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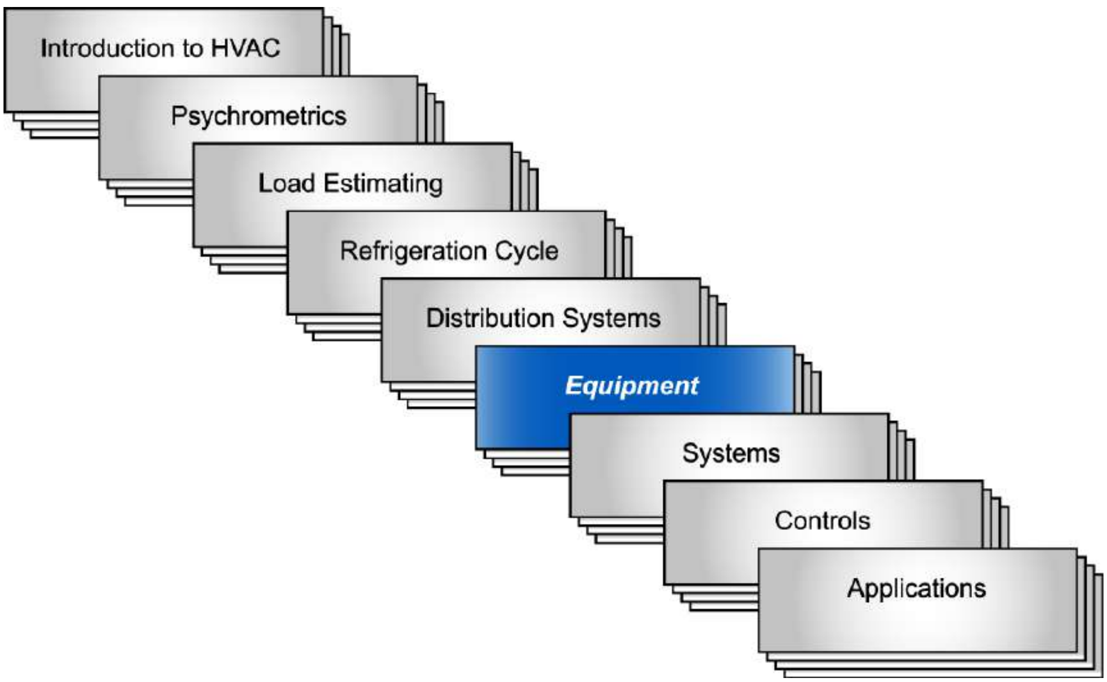
COMMERCIAL
HVAC CHILLER
EQUIPMENT

Air-Cooled Chillers

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.



Chillers are used in a variety of air-conditioning and process cooling applications. Air-cooled chillers can be used as a single piece unit or a split in various configurations. This flexibility has contributed to their overall popularity among designers of chilled-water systems. Air-cooled chillers range in size from small capacity models to several hundred-ton models that are utilized to cool large commercial buildings. This TDP module will cover both packaged single piece air-cooled chillers as well as split system types. This TDP module will also cover the available options and accessories, the applications, as well as criteria for selecting an air-cooled chiller.

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Introduction

Air-cooled chillers utilize the mechanical refrigeration cycle to produce chilled water or a chilled water and antifreeze mixture. They reject the building heat to the ambient with an air-cooled condensing coil. Chillers are the heart of the chilled-water air-conditioning system since they serve the pivotal function of creating the cooling effect required to maintain comfort conditions.

Chillers are used in a variety of comfort air-conditioning and process cooling applications. The chilled liquid is transported by pumps and pipes that can be connected to literally hundreds of room fan coils and terminals. This allows chillers to be applied on applications requiring many zones of control.

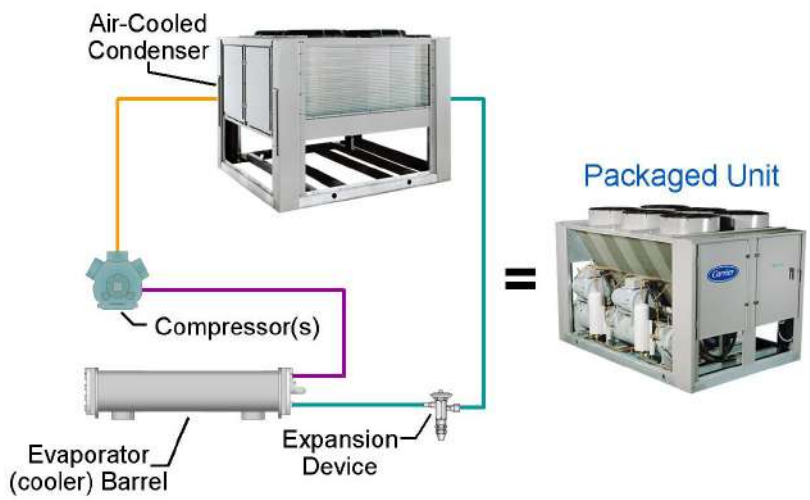


Figure 1

Air-Cooled Chiller Package

Air-cooled chillers are common in modern systems and have been growing in popularity since the 1980s, nearly doubling in the last ten years. Today, air-cooled chillers are applied on small to large commercial jobs and can be used in multiples to form systems reaching several thousand tons of installed capacity.

The popularity is primarily due to the all-inclusive nature of air-cooled chillers and the reduction of costs associated with eliminating cooling tower. On some models, even the hydronic accessories, such as the pump and expansion tank, may be included, assembled, and tested from the factory ready to begin operation.

Typical air-cooled chiller applications include schools, hospitals, retail environment, and offices. Additionally, air-cooled chillers are popular for cooling process or manufacturing operations.

This TDP will cover packaged single-piece, as well as split system air-cooled chillers. To learn more about water-cooled chillers, refer to TDP-623, Water-Cooled Chillers.

Air-Cooled versus Water-Cooled Chillers

A differentiating feature of the types of chillers is the method used to condense the refrigerant as it leaves the compressor. The two methods involve using either air-cooled or water-cooled condensers. Air-cooled condensers employ ambient air as the condensing medium and use a fan to move the air over the coil. For a given surface and airflow rate, the capacity of an air-cooled condenser varies with the refrigerant condensing temperature, which is a function of the entering dry-bulb temperature. Shown in Figure 2 is a typical air-cooled condensing temperature based on 95º F dry bulb ambient air.

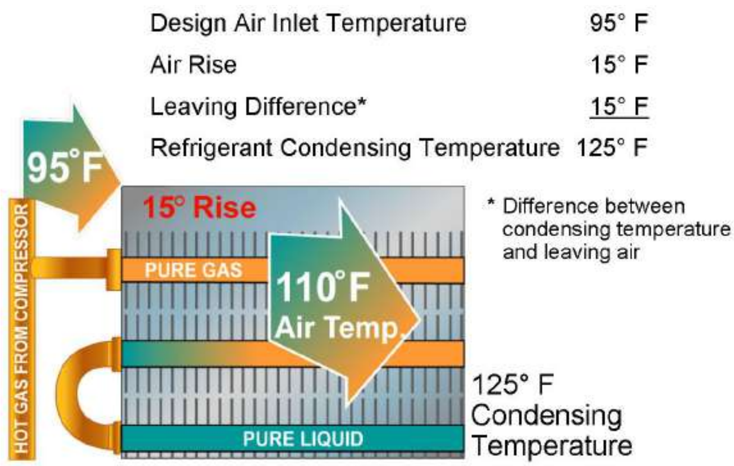


Figure 2

Air-Cooled Condensing Temperature

Water-cooled condensers employ water as the condensing medium and use a pump to circulate the water through the condenser and out to a cooling tower that rejects the heat to the atmosphere.

Operating cost is one of the primary factors when deciding between air-cooled or water-cooled chillers. Air-cooled chiller systems typically have a lower first and maintenance cost since they do not require a cooling tower, condenser water pumps, and associated condenser water chemical treatment. Operating costs, however, generally favor water-cooled chillers. This is because water-cooled chillers can take advantage of lower condensing temperatures than air-cooled chillers.

Air-cooled chillers have a full load kW/ton of approximately 1.25 while water-cooled chillers have a full load kW/ton of between 0.55 and 0.8 kW/ton. The kW draw of the cooling tower fans and condenser water pump should be added to the water-cooled chiller kW/ton for an even comparison. Even after accounting for this added auxiliary energy draw, water-cooled chilled-water systems normally have an efficiency advantage over air-cooled.

Figure 3

Air-Cooled vs. Water-Cooled Chiller Benefits

Air-cooled chillers

are typically available as a package ranging up to 500 tons, while packaged water-cooled chillers are typically available up to 3,000 tons. Some custom water-cooled chillers go even higher in capacity.

Air-cooled chillers eliminate the concerns and maintenance requirements associated with condenser water treatment, condenser-tube cleaning, cooling tower service, tower freeze protection, and the availability and quality of makeup water. This reduced maintenance requirement is particularly attractive to building owners because it can reduce overall costs. Water-cooled chillers must have a condenser water treatment program to eliminate contaminants such as bacteria and algae growth. Fouled condenser tubes, not uncommon with water-cooled chilled-water systems, can also reduce chiller efficiency.

Air-cooled chillers are often selected for use in systems that require year-round mechanical cooling requirements. Air-cooled condensers have the ability to operate in below-freezing weather, and can do so without the freeze protection issues associated with operating the cooling tower in these conditions. Cooling towers often require a basin heater, or even an indoor sump, for safe operation in freezing weather. For process applications, such as computer centers that require cooling year-round, air-cooled chillers have a distinct advantage over their water-cooled counterpart.

Note:

The primary convenience of an air-cooled chiller is that it does not require a cooling tower, condenser water pump, and the associated maintenance.

Figure 4

Condenser water systems are not required with air-cooled chillers.

Basic Refrigeration Cycle for Air-Cooled Chillers

The refrigeration cycle of an air-cooled chiller includes two important processes:

1. The evaporation of the liquid refrigerant in the evaporator, which absorbs heat and lowers the temperature of the chilled-water system
2. The condensation of the refrigerant vapor in the air-cooled condenser and rejection of heat to the atmosphere

In the air-cooled chiller refrigeration cycle, water enters the evaporator (also known as the cooler) and is cooled by the colder refrigerant flowing through the other circuit inside the evaporator. The chilled water is pumped from the chiller to the building coils to provide cooling. In the evaporator, the chilled water cools the building or process load and the cycle is completed when warmer water flows back to the evaporator. A mixture of cold liquid refrigerant and flash gas passes through the evaporator circuit opposite the water to be chilled.

The refrigerant in the evaporator absorbs heat from the warmer return water, evaporates to a vapor, and finally exits the evaporator as a superheated vapor. The superheated refrigerant vapor then enters the suction inlet of the compressor. In the compressor, the refrigerant is compressed, raising its pressure and temperature. High pressure and temperature refrigerant gas exits the compressor, passes through the discharge line and enters the condenser. While in the air-cooled condenser coil, the hot gas condenses to liquid inside the tubes as it gives up heat to the cooler outside air being drawn across the condenser coil by the condenser fans.

The refrigerant

is on the shell side of some evaporator designs and on the tube side of others. When the refrigerant is on the tube side, the evaporator is called a DX evaporator; when on the shell side, it is a flooded cooler.

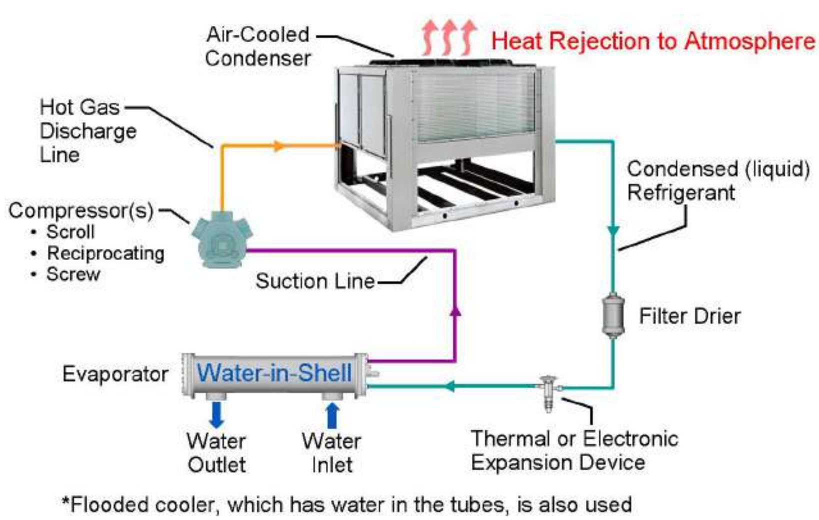


Figure 5

Refrigeration Cycle Components of an Air-Cooled Chiller

The condensed liquid refrigerant then leaves the condenser and enters the expansion device. As the refrigerant passes through the expansion device, its pressure and temperature is decreased to the point that some of the liquid flashes to vapor. The expansion device controls the amount of flashing in order to maintain a certain superheat to ensure no liquid droplets enter into the compressor suction. After leaving the expansion device, the refrigerant enters the evaporator and the cycle is repeated.

Air-Cooled Chiller Components

All air-cooled chillers are comprised of the following components:

- Evaporator (cooler)
- Condenser
- Compressor
- Expansion Device

Let's examine these components individually and the role of each in the air-cooled chiller.

Evaporator

Three types of evaporators are used in air-cooled chillers:

1. Brazed-plate
2. Direct expansion (DX) shell-and-tube
3. Flooded shell-and-tube

Figure 6

Three Types of Evaporators
Photos: Brazed-plate courtesy of API Heat Transfer; DX Shell-and-Tube

The most common choice of evaporator design for larger screw and reciprocating chillers has been the shell-and-tube types while smaller chillers utilize brazed-plate. Shell-and-tube evaporators are widely used and they are larger and heavier than brazed-plate heat exchangers. The tubes for some evaporator types may utilize internal and/or external enhancements to promote turbulence and create increased heat transfer between the fluid and the refrigerant. Turbulence actually increases the heat transfer process by keeping more of the fluid in contact with the heat exchanger surface area. On the refrigerant side and water side, more contact means greater heat transfer and a higher efficiency rating. Enhancement of tubes typically is achieved through a rifling or finning process during manufacturing.

Brazed-Plate

Brazed-plate evaporators are used on chillers up to approximately 60 tons and consist of a series of plates brazed together with every second plate turned 180 degrees. This design creates two highly turbulent fluid channels that flow in opposite directions over a surface area with a high heat transfer coefficient and good performance characteristics. The plates are stacked so they form a multi-layered alternating path for each fluid to travel through. Each layer or circuit is linked to an inlet and outlet via a manifold at either end.

A brazed-plate evaporator offers good heat transfer for the cost. In the multiple layers, or circuits, the fluid comes into contact with the heat exchanger surface over a very large area resulting in fast heat dispersion. The smaller cross sectional area and fluted construction also adds turbulence to the fluid, further increasing the efficiency of heat transfer. The fluid turbulence is also present at low heat exchanger loadings, making the brazed-plate heat exchanger ideal for part-load applications. Brazed-plate heat exchangers are much smaller than their shell-and-tube counterpart. They may be as little as 25 percent of the size of an equivalent shell-and-tube heat exchanger.

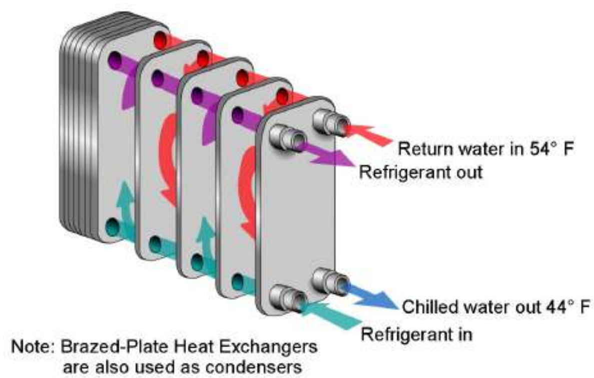


Figure 7

Brazed-Plate Evaporator

> ***Plate type heat exchangers***
>
> ***are also used on some air-cooled chiller designs as a method of increasing performance via an economizer circuit. The purpose is to increase subcooling and thus increase the overall capacity of the refrigeration system.***

This smaller size of brazed-plate heat exchangers results in a smaller overall footprint for the chiller, a benefit for both shipping and installing the chiller. Additionally, the refrigerant circuits can be designed to require considerably less refrigerant than shell-and-tube systems. Because the circuitry of a brazed-plate heat exchanger system holds less volume of refrigerant, fewer pounds will be needed to charge the chiller.

Given the small areas of the multiple circuits, brazed-plate heat exchangers are more susceptible to being plugged. A factory-supplied or field-supplied strainer should be used to remove particles and contaminants from entering the water circuit of the heat exchangers. The brazed-plate design is not mechanically cleanable inside.

Direct Expansion (DX) Shell-and-Tube

In the direct expansion evaporator, the refrigerant flows through the tubes and the water flows around the tubes in the shell section. As heat is transferred to the colder refrigerant from the warmer water or water / anti-freeze mixture, the refrigerant in the tubes evaporates and the water is cooled. Baffles within the shell direct the water flow path over the tubes creating the turbulence that improves heat transfer.

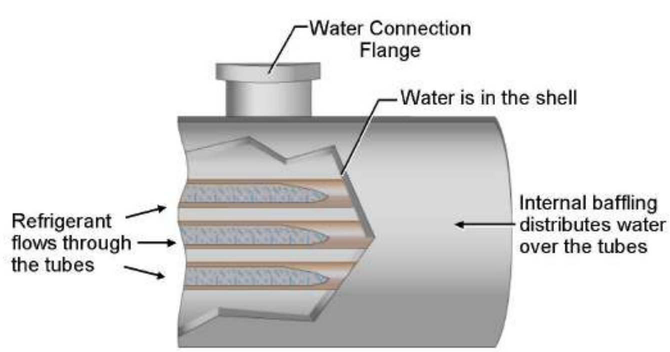


Figure 8

Direct Expansion Shell-and-Tube Evaporator

Air-cooled chillers with reciprocating and scroll compressors typically utilize a DX evaporator design. The direct expansion type evaporator allows the oil to be swept along with the refrigerant inside the tubes to a location on the chiller where it can be separated and returned to the oil pump thus accomplishing the required lubrication these compressors require.

The waterside

of a direct expansion evaporator must be chemically cleaned since mechanical cleaning of the shell is not possible due to the internal baffling.

Flooded Shell-and-Tube

Flooded shell-and-tube evaporators are also called "flooded coolers." They have water or a water/antifreeze mixture flowing through the tubes while the refrigerant is on the shell side. The liquid refrigerant is uniformly distributed along the bottom of the cooler.

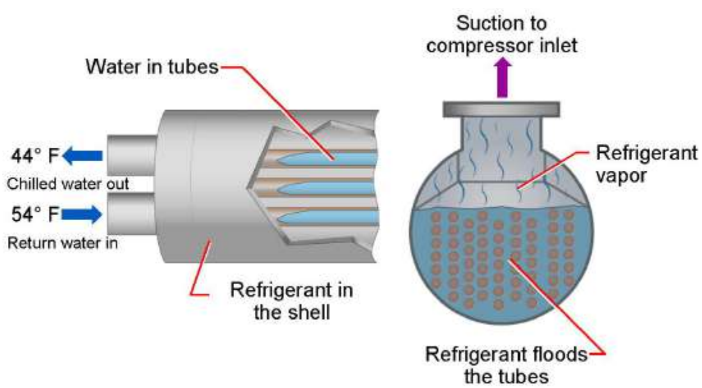


Figure 9

Flooded Shell-and Tube Evaporator

Additionally, the refrigerant charge does not have to be removed during tube cleaning. Flooded evaporators are typically no more efficient a design than DX or brazed-plate, but the chiller types they are used on tend to have a more efficient compressor, such as a centrifugal.

On air-cooled chillers that use flooded shell-and-tube evaporators, the number of tube passes within the vessel may be changed to further increase the efficiency by increasing the tube velocity and turbulence. Or, they may reduce the number of passes to decrease the pressure drop by reducing the tube velocity. Although higher pass arrangements tend to improve heat transfer, they also increase pumping horsepower for the chilled-water circuit because of the higher pressure drop. Thus, an economic balance must be struck between higher pumping horsepower and lower compressor power.

Flooded Evaporator Cleaning:

Since the water flows through the tubes of a flooded evaporator, the waterside can be mechanically cleaned. Brushing is a common method. The ability to mechanically clean the waterside of a flooded shell-and-tube evaporator is a major advantage of this design.

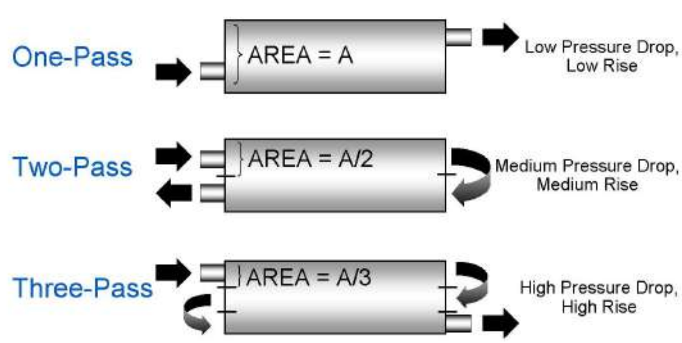


Figure 10

Flooded Evaporator Pass Arrangements

On DX evaporators, there are no "pass" arrangement options because the water is on the shell side. Internal to the shell, changes to the baffling are made to accommodate greater or less water flows.

Evaporator Passes

The method most utilized in selection of heat exchanger passes is to specify reasonable pressure drop limits and allow the manufacturer to recommend the optimal pass arrangement for the load and application under consideration.

Evaporator Types Pros & Cons

Evaporator Type		
Brazed-Plate Evaporator** 	Pro	Smaller footprint
	Pro	Lightweight
	Pro	Cost effective for smaller sizes
	Con	Sensitive to contamination of the water circuit
	Con	Not mechanically cleanable
DX Shell-and-Tube Evaporator* 	Pro	Cost effective for small and medium sizes
	Pro	Familiarity with customers/engineers
	Pro	Design can accommodate heater cable on the shell to prevent freezing of water
	Con	Larger footprint
	Con	Not mechanically cleanable
Flooded Shell-and-Tube Evaporator 	Pro	High efficiency
	Pro	Mechanically cleanable
	Con	Large footprint
	Con	Design cannot accommodate heater cable on the shell to prevent freezing of water in tubes

**Photo courtesy of Standard Refrigeration*
***Photo courtesy of API Heat Transfer*

Condenser

The condenser in an air-cooled chiller is a heat exchanger that condenses the hot refrigerant gas by using cooler outside air passing over a coil. In a typical air-cooled chiller, propeller-type fans are used to draw the outdoor air over the coil. The hot, high-pressure refrigerant vapor flows through the coil tubes and is condensed to a liquid. In the last portion of condenser tubing, the condensed liquid refrigerant is then subcooled. A final portion of the condenser is used to lower the refrigerant temperature below the saturated condensing temperature. This is called subcooling. This increases the refrigeration effect and increases system capacity by about 1 percent for each degree of subcooling provided.

Altitude Adjustment

The airflow over the condenser coil is fixed, but the density of the air is affected by altitude, which affects condenser performance. Chiller selection software will ask for project elevation to adjust the capacity accordingly.

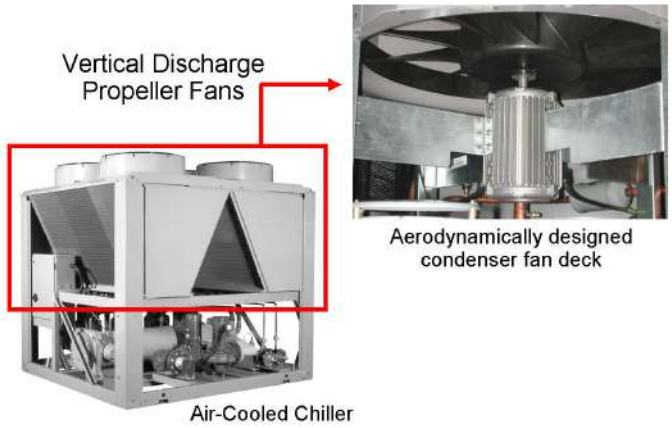


Figure 11

Condenser Design of an Air-Cooled Chiller

Compressor

There are three types of compressors utilized for air-cooled chillers. They are reciprocating, scroll, and screw.

Reciprocating

Reciprocating compressors, like a reciprocating engine, have pistons, rods, and discharge and intake valves. The valves operate on suction and discharge pressure. Compression is achieved by trapping a fixed amount of refrigerant gas into a chamber. For this reason, reciprocating compressors are positive displacement type compressors as are scrolls and screws. Reciprocating compressors were the workhorse of the small chiller market for decades and are still used in many designs. Multiple reciprocating compressors were often installed in a

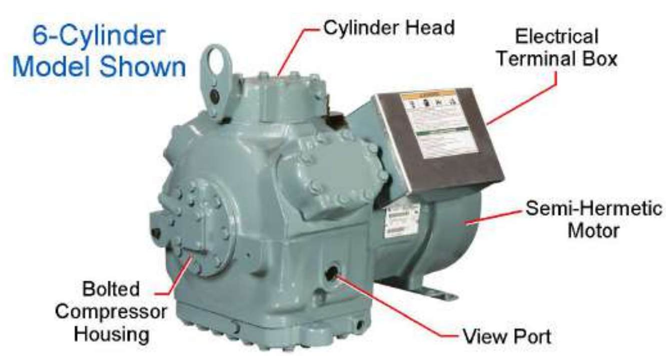


Figure 12

Semi-Hermetic Reciprocating Compressor single chiller to provide chiller capacities of up to 400 tons. The reciprocating compressor is available open, semi-hermetic, or hermetic. Open compressors extend the shaft through a seal in the crankcase for use with an external driver. Hermetic compressors have the motor and compressor contained in the same housing, typically welded and sealed. Semi-hermetic compressors utilize a bolted housing, instead of a welded one, to facilitate repair in the field.

Scroll

Scroll compressors have a unique compression process. A fixed scroll coupled with the movement of an orbiting scroll, ingests suction gas into pockets. As the orbiting scroll moves, the pockets of gas are compressed to an intermediate pressure. In a final orbit, the pockets reach discharge pressure and exit through the discharge port.

Scroll compressors have emerged as a popular alternative to reciprocating compressors and are available in hermetic configurations in capacities up to 25 tons each for use in air-cooled chillers. As with reciprocating compressors, multiple scroll compressors are often used in a single chiller design to meet larger capacities. Scroll compressors are 10 to 15 percent more efficient than reciprocating compressors and have proven to be very reliable, primarily because they have approximately 60 percent fewer moving parts. Reciprocating and scroll compressors are typically used singly or in multiples to provide an air-cooled chiller range from approximately 10 to 400 tons.

Figure 13

Scroll Compressor

Screw

Screw compressors are widely used in medium-sized water chillers, either singly or in multiples to accomplish a chiller range from about 70 to 500 tons. As the screw rotors turn, the suction gas is compressed. Screw compressors have one or more rotors to accomplish the compression. Like scroll compressors, screw compressors have a reliability advantage over reciprocating due to fewer moving parts. Screw compressors, as well as reciprocating and scroll compressors are positive displacement type compressors, which means they compress a fixed amount of gas in a compression chamber. Screw compressors have become popular because of excellent reliability and good efficiency, especially at part loads.

There are several designs of screw compressors featuring single or multiple rotors. Screw compressors unload by slide valve or solenoid valve mechanism that changes the amount of gas volume being compressed, thus reducing the capacity.

Screw Compressors

are also referred to as "rotary" or helical-rotary compressors.

Figure 14

Double-Rotor Screw Compressor

Expansion Device

An expansion device is used to maintain the pressure difference between the high-pressure (condenser) and low-pressure (evaporator) sides of the refrigeration system. This pressure difference allows the evaporator temperature to be low enough to absorb heat from the water being cooled while also allowing the refrigerant to be at a high enough temperature in the condenser to reject heat to the outside air. High-pressure liquid refrigerant flows from the condenser through the expansion device, where it undergoes a pressure drop that reduces the refrigerant pressure to that of the evaporator. This pressure reduction causes a small portion of the liquid to boil off, or flash, cooling the remaining refrigerant to the desired evaporator temperature. In addition to maintaining the high-to-low side pressure differential, the expansion device maintains the proper suction superheat of the vapor entering the compressor, which enables all of the liquid to be vaporized in the evaporator. Heat can still be added to the vapor after it has completely boiled in the evaporator. This additional heat insures no liquid will enter the compression suction. This is referred to as superheat.

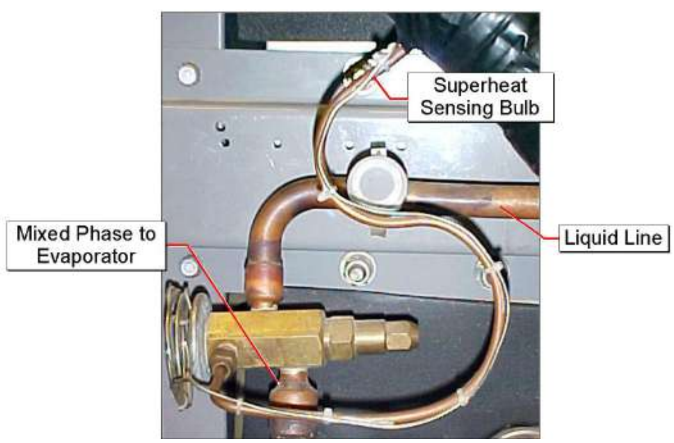


Figure 15

TXV Expansion Device Mounted Horizontally

Air-cooled chillers typically use either thermostatic expansion valves (TXV) or electronic expansion valves (EXV). A TXV consists of a regulating valve and connected sensing bulb. The sensing bulb is placed on the suction line leaving the evaporator. The TXV senses the refrigerant temperature in the evaporator and the refrigerant-filled bulb senses the temperature of the superheated refrigerant leaving the evaporator. This allows the TXV to regulate flow through the evaporator to maintain a set amount of superheat at the exit of the evaporator.

An EXV utilizes external temperature and pressure sensors to measure the superheat and then adjust the flow through the valve using a finely controlled stepper motor. Although the costs are greater for an EXV than a TXV, the precise refrigerant flow that they afford and their extremely rapid reaction to changing conditions allow for lower compressor head pressure resulting in greater chiller efficiencies.

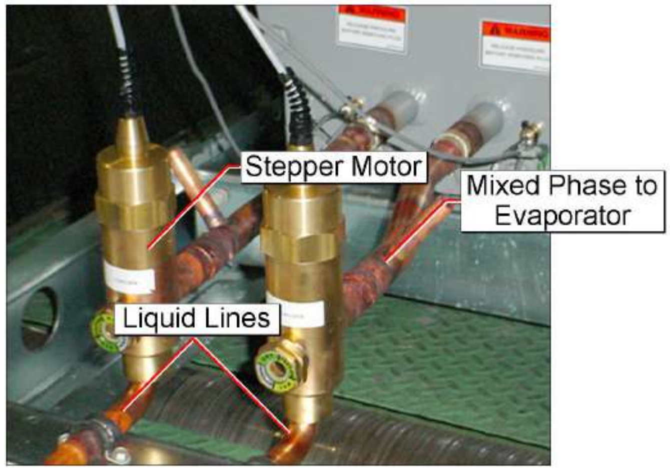


Figure 16

EXV Expansion Device

Some advantages of an EXV are:

- Creates low head pressures (increase part load efficiency)
- Has great range and flexibility of operating conditions
- Provides precise capacity control
- Uses predictive algorithms that can avoid potential operational problems

As an example, an air-cooled chiller applied on a comfort cooling application, would not be allowed to produce low leaving chilled-water temperatures that could cause potential freeze-up.

Note:

For a detailed discussion of TXVs and EXVs, refer to TDP-403, Expansion Devices and Refrigeration Specialties.

Chiller Controls

All chillers need to be properly controlled for safety and efficient operation. Today's chiller equipment is making extensive use of technology to provide this control. A chiller today uses microprocessors, electronic sensors, and digital user interfaces that have changed the look of chiller equipment control systems. This technology is referred to a Direct Digital Control (DDC).

Figure 17

Air-Cooled Chiller Control Panel User Interfaces

DDC system user interfaces give owner-operators and service technicians the ability to do diagnostic evaluation of the operation of the equipment using either equipment-mounted or handheld displays. In DDC systems, information is digital and can be shared by other equipment to function as a system. Most DDC systems will have a communication terminal that allows for network communications or the attachment of a PC for more detailed diagnostic capabilities. DDC systems are capable of sharing information on a communication bus that can be viewed worldwide.

Compressor Starting Methods

A compressor motor draws high starting current called "inrush" or "locked rotor current" when started because the motor rotor is not yet rotating. This high current is required to generate the magnetic field to start the rotor turning and is directly dependent upon both the efficiency and horsepower of the motor. High current draw during a compressor start can cause the line voltage to dip and that may adversely affect other equipment within the facility. This is related to the size and efficiency of the motor. Current draw restrictions may require that larger motors start with reduced inrush current. This is called soft start.

Across-the-Line Starting

> ***Across-the-line starters***
>
> ***On multi compressor chillers, across-the-line starters can be used because the inrush per compressor is manageable and the compressors are not started all at once.***

The simplest and least expensive form of motor starter is an across-the-line starter, which consists of a contactor and an overload protection relay. The contactor consists of a coil and contacts that close the circuit thus applying power to the compressor motor. The overload protection relay opens the circuit to the motor if excessive current is drawn while the motor is running. Upon start, the contactor is closed, applying full line voltage to the motor windings. The motor will draw a very high locked rotor inrush current for a very short time. As the motor accelerates, the current will begin to drop, but not significantly until the motor is about 85 percent of full speed. The actual starting current curve is a function of the motor design and the terminal voltage, but is independent of the motor load. The motor load will affect the time taken for the motor to accelerate to full speed and, therefore, the duration of the high starting current, but not the magnitude of the starting current. For a typical chiller compressor motor, the inrush or locked rotor current with across-the-line starting will be approximately 600 percent of the motor rated load amperage (RLA) rating.

Advantages of across-the-line starting are lower costs and simplified controls. Motors using across-the-line starting will usually be up to speed quickly. However, high current inrush can affect other equipment in the plant.

Part-Winding Starters

A part wind start is a type of soft starting. An electrical engineer typically determines if soft starting is required based on an electrical system study that calculates voltages drop in the system when a load is started. If the power supply is weak or the system is heavily loaded, the system is more likely to be sensitive to motor starting and soft starters are more likely to be required. 208V systems are more likely to require soft starters than 460V systems because of the higher amp draw.

Part-winding starters are a cost effective means of providing a reduced current start where smaller horsepower motors are utilized like on many air-cooled chiller designs using multiple compressors.

Part-winding starters can only be used with part-winding motors that have two sets of identical windings that are intended to be operated in parallel. During a part-winding start, only one winding is energized, reducing the inrush current to 60-70 percent of normal starting values with both windings energized. With only one winding in the circuit, a typical part-winding motor will not accelerate to more than half of the motor rated speed. Because the motor is operated with one winding only during the initial acceleration period, after the transition from start to run mode, the current draw of the motor will be closer to the rated load amps. A part-winding starter essentially provides a two-step start.

Wye-Delta Starting

Wye-delta starters are also used on applications that require reduced inrush current as described above. Wye-delta starters may be applied in applications where larger horsepower motors are utilized, such as a larger screw compressor air-cooled chiller.

Wye-delta motors can only be used with wye-delta starters. These motors have six leads allowing for the motor windings to be connected in either a wye, where one end of each of three windings is attached to a common point and the other end of each is attached to the line, or delta, where one end of each of two windings is attached to each line connection. During start-up, the windings are connected in the wye configuration that reduces inrush current to 33 percent of the delta-connected values. After a set time delay, the motor leads are reconfigured to the delta connection for normal run operation. When using a wye-delta starter, in the delta connection the running current is shared between two contactors.

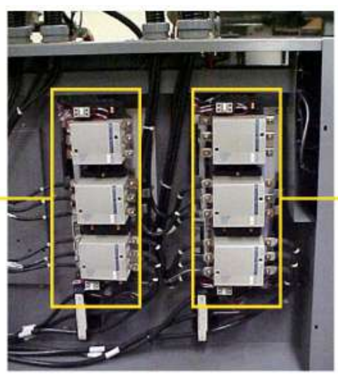


Figure 18

Wye-Delta Starters on a Two-Compressor Screw Chiller

Starting Method	Motor Starting Current as a % of	
	Locked Rotor Current	Full Load Current
Across-the-Line	100	600
Part Wind	65	390
Wye-Delta	33	200

Figure 19

Starter Summary Information

Capacity Control

Like most chillers, air-cooled chillers operate occasionally at full capacity conditions, due to building load variations. Therefore, it is important to understand the three primary methods of capacity control:

- Unloading the compressors
- Cycling the compressor(s) on and off (single or multiple compressors)
- Hot gas bypass

Unloading the compressors is possible with reciprocating and screw compressor types. Scroll compressors do not unload; they are either on or off. Reciprocating compressors utilize unloaders that lift the suction gas valve so that the pistons do not compress the gas. Unloaders are a cost-effective method of reducing capacity, but because the pistons continue to operate at all times, the energy efficiency using unloaders is not as high as with the cycling method. Screw compressors utilize a slide valve to cover the suction inlet ports, effectively shortening the length of the screws and reducing the resulting amount of compressed refrigerant vapor. Capacity control is not continuous with slide valves as the valves cover or uncover the suction ports similar to staging the compressor.

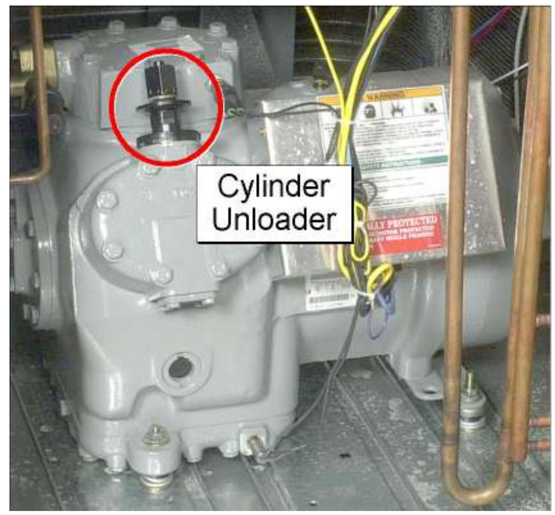


Figure 20

Unloading Reciprocating Compressor

Cycling the compressor(s) is a cost-effective and energy-efficient method for reducing capacity, especially when multiple compressors are used in the system. However, cycling the compressors too frequently may result in compressor motor damage and failure, thus controls are built into the chiller to control the time between cycles. Larger chiller designs that use multiple compressors combined with multiple refrigeration circuits can successfully cycle the compressors to achieve part-load capacity control. During peak loads, all compressors and circuits are operational. During lighter loads, individual compressors on one circuit may be cycled off thus providing an acceptable part-load profile.

Multiple Scroll Chiller Design

Figure 21

Capacity Control – Cycling Compressors

Hot gas bypass is a method that bypasses some of the high-pressure refrigerant gas (hot gas) discharged from the compressor back to the evaporator line without going through the condenser. Naturally, this affects the system capacity, as some of the refrigeration is effectively "lost" from the cycle. The capacity of the chiller on hot gas bypass will be somewhat lower than the capacity at the lowest step of unloading. However, use of hot gas bypass is not considered efficient since the compressor continues to operate while a significant portion of the system does not provide any cooling.

Hot gas bypass is often used

on a chiller with limited unloading capability.

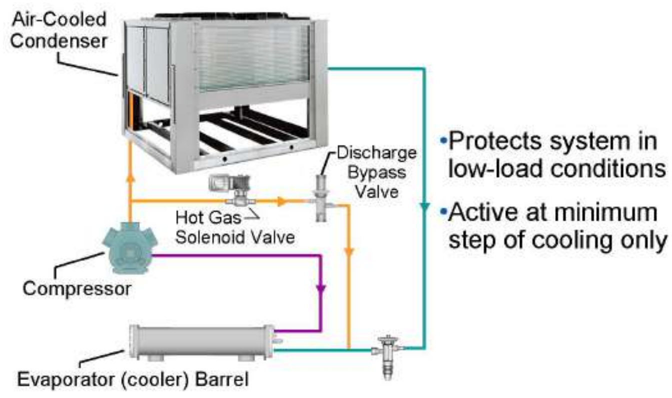


Figure 22

Hot Gas Bypass

Energy Management

Use of energy management practices can significantly reduce operating costs, especially during off-peak modes of operation. Chilled-water temperature reset and demand limiting are two techniques for accomplishing efficient energy management.

Chilled-Water Reset

Chilled-water reset means to change the chilled water temperature leaving the chiller based on some parameter. Increasing the leaving chilled water temperature reduces compressor power usage by reducing lift at both full and part-load conditions. However, at part-load conditions, design chilled water temperature may not be necessary, especially for comfort cooling applications, so reset is possible. Increasing the chilled water temperature may result in greater humidity levels in the conditioned spaces. Higher coil temperatures resulting from the increased chilled water temperature will reduce the latent heat capacity of the coils and the ability of the air distribution system to remove space humidity.

Chilled water temperature can be reset as a function of:

- Ambient air temperature (most common) – used when the ambient temperature is the best indication of load
- Return chilled water temperature – used when return water temperature is the best indication of load. This method is typically used when it is desired to maintain a fixed Δt in the chiller plant.

Note:

Lift refers to the difference between compressor suction and condensing temperature. Reducing lift increase efficiency.

- Temperature within the building – used when space temperature is the best indication of load on the chiller. This is used when there are critical areas in a building such as labs that might require a specific temperature be maintained.

Reset doesn't always mean an increase in water temperature. For example space temperature reset could actually lower the chilled water supply temperature, not raise it, in order to maintain conditions.

Demand Limit and Duty Cycling

Demand limit is a feature that limits the unit capacity and power draw during periods of peak energy usage. When a utility company's demand for electricity exceeds a certain level, users are charged extra money called demand charges. To avoid these charges, loads in the building are limited to keep demand below a prescribed maximum level. Demand limiting may be desirable on hot days when air conditioning is most needed. Demand may be limited on the chiller by increasing the chilled-water temperature or by unloading the chiller to a predetermined percentage of the full current draw which is an indication of load. This may result in temporary increased building or process temperatures if the actual load is greater than the demand limited capacity that the chiller can provide.

> ***Demand***
>
> ***is measured in kW; energy charges are measured in kWh. Together, the two form a typical user's electrical bill.***

Duty cycling will cycle selected electrical equipment in an installation (building, factory, etc.) at regular intervals to limit the electrical demand, thereby lowering demand charges. However, duty cycling is not recommended because constant cycling will cause increased stress and damage to the motor windings, bearing, and controls. If demand must be controlled, the demand limit sequence available from the manufacturer is recommended.

Air-Cooled Chiller Configurations

There are several configuration options for designing an air-cooled chiller system. The design can choose to use a packaged system (all refrigeration components in one unit) or a split system (refrigeration components separated and located in different areas). Packaged systems are simpler to design, install and maintain. However, due to cold weather conditions, it may be more desirable to locate the evaporator inside the building to prevent freezing. Air-cooled chillers offer the flexibility of separating the components. This flexibility allows the system design engineer to place the components where they best fit the available space, while maintaining the acoustic and performance requirements of the customer.

Single Piece Units

A packaged air-cooled chiller has all of the refrigeration components located outdoors in a single chassis. A major advantage of this configuration is factory assembly and testing of all components, including the wiring, refrigerant piping, and controls. This eliminates field design and labor while often resulting in faster installation and improved system reliability. Additionally, all noise-generating components (compressors and condenser fans) are located outdoors, easing indoor noise concerns. Finally, the MER (mechanical equipment room) space requirements are minimized. With all of the components located outdoors, below-freezing ambient temperature conditions must be considered for certain climates. Many engineers incorporate a glycol concentration in the chilled water for freeze protection for outdoor chillers. Adding a glycol concentration will derate the performance of a chiller compared to using fresh water. The capacity derate depends on concentration and chiller type. See the freeze protection methods described in detail later in this TDP.

Figure 23

Single Unit Configuration

Split Systems

An alternative to the packaged air-cooled chiller is to use a split system. There are several variations of the split system.

Remote Evaporator

One configuration of the split system is to have the compressor and condenser located outside the building while the evaporator is remotely mounted in an indoor location. The indoor and outdoor components are then connected with field-installed refrigerant piping. This configuration locates the part of the system that is susceptible to freezing (evaporator) indoors and the noise-generating components (compressor and condenser fans) outdoors. This configuration usually eliminates any further requirements to protect the chilled-water loop from freezing during cold weather.

However, the evaporator will take up some indoor space. Additionally, as there is now refrigerant piped inside the building, ASHRAE 15 Standard for mechanical equipment rooms must now be considered. See a discussion of ASHRAE Standard 15 in the Codes and Standards section of this TDP. Performance of the chiller will be slightly affected because of refrigerant line losses between the compressor/condenser and the evaporator.

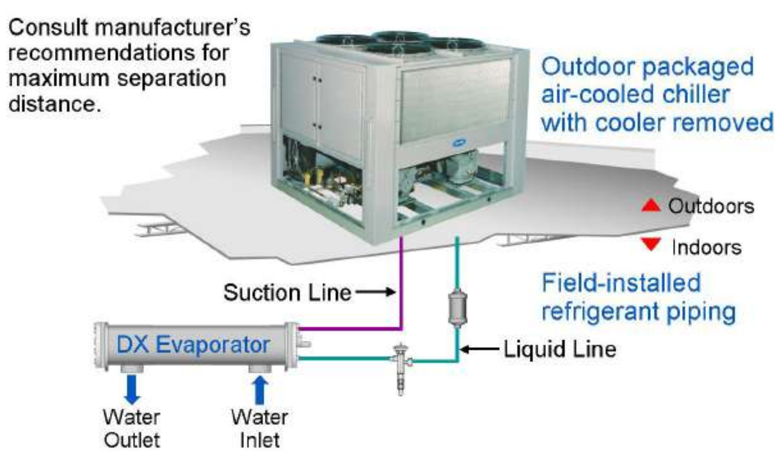


Figure 24

Remote Evaporator

There are greater chances for refrigerant leaks with this configuration as the interconnecting piping is field-installed. Also, within the long piping runs to the remote evaporator, proper oil return to the compressor must be assured by sizing the lines correctly. For more information on sizing split system piping, consult TDP-501, Refrigerant Piping.

Condenserless Chiller

Another configuration is to place only the air-cooled condensers outdoors. The compressors, controls, and evaporator remain indoors in what is called a condenserless chiller. Scrolls, reciprocating, and screw chillers are all available in condenserless split system configurations. These split system chiller configurations start about 15 tons and go over 260 tons per chiller. A large benefit for mounting the compressors, evaporator, and controls indoors is for ease of maintenance and troubleshooting in inclement weather. Some other benefits of this split system chiller configuration are:

Figure 25

Condenserless Split System Chiller

- The roof-mounted condenser(s) do not weigh as much as the compressor section so the structure need not support the single piece air-cooled chiller
- The main electrical users (compressors) are closer to the electrical panel (which is typically near the mechanical equipment room), resulting in lower electrical wiring costs.
- There are more options for sound and noise control with indoor compressors.

This configuration is particularly popular in schools and other institutional applications, primarily due to reduced seasonal maintenance for freeze protection.

The maximum allowable refrigerant line length is less than 100 feet for condenserless air-cooled chiller installations. This is dependent upon the manufacturer, however.

As with the remote evaporator design, there is now a refrigerant vessel inside the building and ASHRAE 15 requirements should be followed. In most all cases with an indoor chiller and outdoor condenser, the chiller must be housed in a mechanical equipment room. Capacity of the split system chiller will be slightly less than a fully packaged outdoor unit due to refrigerant line losses.

Split Systems

A drawback of splitting the components is the requirement for field-installed refrigerant piping. Additionally, longer time is generally required for the proper selection, sizing, and installation.

Indoor Centrifugal Condenser

The next split system configuration includes the condenserless chiller located in an indoor equipment room connected to an *indoor* air-cooled condenser. The air used for condensing is ducted from outdoors through the condenser coil and rejected either outdoors or inside the building as a means for heat recovery. Indoor condensers use a centrifugal fan to overcome the duct static-pressure losses, rather than the propeller fans used in conventional outdoor air-cooled condensers. The components are connected with field-installed piping. This configuration is used where an outdoor condenser is architecturally undesirable, where the system is located on a middle floor of a multistory building, or where vandalism to exterior equipment is a problem. A disadvantage of this configuration is that increased condenser fan energy is required to overcome the duct resistance compared to a conventional outdoor propeller fan air-cooled condenser that has no ductwork to overcome. As with all split systems incorporating field-installed piping, there is a greater chance of refrigerant leaks and due to the increased volume of piping, more refrigerant will be required. Additionally, ASHRAE 15 Standards are applicable. Additional consideration should be given to the indoor condenser fans with respect to generation of sound.

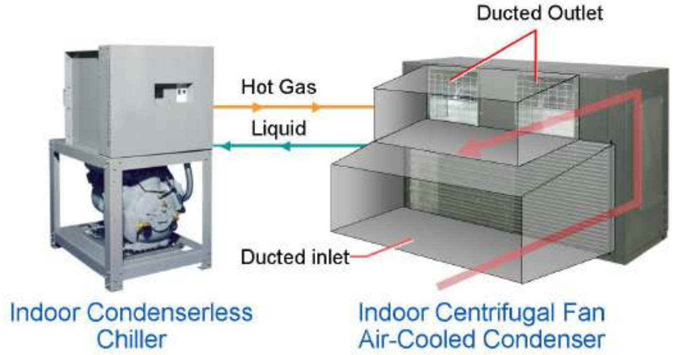


Figure 26

Indoor Chiller, Indoor Centrifugal Chiller Condenser

Subcooling

Chiller manufacturers often require a subcooling circuit on the evaporative condensers. The chiller performance will be adversely affected if the chiller requires subcooling and the evaporative condenser manufacturer does not include it.

Evaporative Condenser

The last application for condenserless chillers is to match them with an evaporative condenser. Evaporative condensers use a spray on the coil to provide lower condensing temperatures due to the evaporative effect. This increases split system efficiency. Because a manufacturer other than the chiller manufacturer typically supplies the evaporative condenser, so care must be taken in the selection. For complete information on evaporative condensers, see TDP-641, Condensers and Cooling Towers.

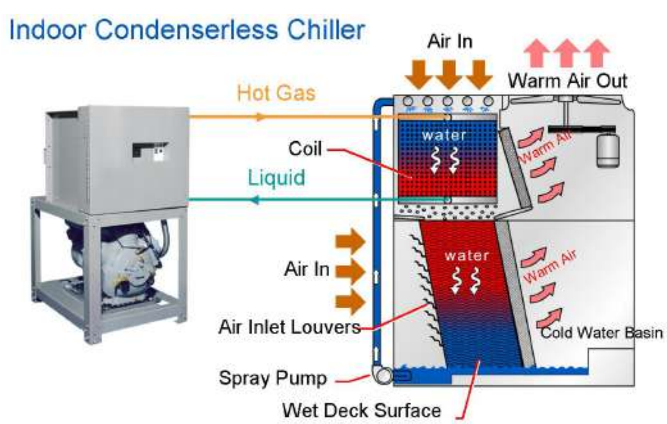


Figure 27

Indoor Chiller, Evaporative Condenser

Application Topics

Typical Operating Limits

There are a number of parameters that define the operating envelope for an air-cooled chiller. Typical representative values are shown in Figure 28 and may vary slightly from manufacturer to manufacturer.

Operation to –20º F will require the addition of a low ambient head pressure control accessory. Operation to 15º F leaving water (brine) temperature will require freeze protection. See the freeze protection methods section in this TDP module.

Figure 28

Typical Operating Limits

Effects of Outside Air Temperature

Air-cooled chillers utilize ambient air to condense the refrigerant. However, as the outside air temperature varies, so does the efficiency and performance of the chiller. As the chilled water leaving the chiller is set to maintain a constant temperature, increases in the ambient temperature result in a higher condensing temperature, larger temperature differentials and greater lift across the compressor. Greater lift requires more work and results in lower efficiency and performance from the chiller.

The climactic design dry bulb temperature is 95º F for most of North America. The resulting design condensing temperature is approximately 125º F. Compressor efficiency and capacity declines as ambient air temperature rises.

Typical Air-Cooled Chiller Full Load

Entering Air °F	Tons	kW/Ton	% Change Capacity	% Change Efficiency
75° F	112.1	0.952	+15	+20
85° F	105.5	1.069	+8	+11
95° F	97.5	1.208	–	–
105° F	89.5	1.384	-8	-15
115° F	81.2	1.621	-17	-35
125° F	73.1	1.923	-25	-60

Figure 29

Example: Air-cooled chiller effect of ambient at full load and 44º F leaving chilled-water temperature.

Effects of Leaving Chilled-Water Temperature

As a general statement, it is economical for the chiller to produce chilled water no colder than is required to maintain space relative humidity conditions. For comfort cooling applications, 44º F or 42º F leaving chilled water is normally adequate. Hospitals often use 42º F because of high outdoor air loads and a greater need to dehumidify. Large chilled-water plants with extensive piping runs have used leaving water temperatures lower than 42º F to minimize pumping costs and offset pipe heat gain. However, these larger plants are typically not the ones that would tend to use air-cooled chillers. Water-cooled centrifugals would be used most often in large chilled-water plants.

Typical Air-Cooled Chiller at 95° F Ambient

Leaving Chilled Water Temperature °F	kW / Ton	% Change Efficiency per °F	% Change Efficiency From 44° F
44	1.237	–	–
43	1.253	-1.1	-1.1
42	1.266	-1.0	-2.2
41	1.280	-1.1	-3.5
40	1.295	-1.2	-4.6

Figure 30

Effects of Lowering the Leaving Chilled-Water Temperature

Shown in Figure 30 is an air-cooled chiller model of slightly different full load efficiency from the one used in Figure 29. From Figure 30, we can see the effects of producing colder leaving chilled water.

The question sometimes arises whether or not there is an advantage to produce and circulate colder water than the 44º F to 42º F range. For colder water designs to make sense, the chiller penalty must be more than offset with chilled water pumping cost reductions resulting from lower flows and the higher rise in the water.

As a general rule of thumb

for each degree lower leaving chilled-water temperature produced, there is between a 1 - 2% efficiency loss of the chiller.

Variable Flow Operation, Minimum and Maximum Flow Rates

Variable flow operation refers to varying the chilled-water flow rate through the chiller evaporator based on the cooling load in order to minimize water-pumping costs. In effect, the chilled-water flow rate is reduced when cooling loads are lower and increased when the loads are greater. The maximum gpm would tend to correspond to the gpm at design load.

Modern electronic chiller controls have allowed for variable evaporator flow applications because of the ability of the controls to respond to changing conditions. However, there are both minimum and maximum values for water flow through the evaporator that apply. If the flow rate through the evaporator becomes too low, the temperature differential between the entering and leaving water becomes too large and may result in leaving water temperatures approaching freezing. Additionally, too low of a flow rate may result in a loss of turbulence that would significantly reduce the heat transfer.

In flooded shell-and-tube evaporators

a typical minimum flow is that which corresponds to 3 feet per second water velocity in the tubes. This is obtainable from the air-cooled chiller selection software. For DX evaporators, the minimum flow will often be published in the product data, and is based on 1 fps water velocity in the shell.

Conversely, flow rates that are too high result in pressure losses within the evaporator that are too great. Maximum cooler flow is often approximated at 5 gpm/ton. Another way to determine maximum cooler flow is that flow resulting in a 5º F Δt in the chilled water. Ratings for air-cooled chillers are based on a 10º F Δ*t* and are generally suitable for a range of 5 to 15º F Δ*t* without adjustment. To accommodate special high flows, some manufacturers offer a low pass option to keep the waterside pressure drop manageable.

For variable flow applications, the rate of change of the chilled-water flow is very important. A maximum rate of change of flow of 10 percent of full flow, per minute, is a suggestion. Always consult the manufacturer's selection software or literature for minimum gpm for variable flow system application.

Recirculation and Bypass Line Piping

When the system water flow is out of the range of the chiller, two piping arrangements can be used. The first piping arrangement recirculates excess flow from the evaporator if the flow rate required by the chiller is too great for the system. The second piping arrangement utilizes a bypass flow around the evaporator of the chiller if the flow required in the system is greater than the normal flow through the chiller.

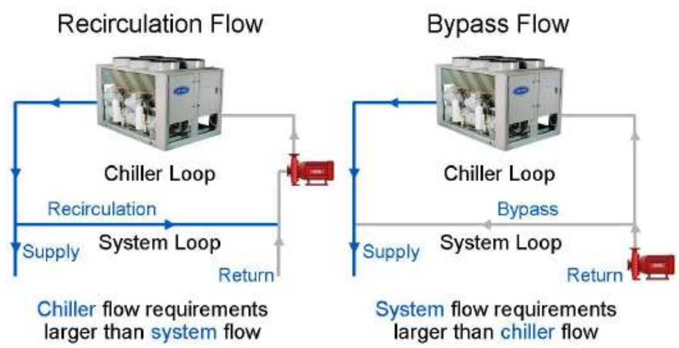


Figure 31

Recirculation and Bypass Line

Freeze Protection Methods

Because air-cooled chillers are usually located outside, evaporators require some procedures to prevent freezing. In areas where the ambient temperature will drop below 32º F, any unprotected water will freeze. Lack of freeze protection can result in consequences ranging from a single burst tube in an air handling unit coil piped to the chiller, to replacement of an entire chiller due to damaged components like evaporator tubes or compressors. Freezing can lead to extensive downtime and cleanup.

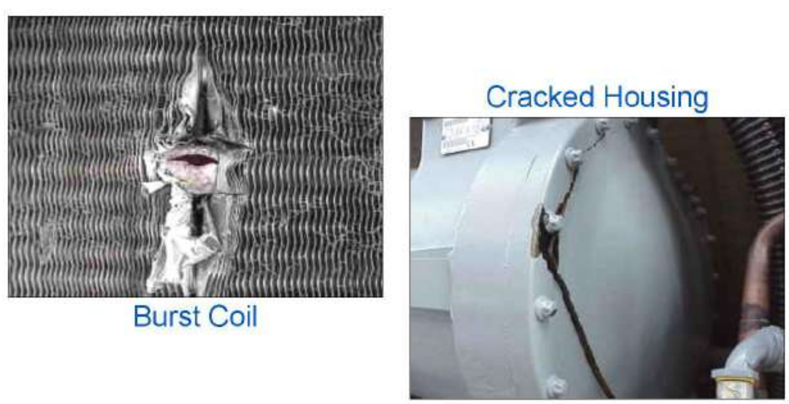


Figure 32

Freeze Damage

Here are the suggested freeze protection methods.

Drain the Chiller Loop

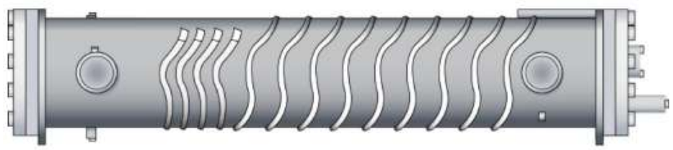
If the unit will not be operational, water can be drained from the exposed piping and evaporator during the off-season. Draining of the chiller loop is limited to applications where requirements for mechanical cooling do not exist while ambient is below freezing for extended periods of time. With increasing use of free outside air-cooling, this is a plausible approach. However, as not all of the water is guaranteed to be completely drained, an antifreeze solution should still be added to prevent freezing of the residual water left in the evaporator.

Use Evaporator Barrel Heaters

Electric heaters installed on exposed pipes and the evaporator barrel is a cost effective solution that requires little maintenance. Chiller manufacturers usually supply evaporator barrel heater options, but the chilled-water piping to the evaporator must be taped with heat trace in the field. However, dependence on electrical power is the key drawback. If an ice storm or a circuit breaker interrupts power to the unit for a long enough period of time, freezing can result. This method is often combined with continuous water circulation.

Evaporator barrel heaters

are usually supplied with a separate power supply and disconnect in order to stay operational when the power to the chiller is cut via the main chiller disconnect, such as when service is performed on the chiller.



- Refrigerant in tubes
- Water (glycol) in shell
- Heater cable wrapped around the DX Evaporator shell
- Factory or field-installed

Figure 33

Evaporator Barrel Heater

Circulate Water Continuously

In this case, the chilled-water pump is energized to circulate the water in the loop to prevent it from freezing. The idea is, moving water will not freeze as quickly. The pump is activated when the cooler temperature gets near or below freezing. This method depends on pump operation and on electrical power being available. Water circulation is often used in conjunction with barrel heaters.

Use an Antifreeze (Glycol/Water Solution)

Glycol is often added to the chilled-water loop and is the preferred method of freeze protection by chiller manufacturers for comfort air-conditioning applications and some low temperature designs also. It is the most reliable system protection, as it does not require electrical power to be effective. It also protects chilled-water coils and other piping that might be exposed to temperatures below freezing. However, adding a glycol solution to the chilled-water system will decrease performance of the chiller because the glycol increases fouling, compressor lift, and pumping power. The quantity of glycol used in the solution should be designed for a temperature 15º F below the minimum anticipated temperature to which the chiller will be exposed. The minimum glycol concentration suggested should be approximately 20-25 percent, but lower concentrations are also used. This is the decision of the local design engineer.

> ***The use of a glycol/water solution***
>
> ***is the preferred method of freeze protection by manufacturers of chillers. A chloride antifreeze solution is often used in low-temperature chiller applications, such as ice rinks.***

Glycol/water antifreeze solutions are capable of providing two levels of protection for the chilled-water system: burst protection and freeze protection. Burst protection allows for the fluid in the chilled-water loop to become slushy, but never to fully freeze solid to the point of rupturing or collapsing tubing. Freeze protection requires the glycol concentration be greater than for burst protection so the chilled fluid constantly remains in a liquid state. In essence, if the unit will not be operational during the cold weather, burst protection may be adequate, as the glycol solution slush will not be pumped throughout the system. However, if the chiller is to be operational during cold weather, freeze protection is necessary because the pumps require the solution to be in a liquid state.

To provide burst protection, the antifreeze concentration only needs to be great enough to prevent the mechanical damage that would happen if the fluid were to solidify. The formation of crystals is not a problem because the fluid is not being pumped through the system when burst protection measures are taken. Burst protection requires less antifreeze than freeze protection. Burst protection is suitable for chilled-water systems that are dormant in the winter. The lower concentration of glycol for burst protection results in lower costs for initial fill of the system and lower system operating costs due to improved heat transfer in the heat exchanger.

> ***Burst protection***
>
> ***levels of glycol may result in a smaller chiller selection than one being selected for freeze protection.***

Propylene Glycol		
Protection Temperature (°F)	**For FREEZE protection ** % by weight**	**For BURST protection ** % by weight**
+20	18	12
+10	29	20
0	35	25
-10	41	29
-20	45	30
-30	48	32
-40	52	34

**Confirm with the local glycol supplier

Figure 34

Freeze versus Burst Protection

As previously stated, the formation of ice crystals is not desirable when the pump or pumps are circulating the fluid at low fluid temperatures. Examples of such applications are ice storage and process cooling systems. The formation of crystals in fluids being pumped could result in erosion of the pump, piping, valves, etc. Typically, these systems comprise the minority of air-cooled chiller installations.

The local antifreeze manufacturer should be consulted for final recommendations based on their formulation of the heat transfer antifreeze fluid. Each antifreeze solution has physical characteristics that determine the percentage of antifreeze in the solution at which the freezing point or first crystals point occurs. This can be found in reference books such as the Carrier System Design Manual Part 4 and publications from antifreeze manufacturers like Dow Chemical Company, etc. Refer to those publications for the freezing point or first crystals point. Antifreeze also has a temperature at which the solution becomes a solid. This information can be found in publications from the antifreeze manufacturers. The temperature at which the antifreeze/water solution becomes a solid is the lowest temperature for burst protection. Above that temperature, the antifreeze/water solution is still slush (a combination of fluid and crystals) and will not burst or collapse the tubes or shell of the heat exchangers.

Refrigerants Used in Air-Cooled Chillers

Currently manufacturers of air-cooled chillers utilize R-22 refrigerant in some of their models. R-22 has been the refrigerant of choice for many years. However, this situation is changing. R-22 contains chlorine which, when released to the atmosphere, has detrimental environmental effects. In addition to R-22, newer chiller designs utilize R-134a, which is used in larger centrifugal chillers and has no chlorine. Also, new blends have been developed for use in air-cooled chillers, like R-410A (Puron™). R-407c is also used.

By the year 2010, R-22 will no longer be shipped in chiller product.

Note:

The phase-out date for R-22 is 2010 when used in brand new equipment and 2020 for service.

With the year 2010 in mind, manufacturers will be modifying their products in phases to the new environmentally sound refrigerants mentioned.

It should be understood that it is not possible to simply replace R-22 in an existing chiller with one of the new blends. The new refrigerant may have far different pressure – temperature and heat of vaporization characteristics than R-22, and major modifications to the chiller would be required and is not practical.

Please consult TDP-401, Refrigerants for a full discussion concerning refrigerants.

Figure 35

Refrigerants Used in Air-Cooled Chillers

Chiller Sizing

Over sizing chillers by more than approximately 15 percent at design conditions must be avoided, as the system operating efficiency will be adversely affected (resulting in greater and/or excessive electrical demand and cycling of compressors). When future expansion of equipment is anticipated, install a single chiller to meet present load requirements, and install a second chiller to meet the additional load demand.

Oversizing

is especially not recommended if the chiller does not have multiple compressors or some unloading capability.

It is also recommended that the installation of two smaller chillers be considered where operation at minimum load is critical. The operation of two small chillers at higher loading is preferred to operating single chiller at or near its minimum recommended value.

Minimum Chilled-Water System Volume

It is important to understand the relationship between loop volume of the chilled-water system and chiller operational stability. Loop volume is the amount of fluid in the cooler, chilled-water piping, cooling coils and optional storage tank that remains in circulation at all times. If the loop volume is too small, rapid changes in water temperature and short cycling of the compressor can occur. In effect, adequate loop volume acts as a "flywheel" so that the chiller cannot cycle off too quickly after cooling down the water. To minimize cycling, the minimum loop volume should be at least three gallons per nominal ton chiller capacity for normal comfort cooling duty applications. Always follow individual manufacturer guidelines for minimum loop volumes. For batch, process, and loads that operate under variable flow conditions, the minimum loop volume should be from six to ten gallons per ton of installed chiller. Applications that operate under low ambient temperatures or use brine typically also require six to ten gallons per nominal ton. Again, all recommendations are manufacturer dependent.

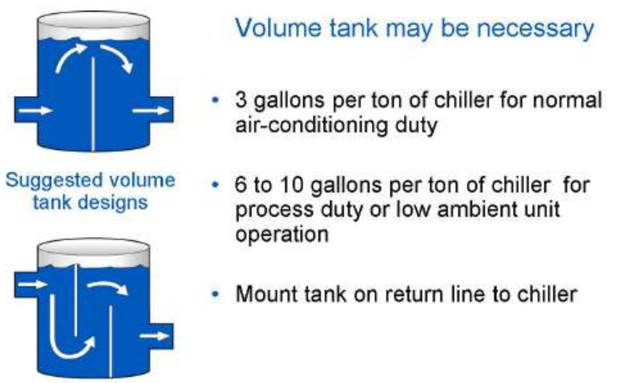


Figure 36

Minimum Chilled-Water System Volume

A method to increase the loop volume of a chilled-water system is the addition of a volume tank.

For example, suppose a chiller installation with a 200-ton capacity chiller has a system loop volume of 400 gallons. The recommended minimum loop volume would be:

(200 nominal tons) * (3 gallons/nominal ton)= 600 gallons

If the loop volume was calculated to be 400 gallons and the minimum required loop volume 600 gallons, a volume tank holding a minimum of 200 gallons would be required. Alternatively, pipe size may be increased to satisfy the loop volume requirements.

Parallel and Series Chillers

Where chiller capacities greater than can be supplied by a single chiller are required, or where stand-by capability is desired, chillers may be installed in parallel. Units may be of the same or different sizes. Usually, equally sized chillers are utilized to accomplish commonality of parts and maintain simplicity. If unequal sized chillers are used, cooler flow rates must be balanced to ensure proper flow to each chiller. Software is available from the chiller manufacturer that automatically stages multiple chillers of equal or unequal size.

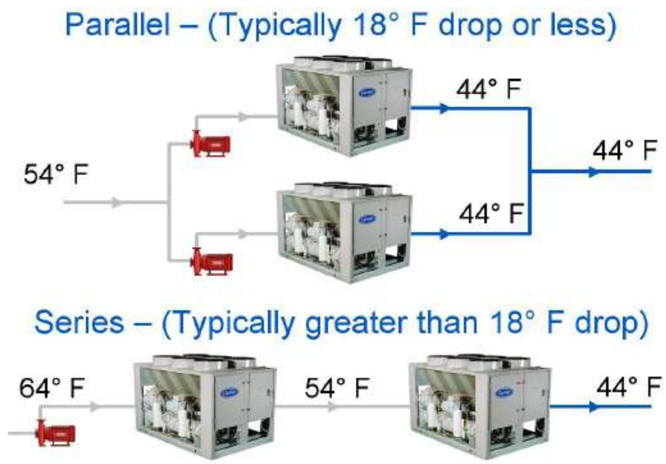


Figure 37

Parallel and Series Chillers

Future Expansion Arrangements

Parallel chiller arrangement lends itself to future expansion because another chiller can simply be added to the "ladder." Two chillers in a series cannot accommodate future expansion since pressure drop in the evaporator circuit would become too great with three chillers.

Where a large temperature drop (greater than 18º F) is desired, chillers may have to be installed in series. This is a rule of thumb. Actual chiller selections should be made to confirm when series chillers are needed. The cooler minimum entering fluid temperature limitations should be considered for the chiller located downstream of other chiller. Use of reduced pass configuration may be required to keep waterside pressure drop at an acceptable level.

Clearances and Installation

There are several design considerations when planning to install an air-cooled chiller. First, the chiller must have adequate clearances on all sides to accommodate the necessary airflow. All chiller manufacturers specify the minimum acceptable clearances in order for the chiller to operate correctly and allow for maintenance. Additionally, the National Electric Code (NEC) has specifications regarding the minimum clearance to electrical panels. Also, external piping should not be placed where it could interfere with the maintenance of the chiller.

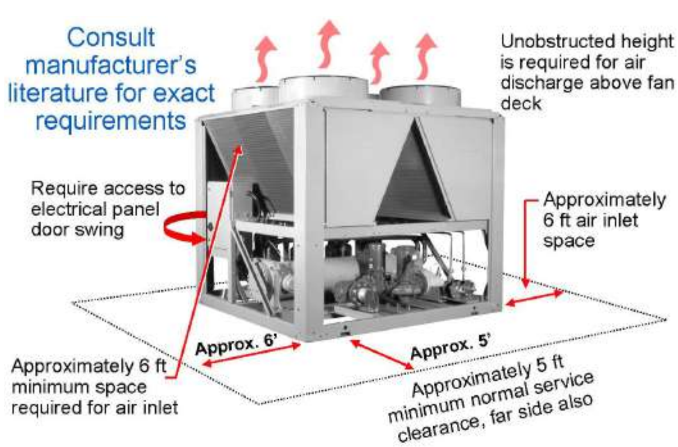


Figure 38

Typical Clearances – Air-Cooled Chiller

Air-cooled chillers generate noise from the condenser fans and compressors that may be an issue in certain environments, such as schools. In these cases, placement behind sound-blocking fences or walls would be required. Sound reduction accessories, as well as security covers for the condensers grilles, may also be used in sensitive areas.

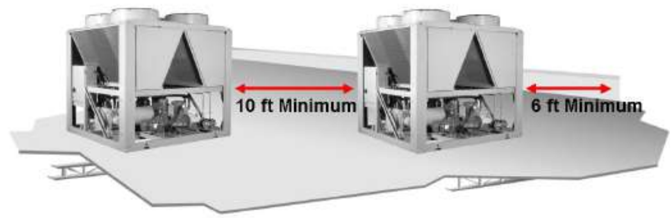


Figure 39

Multiple Unit Separation

Options & Accessories

Some of the options and accessories we will discuss for air-cooled chillers include low-ambient operation, low chilled-water temperature option, condenser coil corrosion protection, and a hydronics package. Typically, options are factory-installed additions to the chiller while accessories are field-installed. Following is a discussion of the more common ones.

Low-Ambient Operation

If the chiller is required to produce chilled water while operating in low ambient environments, head pressure control is required. Air-cooled chillers typically maintain head pressure control in cold weather by cycling and modulating condenser fans. As fans are cycled off due to a reduction in load or ambient temperature or both, the airflow rate through the condenser decreases resulting in elevation of condensing temperatures to correct levels. Depending on the load and unit design, cycling of fans will allow the chiller to operate satisfactorily down to approximately 35º F ambient temperature. If the chiller must operate at ambients below that temperature, then a factory-installed or field-installed option can be used to modulate the speed on the last operating condenser fan. This variable fan speed system allows for stable operation of the chiller for ambient temperatures as low as –20º F depending upon the manufacturer.

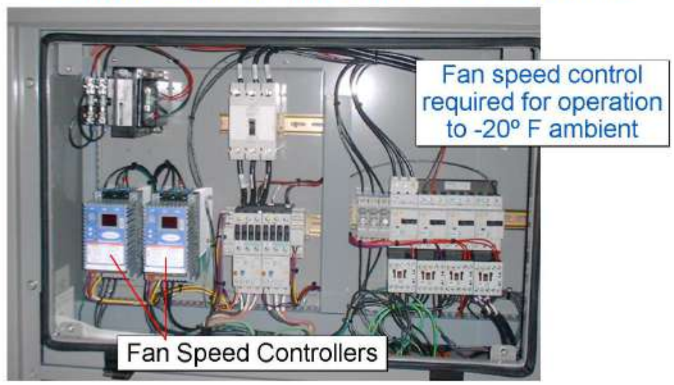


Figure 40

Low-Ambient Operation

Head pressure control

on an air-cooled chiller is the regulation of the condenser fans to maintain correct condensing temperature as ambient temperature changes.

In addition, wind baffles are required for chillers operating in ambients below approximately 32º F. Wind baffles are field-fabricated and installed sheet metal covers placed over the condenser coils that allow air movement through the coil while preventing prevailing winds from affecting the chiller's condensing temperature.

Low Chilled-Water Temperature Option

Some typical applications require chilled water well below 40º F, such as the creation of ice for ice rinks. Many of the same procedures for freeze protection discussed earlier also apply to chillers intended for low chilled-water temperature operation. Typically, a antifreeze solution is used in the chilled-water system and some form of condenser head pressure control is used, generally through condenser fan speed reduction. Chilled-water temperatures leaving the cooler can be reduced to as low as 15º F through the use of an antifreeze solution. If the chiller is required to produce leaving fluid temperature as low as 15º F, a factory modification to the unit is required.

Figure 41

Low Chilled-Water Temperature Option

The term "brine chiller" is often used to designate chillers that are modified for low chilled-water temperature operation. The term "brine" dates back to the early days of fluid cooling when either a sodium chloride/water solution or calcium chloride/water solution was used as the antifreeze or heat transfer solutions. Because both of these were salt solutions, they came to be referred to as brine. That term has continued to be used today for sodium chloride/water solutions, calcium chloride/water solutions, and for glycol solutions even though glycol is technically not a brine.

Condenser Coil Corrosion Protection

By definition, corrosion is the destruction or deterioration of a metal or alloy through chemical, physical, or electrochemical reaction with the environment. As applied to air-cooled chillers, environmental exposure can lead to localized and/or general corrosion of the condenser coil. Improperly protected coils in corrosive environments can lead to premature performance degradation, unsightly surface conditions and, under the most severe conditions, equipment failure. This can result in increased operating, maintenance, and service costs. Fortunately, corrosion can be minimized in most cases with proper coil protection.

Measures can be taken to diagnose potentially corrosive environments prior to equipment selection. With this information, the best-suited coil protection can be applied to minimize the harmful effects of corrosive atmospheres and ensure long equipment life.

Potentially corrosive outdoor environments include areas near the seacoast, industrial sites, heavily populated urban areas, some rural locations, or combinations of any of these environments. Local environments must also be considered, such as close proximity to laundry facilities, diesel-burning devices, exhaust piping, sewer vents, traffic, etc.

The following list shows coil construction along with materials commonly used to combat the effects of corrosive atmospheres for condenser coils on air-cooled chillers.

- Standard coil (copper tubes, aluminum fins)
- Pre-coated coil (copper tubes, aluminum fins)
- All copper coil (copper tubes, copper fins)
- Electro-coated coil (copper tubes, aluminum fins)

Standard Coil Construction

The standard coil construction for air-cooled chillers is copper tubes with aluminum fins. This generally provides the highest performance for non-corrosive environments (e.g., non-polluted rural environments). Application of this coil in any environment containing corrosive constituents is not recommended due to the likelihood of visible deterioration resulting from corrosion. However, standard coil construction meets the requirements for the majority of applications.

Standard coil construction

for air-cooled chillers is copper tubes with aluminum fins.

Pre-Coated Aluminum Fin Coils

Pre-coated aluminum fin coils have a durable epoxy coating factory-applied to the fin. This design offers protection in mildly corrosive coastal environments, but is not recommended in severe industrial or severe coastal environments. Aluminum fin stock is coated with a baked-on epoxy coating prior to the fin stamping process. Coating of the fin material prior to the fin stamping process is known as "pre-coating." The pre-coated fin material is then stamped to form a wavy fin pattern for optimum thermal performance. The dissimilar metals of the coil are insulated from one another by a thin layer of inert epoxy pre-coating material. As a result, the electrical connection between the copper and aluminum is broken, thus preventing galvanic action that leads to corrosion.

Copper Fin Coils

Copper fin coils eliminate the bi-metallic bond found on standard coil construction. A copper wavy fin pattern is mechanically bonded to the standard copper tube. A protective Mylar strip installed between the coil assembly and sheet metal coil support pan further protects the coil from galvanic corrosion. Durability in a coastal unpolluted marine environment can be substantially improved over the standard or pre-coated coil construction, since the bi-metallic construction is not present.

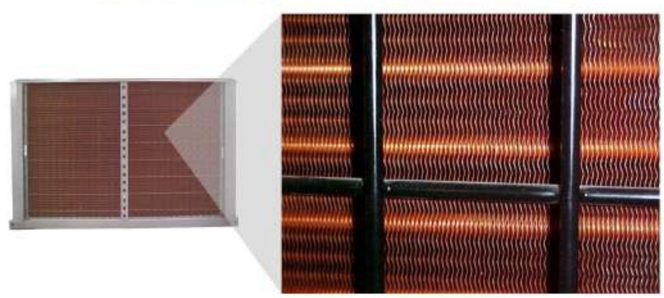


Figure 42

Copper Fin Coil Option

> ***Copper-fin coils***
>
> ***provide increased corrosion resistance in coastal environments where pollution sources are not present.***

Copper is generally resistant to unpolluted coastal environments, since a natural protective film is formed to passivate the copper surfaces. Furthermore, a mono-metal bond exists between the tube and the fin. Uncoated copper coils are not suitable for polluted coastal applications or industrial applications, because many pollutants attack copper.

Electro-Coated Aluminum-Fin Coils

Electro-coated coils provide superior protection against many corrosive atmospheres with the exception of formic acid and nitric acid environments. Electro-coated aluminum-fin coils have an extremely durable and flexible epoxy coating uniformly applied over all coil surfaces for protection from exposure to the contaminated environment. A consistent coating is achieved through a precisely controlled electro-coating process that bonds a thin impermeable epoxy coating on the specially prepared coil surfaces.

> ***Electro-coating***
>
> ***The fundamental principle of electro-coating is that the materials with opposite electrical charges attract each other.***

An electro-coating system applies a DC charge to the coil immersed in a bath of oppositely charged epoxy molecules. The molecules are drawn to the metal, forming an even, continuous film over the entire surface. At a certain point, the coating film insulates the metal, stopping the attraction, and preventing further coating deposition. This is a self-limiting nature of the coating process. A precisely controlled oven bake cures the coating uniformly to ensure consistent adhesion on all coil surfaces. Finally, a UV protective topcoat is applied to shield the finish from ultraviolet degradation and to ensure coating durability and long life. This creates a smooth, consistent and flexible coating that penetrates deep into all coil cavities and covers the entire coil assembly including the fin edges. This process, in conjunction with the coating material, results in a less brittle, more resilient and more durable coating without bridging between adjacent fins when compared to other coating procedures.

This method is superior to conventional phenolic coatings, which are applied manually by dipping and baking. Electro-coating is a more durable, evenly coated, non-brittle, non-flaking coil protection product than phenolic coatings.

Hydronics Packages

Some models of air-cooled chillers are available utilizing factory-installed and tested hydronics packages. The hydronics package can include a factory-supplied chilled-water pump, strainer, expansion tank, volume tank (not shown in figure), valve, and piping – basically items that traditionally would have to be supplied and installed by the contractor. In the description that follows,

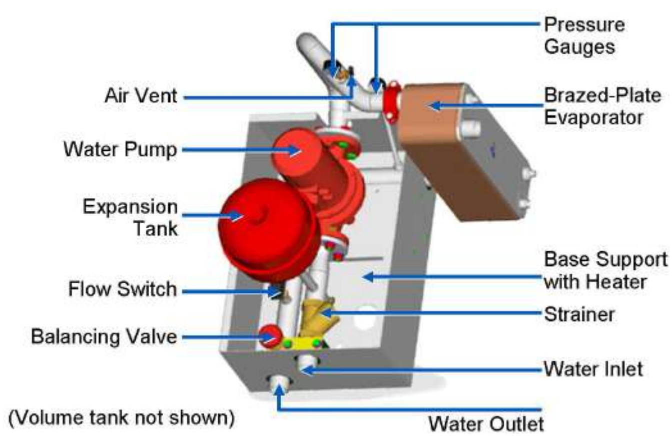


Figure 43

Hydronics Package – Factory-Installed in an Air-Cooled Chiller keep in mind these hydronic components are necessary on all air-cooled chiller system installations whether or not they come factory-installed as part of the chiller or are provided by the contractor. The volume tank may not be required on all projects if installed loop volume meets or exceeds minimum requirements. For a detailed discussion of all hydronic components in piping systems, refer to TDP-502, Water Piping and Pumps.

Pump

Pumps are an integral part of the chilled-water system and should be selected based on their design, size, serviceability and performance. In a hydronics package, the pump is factory selected. In terms of performance, the pump is selected to provide the required chiller flow rate at the design total head while achieving the lowest possible horsepower.

If the pump is not included as part of a chiller hydronics package, pump selection must be made by the engineer.

Figure 44

Pump Included in Hydronics Package

Expansion Tank

Temperature changes cause the water to expand or contract within a closed loop piping system. Expansion tanks support the expansion or contraction of water within the system.

> ***Expansion of System Volume***
>
> ***Practically speaking, the change in water system volume is about 1 percent for chiller water systems.***

The change in water system volume is about 1% for chilled-water systems

Figure 45

Expansion Tank in Hydronics Package

Volume Tank

As discussed previously, all chiller manufacturers require a minimum loop volume for proper operation of their chillers to prevent rapid changes in water temperature and short cycling of the compressor. See the minimum chiller water system volume section in this TDP module.

A volume tank is often missed and system problems can occur. That is why this feature is now made available as a factory-supplied and installed option on some chiller designs.

> ***Volume Tank Option***
>
> ***The volume tank is fitted under the chiller when this factory-supplied option is selected on an air-cooled chiller.***

Air Separator (Field-Supplied)

Air separators are not included in the hydronics package, but deserve a discussion at this point. Air separators eliminate entrained air from the system. As an example, 50° F water at 30 psig can contain up to 9 percent dissolved air. Circulation of the water through an air separator can remove a large percentage of this air and will improve the overall efficiency of the system because air acts as an insulator. It also reduces the corrosion effect caused by oxygen.

Codes and Standards

There are a number of codes and standards applicable to air-cooled chillers that are important to understand. They have been divided into performance and safety related categories in this section.

Performance Related

ARI

ARI (Air Conditioning and Refrigeration Institute) is a trade association for the industry that has established a chiller certification program with defined testing procedures and tolerances. Manufacturers whose equipment bears the ARI label participate in a program of random audit certification testing. The testing is to check that the "as built" chiller performs per the manufacturer's ratings as represented in product rating literature such as selection software and catalogues. The ARI standard for electric chillers is ARI 550/590, "Water-chilling Packages Using The Vapor-Compression Cycle." To verify performance, ARI at any time may randomly select from a manufacturer's inventory listed units. These units are sent to an independent laboratory for performance testing. The equipment performance must match the listed values within a tolerance dependent upon the application temperature rise of the cooler fluid. The tolerance is 5 percent at standard full-load ARI conditions. Part-load tolerances are generally greater.

Figure 46

Codes and Standards

Here are the ARI Standardized Conditions for air-cooled chillers:

- Leaving chilled water = 44º F
- Chilled-water flow rate = 2.4 gpm / ton
- Cooler fouling factor = 0.0001 hr ∗ ºF ∗ ft^2 / Btu
- Entering air temperature = 95º F

Following is a discussion of performance-related terms used by ARI for air-cooled chillers.

Efficiency

EER is measure of a chiller's efficiency at full load based upon the rating condition. COP and kW/ton are other methods of depicting the efficiency.

EER	=	Output, Cooler Tons (Btuh) / Input, Total Chiller (Watts)
COP	=	Output, Cooler Tons (Btuh) / Input, Total Chiller (Btu/hr)
kW/ton	=	Input, Total Chiller (kW) / Output, Cooler (tons)
COP	=	EER / 3.414
EER	=	12 / (kW/ton)

IPLV

Integrated Part-Load Value (IPLV) is used to evaluate the efficiency of a chiller operating in the cooling mode over a range of points. IPLV is a weighted average of the EER calculated at 100, 75, 50, and 25 percent of chiller capacity. The IPLV conditions may not represent any specific project but are considered typical. The conditions and equation for IPLV are listed in the table below:

Conditions for Calculating IPLV

% Load	Entering Air Dry Bulb Temperature (°F)	Weighting
100	95	1%
75	80	42%
50	65	45%
25	55	12%

$$IPLV = 0.01A + 0.42B + 0.45C + 0.12D$$

Where:

A = [EER or COP] at 100% load

B = [EER or COP] at 75% load

C = [EER or COP] at 50% load

D = [EER or COP] at 25% load

Selection Software

Manufacturer's air-cooled chiller selection software automatically calculates IPLV or NPLV when a selection is made.

IPLV is commonly expressed as either an kW/ton value or in unites of EER. There is a fixed relationship between kW/ton and EER.

EER = 12(kW/ton)

This relationship shows that EER increases as kW/ton decreases, and vice versa. Therefore, a "better" IPLV is shown as a lower value when the units are kW/ton, and, due to the relationship just described, a "better" IPLV is a higher value when the units are expressed in terms of EER.

NPLV

Non-Standard Part-Load Value is similar to IPLV, except NPLV is the term used if the chiller selection conditions are not exactly at the ARI conditions specified earlier.

ASHRAE 90.1

ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) is an organization that establishes and maintains standards for the heating, ventilation, and air-conditioning industry. At the basic level, you may consider ASHRAE Standard 90.1 as defining minimum energy efficiency standards for a variety of building components, including air-conditioning equipment. This standard applies to air-cooled chillers and it defines the minimum EER, IPLV, & COP of the chiller. At the time of printing this TDP, here are the air-cooled chilled efficiency requirements.

Air-Cooled Chillers

Equipment Type	Size Category	Minimum Efficiency kW/Ton
Air-cooled with condenser	< 150 tons ≥ 150 tons	1.255 full load 1.153 IPLV
Air-cooled without condenser	All	1.134 full load 1.019 IPLV

Figure 47

ASHRAE 90.1 Efficiency Requirements

Safety Related

ASME

ASME (American Society of Mechanical Engineers) establishes and maintains rigorous safety related design construction and inspection standards. ASME is responsible for pressure vessel standards as defined in Section VIII Division I of the current ASME Code. The requirement for an ASME stamp is dependent on the physical size and the refrigerant pressure rating on the chiller. For example, evaporator vessels whose size falls under the minimum 6 inch inside diameter size may be constructed to comply with another nationally recognized testing laboratory other than ASME. This may vary from manufacturer to manufacturer.

UL / CSA & ETL

Several safety standards apply to chillers. There are also several widely accepted agencies such as Underwriters Laboratories, Inc., Canadian Standards Association, and ETL Testing Laboratories, which test for compliance to those standards. When a chiller is approved as meeting the required testing, it will bear a mark or label from the certifying agency.

UL (Underwriters' Laboratories, Inc.) is an independent nonprofit organization that tests products for safety and certifies them. The Canadian Standards Association (CSA) is a non-profit association serving business, industry, government, and consumers in Canada. Among many other activities, CSA develops standards that enhance public safety. For heating, ventilation, and air conditioning, UL/CSA Standard UL 1995 / CSA C22, Heating and Cooling Equipment applies.

ETL Testing Laboratories, like UL, conducts electrical performance and reliability testing. OSHA (Occupation Safety and Health Administration) recognizes ETL as a nationally Recognized Testing Laboratory as is Underwriters Laboratories. The ETL Listed Mark and Canadian-

ETL Listed Mark are accepted throughout the United States and Canada compliance with nationally recognized standards such as ANSI (American National Standards Institute), UL, and CSA. This certification mark indicates that the product has been tested to and has met the minimum requirements of a widely recognized U.S. product safety standard, that the manufacturing site has been audited, and that the applicant has agreed to a program of periodic factory follow-up inspections to verify continued conformance. If the mark includes a small "US" and/or "C," it follows product safety standards of United States and/or Canada respectively.

NEC / CEC

The NEC (National Electric Code) and CEC (Canadian Electric Code) are published by organizations whose members come from various government agencies, power utilities, insurance companies, electrical manufacturers, and other organizations. The NEC and CEC address proper design and installation of electrical systems and equipment to protect people and property from hazards arising from the use of electricity in building systems. Wiring design and installation in air-cooled chillers follows NEC guidelines.

ASHRAE 15

ASHRAE 15, Safety Standard for Refrigeration Systems, is a Mechanical Safety Standard relating to the design of systems containing refrigerants within buildings. Its primary goal is to mitigate safety risks to the environment, mechanical equipment room operators, and the general public from any harmful effects of refrigerants. Because air-cooled chillers are mounted outdoors, ASHRAE 15 is not usually applicable. However, if a split system with an indoor condenserless chiller or a remote indoor cooler barrel is used, ASHRAE 15 must be considered because if a refrigerant leak developed, refrigerant could enter the building.

ASHRAE 15

An additional benefit of single piece outdoor air-cooled chillers is that the extra expenses of complying with ASHRAE 15 do not apply. Those expenses include a refrigerant monitor, alarm system, relief piping and a ventilation system.

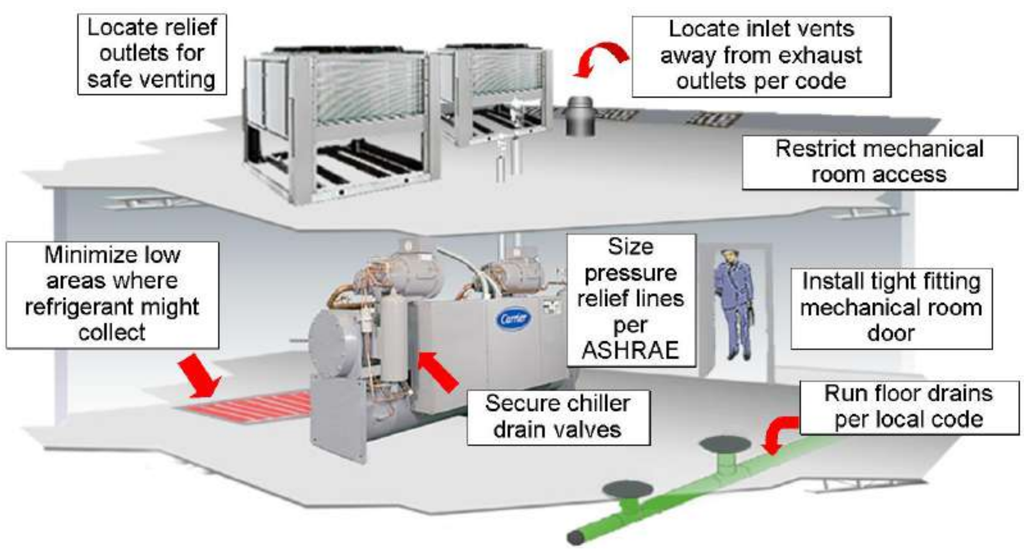


Figure 48

ASHRAE Standard 15 and Split System Air-Cooled Chiller

Selection Criteria

Input

The primary inputs for selecting an air-cooled chiller are listed below along with a typical chiller selection software program's screen capture:

Capacity/Cooling Load (tons)

Fouling Factor for the cooler

Water Type
(fresh, brine concentration, etc.)

Glycol Percentage by weight

Entering Water Temperature or
gpm or gpm/ton

Leaving Water Temperature

Ambient Air Temperature

Altitude (air density for condenser)

Voltage

Condenser Type

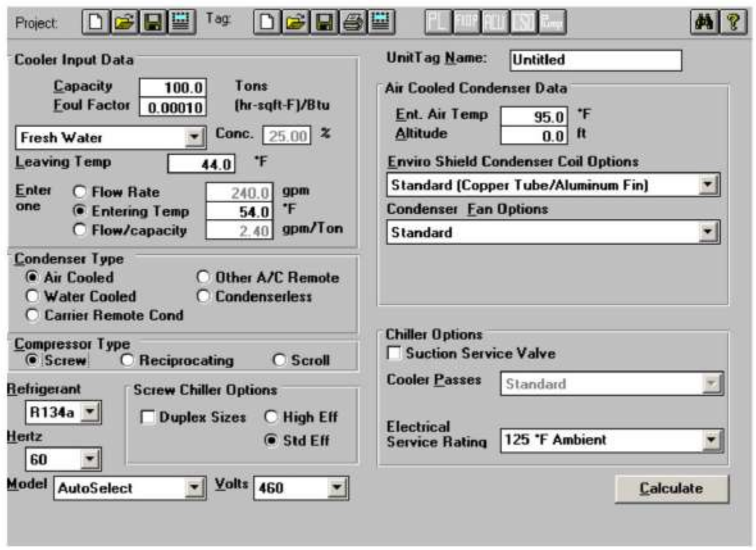


Figure 49

Selection Input

Output

The following is typical output from a chiller selection program:

Unit Size	30GXR114
Cooling Capacity	106.0 Tons
Compressor Input Power	120.5 kW
Unit Input Power	130.1 kW
Minimum Outdoor Operating Temp	-20°F
Capacity control steps	6
Minimum Capacity	20.0%
Input kw/Ton	1.227
Unit EER	9.78
Efficiency Level	Standard
Refrigerant	R134a
Cooler Data	
Fluid Type	Fresh Water
Fluid Entering Temperature	54.0° F
Fluid Leaving Temperature	44.0° F
Fluid Flow Rate	254.2 gpm
Fluid Pressure Drop	13.8 ft wg
Fluid Velocity	5.6 ft/s
Fouling Factor	0.0001 (hr-sq ft-°F)/Btu
SST	
Circuit A	43.1° F
Circuit B	42.5° F

Condenser Data	
Entering Air Temp	95.0° F
Air Flow Rate	68,400 cfm
Number of Fans	6
Fan Speed	1,140 rpm
Altitude	0 ft
SDT	
Circuit A	130.9° F
Circuit B	124.4° F
SCT	
Circuit A	128.8° F
Circuit B	123.0° F
Subcooling	
Circuit A	22.0° F
Circuit B	19.2° F
Heat Rejection	
Circuit A	80.5 Tons
Circuit B	54.6 Tons
Nameplate Voltage	460 Volts
Elec. Power Frequency	60 Hertz
Power Supply to control circuit control circuit	115 Volts
Power Supply to control circuit Phases	1
Minimum Circuit Amps Circuit 1	234
MOCP - Circuit 1	300
Max Instant Current Flow	354
Control Circuit Fuse Amps	300
Electrical Service Rating	125° F

Summary

In this TDP module, we first discussed the differences between air-cooled chillers and water-cooled chillers. The major difference revolves around the convenience of utilizing a single piece outdoor chiller versus an indoor water-cooled design that requires a separate cooling tower and condenser water system. However, as we learned, the full load kW per ton favors the water-cooled chiller.

Air-cooled chillers can be used as a single piece unit or a split system in various configurations. This flexibility has contributed to their overall popularity among designers of chilled-water systems.

There are a myriad of different application recommendations for air-cooled chillers. Variables like ambient temperature, leaving chilled-water temperature, variable flow in the evaporator, freeze protection methods and system water volume, all have an affect on the operation of an air-cooled chiller. Each of these was discussed in this TDP module.

Manufacturers offer different options to fit the application desired and it is important to apply them correctly. Many items, such as hydronic accessories, are now incorporated in some air-cooled chiller models from the factory.

The selection of an air-cooled chiller is performed on selection software furnished by the chiller manufacturer. All the necessary items that affect the performance of the chiller are included in the input data set.

The popularity of air-cooled chillers is increasing as a result of their features and their convenience of use. The ability of designers to use multiple air-cooled chillers together to achieve even the largest of installation capacities is an added attraction for designers of chilled-water systems.

Notes:

Work Session

1. What are the four major components of the air-cooled chiller refrigeration cycle?

   Condensor

   Compressor

   ____

   ____

2. List the three types of compressors used in air-cooled chillers.

   Screw

   ____

   ____

3. List the three types of evaporators used in air-cooled chillers.

   ____

   ____

   ____

4. What are five configurations of air-cooled chillers?

   1. ____________________
   2. ____________________
   3. ____________________
   4. ____________________
   5. ____________________

5. What are the three methods of capacity control used in air-cooled chillers?

   ____

   ____

   ____

6. What can happen if a chiller is improperly sized?

   ____

   ____

   ____

7. List three types of motor starters for air-cooled chillers.

   ____

   ____

   ____

8. List four methods of freeze protection for air-cooled chiller evaporators.

   ____

   ____

   ____

   ____

9. List three methods of increasing the corrosion protection for condenser coils.

   ____

   ____

   ____

10. Which type of starter is most likely to be used on a 208V reciprocating air-cooled chiller compressor? ____________________

11. If the refrigerant is on the shell side of an evaporator, what type of evaporator is that? ____________________

12. What is a typical kW/ton at full load of an air-cooled chiller? ____________________

13. What are the 4 dry bulb temperatures and the corresponding percent of full load used by ARI to calculate the IPLV of an air-cooled chiller?

Percent Load	Entering Dry Bulb Temperature

14. What is the rule of thumb for chilled-water system volume for comfort air-conditioning applications? ____

15. What is the rule of thumb for chilled-water system volume for process cooling applications?

   ____

Notes:

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

ASHRAE Standard 15, "Safety Standard for Refrigeration Systems."

ASHRAE Standard 90.1, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings

Carrier Corporation, Syracuse, NY. Packaged Chiller Selection Program, Version 2.8. http://www.carrier.com/

Honeywell International, LLC, Morristown, NJ. http://www.honeywell.com/

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

Notes:

Work Session Answers

1. compressor, condenser, expansion device, and cooler or evaporator
2. reciprocating, screw, and scroll
3. flooded shell-and-tube, direct expansion shell-and-tube, and brazed plate
4. single unit, remote evaporator, condenserless chiller, indoor centrifugal condenser, evaporative condenser
5. unloading compressors, cycling compressors, and hot gas bypass
6. If the chiller is undersized, it will not be able to sufficiently cool the load under full load operation. However, if the chiller oversized, the reliability of the system, especially the compressors, may be reduced due to continuous cycling or operating at a very low capacity. As the highest stress on motors is greatest during start-ups, decreasing the number of start-ups from cycling is a significant factor in maintaining compressor reliability, efficiency, and limiting electrical demand charges.
7. across-the-line, wye-delta, and part-winding
8. draining the water loop, adding heaters to the cooler and water piping, circulating water constantly throughout the system, and adding antifreeze to the water loop
9. pre-coating; copper fin, copper tube; electro-coating
10. part-winding
11. flooded
12. 1.25 kW/ton
13.

Percent Load	Entering Dry Bulb Temperature
100	95
75	80
50	65
25	55

14. 3 gallons of water in the chilled-water piping loop per ton of installed chiller
15. 6-10 gallons of water in the chilled-water piping loop per ton of installed chiller.

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-301	796-034	797-034	Load Estimating, Level 2: Fundamentals
TDP-400	796-037	797-037	Mechanical Refrigeration, Level 1: Introduction

Learning Objectives:

After reading this module, participants will be able to:

- List the various types and tonnages of packaged air-cooled chillers and their operational characteristics.
- Describe the correct application of air cooled-chillers versus water-cooled chillers.
- Identify the options and accessories available for air-cooled chillers.
- Use the selection criteria required to make efficient air-cooled chiller selections.

Supplemental Material:

Form No.	Book Cat. No.	Instructor Presentation Cat. No.	Title
TDP-623	796-055	797-055	Water-Cooled Chillers
TDP-703	796-068	797-068	Chilled-Water Systems

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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