 29

Air Cooled Condensing versus Unit Air-Cooled Condenser

Their primary disadvantage is that they usually must operate at higher condensing temperatures than water-cooled condensers or evaporative condensers to keep their physical size reasonable.

The following is a calculation showing condensing temperature requirements for a typical air-cooled condenser:

- Inlet (ambient) air temperature: 95° F
- Air Rise: 15° F
- Leaving Difference: 15° F
- Condensing Temperature: 125° F

The higher condensing temperatures, of course, increase compressor kW input and increase operating costs. One must consider potentially higher maintenance and water treatment costs for water-cooled condensers used with cooling towers versus the simplicity of air-cooled condensers.

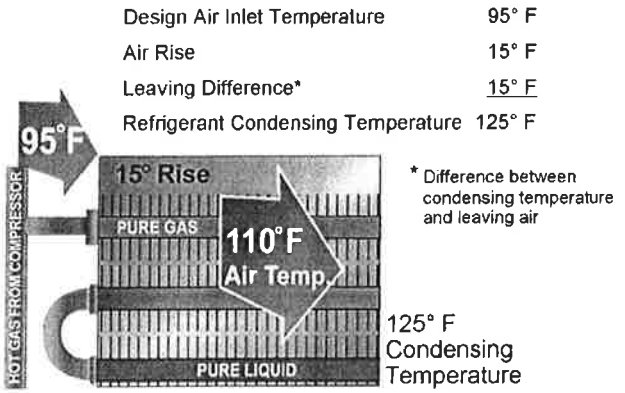


Figure 30

Approximate Design Air-Cooled Condensing Temperature

Higher design air temperatures ***can occur on hot roofs and in direct sunlight than what is listed as the design temperature for an area.***

The circulation of air over an air-cooled condenser is normally provided in an upward draw-thru flow as previously shown. The condenser surface is usually of the copper tube and aluminum plate fin type as illustrated. Fans for air-cooled duty, just as with cooling towers, most often are axial type. Centrifugal fan condensers are available especially if indoor placement and/or ductwork is required.

Subcooling Circuit

The addition of a separate liquid subcooling circuit to an air-cooled condenser increases the compressor capacity approximately 1/2 percent for each one degree of liquid subcooling. Liquid subcooling increases the refrigeration effect, that is Btu, absorbed in the evaporator per pound of refrigerant. Liquid subcooling also helps to prevent the flashing of gas within the liquid line. Flash gas is the flashing of liquid refrigerant into a gas as a result of pressure change. When compressor capacity is marginal, liquid subcooling will frequently permit use of a smaller compressor.

Subcooling coils are generally sized to provide from 10 to 20 degrees of subcooling. This produces a 5 to 10 percent increase in compressor-condenser capacity at a given condensing temperature.

The diagram shows schematically the circuiting of an air-cooled condenser with integral subcooling circuit. Liquid from the condensing section is collected in the return header. It then passes into a separate circuit for subcooling. To obtain subcooling, the system must be charged with refrigerant so that the sub-cooling circuit is completely filled with refrigerant. Additional charge is then added according to the manufacturer's charging recommendations to fill the subcooling circuit.

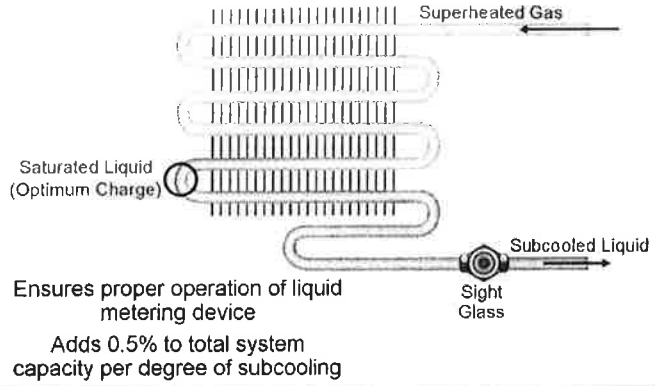


Figure 31

Subcooling Circuit

Air-cooled condenser ratings with subcooling circuits are divided into two categories, "Optimum Charge" and "Minimum Charge."

Optimum charge ratings are for a system charged with refrigerant to obtain the design number of degrees of subcooling. In this case, gross heat rejection is the sum of desuperheating, condensing, and subcooling. Liquid leaves at the saturated condensing temperature.

Minimum charge ratings are those obtained when the subcooling coil is not charged with liquid and the subcooling circuit is used for condensing refrigerant. Gross heat rejection then equals the sum of de-superheating and condensing of the refrigerant. The liquid refrigerant leaves at the saturated condensing temperature.

Minimum charge ratings will give higher values of heat rejection than optimum charge. This is because the subcooling circuit occupies condenser surface. The heat transfer for condensing is much higher than for subcooling. However, the combined compressor-condenser rating will be higher with optimum charge because of the increased refrigeration effect per pound of refrigerant circulated.

Placement

Air-cooled condensers are available for either an inside or outside location. However, the vast majority are for outside application. Inside placement often requires a centrifugal fan to overcome the resistance of the inlet and discharge ductwork.

When installed outside, they may be located on the ground, or on the roof. Roof locations are common for commercial applications. Again, design consideration must be given for higher temperatures associated with units installed on black roofs in direct sunlight.

The vertical coil condensers should be oriented so that the prevailing winds for the area, in summer, will tend to help the fan produce airflow. In addition, field-fabricated and installed wind baffles are recommended for the discharge side of the condenser to reduce the wind effect, especially during cold weather cooling operation. The wind effect may reduce the temperature of the coil in winter, making head pressure control difficult.

Mounting of an outdoor air-cooled condenser or condensing unit indoors is not recommended. The unit nameplate may indicate, "outdoor use only" and building inspectors can question the application. If the area is large enough (such as an airplane hangar) there would be little concern about elevation of the temperature in the space from the rejected heat. However, equipment should only applied in its intended location and local inspectors have the final say.

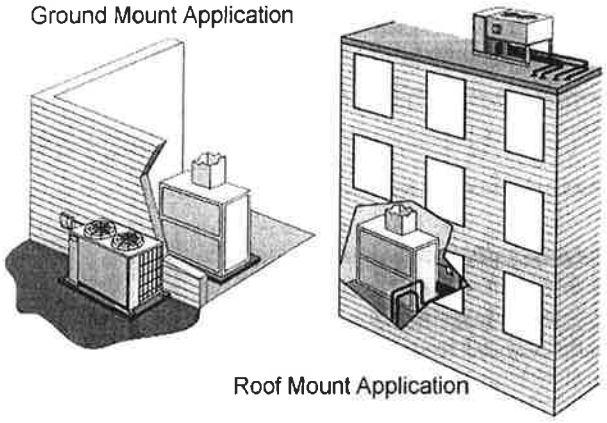


Figure 32

Placement Choices for Air-Cooled Condensers

Select placement areas

that are relatively clean, otherwise foreign material such as leaves, papers, and other debris will block airflow through the coil. This will unnecessarily increase condensing temperature and compressor kW. It is recommended that a pad be used to keep adequate clearance from vegetation when ground mounting is used.

Selection

Air-cooled condenser ratings are usually presented in terms of Btuh or tons of total heat rejection or refrigeration effect versus temperature difference, where:

Temperature Difference (Δt) = condensing temperature - entering outdoor air temperature.

As Δt increases, the heat rejection capacity increases proportionately. An increase in condensing temperature reduces the compressor capacity and increases the power required.

Typical inputs required for computer selection software are:

- entering air temperature
- total heat of rejection
- Δt
- subcooling amount (typically 15° F)
- estimated discharge line loss (typically 2° F)

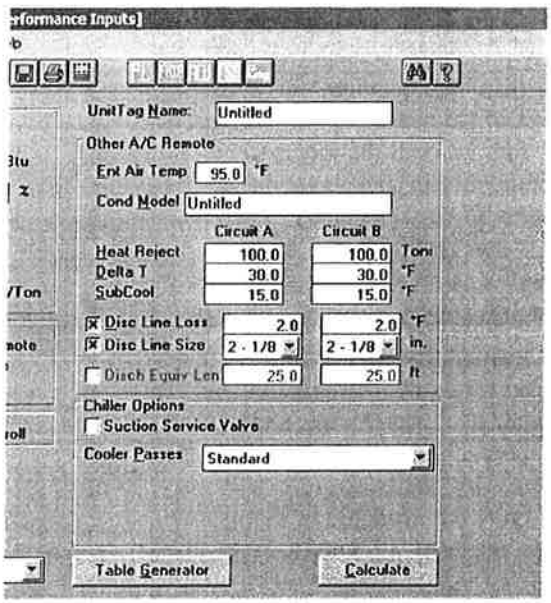


Figure 33

Selection for Air-Cooled Condenser

An analysis of cost, both first and operating, will frequently show that a larger condenser, although higher first cost, can result in better overall economies for the buyer. This is the result of the larger condenser lowering the condensing temperature. However, the law of diminishing returns will prevail. Most air-cooled condensers are selected as part of a split system with selection software as shown in Figure 33. The balance capacity between indoor unit and outdoor air-cooled condenser is automatically calculated

Evaporative Condensers

Evaporative condensers combine the functions of water and air-cooled condensers into one design. The hot gas discharged from the compressor is circulated through coil tubes that are sprayed on the outside with water. The evaporative effect of the water on the tube surface helps condense the refrigerant gas inside. The net effect when the sprays are operating is to deliver higher system efficiency than a dry, air-cooled condenser.

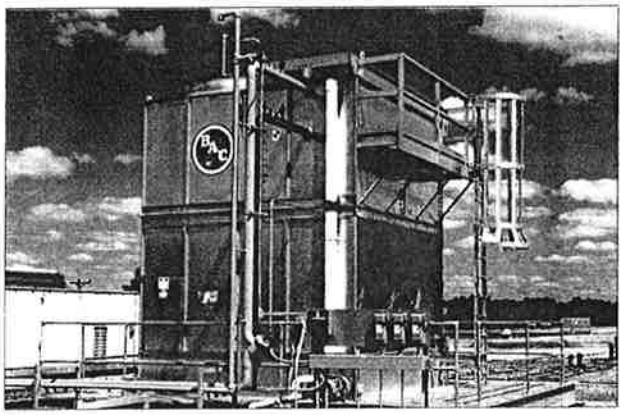


Figure 34

Evaporative Condenser
Photo: Courtesy of Baltimore Aircoil Company

In a water-cooled system using a cooling tower, all the water required for the condenser (about 3 gpm/ton) is pumped through the cooling tower condenser circuit. In an evaporative condenser, only enough water is circulated within the condenser casing to insure a constant wetting of the condenser coil tubes. The spray-pumping horsepower will be less than that required for a cooling tower of the same capacity. However, the fan hp will be comparable for cooling towers and evaporative condensers of equal capacity. The make-up water requirements are also the same for an evaporative condenser or a cooling tower.

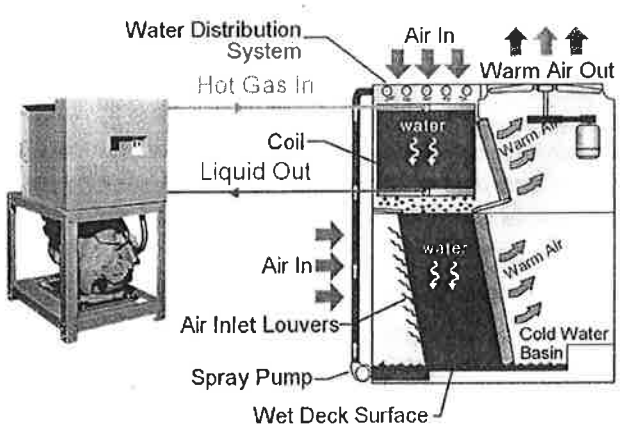


Figure 35

Evaporative Condenser with Condenserless Chiller
Condenser Photo: Courtesy of Baltimore Aircoil Company

Evaporative condensers are designed for outdoor installation and are available in horizontal and vertical component arrangements. The sizes offered by manufacturers will vary, but units are available in the approximate range of 15 tons to over 2000

tons of total heat rejection. The primary use of evaporative condensers is to condense refrigerant. They may also have supplemental circuits in the coils to be used to cool engine jacket water, oil-cooled transformers, or process fluids. When installed outside, ductwork is not normally required.

Evaporative condensers

provide a lower condensing temperature than a dry air-cooled condenser because of the evaporative effect of the sprays.

Evaporative condensers are usually mounted on steel platforms either on roofs or on concrete pads at grade level.

If winter operation of the unit is required, consideration must be given to freeze-up problems just as with cooling towers. Evaporative condensers can be drained of water and run as a dry coil unit (air-cooled condenser).

If more than 45% of design capacity is required in winter, it will be necessary to select the unit on its dry coil capacity. Then the unit will likely be oversized in summer and control of head pressure with air volume dampers or a VFD (Variable Frequency Drive) may be necessary to reduce unit capacity.

The capacity

of an evaporative condenser with dry coil in winter with 30° F entering air is about 45% of the unit's capacity in summer with wet coil.

As a second possibility, consideration should be given to including a remote indoor sump or locating the unit within a heated space where freezing during off cycles will not be a problem. If the entire unit is located inside, ductwork is usually required on both the inlet and discharge of the unit. Dampers in the ductwork should be provided to close during off cycle to prevent gravity flow of outdoor air.

As the tonnage of the job grows

to where multiple evaporative condensers would be required, designs often switch to a cooling tower. This can be attributed to greater refrigerant management issues and the larger refrigerant charge associated with the evaporative condenser scheme.

Evaporative condensers are more expensive on a cost-per-ton basis than a cooling tower. The reason is the cost of the coil in the evaporative condenser. However, this expense can be offset since a water-cooled condenser and condenser water pump can be eliminated by the use of an evaporative condenser.

Evaporative Condenser Selection Parameters

There are two acceptable practices for selecting an evaporative condenser: the evaporator ton method and the heat rejection method. Although both are used and acceptable, the preferred is the heat rejection method. The principle reason is accuracy. The evaporator ton method estimates the power required for an open reciprocating compressor and uses this as the basis for selection. The heat rejection method uses the total heat of rejection.

Evaporator Ton Method:

- Select the type of refrigerant
- Enter the proper evaporator tonnage
- Enter the condensing temperature
- Enter the outdoor design wet bulb temperature
- Enter the saturated suction temperature

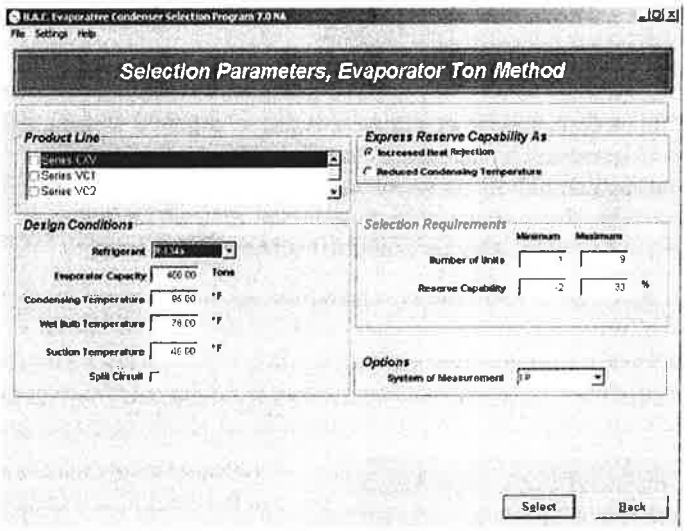


Figure 36

Evaporator Ton Method of Selection
Screen Capture: Courtesy of Baltimore Aircoil Company

Heat Rejection Method:

- Select the refrigerant used
- Enter the specific heat rejection capacity required
- Enter the condensing temperature
- Enter the outdoor design wet bulb temperature

Selection programs also have the ability to match chillers that have independent refrigeration circuits due to multiple compressors with dedicated evaporative condensers.

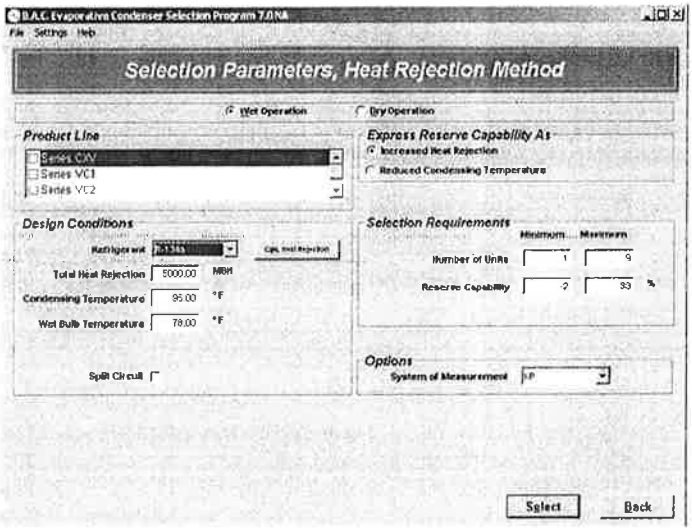


Figure 37

Heat Rejection Method of Selection
Screen Capture: Courtesy of Baltimore Aircoil Company

Subcooling Coils in Evaporative Condensers

Manufacturers of evaporative condensers can provide subcooling coils as options. This generally is an excellent and necessary recommendation when matching an evaporative condenser with a packaged condenserless chiller. Each degree of liquid sub-cooling increases the refrigeration capacity of a system by about 0.5 percent. Also, packaged chillers may *require* subcooling in the condenser to assure that pure liquid refrigerant arrives at the chiller metering device for proper control. A liquid-gas mixture at the chiller expansion device is not desirable and is to be avoided.

It should be noted that some manufacturers rate their chillers and compressors with various degrees of subcooling. If a compressor is so rated and a subcooling coil is not used with the evaporative condenser, derating and operational problems could occur. If a subcooling coil is used, the compressor rating must be corrected for the difference in the actual subcooling available from the subcooling coil at job conditions and the number of degrees of subcooling actually included in the compressor rating.

Fan Performance Data

Limited airflow data is provided by the evaporative condenser manufacturer. Standard hp motor sizes are based on zero external static pressure.

Whenever ductwork is required, it is necessary to qualify the motor and fan selection in the standard unit. Only centrifugal fan evaporative condenser units should be considered for ducted applications.

The 100 percent air quantity given for each unit is based on wet coil operation. If this cfm is exceeded, moisture carryover may result. The limiting cfm for dry coil operation is dependent on the fan performance, based on motor horsepower and noise level.

At a given rpm

the fan cfm would be higher for dry coil operation than for wet coil operation because of the reduced resistance through the coil. Therefore, the motor horsepower must be checked for both wet and dry coil operation to be sure that the motor is not overloaded on dry coil operation.

Condenser Economics

Thus far, we have discussed water-cooled condensers using natural water on a once-thru basis, as well as recirculating water from a cooling tower. We have also described evaporative and air-cooled condensers.

Let's summarize our discussion so far. Figure 38 shows the effect of the condensing medium and condensing method on condensing temperature.

Condensing Media	Inlet Temperature (° F)	Rise (° F)	Outlet Temperature (° F)	Leaving Difference (° F)	Condensing Temperature (° F)
Once-Thru Water	75 80	20 20	95 100	5 5	100 105
Cooling Tower 75-78° F wb	85	10	95	5-10	100-105
Evaporative Cond 75-78° F wb	– –	– –	– –	– –	100 105
Air	95 105	15 15	110 120	15 15	125 135

Figure 38

Condensing Temperature versus Condensing Media

In selecting a compressor or condensing unit, the designer must assume a tentative condensing or discharge temperature in anticipation of balancing the compressor against the condenser. The table shown may be used to determine tentative condensing temperatures consistent with the condensing medium to be used. It may be noted that condensing temperatures range from 105° F (which is a typical value for all packaged water-cooled equipment) with 75° F once-thru water to 130° F with 110° F condenser air.

Figure 39 shows a second table showing the effect of discharge temperature on compressor refrigeration effect and required kW input.

As the condensing temperature and corresponding pressure increases, it is apparent that the refrigeration capacity is decreasing and the kW/ton of refrigeration effect (RE) is increasing.

From the table, it is apparent that the condensing temperature of the compressor has an important influence on compressor capacity and power requirements.

CONDENSING TEMP (°F)	CAPACITY		kW INPUT	kW/TON	% kW/TON
	TONS	%			
100	52.86	100	38.2	.72	100
105	52.15	98.6	40.4	.77	107
110	51.41	97.0	42.7	.83	115
120	49.84	94.0	47.9	.96	133
130	48.10	91.0	53.6	1.15	159

Based on Screw Compressor, 40° F Suction R-134a

WATER-COOLED

AIR-COOLED

Figure 39

Effect of Condensing Temperature

Remember that savings in water costs like chemical treatment and makeup might offset the increased power costs of air-cooled condensers.

One should not generalize about the relative merits and costs of a given condensing method as compared to another. There are too many variables involved such as outside design conditions, availability and quality of water, and relative costs of power and water. Each situation should be analyzed on its own merits and the best selection should be made consistent with the circumstances. Whichever heat rejection equipment chosen, lowering the condensing temperature to the unit's optimum, gives the maximum energy savings.

Cooling Towers

In a cooling tower system, the warm water leaves the water-cooled condenser and is pumped to the top of the tower. This water is then distributed and broken up into droplets by one of several methods so that a large surface area may be brought in contact with outdoor air.

Cooling towers are heat rejecters. They do not condense refrigerant so they are not considered condensers.

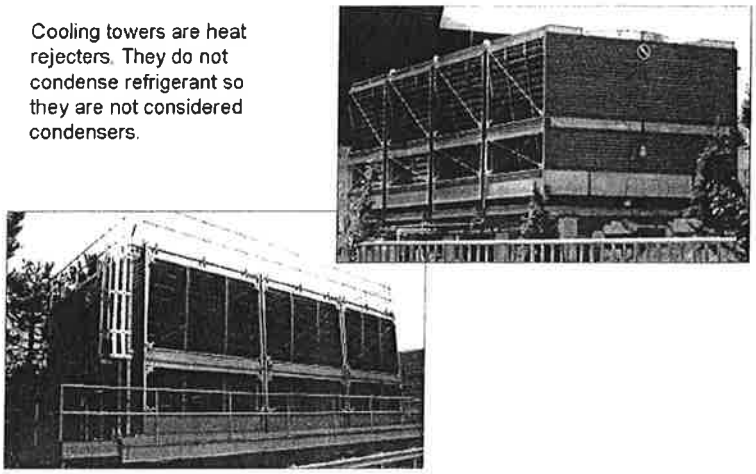


Figure 40

Cooling Towers
Photos: Courtesy of Baltimore Aircoil Company

The vapor pressure of the air is lower than that of the water so a small percentage of the water is evaporated. The latent heat of evaporation for this process is taken from the remaining water, thereby cooling it. The cooled water collects in a sump at the bottom of the tower where it is returned to the condenser to once again pick up the heat load.

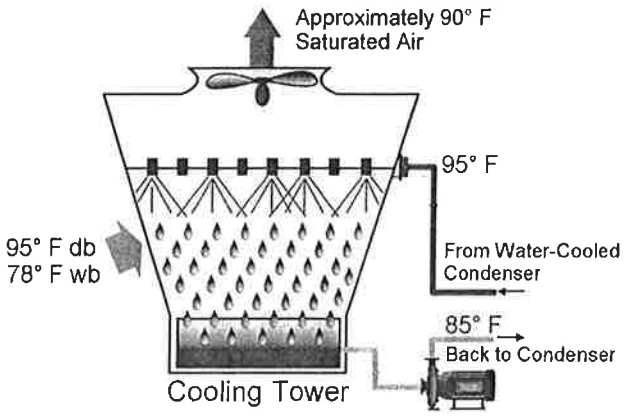


Figure 41

Basic Cooling Tower Operating Characteristics
Illustration: Courtesy of Baltimore Aircoil Company

Basic Terms

Entering Wet Bulb Temperature

Wet bulb temperature is the lowest temperature that water can reach by evaporation.

Design entering wet bulb temperature (ewbt) is the most important parameter in tower selection and should be determined for the specific climate zone. For many areas in North America, 78° F is common. Consult cooling tower application data from manufacturers or ASHRAE for design wet bulb values.

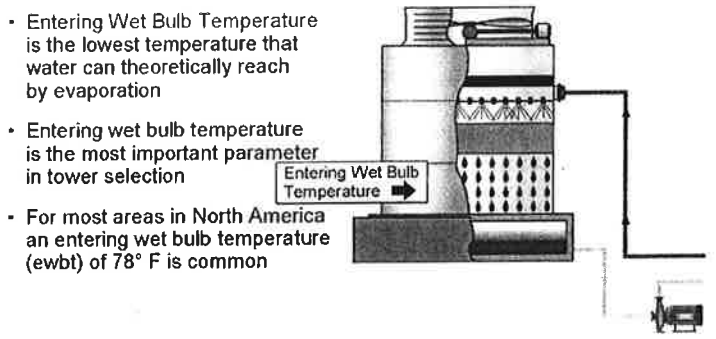


Figure 42

Entering Wet Bulb Temperature

> ***Note***
>
> ***In dry Southwestern areas of North America, ewbt will be lower. In warmer, more humid areas like Houston, 80° F ewbt is often used.***

Typically the 0.4 percent data is used for design, which means this value is exceeded 0.4 percent of the hours in a year. The percentages refer to the percentage of 8760 hours in a typical year. Therefore, 0.4 percent means about 35 hours per year.

There is some variation in engineering practice. Some engineers use the 1 or 2 percent design value, which is their personal preference. When in doubt, consult with the local cooling tower supplier.

Approach

Approach is the difference between the water leaving the tower and the entering wet bulb temperature of the air.

Establishment of the approach fixes the operating temperature of the tower and is an important parameter in determining both tower size and cost.

A 7° F approach is common in HVAC because many geographic regions in North America have a 78° F ewbt design and use 85° F water leaving the tower.

The closer the approach, the larger the cooling tower and vice-versa. In fact, as the approach "approaches" zero, the tower cost and size starts to "approach" infinity. A 7° F approach in most cases results in a reasonably priced tower capable of providing the cooler condenser water required for efficient system operation.

Larger approaches may reduce the size and cost of the tower, but at a higher energy cost for the chiller resulting from the warmer condenser water temperature. Smaller approaches for a fixed wet bulb result in cooler condenser water, in turn increasing the efficiency of the chiller.

Minimum Approach

An approach of 5° F is considered a practical minimum when comparing the additional first cost of the tower versus the benefit in energy consumption of the chiller.

- Approach is the difference between the water leaving the tower and the entering wet bulb temperature of the air
- A 7° F approach is common in HVAC for systems with 78° F entering wet bulb and 85° F water leaving the tower

(85° F - 78° F = 7° F)

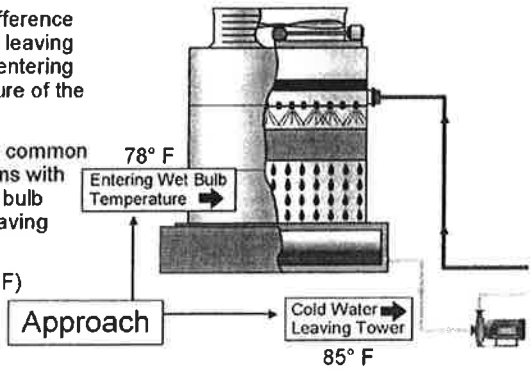


Figure 43

Cooling Tower Approach

Usually, the ewbt will be less than design. That means the cooling tower will be capable of delivering cooler ecwt. The result is greater chiller efficiency.

Range

Cooling tower range is the difference in temperature between the water entering the tower and the water leaving the tower.

An approximate 9.4 to 10° F range is most common in HVAC (95° F inlet minus 85° F outlet is a 10° F range).

- Range is the difference in temperature of water entering the tower and water leaving the tower
- An approximate 9.4 - 10° F range is most common in HVAC applications

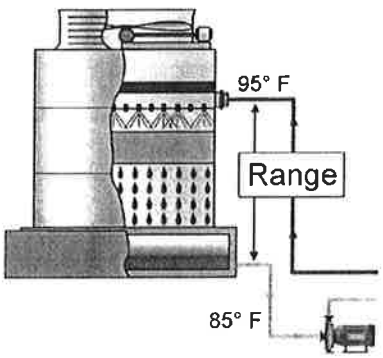


Figure 44

Cooling Tower Range

Total Heat of Rejection

Total heat of rejection (THR) is the amount of heat to be removed from the circulating water within the tower. This consists of the peak cooling load of the building plus the heat of the compressors (work of compression).

Manufacturers' equipment selection programs for water-cooled equipment will calculate the total heat of rejection for the application. This can be used to properly size the tower.

- Total Heat of Rejection is the amount of heat to be removed from the circulating water within the tower
- It is equal to the refrigeration effect plus the work of compression
- For water-cooled chillers THR = (1.15 to 1.18) * Cooling Tons

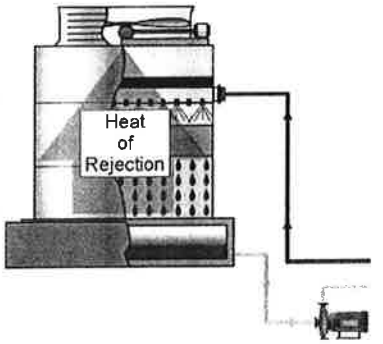


Figure 45

Total Heat of Rejection

Drift (Windage)

Drift is water that is entrained in the airflow and discharged to the atmosphere. Drift can vary widely based on tower location and prevailing winds. It is approximately 0.001 to 0.002 percent of the circulated condenser gpm, so, at 3 gpm/ton, that value is 0.00006 gpm/ton or 0.006 gallon for an hour full-load operational on a 100-ton cooling tower.

Drift loss
can be neglected in most calculations for water makeup.

- Drift is water that gets entrained in the airflow and discharged to the atmosphere
- Drift can vary widely and does not include water lost by evaporation
- Drift is very small and can usually be neglected in most calculations for make up
- Drift is approximately 0.001 to 0.002% of the tower gpm

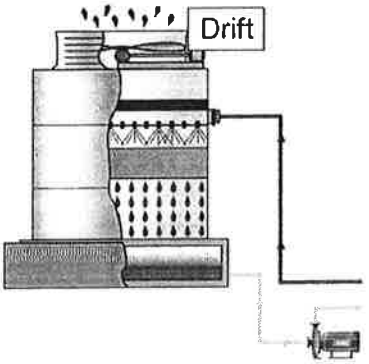


Figure 46

Drift (Windage)

Evaporation

For each pound of water that a cooling tower evaporates, it removes approximately 1050 Btu from the water that remains. The exact value is dependent on water temperature and can be found in the thermodynamic properties of water under the enthalpy (h_{fg}) heading.

The more evaporation that takes place, the more heat that is removed. Lower entering wet bulb temperatures create a greater evaporative effect.

Evaporation rate = approximately 1 percent, at 3 gpm/ton, that is 0.01 * 3 gpm = 0.03 gpm/ton.

- For each pound of water that a cooling tower evaporates, it removes about 1050 Btu from the water that remains
- A lower entering wet bulb creates a greater evaporative effect
- Evaporation rate equals approximately 1 percent of the tower gpm

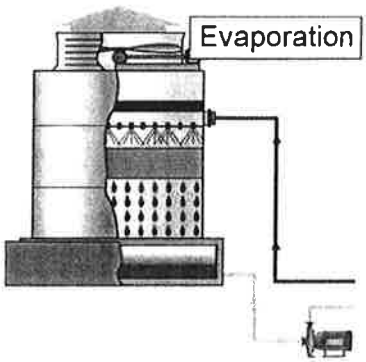


Figure 47

Evaporation

Blow-down (Bleed)

Water contains impurities. When water is evaporated, most of these impurities are left behind. If nothing were done about it, the concentration of impurities would build up rapidly. Blow-down of some of the water is continuously required to limit this build up.

The blow-down rate required is best determined by a water treatment specialist. They are prepared to make the necessary tests and recommendations for the specific site conditions

The blow-down rate determines the water chemistry, or cycles of concentration of the water. This can vary depending on the makeup water quality, the treatment program, and the materials of construction of the tower.

- Water contains impurities and when it is evaporated these impurities are left behind
- If no action is taken, the concentration of impurities will build up rapidly
- Bleeding off some of the water is continuously required to limit this build up
- The bleed rate is best determined by a water treatment specialist who is trained to perform the necessary tests and make recommendations

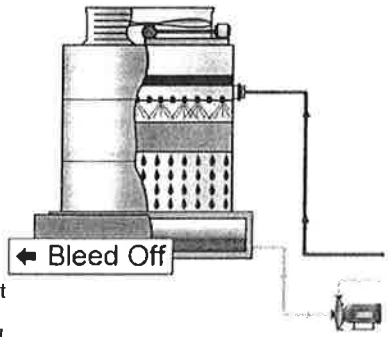


Figure 48

Blow-down (Bleed)

Cycles of concentration (COC) is a term used with blow-down and is defined as the ratio of dissolved solids in the recirculating water to the concentration found in the entering make-up water. The higher the COC the lower the blow-down or bleed rate. If the COC valve is high, you have a low bleed rate.

Makeup

Makeup is the amount of water required to replace normal losses caused by drift, evaporation, and blow-down.

The efficiency of a cooling tower is influenced by all of the factors governing the rate at which water will evaporate into the air. With that in mind, let's look at the various types of cooling towers on the market. First let's see how a cooling tower process looks on the psychrometric chart.

- Makeup is the amount of water required to replace normal losses caused by drift, evaporation, and blow-down.

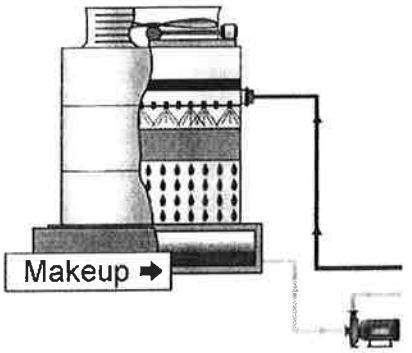


Figure 49

Makeup

Cooling Tower Psychrometric Plot

The cooling tower process can be plotted on the psychrometric chart. Let's assume we have outside design conditions of 95° F dry bulb and 78° F wet bulb. For this example we will use 85° F ecwt and a range of 10° F for the tower water.

The total heat gain of the air equals the heat given up by the water flow. The tower airflow multiplied by the difference in enthalpy of air entering and leaving the tower will equal the water flow multiplied by 500, multiplied by the Δt of the condenser water.

We can plot the entering air conditions of 95/78° F. Notice the air undergoes sensible cooling and humidification as it exits the tower at saturated several degrees less than the water temperature of 95° F.

In this example, our approach is the traditional 7° F discussed earlier for climates with a design wet bulb of 78° F.

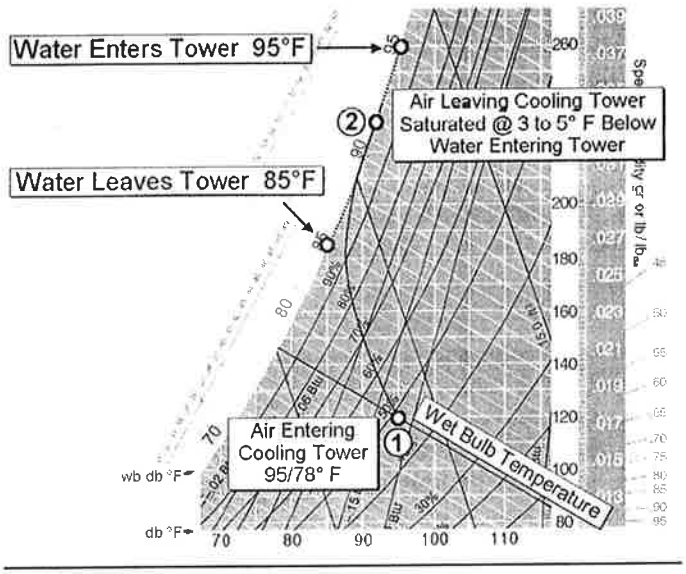


Figure 50

Cooling Tower Psychrometric Plot

Types of Cooling Towers

Cooling towers are classified according to the method of air circulation.

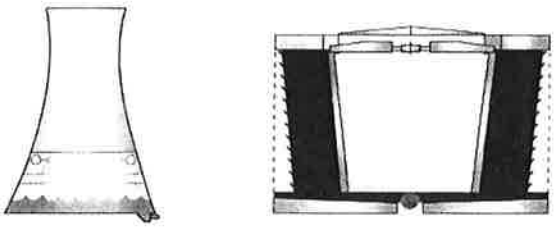


Figure 51

Types of Cooling Towers

Natural Draft (Atmospheric)

When air circulates through the tower by natural convection, it is classified as a natural draft or atmospheric tower.

The capacity of natural-draft towers varies with wind velocity, as does the drift loss. Outdoor location is required. Because of the relatively slow air movement, atmospheric towers are inherently large.

Atmospheric towers are generally not the type used for standard comfort air conditioning systems because of their large size and uncertain capacity. Therefore, we will not devote any more time to natural-draft towers in this TDP.

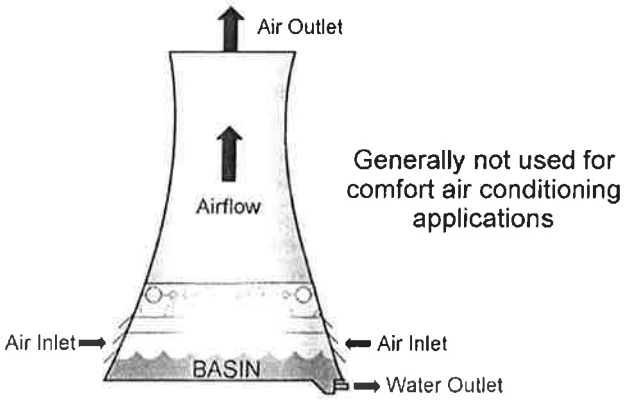


Figure 52

Natural Draft

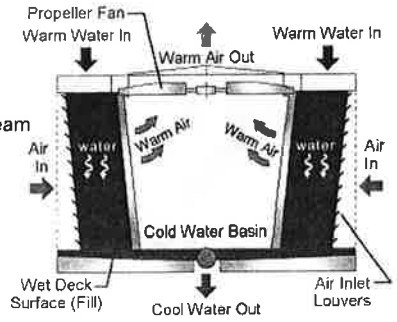
Mechanical Draft

When air circulation is provided by a fan or blower, the tower is called a mechanical draft tower. Towers of this type are further classified as induced draft or forced draft.

Induced-draft

With induced-draft towers, the fan moves larger air quantities at higher velocities than natural draft type. This reduces tower footprint compared to natural draft towers. Water distribution may be accomplished by spray nozzles or by some type of gravity-based perforated distribution basin. Some manufacturers provide spray eliminators at the air discharge to limit drift losses.

- Air exit velocity
  - Like a 5 mph wind
  - No recirculation
  - Fan in warm airstream
- Widely used
  - Crossflow or counterflow design
- Applications:
  - HVAC (chillers)
  - Clean process



Air is drawn through the tower with a fan

Figure 53

Mechanical Draft – Induced Type
Illustration: Courtesy of Baltimore Aircoil Company

Because the fans are located in the moist discharge air stream, they should be made of corrosion-resistant materials such as aluminum.

Some atmospheric towers, and almost all mechanical-draft towers, contain "fill," a material that acts to increase heat transfer and gain maximum exposure of the water to the airflow. In years past, fill was primarily made of slatted lumber. Current designs do not use wood. The heat transfer surface referred to as "fill" or "wetdeck" is typically PVC (poly vinyl chloride).

Steel, redwood, and ceramic based materials are also used for fill, although much less frequently, and usually only for unique process or industrial applications.

- Fill helps the water gain maximum exposure to the airflow
- PVC is the most commonly used material
- Current designs for HVAC tend not to use wood for fill

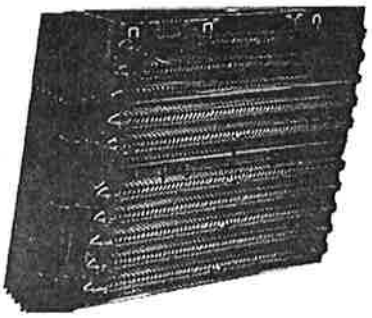


Figure 54

Cooling Tower Fill
Photo: Courtesy of Baltimore Aircoil Company

Fill is typically available in a "film type" design. The fill causes the water to spread into a thin film and flow over a large vertical area. This design is significantly more efficient than the splash type used in the past.

Mechanical-draft towers may be classified as crossflow or counterflow. This nomenclature refers to the heat transfer arrangement used to cool the water. In a crossflow-tower, which is most common, the fill sheets hang vertically in the tower. Fill heights can be from 2 feet long to over 20 feet.

Crossflow towers

may have fill on one or two sides. Single side fill towers are particularly useful when prevailing wind conditions dictate or when access to the tower is limited by site restrictions.

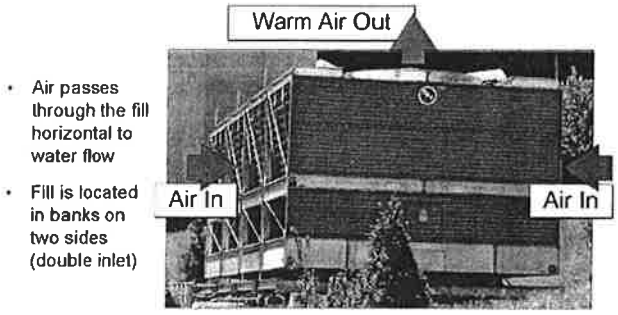


Figure 55

Induced-Draft Crossflow – Double Inlet
Photo: Courtesy of Baltimore Aircoil Company

In a crossflow tower, warm water is distributed over the top of the sheet and flows by gravity down both sides of each sheet. The cooling air enters the front face of the fill and traverses across the sheet horizontally at 90° to the waterflow, exiting through a set of drift eliminators.

In a counterflow tower, the warm water is distributed over both sides of the fill sheets, which are typically 12 inches tall, and arranged in layers up to six feet high in the tower. The entering air moves 180 degrees opposite of the falling water in an upward direction, or counter to the falling water. The eliminators in a counterflow tower are mounted above the water distribution system. Figure 56 shows a counterflow cooling tower with a blow-thru design, which is discussed in the next section.

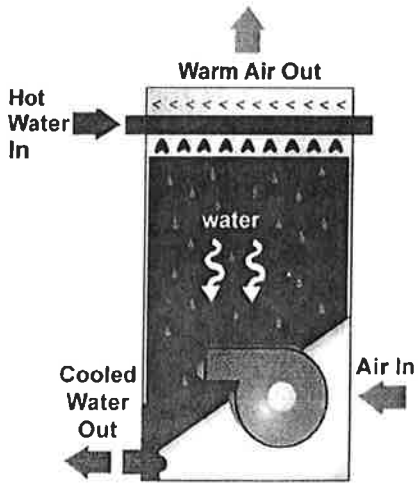


Figure 56

Forced-Draft Counterflow – Tower
Photo: Courtesy of Baltimore Aircoil Company

Forced Draft Blow-Thru

Forced-draft towers use a centrifugal or axial fan to blow air through the fill. Today, over 80 percent of cooling towers on HVAC applications use axial fans. Axial fans conserve energy because they require less horsepower than centrifugal fans in cooling tower designs. While the axial fan is a less efficient type of fan than a centrifugal, its use in low static draw-thru cooling tower designs results in lower overall horsepower than centrifugal fans. Centrifugal fans in cooling tower design are applied in the blow-thru configuration.

- Fan forces air through tower
- Uses centrifugal fans
  - High horsepower
  - High static pressure
- High entrance velocity
- Small footprint
- Counter-flow
  - Air flows opposite to water
- Applications
  - HVAC (Chillers)
  - Clean process

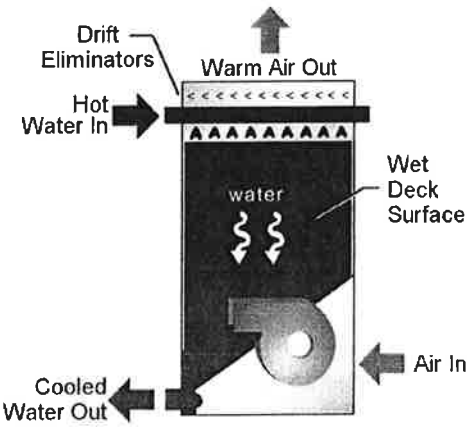


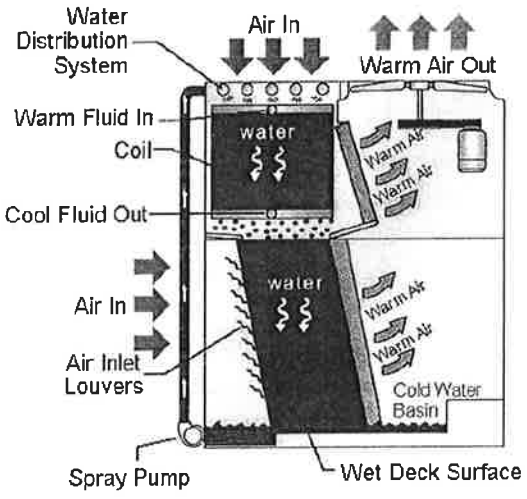
Figure 57

Forced-Draft Blow-Thru
Illustration: Courtesy of Baltimore Aircoil Company

Closed-Circuit Cooling Towers (Fluid Coolers)

A closed-circuit cooling tower is an evaporative condenser except that instead of refrigerant, water or glycol is circulated inside the coil. A common application is in closed-loop water source heat pump systems. The purpose is to maintain the water loop between a fixed minimum and maximum temperature by staging the spray and fan. A water sensor instead of a refrigerant sensor sequences the fan and spray stages.

Closed-circuit cooling towers benefit from the evaporative cooling spray coil concept and resemble evaporative condensers closely except for the physical design and circuiting of the coil inside.



Often used with WSHP systems and chillers where a closed condenser loop is desirable

Figure 58

Closed-Circuit Cooling Towers (Fluid Coolers)
Illustration: Courtesy of Baltimore Aircoil Company

Closed-circuit cooling towers are also used with water-cooled chillers when a closed condenser water loop is being used. The coil and fan design result in a higher first cost than cooling towers for the same tonnage.

Closed-circuit cooling towers can often be justified based on the benefits they supply: less maintenance, ability to run dry in winter, less down time, and limited fouling (if any) occurs on the outside of the tubes where it can be controlled by water treatment.

Use of closed-circuit cooling towers results in less condenser and piping fouling than with an open cooling tower.

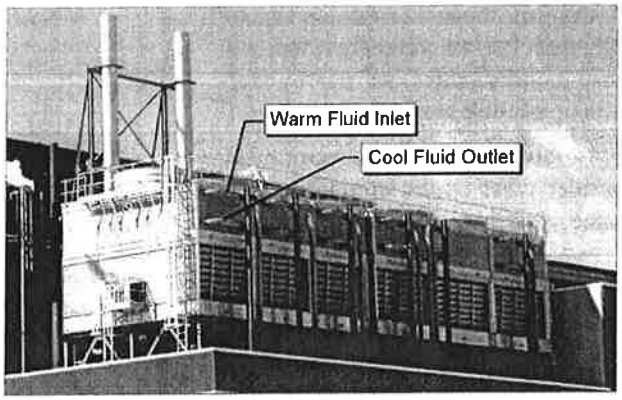


Figure 59

Closed-Circuit Cooling Tower (Fluid Cooler)
Photo: Courtesy of Baltimore Aircoil Company

Application of Cooling Towers

Placement

When selecting the cooling tower location, sufficient clearance should be allowed for the free flow of air to the inlet of the tower and for its discharge from the tower.

Obstructions will reduce airflow causing a reduction in capacity.

The top of unit discharge must be level with or above any adjacent walls.

Small amounts of recirculation can result in a decrease in actual heat rejection capacity.

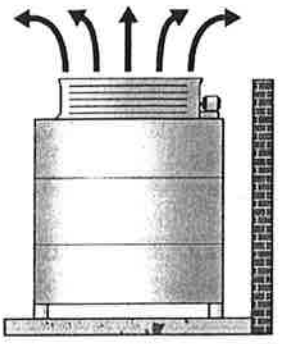


Figure 60

Placement of Cooling Towers

Cooling tower location should be such that the air discharge will not cause condensation on nearby surfaces or wetting because of drift.

Before the tower is positioned, consider what issues would arise if a plume (visible fog-like discharge) existed. Generation of a plume depends on outside conditions, so is not predictable.

Note the direction of prevailing wind. The tower should be located away from the source of exhaust heat and contamination.

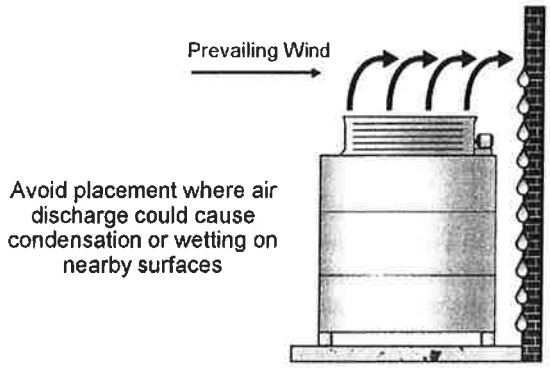


Figure 61

Cooling Tower Discharge Concern

Locate cooling towers

to minimize the impact of sound created by air or water. If location choices are limited, intake and discharge sound attenuation can be added. Additionally, consider oversizing the tower, which will slow down the fan and lower the sound level.

Each cooling tower should be located and positioned to prevent the introduction of the warm discharge air and the associated drift into nearby outdoor air intakes and building openings. This drift may contain water treatment chemicals or biological contaminants, including Legionella. Always avoid situations that may allow hazardous materials to get into the ventilation systems of buildings.

Effects of Reduced Cooling Tower Water Temperature

There is a limit on how low the temperature of the condenser water entering the water-cooled chiller can be without head pressure controls being required. For water chillers, an entering condenser water temperature of approximately 55 to 60° F is typically the minimum acceptable at full condenser flow. Below that, the minimum differential pressure between cooler and condenser may not be maintained and some form of head pressure control is required.

As a rule of thumb, water-cooled equipment efficiency is increased approximately 2% for every 1° F decrease in entering condenser water temperature



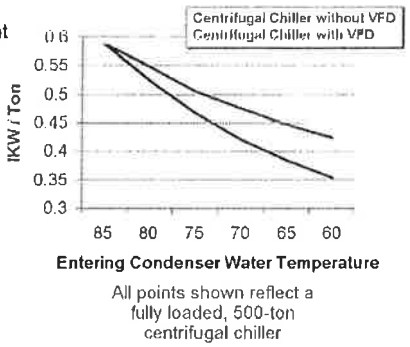


Figure 62

Effects of Reduced Cooling Tower Water Temperature

Rule of Thumb

Water-cooled equipment efficiency is increased approximately 2 % for every 1° F decrease in entering condenser water.

Head pressure control

on a water-cooled condenser system refers to a method of controlling the water flow or temperature of the condenser water to maintain minimum condensing temperatures in the refrigeration circuit.

While cooler condenser water increases chiller efficiency, certain situations can exist where the tower water temperature will be too cold for chiller operation. For instance, after the system has been off all night, an early morning start-up of a chiller may require head pressure controls because the water from the tower is below the minimum of 55 to 60° F.

Figure 63 is an example of the effect on a typical screw chiller of reduced entering condenser water temperatures.

The data is for Based on a R-134a screw chiller, with a leaving chilled water temperature of 45° F.

Condenser Entering Water Temp	Capacity Tons	kW Input	kW Ton
80.0	110.8	71.6	0.65
85.0	106.3	76.0	0.71
90.0	101.6	80.4	0.79
95.0	97.1	86.5	0.89

Figure 63

Condenser Entering Water Temperature (ecwt) Effect

A typical way to provide head pressure control is to use a cooling tower bypass with a three-way valve controlled directly by the chiller head pressure. Refer to the control section of this TDP for details.

Hydronic Free Cooling

Hydronic free cooling is often used in systems that do not incorporate an airside free cooling cycle but have a cooling tower.

In fall and spring, the wet bulb temperature will be lower than the summertime periods. The cooling tower can use these lower wet bulbs to supply cold water to the building, allowing the chiller to remain off line as long as possible.

When return condenser water form the cooling tower is sufficiently cold, it is diverted through a plate-frame heat exchanger where it cools water in the chilled water loop, and all chillers in the system are turned off. Because condenser and chilled water streams do not mix, fouling of the chilled water loop is not a concern.

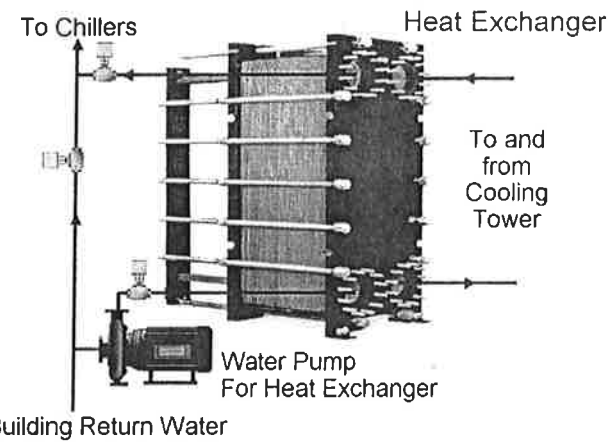


Figure 64

Hydronic Free Cooling Cycle
Photo: Courtesy of API Heat Transfer

Example:

The operating leaving chilled water temperature for a system is 44° F. A plate-frame heat exchanger is used and provides an approach of 2° F. For a certain set of operating conditions, the cooling tower is able to produce 42° F supply water. With the 2° F heat exchanger approach, cooling tower water can be used to produce 44° F water in the chilled water loop. Therefore, the plate frame heat exchanger can be used to supply cooling to the building. All chillers can be turned off.

Heat exchanger approach defines the performance of the plate-frame heat exchanger. The approach is the difference between the temperature of supply water from the cooling tower entering the heat exchanger and the temperature of water leaving the heat exchanger.

Some packaged products, like vertical indoor units, can incorporate a hydronic water-to-air economizer coil inside the unit to supply free cooling for that unit.

In a strainer-cycle method of free cooling, tower water is strained, and then introduced directly into the chilled water loop to produce cooling. Because the open tower water is being mixed into the closed system, a high quality strainer (side-stream filter) is recommended at the tower.

A strainer cycle

introduces oxygenated water directly into the chilled water loop. This is not a common practice.

The presence of an intermediate heat exchanger reduces the overall effectiveness of the plate-frame method versus the strainer cycle. However, far more building operators like having no additional water quality concerns since plate-frame heat exchangers do not mix the open loop with the closed chilled water loop.

Cooling Tower Relief Profiles

"Relief" pertains to how much the cooling tower delivers progressively colder water as a function of reduced load on the chiller and reduced ewbt profile.

The term cooling tower "turndown" is also used interchangeably with relief to designate the same concept.

In most regions of North America the relief profile might resemble the values in the ecwt column. An exception might be areas like Houston and Miami. At less than 100% of load, the assumption is the outdoor conditions of dry bulb and wet bulb have fallen off. As a result, the cooling tower can produce cooler water in the fashion shown.

The two right-hand columns reflect progressively more humid locations offering less relief. This is a direct result of the wet bulb profile.

Chiller Capacity	ECWT ARI (° F)	ECWT Humid Areas of North America 1.0° F/10%	ECWT ASIA 0.5° F/10%
100%	85.0	85.0	89.6
90%	81.0	84.0	89.1
80%	77.0	83.0	88.6
70%	73.0	82.0	88.1
60%	69.0	81.0	87.6
50%	65.0	80.0	87.1
40%	65.0	79.0	86.6
30%	65.0	78.0	86.1
20%	65.0	77.0	85.6
10%	65.0	76.0	85.1

The term "turndown" is used interchangeably with relief

Figure 65

Cooling Tower Relief Profiles

The third column reflects a 1° F lowering of the tower water temperature per each 10% reduction in chiller load. The fourth column is 0.5° F per 10% load reduction.

Column 4 reflects some Asian climates where the design entering wet bulb is initially higher, so the design entering condenser water to the chiller needs to be 89.6° F.

Matching Tower Profiles

It is very important in centrifugal chiller applications, that the design engineer research which tower turndown profile most closely applies to the location of the project. Centrifugals are non-positive displacement chillers. Their impeller(s) must be selected to overcome the resulting head pressure at both full and part load that results from the tower relief profile. For screw, scroll, and reciprocating chillers, this is not an issue. For more details on centrifugal chiller full and part-load stability, refer to TDP-623, Water-Cooled Chillers.

Selecting a centrifugal chiller selection at full and part load for use with the cooling tower profile, is a task normally provided by the chiller manufacturer's representative working with the design engineer.

Cooling Tower Differences: Electric versus Absorption Chillers

Both electric and absorption chiller types require the cooling tower to be sized to handle the total heat of rejection. As discussed previously, the total heat of rejection is equal to the cooling capacity of the chiller plus internal heat generated by the compressor in an electric motor-driven chiller

Total heat of rejection

and gpm required for tower selection should be taken directly from the manufacturer's electronic catalog selection data on a specific project basis.

The internal heat of electric chillers is generated primarily by the compressor motor doing its work. Water-cooled electric chillers utilize a multiplier of about 1.17 on the cooling load to represent the total heat of rejection. For example a 500-ton electric chiller typically requires a cooling tower to be sized to handle 500 * 1.17 or about 585 tons total heat of rejection.

Absorption chillers have no compressor, but they generate a greater amount of heat than electric chillers per cooling ton. This heat must be rejected by the tower.

	Heat Rejection Factor	ARI gpm/ton
 Electric	1.17	3.0
 Single-Effect Absorption	2.50	3.6
 Double-Effect Steam	1.80	4.0
 Double-Effect Direct-Fired	1.80	4.5

Figure 66

Cooling Tower Differences – Electric versus Absorption Chillers

The large heat rejection factors

for absorption chillers result in larger cooling towers than with electric chillers.

The absorption cycle has an ongoing reaction in the absorber section. This "exothermic" reaction generates heat and, coupled with the heat input into the generator, creates a large total heat of rejection requirement.

Single-Effect Absorption Chiller

- Cooling tons * 2.5 (approx) equals total heat of rejection tons for tower sizing
- At ARI selection conditions, 3.6 gpm/ton is typical for single-effect absorption.
- Individual job selections can vary.

Double-Effect Absorption Chiller (Direct fired or Steam)

- Cooling tons * 1.80 (approx.) equals total heat of rejection tons for tower sizing
- At ARI selection conditions, 4 to 4.5 gpm/ton is typical for double-effect absorption.
- Individual job selections can vary.

If considering a new project with absorption chillers, the larger cooling tower flow rate, size, and first cost must be factored into the analysis.

When replacing absorption chillers

with same tonnage electric chillers, the existing tower size and condenser water pump flow rate should be more than adequate. The electric chiller selection should benefit from higher flow rates and a bigger tower frame. If existing tower flow rates are too much, consider trimming the pump impeller.

If replacing electric with same tonnage absorption chillers, the existing frame tower will usually not accommodate the increased heat rejection requirements. The absorption chiller condenser water flow and heat rejection requirements should be used to make a new tower selection. The existing condenser water pump's ability to handle the new flow must also be verified.

Cooling Tower Selection

To select a cooling tower, the following must be determined:

Entering Wet Bulb Temperature (ewbt)

Typically this is the "design" wet bulb for your exact location. In selecting a tower, we need to determine the worse case condition under which the tower must function. Thus the wet bulb temperature of concern is not the mean coincident wet bulb, which is an average type value. When selecting a tower, the 0.4 percent wet bulb temperature from the ASHRAE Fundamentals book is typically used.

- Entering wet bulb temperature
- Entering condenser water temperature (ecwt)
- Leaving condenser water temperature (lcwt)
- Gallons per minute through the condenser

Figure 67

Cooling Tower Selection Parameters

Entering Condenser Water Temperature (ecwt)

This is sometimes called the cold-water temperature exiting the tower. This value is used in the selection of a water-cooled chiller and is usually 85° F for most of North America. However, there are several locations where lower temperatures can be selected.

Leaving Condenser Water Temperature (lcwt)

This is sometimes referred to as hot water temperature entering the tower.

Gallons per Minute (gpm) of the Condenser

Usually three gpm/ton is used. When considering a non-standard flow rate such as two gpm/ton, as discussed earlier, consider the effects of increased fouling and the higher condenser water temperature energy penalty on the chiller.

The total heat of rejection is normally printed out on the water-cooled equipment selection program. If the selection program did not calculate total heat of rejection, it is easy to do by hand. If there is fresh water in the tower and you already know the range and gpm you desire, (say 95 - 85 = 10° F range) you can calculate the THR with the equation:

Btuh = 500 * condenser gpm * (Δt).

Today, with computerized selection programs and CTI Certified ratings, cooling towers can easily be selected by simply providing the above information. Site specific needs will help determine the type of tower.

CTI
(Cooling Tower Institute)

is a certification agency for the tower industry that assures published manufacturers' capacities are met by actual product performance.

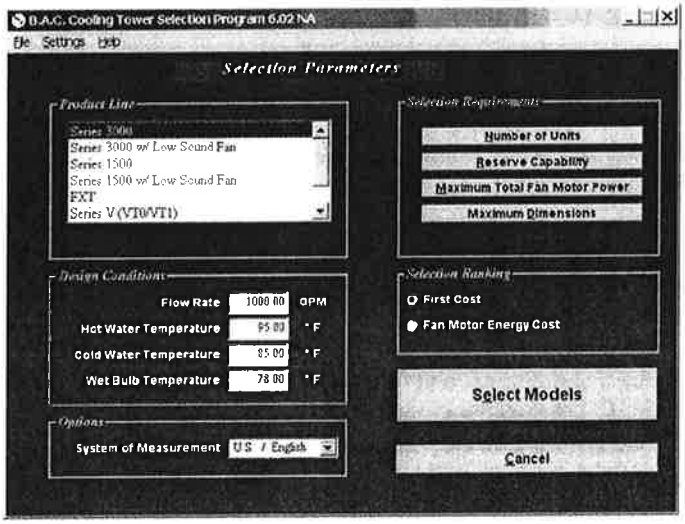


Figure 68

Cooling Tower Selection Program
Screen Capture: Courtesy of Baltimore Aircoil Company

Water Treatment[1]

A water treatment specialist is a wise investment. A specialist is trained and knowledgeable on creating treatment programs for cooling tower condenser systems, evaporative condensers, and closed-circuit cooling towers. Problems a water treatment specialist can help prevent include: scale, corrosion, sludge formation and microbiological contamination.

Cooling tower fill and tubes affected by:
- Scale
- Corrosion
- Sludge
- Contamination

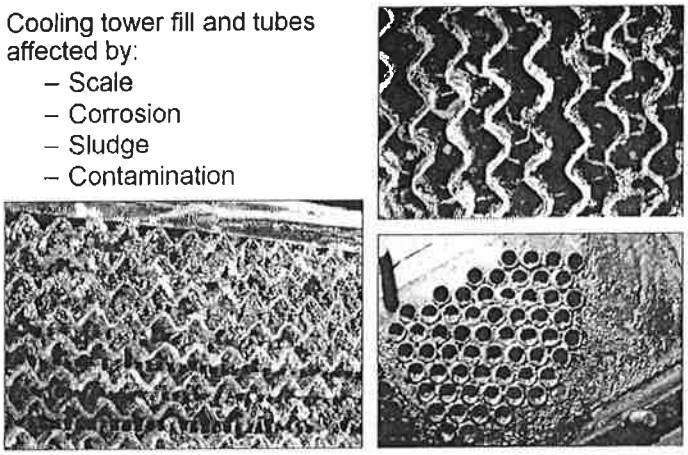


Figure 69

Effects of Scale, Corrosion, and Contamination
Photos: Courtesy of Baltimore Aircoil Company

[1] Information/text in this section provided by ChemSearch

Scale

Scale is an accumulation of mineral deposits and acts as an insulating barrier, reducing the system's ability to transfer heat, thus increasing energy costs to operate the system. Scale can also increase refrigerant head pressure, which can cause serious mechanical damage to the compressor, thereby adding replacement expense, downtime, and inconvenience. High head pressure is caused by the build-up of scale in the condenser tubes, and on the tube surfaces within evaporative condensers and closed-circuit cooling towers. This causes compressors to work harder.

Scale build-up

of just 1/32 inch may decrease heat transfer by as much as 40 percent.

Corrosion

Uniform and pitting corrosion can occur in both the chilled-water system and cooling tower/condensing system. Uniform corrosion is caused by low pH levels indicating an acidic condition, which generally thin the metal throughout the system; whereas pitting is a localized cavity caused by local cell action associated with a presence of oxygen bubbles. A combination of the oxygen level, temperature, and pH cause localized pitting. It is important to maintain a proper pH level. Erosion corrosion is caused by the friction of the solids moving through the system; this can be minimized by maintaining a system as clean and as free of suspended solids as possible.

Corrosion

can lead to pipe and tubing failure, and internal damage of buildings and loss of system water.

Sludge Formation

Cooling towers either push (blow-thru), or pull (induced-draft), air into the tower in a cross-flow or counterflow direction to the water droplets. Air brought into the system will contain airborne particles and debris.

Note

A cooling tower can be considered a large "air washer" of airborne particles debris.

Sludge that fouls the condenser tubes is as serious as scale. The resulting sludge will adhere or deposit on condenser tubes, causing poor heat transfer and subsequently high condenser head pressure. Sludge can also plug condenser tubes or lines, impeding water flow, causing poor heat transfer, and providing a growth environment and food source for bacteria.

Biological Growth

Microbiological contamination (algae, bacterial slime, and fungi), when circulated through a cooling tower/condenser system, can reduce the effectiveness and efficiency of the system. The specific aspects of the problems generated by these microorganisms are outlined next.

Algae needs

sunlight and air to survive. They are generally found growing in those sections of the cooling tower system that are exposed to sunlight, such as the cooling tower top water distribution deck and the cooling tower louvers.

The formation of algae in a cooling tower/condenser system occurs because of the special environmental conditions prevalent in the system. Algae are chlorophyll-containing microorganisms capable of multiplying rapidly and producing large masses of plant material.

Algae growth can compromise the water distribution system by clogging the water distribution in the system and affect the cooling tower's operating efficiency. In addition, dead algae can combine with airborne debris and other contaminants to form sludge, which can foul the condenser, causing major mechanical breakdowns or further reduced efficiency. Sludge can be a food source for bacteria growth and provide a friendly environment for such organisms as sulfate reducing bacteria.

Control of biological growth

is relatively easy to accomplish and is essential to the safe operation of the tower. ASHRAE has published Guideline 12, entitled "Minimizing The Risk Of Legionellosis Associated With Building Water Systems." This common-sense guideline is available from ASHRAE and is also downloadable from several manufacturers' websites.

Slime deposits, are caused by the presence of excessive amounts of bacteria in the cooling tower/condenser system water supply. Slime-forming bacteria will adhere to condenser tubes, causing poor heat transfer as serious as that created by scale. Dead algae and slime in a system can become lodged in condenser tubes and clog the system's filtering screens. Finally, excessive slime buildup can produce a foul and disagreeable odor.

Fungi are non-chlorophyll organisms that live and grow in the dark areas of a cooling condenser system. Fungi thrive in the dark areas of the system and usually attack wood materials, which used to be more common in earlier tower designs, causing premature failure of components.

(Info/text provided by ChemSearch)

Condenser and Cooling Tower Control Systems

For a refrigeration system to function properly, the condensing pressure and temperature must be maintained within certain limits. This is known as head pressure control.

Abnormally high condensing temperatures cause loss of capacity, extra power consumption, and overloading of the compressor motor and possible permanent damage to the compressor and motor. Safety or limit controls normally protect against these conditions.

Too low of a condensing pressure will cause insufficient pressure for liquid feed devices, which will starve the evaporator, resulting in loss of capacity.

A head pressure control system maintains system head pressure at a predetermined minimum level.

Why?

- Maintain liquid subcooling and prevent liquid line flash gas
- Provide sufficient pressure drop across TXV

How?

1. Water regulating valve
2. "Flooded" head pressure control (uncommon in comfort air-conditioning)
3. Condenser fan cycling (common)
4. Variable condenser fan speed control (common)
5. Vane/damper control system

Figure 70

Condenser Head Pressure Control Methods

Consequently, controls and control algorithms can be used to regulate condensing temperatures. The method used will vary depending on the temperature range of the condensing media, the type of condensing equipment used, and the load variation of the system.

Water-Cooled Condensers

On once-thru water systems, both the ecwt and the refrigeration load may vary widely. The water flow rate through a water-cooled condenser may be controlled automatically with a water-regulating valve. The valve is installed in the discharge water line and operates in response to the condensing pressure in the condenser. Many new chillers come equipped with a built-in head pressure control feature that can control the valve to maintain proper head pressure.

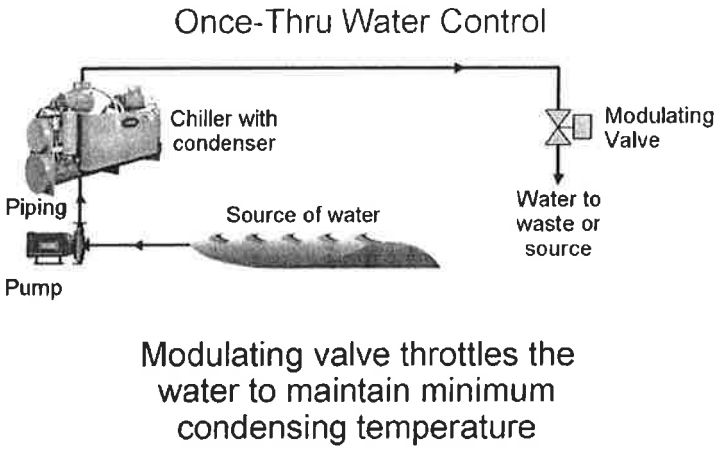


Figure 71

Water-Cooled Condenser Head Pressure Control

Installing the regulating valve in the discharge of the condenser keeps the water circuit full, which minimizes scale formation and possible alternate wetting and drying action. As the condensing temperature drops, the valve throttles the water flow to maintain head pressure. On shutdown, the valve closes off as the head pressure reduces and finally gives complete shutoff. The valve is set to handle peak load conditions.

Air-Cooled Condensers

Two general categories of head pressure control for air-cooled condensers meet the requirement of maintaining a minimum head pressure at the inlet to the liquid feed device. These two categories are:

1. Refrigerant side control
2. Air side control

Refrigerant Side Control

Refrigerant side control is accomplished by reducing the amount of active condensing surface available in the condenser by flooding the coil with the liquid refrigerant. This type of control requires the use of a receiver and an excess charge of refrigerant to back up into the coil.

Refrigerant side head pressure control

is not as common as airside control on packaged air-cooled condensers and condensing units.

There are several ways this may be accomplished. One method uses a bypass valve to bypass hot gas into the liquid line to restrict the flow of refrigerant from the condenser and apply discharge pressure to a receptacle for the liquid refrigerant called a receiver.

The hot gas works against head pressure to maintain a fixed minimum pressure. This system of head pressure control can be used at very low ambient conditions.

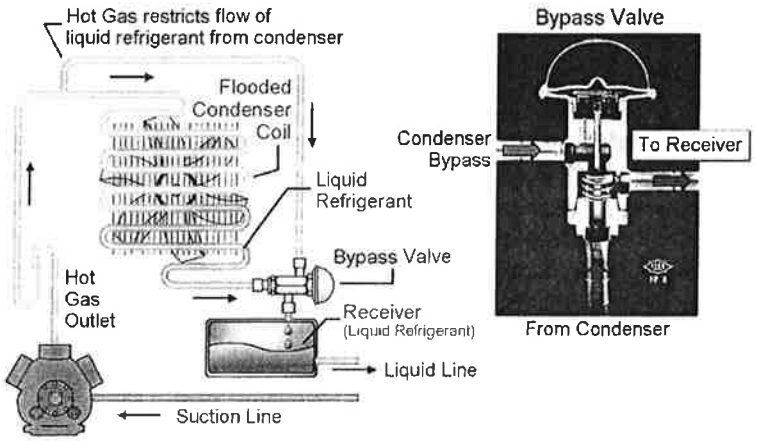


Figure 72

Air-Cooled Condenser Head Pressure Control

Airside Control

Airside control has the advantage of not requiring a receiver or an excess charge of refrigerant. A means of starting the compressor during winter operation is usually required. This can be accomplished by bypassing the low pressure cut-out on start-up until the head pressure has built up to maintain refrigerant flow through the liquid feed device.

Control of condensing pressure with airside control may be accomplished by the following methods:

- Cycling the fans
- Fan speed control
- Cycling of the fan combined with fan speed control

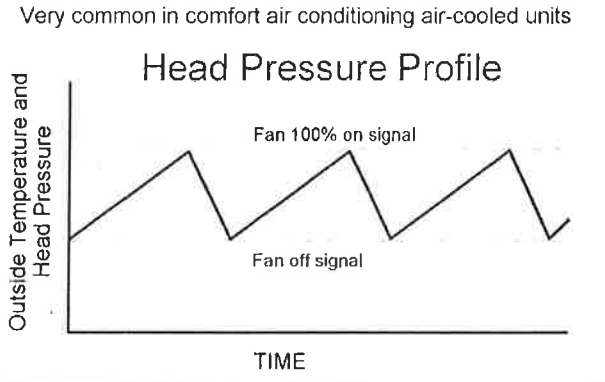


Figure 73

Head Pressure Affecting Fan Cycling

Fan cycling can be accomplished in response to variations in head pressure or to outdoor ambient temperatures.

Fan speed control is accomplished with accessory electronic speed controller that take a signal from the condenser pressure/temperature sensors. Fan speed control requires the controlled fan motor be capable of speed reduction. If not, it must be replaced with a compatible motor in the field provided by the manufacturer.

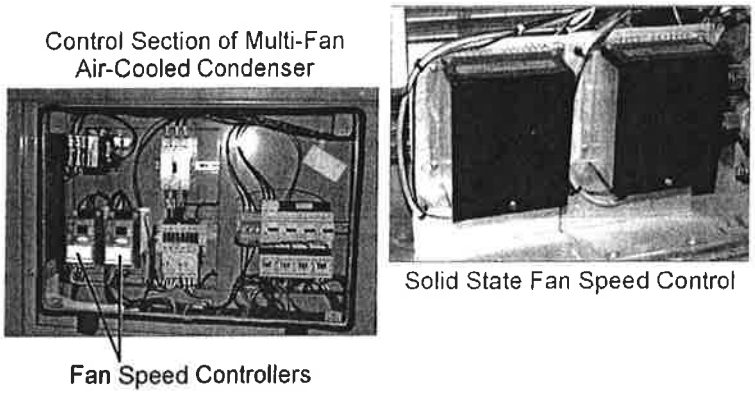


Figure 74

Solid State Speed Control

On multi-fan units, usually one fan will be cycled on outdoor temperature, another fan on pressure and the last fan speed controlled off of condenser coil temperature or pressure by a condenser fan motor speed control.

Modulating damper control is not as common as the previous methods but merits a discussion. Damper control has been used in combination with fan cycling. The damper is mounted on the active fan section and modulates to reduce airflow to reduce the airflow when the other fans are off.

Propeller fans have a characteristic opposite that of centrifugal fans: increasing power input with increasing resistance. Therefore, the motor must have adequate horsepower for operation with the dampers throttled.

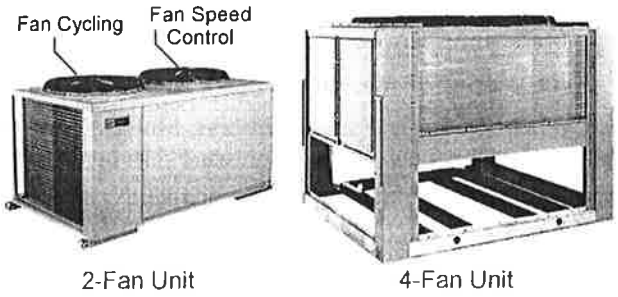


Figure 75

Air-Cooled Condenser Head Pressure Control

Mechanical Control

of modulating dampers has given way to electronic speed control as a method of head pressure control.

Evaporative Condensers

An evaporative condenser has characteristics much like a cooling tower. At light loads or low outdoor wet bulb conditions, condensing temperatures will drop to unacceptable levels unless suitable controls are used. In addition, the condenser can experience icing caused by lower-than-acceptable spray water temperatures.

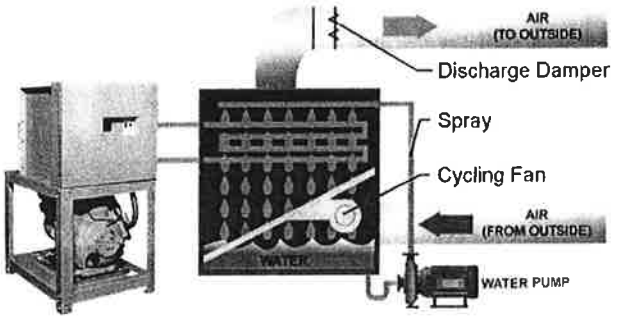


Figure 76

Ducted Evaporative Condenser

Evaporative condensers use several types of control that are staged to maintain the correct head pressure range. These stages are:

- unit is started with dry coil
- spray water is initiated
- low-speed fan airflow initiated
- high-speed airflow initiated

Control of an evaporative condenser may also be accomplished by any or a combination of the following methods:

- Cycling the fans
- Modulating dampers
- Variable frequency drives (VFDs)

Cycling the fan is a simple process. Motor operation is controlled by a condensing-pressure controller. When the condensing pressure falls below a prescribed limit, the fan is cycled off. The spray pump continues to run. Depending on physical arrangement and load characteristics, rapid cycling of the fan can occur. The general rule calls for a maximum of six starts per hour.

Modulating dampers on centrifugal fan units may be installed in the discharge air connection of the unit. The dampers modulate airflow through the unit in response to condensing pressure. If the unit is to run year-round on a wet-coil basis, outdoor installations are not recommended because of the problems of control and protection from freezing. Decreasing airflow through the evaporative condenser will prevent freezing of the recirculated water during winter operation.

The most precise means to control an evaporative condenser is with the use of a variable frequency drive (VFD) to control the airflow through the unit. The VFD controls the fan(s) speed in response to condensing pressure. As the condensing pressure drops, the fan speed can be reduced to allow only the minimum required airflow to maintain the predetermined condensing pressure. Installations that are to be controlled by VFDs require the use of an inverter duty motor designed per NEMA standards, which recognizes the increased stresses placed on motors by a VFD.

In intermediate seasons

or unexpectedly warm days, provisions should be made to rapidly fill the sump with water in order to handle the increased load that may suddenly occur.

Operating the unit dry was suggested earlier in our discussions on the application of evaporative condensers. Such an arrangement permits the unit to be located outside and operated in freezing weather. Remember, condensing capacity with a dry coil in freezing weather is only about 45 percent of wet-coil capacity.

If dry coil operation is satisfactory, it will probably be desirable to provide a means of condensing temperature control such as modulating dampers, or cycling the fan motor to handle low outdoor air temperatures below 35° F.

Note:

Cycling of the recirculating water pump on an evaporative condenser is not recommended. The scaling rate on the coil will be accelerated because of the alternate wetting and drying of the coil.

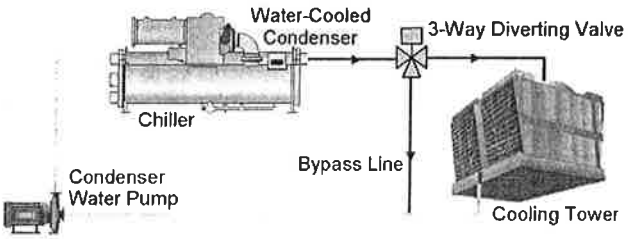
Cooling Towers

The capacity of a cooling tower is a function of the entering wet bulb temperature. In cases where it is desirable to maintain condensing temperatures in the water-cooled condenser above a minimum limit, several control methods have been used.

Water Bypass of the Cooling Tower

This method is used to prevent nuisance tripping of the chiller during morning start-up. At night, the water temperature in the tower sump may have dropped below the minimum temperature the chiller can handle. This is approximately 55 to 60° F for most chillers.

At start-up, heated water exiting the condenser bypasses the tower and raises the tower loop temperature to acceptable chiller operating water temperatures. Care should be taken to locate the control valve so that the loop volume of the bypass circuit isn't too large. If the bypass is far away from the chiller, the circuit may take too long to heat up and the chiller can still trip off on low pressure at start-up.



3-way diverting valve bypasses some of the water around the tower to maintain a minimum water temperature (55 to 60° F)

Figure 77

Water Bypass of Cooling Tower

As shown in the diagram, a diverting valve is installed between the condenser inlet and discharge lines. Sometimes operating personnel like to control this valve manually. Normally, the valve is controlled automatically from entering condenser water temperature, or more recently directly from the reference head pressure control signal on the chiller.

Fouling can increase

if flow through the condenser is reduced for long periods. Head pressure controls can reduce condenser water flow from design levels. Reducing tower water flow is not popular with the tower manufacturers for the same reason, wet/dry spots can occur, which can promote the formation of scale in the tower.

As the temperature of water leaving the tower decreases, the warm water from the condenser discharge is bypassed to warm the inlet water to a minimum level. This action reduces the amount of water to the tower and decreases its ability to cool water.

Instead of constant water flow with a diverting valve arrangement, another method utilizes a 2-way modulating valve. This valve could also be controlled from chiller head pressure. Since there is a reduction in flow through the condenser water loop, the pump must ride the curve or be fitted with a VFD during periods of lower flow requirement. That is because deadheading the pump is a concern.

Water bypass methods of head pressure control should be limited to morning start-up. For prolonged operation, airflow control on the tower as a method of capacity control is more desirable.

Airflow Control on Cooling Towers

The primary method of controlling capacity on a cooling tower is to modulate the airflow through the tower in proportion to the load. ASHRAE 90.1 requires that all motors above 7.5 hp have the ability to be run at 2/3 speed or less to save energy. The methods to meet this requirement and maintain the desired leaving fluid temperature from the tower are as follows:

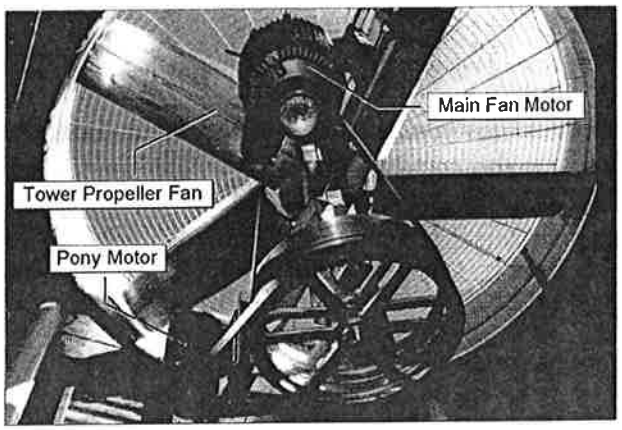


Figure 78

Cooling Tower Fan with Pony Motor
Photo: Courtesy of Baltimore Aircoil Company

Cycling the Fan Motor(s) On and Off

This method may be sufficient where close control of the leaving water temperature is not critical. The more cells or motors there are in the cooling tower installation, the more stages of control are possible. Wear and tear on the machinery must be considered.

Two-Speed Motors

Two-speed motors provide an additional stage of control, which can be important on one and two-cell tower installations. However, the used of two-speed motors has declined because VFDs are a more popular choice for approximately the same cost.

Pony Motors

Pony motors provide an additional stage of control like two-speed motors, but have the advantage of motor redundancy. Should one motor fail, the unit can be run on the other motor until a repair is possible. Standard single-speed motors are also used, which are usually available "off-the-shelf" at supply houses (versus two-speed motors, which are often special order). Traditionally, pony motors are about 1/3 the size of the main fan motor. However, some designs utilize a pony motor equal in size to the main fan motor. At that point it is simply a second motor.

Variable Frequency Drives (VFDs)

VFDs adjust the motor speed and thus the fan speed. VFDs provide the closest control of the leaving fluid temperature of all the methods. The cost of a VFD is similar to the two-speed motor. The cost of a VFD is also offset by the fact that VFDs eliminate the need for separate motor starters.

Air Volume Dampers on Centrifugal Fan Cooling Towers

By adding static to the discharge of the centrifugal fan, actuator-controlled dampers reduce the fan horsepower, saving energy. However, this method is not as energy efficient as VFD control, and may be plagued by actuator and linkage problems in the field.

Combination Methods

Combination methods, such as when a VFD is used on one cell of a two-cell installation and the other cell is cycled on and off to meet the load, are also used.

All of these methods can be controlled by a temperature sensor in the leaving fluid line from the tower.

Water-cooled chillers

have greater efficiencies resulting from a lower leaving water temperature from the tower. This occurs when the entering wet bulb temperature is below design and/or the load is below design. This should be taken into account in any tower control sequence.

Winter Operation of Cooling Towers

Where it is necessary to operate a cooling tower in winter when freezing temperatures are encountered, precautions must be taken to prevent freezing of water in exposed piping and the tower sump during shutdown periods.

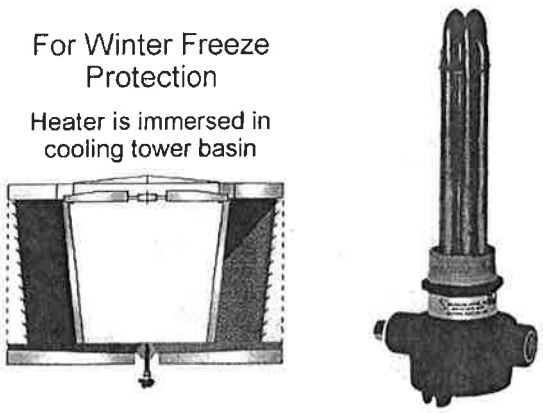


Figure 79

Winter Operation – Tower Heating Element

There are two commonly used methods to overcome these freezing dangers:

1. A remote sump is located inside in a heated area, and the condenser water pipes are run and sized so that water drains rapidly from the tower and does not remain in the tower or the piping.
2. An electric, or steam or hot water heater is located in the tower basin or sump and operates whenever the sump water temperature falls below 40° F. This is a very common method of freeze protection for normal air-conditioning applications.

In all applications, where freezing temperatures are encountered, provision must be made for draining all exposed lines and equipment during extended shutdown periods. Often, the lines are heat traced which means they are wrapped with an electric heater cable and heavily insulated.

Summary

In this module we have discussed the function of the condenser in the refrigeration cycle. We have described the various types of condensers available and the condensing media they employ.

We have presented application data for water-cooled condensers, open and closed-circuit cooling towers, and evaporative and air-cooled condensers.

The various types of controls used for maintaining condensing temperature and head pressure have been reviewed. Factors that influence the selection of proper heat rejection equipment are listed here in order of importance:

1. Availability of water
2. Energy costs
3. Size and scope of cooling plant required
4. Space requirements
5. Quality and availability of maintenance staff
6. Water treatment costs
7. Length of operating season
8. Customer preference (may change priority on a per-job basis)

As with any equipment selection, careful review of key job parameters and owner/occupant needs will guide the designer in selecting the proper type and size of condensing equipment and control schemes to use.

Work Session

1. Name three types of condensers used in the HVAC industry.

   _____
   _____
   _____

2. Name the two components that comprise total heat of rejection:

   _____, _____

3. What is a typical heat rejection factor for air-cooled equipment?

   _____
   _____

4. List 3 factors that affect fouling rate on water-cooled condensers.

   _____
   _____
   _____

5. Sketch a typical air-cooled refrigeration cycle and show the position of the condenser relative to the other three components. Describe the function of the condenser.

   _____
   _____
   _____

6. What type of condenser is used on larger water-cooled chillers and why?

   _____
   _____
   _____
   _____

7. How does a crossflow tower differ from a counterflow tower?

   _____
   _____
   _____

8. Name the four factors required for cooling tower selection.

9. Define cooling tower relief profiles and explain on what type of chiller they are extremely important.

10. What kind of tower is typically used with a closed-loop water source heat pump system?

11. Why does the cooling tower size for an absorption chiller differ from a typical vapor compression chiller?

12. Define these four terms:

    Entering Wet Bulb Temperature:

    Approach:

    Range:

    Total Heat of Rejection:

13. Describe the methods of head pressure controls for each of the following:

    Water-Cooled Condensers:

    Air-Cooled Condensers:

Appendix

References:

API Heat Transfer, Buffalo, NY. http://www.apiheattransfer.com/

ARI Standard 550/590, "Water Chilling Packages Using the Vapor Compression Guide." http://www.ari.org/std/

BAC Cooling Tower Selection Program 6.02 with Product Information, 1/2003. http://www.baltaircoil.com/

BAC Evaporative Condenser Selection Program 7.1 with Product Information, 6/2004. http://www.baltaircoil.com/

Carrier Corp. Syracuse, NY, System Design Manual Part 1, Load Estimating. Cat. No. 510-304. http://training.carrier.com/

Cooling Tower Institute, Houston, TX. http://www.cti.org/

Standard Refrigeration, Melrose Park, IL. http://www.stanref.com/

ChemSearch, Cicero, New York. http://www.chemsearch.com/

Work Session Answers

1. water-cooled, air-cooled, evaporative

2. Refrigeration effect and heat of compression

3. It is a multiplier (typically 1.25). When applied to the refrigeration effect, it equals the heat of rejection that the condenser must handle.

4. water velocity, water quality, water temperature

5. See Figure 7 on page 4. The condenser rejects the refrigeration effect of the evaporator plus the compressor heat.

6. Shell and tube condensers, they are very efficient and offer mechanical cleanability of the water tubes.

7. In crossflow, the air passes through the fill horizontally with water flow downward. In counterflow, water and air are in opposite directions.

8. design entering wet bulb temperature, entering condenser water temperature, condenser water gpm, leaving condenser water temperature

9. Relief profiles depict the reduction in water temperature leaving a cooling tower as a function of outdoor wet bulb temperature. This is most important to centrifugal chillers since they must be selected to function correctly at part load with the tower water temperature that results from the relief profile. If not, surge can occur.

10. A fluid cooler, which has a closed water loop

11. The heat rejection per ton of cooling produced by an absorption chiller is greater than a conventional electric chiller. The tower will be larger with greater flow rates.

12. Entering Wet Bulb Temperature: the lowest temperature that water can reach by evaporation. The design entering wet bulb temperature is dependent on the geography and directly affects the approach.

    Approach: the difference between the temperature of the water leaving the tower and the entering wet bulb of the air entering the tower.

    Range: Difference between the temperature of the water entering the tower and the water leaving the tower.

    Total Heat of Rejection: the amount of heat to be removed from the circulating water within the tower

13. Water-Cooled Condensers: diverting valve bypass of either cooling tower or condenser and regulating valve

    Air-Cooled Condensers: fan cycling on outside air temperature, fan cycling on refrigerant pressure, and fan speed control

Prerequisites:

Form No.	Book Cat. No.	Instructor Presentation Cat. No.	Title
TDP-102	796-026	797-026	ABCs of Comfort
TDP-103	796-027	797-027	Concepts of Air Conditioning
TDP-201	796-030	797-030	Psychrometrics, Level 1: Introduction
TDP-400	796-037	797-037	Principles of Mechanical Refrigeration, Level 1: Introduction

Learning Objectives:

After reading this module, participants will be able to:

- Describe the types of condensers used in the HVAC industry and their characteristics.
- Show the condenser in the refrigeration cycle and explain its relationship to other components.
- Name the types of water-cooled condensers and describe their applications.
- Explain the process for selection of cooling towers and describe important terms.
- Compare the various types of cooling towers and understand their strengths and limitations.
- Identify the various methods of head pressure control for water cooled and air-cooled condenser systems.

Supplemental Material:

Form No.	Book Cat. No.	Instructor Presentation Cat. No.	Title
TDP-622	796-054	797-054	Air-Cooled Chillers
TDP-623	796-055	797-055	Water-Cooled Chillers
TDP-502	796-043	797-043	Water Piping and Pumps
TDP-501	796-042	797-042	Refrigerant Piping

Instructor Information

Each TDP topic is supported with a number of different items to meet the specific needs of the user. Instructor materials consist of a CD-ROM disk that includes a PowerPoint™ presentation with convenient links to all required support materials required for the topic. This always includes: slides, presenter notes, text file including work sessions and work session solutions, quiz and quiz answers. Depending upon the topic, the instructor CD may also include sound, video, spreadsheets, forms, or other material required to present a complete class. Self-study or student material consists of a text including work sessions and work session answers, and may also include forms, worksheets, calculators, etc.



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