HVAC Hacks – Module 10: HVAC Cooling Tower & Condensers – Essential Tips & Thumb Rules

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HVAC COOLING TOWER & CONDENSERS – ESSENTIAL TIPS & THUMB RULES

Struggling to choose the right heat rejection equipment for your HVAC system? Look no further! This course provides everything you need, from basics to best practices for cooling towers and air-cooled condensers.

In this 8-hour comprehensive course, you will gain a deep understanding of heat rejection principles, design tips, and operational strategies that will boost performance, cut energy costs, and enhance system reliability. You'll learn how to size and select cooling towers and condensers that align with industry standards and regulations. Additionally, you'll gain essential insights into water treatment, with techniques for managing corrosion, scaling, and microbial growth.

This course includes several metrics and easy-to-understand "Rules of Thumb" guidelines based on experience and commonly accepted practices in the HVAC industry.

You can find **Key Rules of Thumb in Annexure - 1** for quick and easy reference. These guidelines, metrics, and thumb rules are based on sound engineering practices and the author's experience, but they may vary depending on operating conditions and other factors. This document is a live resource that will be updated regularly as new information becomes available.

Read to explore heat rejection principles, design strategies, and options? Let's get started!

Important Note: We have covered the essentials of the chilled water system, focusing on refrigeration chillers (Module #8) and the hydronic distribution network (Module #9) in the HVAC Hacks series. Now, Module #10 will delve into the heat rejection system. By building on what you learned in Modules #8 and #9, you'll gain a comprehensive understanding of chilled water system design for large, centralized HVAC applications.

CHAPTER - 1: HEAT REJECTION OVERVIEW

In a chilled water system, the chiller acts as the heart, removing heat from water and lowering its temperature for building cooling. The figure below illustrates a typical chiller refrigeration cycle, which includes four main components: the compressor, condenser, metering device, and evaporator. The refrigerant serves as the working fluid within the chiller, absorbing heat from the chilled water loop and rejecting it to the heat rejection loop.

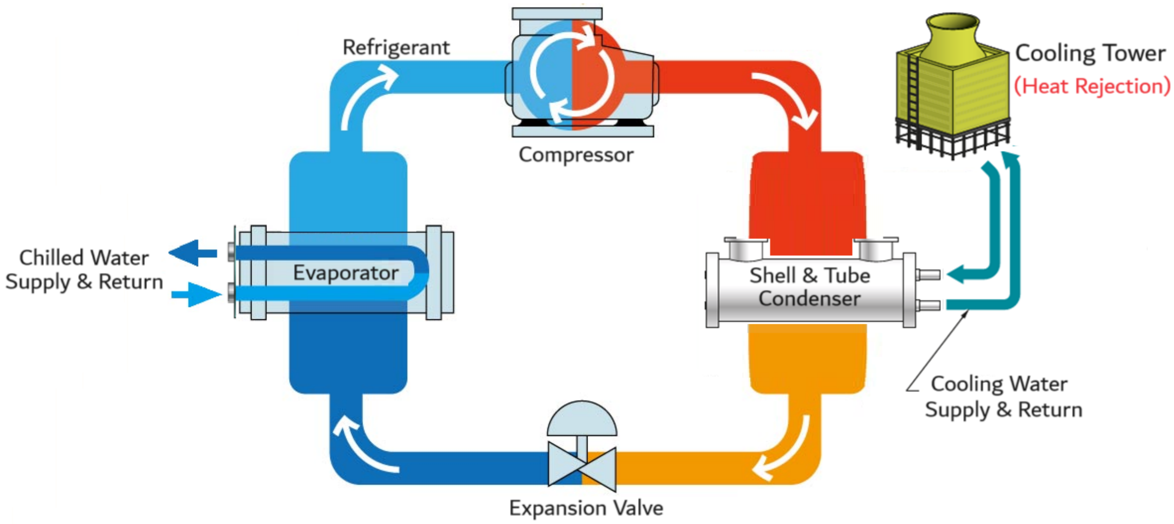


Figure 1. Water-Cooled Chiller Schematic

Let's revisit the fundamental principles of the refrigeration cycle to refresh our understanding.

1.1 Refrigeration Cycle Loop

The refrigeration cycle operates through four essential stages: evaporation, compression, condensation, and expansion. Each stage plays a critical role in facilitating heat transfer and maintaining the desired cooling effect. The following table provides a summary of these four stages, describing the processes involved and the changes in the refrigerant's state at each phase. Together, these stages form a continuous loop that drives the refrigeration process, ensuring efficient cooling in HVAC systems.

Table 1. Refrigeration Cycle Overview

	Stage	Process	State Change
	Evaporation	Absorbs heat from chilled water in the evaporator.	Liquid to Gas

	Stage	Process	State Change
	Compression	Compressor increases refrigerant pressure and temperature.	Gas
	Condensation	Refrigerant releases heat to surroundings in the condenser.	Gas to Liquid
	Expansion	Expansion valve reduces refrigerant pressure and temperature.	Liquid

Refer to the schematic below for a visual representation of the refrigeration cycle for an air-cooled chiller.

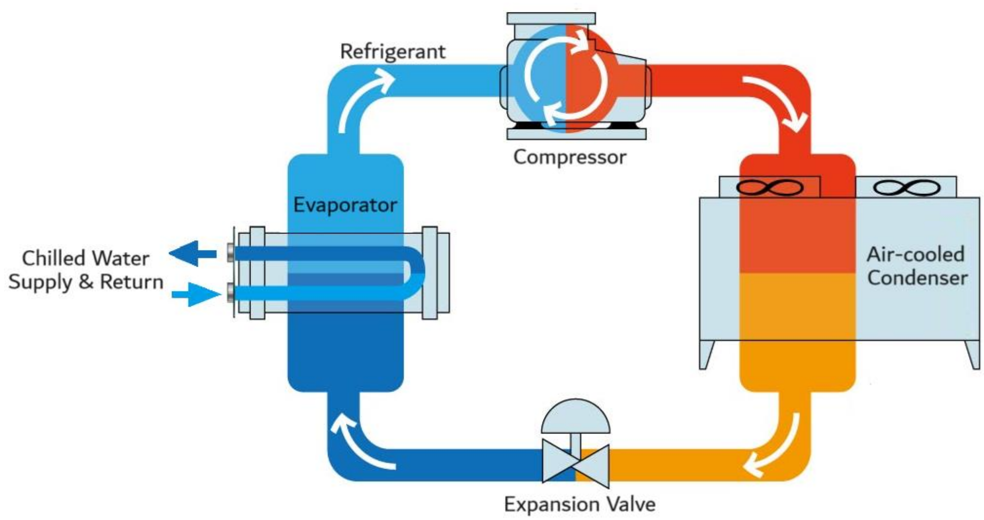


Figure 2. Air-Cooled Chiller Schematic

Efficient condenser heat rejection is crucial for refrigeration cycle performance. Inadequate cooling leads to higher energy use, reduced cooling, and equipment damage. The condenser dissipates heat absorbed by the refrigerant using air or water. We'll discuss both these methods in this course.

1.2 Water-Cooled Chillers

Water-cooled chillers use water as the cooling medium for heat rejection. These work by transferring heat from the refrigerant to the water in a shell & tube type condenser. A cooling tower is the unit in a water-cooled system that rejects the condenser water heat into the atmosphere. This type of chiller is commonly used in large-scale HVAC systems and industrial processes where a large amount of heat needs to be removed. The figure below illustrates a typical chiller operation, featuring four distinct heat transfer loops or subsystems along with their approximate design temperatures. While all four loops are essential, the heat rejection system is represented by the loop on the far right (red color).

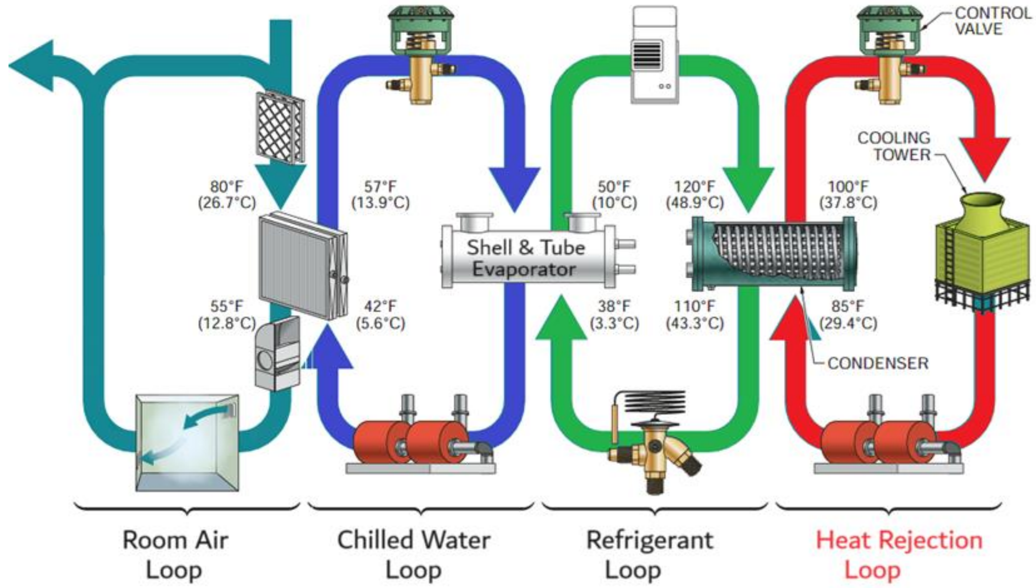


Figure 3. Typical Chiller System Heat Transfer Loops

Table 2. Heat Transfer Components of Water-Cooled Chiller

	Components	**Function**
👍	Condenser	Cools refrigerant by releasing heat to water, which is then sent to the cooling tower.
👍	Cooling Tower	Expels heat from the water to the atmosphere, cooling it before recirculation.
👍	Condenser Water Pump	Circulates water between condenser and cooling tower.
👍	Expansion Valve	Regulates refrigerant flow into evaporator.
👍	Evaporator	Cools water by absorbing heat from water that needs to be chilled.

Advantages

a. Higher Efficiency: Generally, more efficient than air-cooled systems, especially in larger installations.
b. Lower Operating Costs: Reduced energy consumption for heat rejection compared to air-cooled chillers.

Disadvantages

a. Higher Initial Cost: More complex and costly to install due to additional components like the cooling tower and associated piping.
b. Water Usage: Requires a consistent water supply and management of water treatment.
c. Maintenance: More maintenance is needed due to the additional equipment.

1.3 Air-Cooled Chillers

Air-cooled chillers work by transferring heat from the refrigerant to the surrounding air. They utilize fans to blow outside air over a finned-tube heat exchanger, with the refrigerant flowing through the tubes and the air passing over the fins. As the air moves over the fins, it absorbs the heat from the refrigerant, causing the refrigerant to condense and release heat to the surroundings. For air-cooled chillers, there is no need for cooling towers, condenser water pumps, blow down or make up water system, water treatment system and the likes. Refer to the schematic arrangement below:

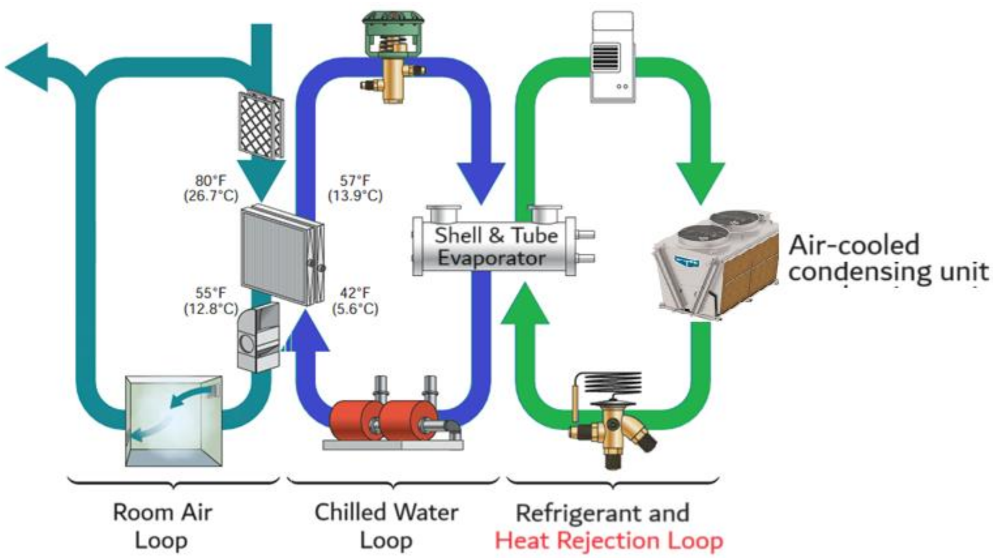


Figure 4. Typical Air-cooled Chiller System Heat Transfer Loops

Air-cooled chillers can be configured in two ways:

a. Split System: The compressor and condenser are separate units.
b. Packaged Unit: The compressor and condenser are housed together in a single casing. In this common arrangement, it is called condensing unit.

Air-cooled condensers are ideal for areas where water resources are limited or where water conservation is a priority. However, they require careful consideration of factors such as airflow, ambient temperature, and refrigerant type to achieve optimal performance.

Table 3. Heat Transfer Components of Air-Cooled Chiller

	Component	Function
	Condenser	Cools refrigerant by releasing heat to ambient air, expelled by fans.
	Fans	Circulate air over the condenser coils to remove heat from the refrigerant.
	Expansion Valve	Regulates refrigerant flow into evaporator.
	Evaporator	Cools water by absorbing heat from water that needs to be chilled.

Advantages

a. Lower Initial Cost: Simpler and cheaper to install as they do not require a cooling tower, extensive piping and associated water treatment equipment.
b. No Water: No need for a water supply or water treatment, making it suitable for locations with water scarcity.
c. Performance: Excellent in humid climates where evaporative cooling towers are not much effective.
d. Easier Maintenance: Generally easier to maintain due to the fewer components.

Disadvantages

a. Lower Efficiency: Air- cooled chillers tend to be less efficient, particularly in hot climates, as their performance relies heavily on cooler ambient air temperatures.
b. Higher Operating Costs: More energy is required for heat rejection due to ambient temperature fluctuations.
c. Performance Sensitivity: In hot climates, high ambient air temperature can affect heat removal and performance. Additional derating factor and chiller oversizing may be needed.

Key Takeaways….

Proper heat rejection is crucial for chiller efficiency. Water-cooled chillers with cooling towers are generally more efficient but require higher initial costs and maintenance. Air-cooled chillers offer simpler operation but are less efficient. The best choice depends on factors like climate, space, and water availability. We'll explore these systems in detail.

CHAPTER - 2: COOLING TOWER BASICS

Cooling towers dissipate heat from recirculating water used to cool the condenser of water-cooled chillers, or other process equipment. They work by evaporating a small portion of the water they circulate into the atmosphere. The evaporation results in cooling the remaining water. This cooled water is then recirculated back into the HVAC system to absorb more heat from the refrigerant, condensing it and continuing the cycle.

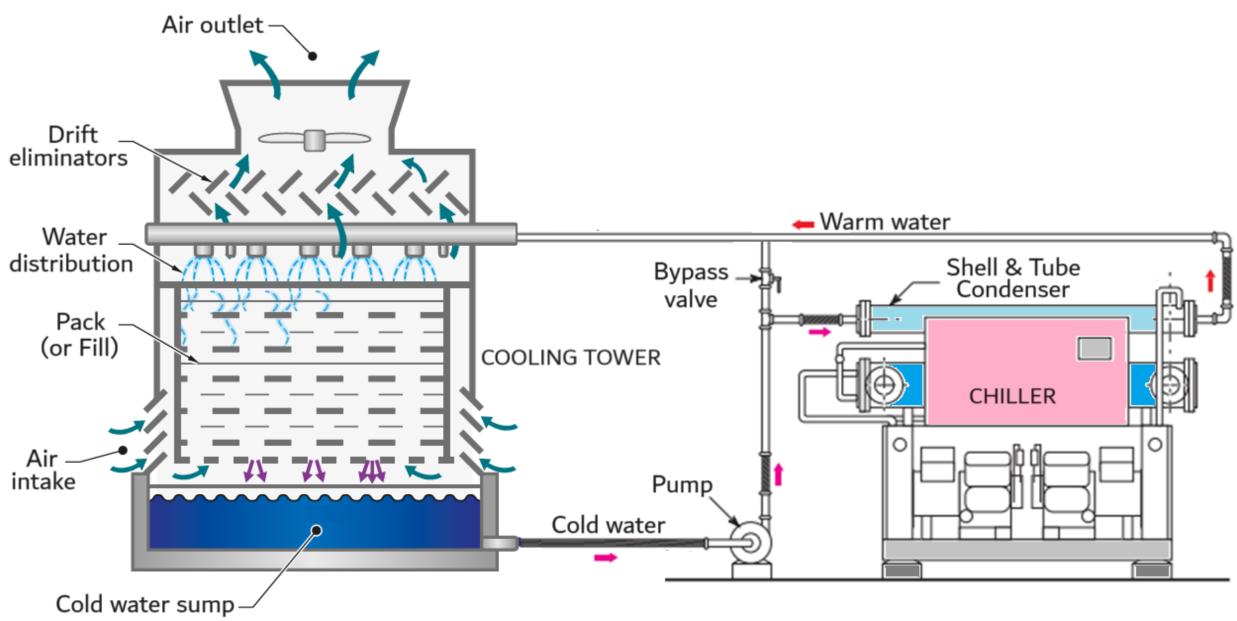


Figure 5. Water-Cooled Chiller With Cooling Tower

Table 4. Type of Chillers

	Chiller Type	Rules of Thumb
	Water-Cooled Chillers	Cooling towers are required for dissipating heat.
	Air-Cooled Chillers	Do not require cooling towers; they use ambient air for cooling.

2.1 Cooling Towers – How do they Work?

Cooling towers use evaporative cooling to lower water temperatures. A portion of the water evaporates into a moving air stream, which carries away heat. The main components are:

a. Water Distribution: Hot water from the chiller is pumped to the top of the cooling tower, either by gravity through spray nozzles or via pressurized piping.
b. Fill (Heat Transfer Medium): Fill provides the required surface area for heat transfer between air and the water.
c. Air Flow: Fans or blowers generate airflow to enhance evaporation and cooling. Variable-speed drives (VSDs) are often used for efficient airflow control.

2.2 Cooling Tower Capacity

HVAC cooling towers are rated in tonnage, measured in BTU/hr. While a refrigeration ton equals 12,000 BTU/hr, a cooling tower ton equals 15,000 BTU/hr. The extra 3,000 BTU/hr accounts for the heat from the compressor, which the cooling tower dissipates.

Table 5. Cooling Tower Capacity

	Parameters	Rules of Thumb
	Refrigeration Ton	1 refrigeration ton = 12,000 BTU/hr
	Chiller Nominal Tons	1 chiller nominal ton = 12,000 BTU/hr
	Cooling Tower Sizing	1.15 to 1.25 x Chiller Nominal Tons to account for compressor heat.
	Cooling Tower Ton	1 cooling tower ton = 15,000 BTU/hr (@ 25% extra heat)

2.3 Industry Standard Metrics

Cooling towers for HVAC use are often rated in "tons," but this is not an accurate metric for other process applications.

Industry standards such as Cooling Tower Institute, CTI-210 rates all cooling towers based on the following design conditions:

a. 95°F entering water/85°F leaving water
b. Ambient wet bulb temperature 78°F
c. 10°F Range and 7°F Approach
d. 3 GPM per ton

It’s a snapshot of a common operating design condition, but not necessarily reflect the real-world design conditions. Actual tower selection should consider specific chiller design range and the site wet bulb conditions specific to your region.

2.4 Cooling Tower Terminology

Here are some basic cooling tower terminologies to help you comprehend the rest of the topics. The definitions are arranged in alphabetical order.

Table 6. Common Terms used in Cooling Towers Design

Parameters	Definition	Importance	Rules of Thumb
Approach	Difference between cold water leaving the tower and the air's wet-bulb temperature.	Most Crucial	Lower approach = Larger and costly tower.
Blowdown	Water deliberately removed from the system to control concentrations of salts or impurities.	Prevents scaling and corrosion.	Minimize blowdown to reduce water usage but ensure adequate control of dissolved solids.
Biocide	A chemical used to control algae and bacteria growth within the tower.	Maintains water quality and tower efficiency.	Use biocide according to manufacturer's instructions and regulations.
BTU (British Thermal Unit)	Unit of heat energy.	Used to express heat load capacity of the tower.	Consider using tons (15,000 BTU/hr.*) for cooling tower sizing.
Cooling Range	Difference in temperature between the hot water entering the tower and the cold water leaving the tower.	Higher range = Greater heat rejection capacity.	Balance cooling range with approach for optimal tower selection.
Cycles of Concentration	Compares dissolved solids in makeup water with solids concentrated through evaporation in the circulating water.	Minimizes water usage and lowers operating costs.	Aim for higher cycles of concentration while maintaining acceptable water quality.
Dissolved Solids	Total solids that have been dissolved into the circulating water.	Excessive levels can cause scaling and reduce efficiency.	Monitor dissolved solids and adjust bleed-off rate as needed.
Drift	Water entrained in the airflow and discharged as mist.	Minimize drift to reduce water loss.	Select a tower design with low drift loss (typically < 0.005% of circulating water flow).
Heat Load	The amount of heat to be removed from the circulating water within	Affects tower size, cost, and pump selection.	Critical for initial tower sizing.

Parameters	Definition	Importance	Rules of Thumb
	the tower.		
Makeup Water	The amount of clean water required to replace normal losses caused by bleed-off, drift, and evaporation.	Maintains water quality and circulation volume.	Minimize makeup water usage through proper bleed-off and drift control.
Plume	The visible mixture of heated air and water vapor discharged from the tower.	Plume size and characteristics can be regulated.	Consider local regulations and plume visibility when selecting a tower location.
Pumping Head	The pressure required to pump the water through the entire cooling tower system.	Depends on tower height, water flow rate, and pipe friction.	Factor pumping head into overall system design and pump selection.
Recirculation	Occurs when the discharge air re-enters the system by mixing with fresh air.	Lowers cooling efficiency and should be minimized.	Proper tower placement and design can minimize recirculation.
Cooling Tower Ton (Evaporative Cooling)	Unit of cooling capacity equal to 15,000 BTU per hour.	Used to specify chiller and tower capacity.	25% more than conventional cooling ton of 12000 BTU per hour due to added heat of compression.
Wet Bulb Temperature	The lowest temperature that water theoretically can reach by evaporation.	Crucial parameter for tower selection and design, affecting cooling performance.	Local wet bulb temperature data is essential for tower performance calculations.

2.5 Types of Cooling Tower

Cooling towers are classified based on how air is moved through the tower.

a. **Natural Draft Cooling Towers:** Natural draft cooling towers rely on the buoyancy, created by the head density difference between cold outside air and humid inside air to draw air through the tower. They are generally tall structures to enhance airflow through the tower.
b. **Mechanical Draft Cooling Towers:** Mechanical draft cooling towers use fans to force or draw air through the tower. They can be further divided into forced draft and induced draft types.

Table 7. Mechanical Draft Cooling Towers

	Type	Description
	Forced Draft Cooling Towers	Fans located at the base push air into the tower.
	Induced Draft Cooling Towers	Fans located at the top pull air through the tower.
	Preferred System	Mechanical induced draft towers are commonly used in commercial and industrial HVAC systems.

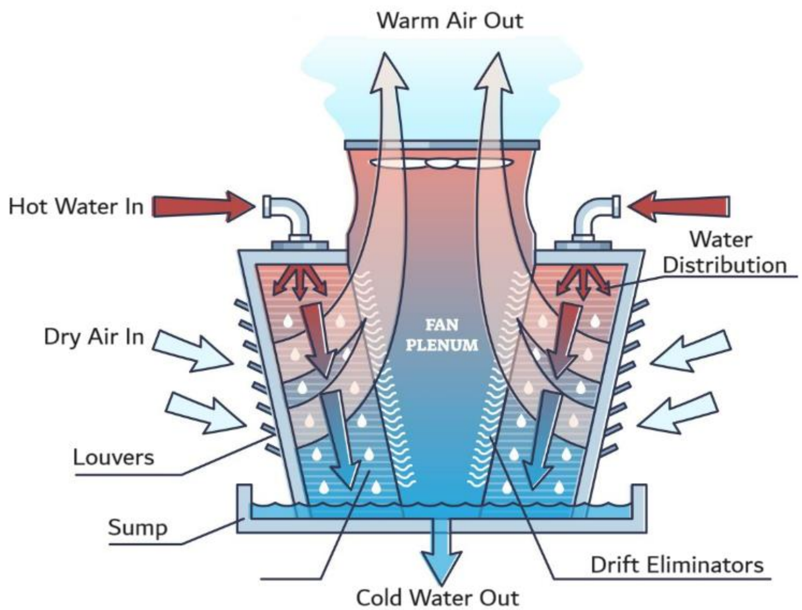


Figure 6. Induced Draft Cooling Tower

Table 8. Key Components of Induced Draft Cooling Tower

	Component	Description
	Fill	Increases the surface area for air and water interaction, enhancing heat transfer efficiency.
	Distribution System	Evenly distributes hot water over the fill for consistent cooling.
	Drift Eliminators	Capture water droplets in the air stream to reduce water loss.
	Louvers	Improve airflow and protect against sunlight, splash-out, noise, and debris.
	Casing	Provides structural housing and contains water within the tower.

	Component	Description
	Fan and Motor	Generate airflow, essential for the cooling process.
	Collection Basin	Collects cooled water at the bottom of the tower.

2.6 Matching Cooling Towers with Condensers: Key Considerations

Matching a cooling tower with the condenser is critical for ensuring optimal performance in a water-cooled chiller system. Key considerations include ensuring that the cooling tower's capacity can handle the total heat rejection from the chiller, typically about 1.25 times the nominal chiller capacity. Additional factors include matching water flow rates (GPM) and temperature range. Consider the following factors.

Table 9. Matching Cooling Tower and Condenser

	Factors	Rules of Thumb
	Equivalent heat rejection capacity (tons)	The cooling tower must be able to handle the heat rejected by the condenser. A common rule of thumb is to size the cooling tower 25% higher or 1.25 times the nominal capacity of the chiller, around 15,000 BTU/h per ton (e.g., 100-ton chiller = 1,500,000 BTU/h).
	Compatible water flow rates (GPM) and pressure drops	Match cooling tower water flow rate to condenser flow rate, typically 3 GPM per ton for a 10°F temperature range (e.g., 100-ton system requires 300 GPM flow).
	Matching temperature ranges (entering and leaving water temperatures)	The cooling tower and condenser should operate within the same temperature range of inlet and outlet water temperatures. The cooling tower should be able to cool the water to a temperature that is lower than the condenser's entering water temperature.
	Approach Temperature	5-7°F (ambient wet-bulb temp - leaving water temp). A lower approach temperature generally results in better cooling performance but may require a larger cooling tower. Example: 95°F entering water, 85°F leaving water, and a 7°F approach.
	Piping and Controls	Design for proper water distribution and flow. Recommended velocity: 6-10 fps to prevent erosion and fouling.

2.7 Challenges and Performance Issues

HVAC cooling towers face numerous challenges like water quality, scaling, and fouling, which reduce heat transfer efficiency. Poor water treatment can lead to corrosion, algae growth, and biofouling, further hindering performance. Inadequate airflow due to improper maintenance or obstructions can decrease cooling capacity. Additionally, fluctuations in ambient wet-bulb temperature, insufficient capacity sizing, or improper control settings may cause operational inefficiencies, increased energy consumption, and higher maintenance costs.

Table 10.Challenges and Performance Issues

	Challenge/Issue	Description	Impact
	Water Quality	Scale and fouling can reduce cooling tower efficiency.	Reduced performance, increased energy consumption.
	Legionella Bacteria	Cooling water provides a breeding ground for Legionella bacteria, which can cause Legionnaires' disease.	Health risks, liability, and maintenance costs. Proper maintenance and disinfection are crucial to prevent contamination.
	Noise	Noise pollution from fans and operation.	Noise reduction measures, such as acoustic enclosures, may be necessary.
	Drift	Water loss through evaporation and entrainment.	Increased water consumption, treatment costs
	Environmental Impact	Water consumption and evaporation, as well as the release of water droplets into the atmosphere.	Environmental implications, regulatory compliance.
	Efficiency	Inefficient cooling towers can consume excessive fan/pump energy.	Reduced performance, increased energy consumption & operating costs.
	Scaling and Fouling	Mineral buildup and debris accumulation.	Reduced heat transfer, increased pressure- drop.
	Corrosion	Material degradation due to water chemistry.	Increased leakages, reduced efficiency and increased maintenance costs.
	Biological Growth	Microbial growth in water and on surfaces.	Fouling, corrosion, and health risks.
	Flow Rate Imbalance	Inadequate or excessive water flow.	Reduced performance, increased energy consumption.

2.8 Cooling Tower Costs per Ton

The cost of a cooling tower is typically expressed as a price per ton of cooling capacity. Several factors influence this cost, including the type of cooling tower, its size, and the specific materials used.

Table 11. Cooling Tower Costs per Ton

	Type of Cooling Tower	Description	Cost per Ton of Cooling Capacity
	Induced Draft Cooling Towers	Use fans to pull air through the system.	$120 - $200 per ton
	Forced Draft Cooling Towers	Use fans to push air through the system; compact but higher energy consumption due to greater fan power.	$100 - $180 per ton. Slightly lower upfront cost compared to induced draft, but higher operational costs.
	Closed-Circuit Cooling Towers	Utilize a heat exchanger to prevent direct contact between water and air, reducing water consumption.	2.5 to 5 times the cost of open circuit towers but offers advantages like reduced water consumption and improved water quality.

Factors Affecting Cooling Tower Cost

Beyond the type of cooling tower, several other factors influence the overall cost:

a. Size: Larger cooling towers generally have a lower cost per ton due to economies of scale.
b. Materials: The choice of materials for the tower's construction (e.g., fiberglass, concrete, steel) impacts the cost.
c. Additional features: Options such as sound attenuation, corrosion protection, and water treatment systems can increase the cost.
d. Installation and labour: Costs associated with site preparation, installation, and labour can vary significantly.

2.9 HVAC Cooling Tower Selection Process

Here are the general steps to follow when sizing a cooling tower:

1. **Step 1:** Determine Cooling Load: Calculate the building's heat removal needs in Tons or BTU/hr.
2. **Step 2:** Select Chiller: Choose a chiller matching the building's peak cooling load, efficiency, capacity, and operational considerations.
3. **Step 3:** Estimate Cooling Tower Load: Apply a 1.25 multiplier to the chiller tonnage for initial sizing (1 ton of cooling tower load = 15,000 BTU/hr.).
4. **Step 4:** Determine Range: Match the condenser range of the chiller (temperature difference between hot water in and cold water out).

5. **Step 5:** Calculate Water Flow: Determine water flow based on cooling tower heat load and desired temperature range (3 GPM per ton for a 10°F range).
6. **Step 6:** Determine Site Wet Bulb Temperature and Evaluate Approach: Consider site ambient wet bulb temperature to determine approach (actual leaving water temperature).
7. **Step 7:** Evaluate Tower Options: Compare types, materials, fill, fan efficiency, noise levels, physical footprint, and costs.
8. **Step 8:** Consider Site Conditions: Account for local climate, water quality, and space constraints.
9. **Step 9:** Perform Detailed Calculations: Refine sizing using software or manual methods to meet required cooling load under various conditions.
10. **Step 10:** Optimize Design: Balance efficiency, cost, and environmental factors.
11. **Step 11:** Implement Best Practices: Employ energy-saving measures (VFD for fans, pumps), water conservation, treatment, and noise reduction.
12. **Step 12:** Review Maintenance and Operational Requirements: Consider cooling tower maintenance needs, operational costs, and lifespan to ensure compatibility with the overall system's design and operational strategy.

By carefully considering these design steps, engineers can optimize cooling tower performance while minimizing operational costs and environmental impact. We will discuss more in subsequent chapters.

CHAPTER - 3: KEY PERFORMANCE FACTORS

Cooling towers are specified to cool a certain flow rate from one temperature to another temperature at a certain wet bulb temperature.

3.1 Cooling Tower Sizing Factors

Four fundamental factors affect tower design, size, and performance:

a. Heat Load
b. Wet Bulb Temperature
c. Range
d. Approach

The following relationships are true when three of four sizing factors are held constant.

Table 12. Influence of Heat Load, Range, Approach and WBT on Cooling Tower Size

	Factors	Impact on Cooling Tower Size
	Heat Load	Cooling tower size varies directly with heat load.
	Range	Cooling tower size varies inversely with range.
	Approach	Cooling tower size varies inversely with approach.
	Wet Bulb Temperature (WBT)	Cooling tower size varies inversely with wet bulb temperature.

3.2 Heat Load

The heat load of a chiller and condenser cooling water is directly related to the flow rate (GPM) and temperature range (°F) in the evaporator and condenser. Chiller removes heat from chilled water while cooling tower dissipates heat from condenser water loop, which is 1.15 to 1.25 times higher than the chilled water heat load due to added heat of compression.

Table 13. Cooling Tower Heat Load

	Parameters	Rules of Thumb
	Heat Load Determination	Based on heat removed from building via chilled water (tons or BTU/hr.).
	Cooling Tower Design	Consider maximum cooling load + 15 to 25% for heat of compression.

3.3 Wet Bulb Temperature

The wet-bulb temperature (WBT) is the lowest temperature to which water can be cooled through evaporation at constant pressure. The wet-bulb temperature is an extremely important parameter in the selection and design of cooling towers because it allows the temperature and humidity conditions to be accurately defined according to the location of the system. Therefore, the wet bulb temperature is the primary basis for the thermal design of any evaporative cooling tower.

Table 14. Cooling Tower Wet Bulb Temperature

	Parameters	**Rules of Thumb**
	Cooling Tower Size	Depends on local WBT; high WBT limits cooling, low WBT allows better cooling
	Lowest Achievable Water Temperature	Ambient WBT + Approach
	Dry Cooling Towers	In regions with high WBT (humid climates), evaporation is less effective, making dry cooling towers a better option.
	Capacity Reduction	A 7°F increase in WBT can reduce cooling capacity by 32% (e.g., A cooling tower rated for 500 tons at a 71°F WBT may provide only about 340 tons if the WBT rises to 78°F.).

3.4 Cooling Range

Cooling range is the temperature difference between water entering and leaving a cooling tower. It measures cooling effectiveness.

Table 15. Cooling Tower Range

	Parameters	**Rules of Thumb**
	Cooling Tower Range	Typically, 10-12°F, influenced by chiller condenser design.
	Effect of Range	Higher range lowers water flow and pump power, but increases chiller load, potentially raising costs.

3.5 Approach

The approach is the temperature difference between the cooled water entering the basin, i.e., the water leaving the cooling tower and the wet-bulb temperature.

Approach = Leaving Water Temperature - WBT

Example: If the ambient wet bulb temperature is around 82°F and the cooling tower is designed for 5°F approach, the cooling tower leaving water temperature will be around 87°F.

Table 16. Cooling Tower Approach

	Parameters	Rules of Thumb
	Approach	Measures how close water temperature gets to wet bulb temperature (WBT). Leaving Water Temperature = WBT + Approach.
	Cost Economics	Approach less than 5°F may not be economical.

3.6 Evaporation Rate

The amount of water evaporated from a cooling tower depends on the circulation rate and cooling range, with higher humidity reducing evaporation. It takes about 1,000 BTUs to evaporate 1 pound of water, cooling the remaining water by roughly 1°F. The table below summarizes key rules of thumb for estimating evaporation rates and practical considerations.

Table 17. Cooling Tower Evaporation Rate

	Parameters	Rules of Thumb
	Evaporation Rate	Approximately 0.1% of circulating water evaporates per 1°F cooling range and 1% for every 10°F cooling range.
	Evaporation Rate Formula (10°F Range)	Evaporation Rate = 0.001 × Water Circulation Rate (GPM) per 1°F cooling range. Evaporation Rate = 0.01 × Water Circulation Rate (GPM) for 10°F cooling range.
	Energy Requirement	About 1,000 BTUs to evaporate 1 pound of water.
	Temperature Drop	1°F for every pound of water evaporated.
	Evaporation Factor for Actual Cooling	Only 75% of cooling comes from evaporation; Convective cooling accounts for 25% of cooling, so evaporation factor (f) is typically 0.75. Adjusted Evaporation Rate = 0.001 × Water Circulation Rate (GPM) × Range (°F) × f.

3.7 Predictive Performance of Cooling Tower

Cooling tower efficiency is influenced by the wet bulb temperature. The table below outlines how wet bulb temperature and humidity levels influence cooling tower efficiency.

Table 18. Cooling Tower Performance Factors

	Parameters	Rules of Thumb
	High Wet Bulb Temperature	High wet bulb = high humidity = lower cooling capacity.
	Low Wet Bulb Temperature	Low wet bulb = low humidity = higher cooling capacity.
	Difference between Dry Bulb and Wet Bulb Temperatures	Larger difference between dry and wet bulbs = lower humidity = better cooling tower performance. Smaller difference = higher humidity = reduced cooling capacity.
	Wet Bulb Equals Dry Bulb	When wet bulb and dry bulb temperatures are equal, relative humidity is 100% and no evaporation can occur, reducing cooling efficiency.

3.8 Cooling Tower Efficiency

Cooling tower efficiency measures how effectively a cooling tower transfers heat from the water to the surrounding air through the evaporation process. It is the ratio of the actual cooling achieved to the maximum cooling theoretically possible, given the ambient wet-bulb temperature.

Equation 1. Cooling Tower Efficiency

The cooling tower efficiency is simply expressed as:

$$\text{Cooling tower efficiency} = \frac{\text{Range}}{\text{Range} + \text{Approach}} \times 100\%$$

$$\text{Cooling tower efficiency} = \frac{(\text{Hot water temperature} - \text{Cold water temperature})}{(\text{Hot water temperature} - \text{Wet bulb temperature})} \times 100\%$$

The numerator represents the actual temperature reduction of the water.

The denominator represents the maximum potential temperature reduction (the theoretical limit).

Table 19. Impact of Approach, Range & Wet Bulb Temperature on Efficiency

	Parameters	**Rules of Thumb**
	Tower Approach vs. Efficiency	A cooling tower is most efficient when the approach temperature (the difference between the leaving water temperature and the wet-bulb temperature) is small. However, smaller approach will necessitate a larger tower, increasing both costs and energy consumption. An ideal approach is 5 to 7°F - neither too far nor too close to reference wet-bulb temperature.
	Tower Range vs. Efficiency	Cooling tower range is determined by the chiller condenser design, giving you limited control over this parameter. However, condenser designed for higher range impacts cooling tower efficiency.
	Condenser Range vs. Pumping Energy	Higher range reduces the water flow rate and pumping energy. • 10°F Range = Water flow rate 3 GPM per ton, requiring larger pumps and more pump energy. • 15°F Range = Water flow rate decreases to 2 GPM per ton, requiring smaller pumps and less energy.
	Condenser range vs. Chiller Energy	Higher range increases condensing water temperature and increased chiller kW consumption. • 10°F Range = Average condensing water temperature is 90°F, leading to moderate chiller load. • 15°F Range = Average condensing water temperature increases to 92.5°F, raising chiller kW consumption.
	Ideal Condenser or Cooling Tower Range	10 to 12°F.
	Important Limitation for Cooling Tower	Range is dictated by chiller condenser design. Cooling tower design follows chiller condenser design.
	Wet Bulb Temperature vs. Approach vs. Efficiency	For each 1°F increase in wet-bulb temperature, the cooling tower efficiency drops by 2-3%.

3.9 Understanding Equipment Loads

Chiller Heat Load (BTU/hr.)

Chiller heat load refers to the amount of heat that a chiller must remove from a building or space to maintain a desired temperature. This heat load is derived from the building's cooling requirements, which include internal heat gains and external heat gains. It is typically expressed in British Thermal Units per hour (BTU/hr.) or Tons of refrigeration where 1 Ton of Refrigeration = 12,000 BTU/hr.

Chiller Capacity (Tons)

Chiller Capacity (Tons) = Building Cooling Load (BTU/h)/12000 BTU/h/Ton

For example, if a building's total cooling load is 240,000 BTU/h:

Chiller Capacity (Tons) = 240,000/12000 = 20 Tons

Heat Rejection by Chiller

Chiller rejects heat in its condenser. The total heat rejected by the chiller includes the heat removed from the building and the heat generated by the chiller itself (compressor work).

Condenser Heat Load

The condenser load refers to the total amount of heat that must be rejected by the chiller's condenser to the cooling tower. This includes both the chiller load (heat absorbed from the building), and the heat generated by the chiller's compressor during the refrigeration process.

Condenser load is roughly 15-25% greater than the chiller and typically, a factor of 1.25 (i.e., 25%) is applied to obtain the total condenser heat load. Therefore,

a. Condenser Heat Load = 1.25 × Chiller Heat Load (BTU/h)
b. Condenser Heat Load = 1.25 × 12000 BTU/hr. per Ton
c. Condenser Heat Load = 15000 BTU/hr. per Ton
d. Condenser Heat Capacity (BTU/h) = Chiller Capacity (Tons) × 15,000BTU/h per Ton

For example, for a 100-ton chiller:

Condenser Heat Load = 100 Tons × 15,000 BTU/h per Ton = 1,500,000 BTU/h

Cooling Tower Heat Load

The cooling tower heat load is the total amount of heat that needs to be rejected to the atmosphere by the cooling tower. This heat comes from the condenser load and is transferred to the cooling tower through the condenser water loop. The cooling tower must reject the total heat load from the condenser, therefore:

Cooling Tower Heat Load (BTU/h) = Condenser Heat Load (BTU/h)

Table 20. Differentiating Chiller Load, Condenser Load and Cooling Tower Load

	Different Loads	Rules of Thumb
	Chiller Load	Amount of heat removed from building/process (BTU/h or tons). Chiller Load (or Chiller Capacity) = Building Cooling Load
	Condenser Load	Amount of heat rejected from chiller to condenser (BTU/h or tons). It is typically 25% higher than chiller load due to added heat of compression. Mathematically, Condenser Load = Chiller Heat Load x 1.25
	Cooling Tower Heat Load	Amount of heat rejected from condenser to atmosphere (BTU/h or tons). It is same as the condenser load. Cooling Tower Load = Condenser Load

3.10 Key Equations for Cooling Towers

The heat load of cooling tower is directly related to the water flow rate and the difference between the entering and leaving water (range). Similarly, the heat load of chiller and condenser is related to the water flow rate and the difference between the entering and leaving water (range). Let's check all these equations.

Equation 2. Heat Load and Mass Flow Rate in Lbs.

$Q = m\ Cp\ \Delta T$

Where:

- Q = Heat load (BTU/hr.)
- m = Mass of the water (lbs.)
- Cp = Specific heat of water (BTU/lb.-°F)
- ΔT= Inlet/outlet temperature differential (°F)

This equation can be converted to volumetric flow rate in gallons per minute (GPM) as below.

Equation 3. Heat Load and Volumetric Flow Rate in GPM

$Q = q \times 8.34 \times 60 \times Cp \times \Delta T$

Where:

- q = Volumetric water flowrate (GPM)
- Q = Heat load (BTU/hr.)
- Cp= Specific heat, for water = 1 BTU/lb.-°F
- 8.34 = Conversion factor for pounds per gallon
- 60 = Conversion factor for hour to minutes
- ΔT= Inlet/outlet temperature range (°F)

Equation 4. Water Circulation Rate thru Heat Exchangers

The water circulation rate through a heat exchanger is determined by the following equation:

$$\text{Water circulation rate (GPM)} = \frac{\text{Heat load, BTU/hr}}{\text{500 x Range (°F)}}$$

This equation helps you determine the required flow rate through a chiller evaporator and condenser, which is a determining factor in selecting the right cooling tower in terms of both size and initial investment.

Equation 5. Chilled Water Flow Rate in GPM

Going by the heat load equation: $Q = q \times 500 \times \Delta T$

$$q\ (\text{evaporator}) = \frac{Q}{500 \times \Delta T}$$

Where:

- q (evaporator) = Volumetric water flowrate thru Chiller Evaporator (GPM)
- Q = Heat load Capacity of Chiller (BTU/hr.)
- ΔT= Evaporator Range (°F) ----------(entering - leaving water temperature)

Equation 6. Condenser Water Flow Rate in GPM

Going by the chiller water flow rate equation: $q\ (\text{evaporator}) = \dfrac{Q}{500 \times \Delta T}$

$$q\ (\text{condenser}) = \frac{(Q \times 1.25)}{500 \times \Delta T}$$

Where:

- q = Volumetric water flowrate thru Chiller Evaporator (GPM)
- Q = Heat load Capacity of Chiller (BTU/hr.)
- Q x 1.25 = Heat load Capacity of Condenser (BTU/hr.) ----- (25% extra for heat of compression over chiller heat load)
- ΔT= Condenser Range (°F) ----------(entering - leaving water temperature)

Equation 7. Cooling Tower Flow Rate in GPM

Once you have the condenser water heat load, you can calculate the condenser flow rate (GPM) using the following equation:

1. Cooling Tower Load = Condenser Load
2. Cooling Tower Flow Rate = Condenser Water Flow Rate

   Or

3. $q\ (\text{cooling tower}) = \dfrac{(Q \times 1.25)}{500 \times \Delta T}$

Where:

- q = Volumetric water flowrate thru Chiller Evaporator (GPM)
- Q = Heat load Capacity of Chiller (BTU/hr.)
- Q x 1.25 = Heat load Capacity of Condenser (BTU/hr.) ----- (25% extra for heat of compression over chiller heat load)
- ΔT= Condenser Range (°F) ----------(entering - leaving water temperature)

Example: Estimate water circulation rates in GPM/Ton for ΔT = 10°F range

Calculation:

1 Ton refrigeration capacity = 12000 BTU/h

1 Ton condenser capacity = 12000 x 1.25 = 15000 BTU/h ------- (25% extra for heat of compression).

Range, ΔT= 10°F ----------(Inlet/outlet temperature differential)

$$\text{Chilled Water Flow Rate} = \frac{12{,}000\ \text{BTU/hr}}{500 \times 10°\text{F}} = 2.4\ \text{GPM/TR}$$

$$\text{Condenser Water Flow Rate} = \frac{15{,}000\ \text{BTU/hr}}{500 \times 10°\text{F}} = 3\ \text{GPM/TR}$$

Table 21. Water Circulation Rates at Different Temperature Ranges

	Range, ΔT (°F)	Chiller GPM/Ton	Condenser GPM/Ton	Cooling Tower GPM/Ton
	10°F	2.4	3.0	3.0
	12°F	2.0	2.5	2.5
	16°F	1.5	-	-
	18°F	1.33	-	-

Notes:

a. Chillers evaporators are available in 10°F, 12°F, 16°F and 18°F ranges.
b. Condensers are generally applied in 10°F and 12°F ranges.
c. Cooling towers are selected matching the condenser range.
d. 1 Ton chiller capacity = 12000 BTU/h
e. 1 Ton condenser capacity = 12000 x 1.25 = 15000 BTU/h ------- (25% extra for heat of compression).

Example

For a 100-ton chiller system designed for 16°F chiller range and 10°F condenser range, refer the table above to determine GPM/Ton specific for the designed temperature range.

Chiller water flow rate = 1.5 GPM/Ton @ 16°F ΔT

Therefore, for 100 Ton chiller: Chilled water flow rate = 100 x 1.5 GPM/Ton = 150 GPM

Condenser water flow rate = 3 GPM/Ton @ 10°F ΔT

Therefore, for 100 Ton chiller: Condenser water flow rate = 100 x 3 GPM/Ton = 300 GPM

3.11 Pumping Power

The water-side power input for a cooling tower refers to the power required to pump water through the tower.

Equation 8. Pump Power

The pump power is estimated as:

$$\text{Pump power (BHP)} = \frac{\text{GPM x ft. Head}}{\text{3956 x Pump } \eta}$$

$$\text{Pump Power (HP)} = \frac{\text{GPM x ft. Head}}{\text{3956 x Pump } \eta \text{ x Motor Efficiency}}$$

$$\text{Pump Power (KW)} = \frac{\text{GPM x ft. Head x 0.746}}{\text{3956 x Pump } \eta \text{ x Motor Efficiency}}$$

Pump efficiency ranges between 0.65 to 0.75 and motor efficiency around 0.85 to 0.9.

Table 22. Rules of Thumb for Cooling Water Pump Power & Efficiency

	Parameters	**Rules of Thumb**
	Pump Power	20 Watts per GPM @ 60 feet head at 70% pump efficiency and 85% motor efficiency.
	Pump Efficiency	70%
	Motor Efficiency	85%

	Parameters	Rules of Thumb
👍	Calculated Pump Power	20 Watts/GPM x Flow Rate (GPM) x (Head/60)

Example: A 100 TR cooling tower has a pump delivering at 3 GPM/TR. The other conditions are:

a. Pump flow rate: 100 TR x 3 GPM/TR = 300 GPM
b. Head: 80 ft.
c. Pump efficiency: 70%
d. Motor efficiency: 85%

Pump power Input applying empirical formula:

$$\text{Pump power (HP)} = \frac{\text{GPM x ft. Head}}{\text{3956 x Pump } \eta \text{ x Motor Efficiency}}$$

$$\text{Pump power (KW)} = \frac{\text{300 GPM x 80 ft. x } 0.746 \frac{KW}{HP}}{3956 \text{ x } 0.7 \text{ x } 0.85} = 7.6 \text{ KW}$$

Pump power input applying rule of thumb:

$$\text{Pump Power} = 20 \frac{\text{Watts}}{\text{GPM}} \text{ x 300 GPM x} \frac{80\text{ft}}{60\text{ft}} = 8 \text{ kW}$$

3.12 Air Flow Rate (CFM/Ton)

The airflow rate through a cooling tower is a measure of the amount of air that is required to cool a certain amount of refrigeration capacity. The airflow should be sufficient to achieve a high level of evaporation and prevent stagnant air pockets.

Table 23. Air Flow Rate thru Cooling Tower

	Parameters	Rules of Thumb
👍	Airflow rate (CFM/TR)	50-60 CFM/TR of cooling tower capacity.
👍	Static pressure (inches WG)	1 to 2 inches of water gauge (WG).
👍	Pressure drop factors	Influenced by airflow rate, packing material, and tower height. Higher airflow or denser packing increases pressure drop.

3.13 Fan Power Input

The air-side power input for a cooling tower refers to the power required to move air through the tower.

Equation 9. Fan Power

$$\text{Fan power (BHP)} = \frac{\text{CFM x Inch WG Static pressure}}{\text{6343 x Fan } \eta}$$

$$\text{Fan power (HP)} = \frac{\text{CFM x Inch WG Static pressure}}{\text{6343 x Fan } \eta \text{ x Motor } \eta}$$

$$\text{Fan power (KW)} = \frac{\text{CFM x Inch WG Static pressure x 0.746}}{\text{6343 x Fan } \eta \text{ x Motor } \eta}$$

Fan efficiency ranges between 0.65 to 0.75 and motor efficiency around 0.85 to 0.9.

Table 24. Rules of Thumb for Cooling Tower Fans Power & Efficiency

	Parameters	Rules of Thumb
	Fan Motor Power	Approximately 0.2 Watts per CFM per 1 inch-WG static pressure with fan efficiency of 70% and motor efficiency of 85%.
	Fan Efficiency Grade (FEG)	Measures fan efficiency for centrifugal fans per ASHRAE Standard 90.1 (not axial fans).

Example: For a 200 TR cooling tower fan with the following conditions:

a. Airflow rate: 50 CFM/TR
b. Static pressure: 2 inch-WG
c. Fan efficiency: 70%
d. Motor efficiency: 85%

<u>Power Input applying empirical formula:</u>

$$\text{Fan power (HP)} = \frac{\text{CFM x Inch WG Static pressure}}{\text{6343 x Fan } \eta \text{ x Motor } \eta}$$

$$\text{Fan power (KW)} = \frac{200\text{ TR} * 50\frac{\text{CFM}}{\text{TR}}\text{ x 2 inch WG x 0.746}\frac{\text{KW}}{\text{HP}}}{\text{6343 x 0.7 x 0.85}} = 4\text{ KW}$$

<u>Power input applying rule of thumb:</u>

$$\text{Fan power} = 200\text{ TR} * 50\frac{\text{CFM}}{\text{TR}} * 0.2\frac{\text{Watts}}{\text{CFM} - \text{inch WG}} * 2\text{ inch WG} = 4\text{ kW}$$

3.14 L/G Ratio of Cooling Tower

The L/G ratio (Liquid-to-Gas ratio) is a key parameter in cooling tower design, representing the ratio of the mass flow rate of the circulating water (L) to the mass flow rate of the air (G) passing through the tower. It is typically expressed as a dimensionless number or in units of GPM/cfm.

The L/G ratio is crucial for determining the cooling tower's performance and efficiency.

Table 25. Cooling Tower L/G Ratios Guidelines

	Parameters	**Rules of Thumb**
	Higher L/G	Means more water is being circulated relative to the amount of air, which can improve the cooling efficiency but increases pump power.
	Lower L/G	Means less water is being circulated relative to the airflow, which can reduce pumping energy but increases fan energy and may decrease the cooling efficiency.
	Typical L/G ratios	HVAC applications: 0.8-1.2 High efficiency cooling tower: 1.2-1.5 Water conservation: 0.6-0.8
	Climate	Lower L/G in humid climates Higher L/G in dry climates.
	Balanced design	Aim for L/G ~1.0 for standard HVAC.

Final Takeaway….

When selecting or designing a cooling tower for an HVAC system, the L/G ratio should be carefully considered along with other factors like the wet bulb temperature, range, approach, and system water flow rate. By understanding the typical benchmark values and applying rules of thumb, HVAC professionals can optimize cooling tower design for a variety of applications, ensuring both effective cooling and energy efficiency.

CHAPTER - 4: TYPES OF COOLING TOWER

Cooling towers can be classified based on their heat rejection mechanism. Primarily, they fall into three distinct types: wet, dry, and hybrid. Each type employs a different approach to dissipate heat from the condenser water.

4.1 Wet Type Open Loop Cooling Towers

Wet cooling towers utilize the evaporation of water to dissipate heat, making them highly efficient but susceptible to water loss and quality issues. They are also called an open loop system.

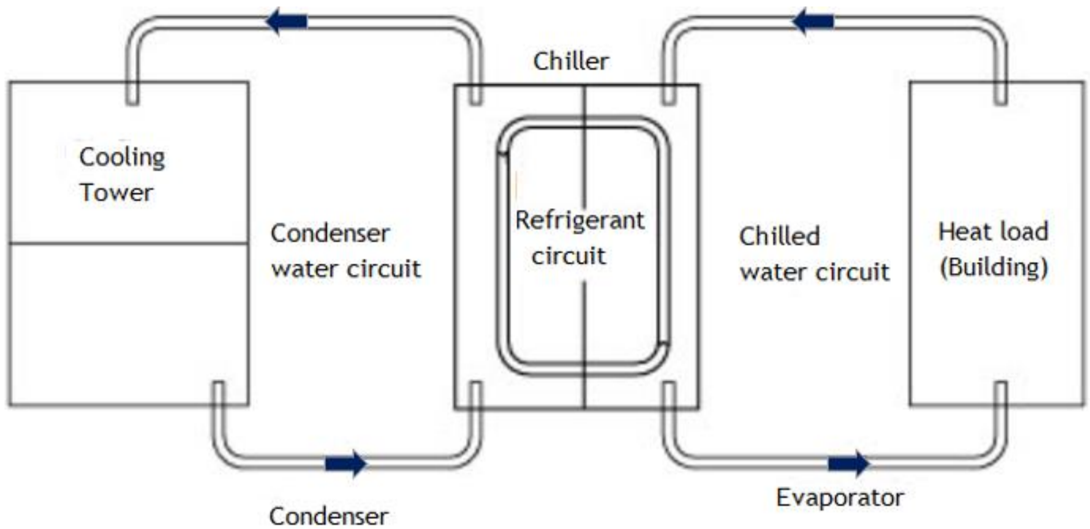


Figure 7. Open Loop Cooling Tower Schematic

The open cooling tower uses a plastic fill, to create a large surface area to evaporate water by mixing with an air stream.

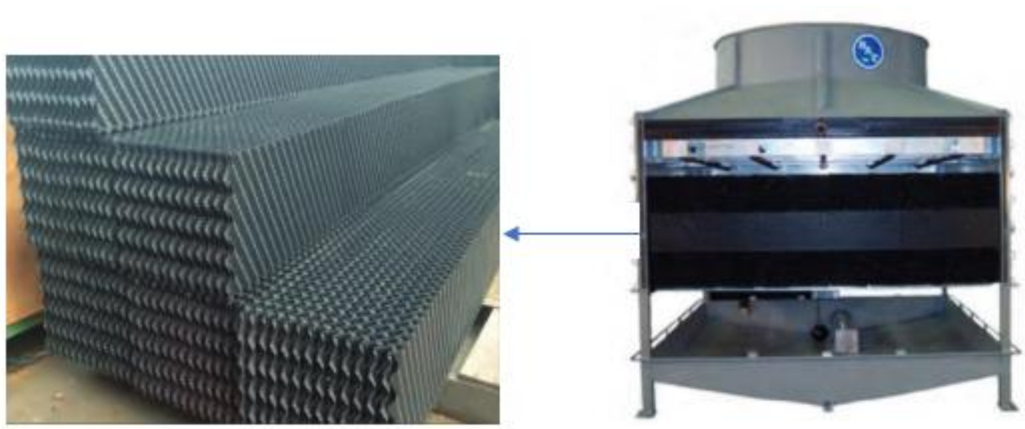


Figure 8. Cooling Tower with Honeycomb Plastic Fill

Table 26. Advantages of Open Loop Cooling Towers

	Parameters	**Description**
	Initial Cost	Lower cost due to simple design with fewer components. Average cost somewhere between $120 to $200 per TR of cooling tower capacity.
	Cooling Efficiency	Higher due to direct contact between water and air for efficient heat transfer.
	Pumping Energy	Requires less energy to circulate water.
	Scalability	Can be easily expanded to accommodate increased cooling loads.

Figure 9. Drawbacks of Open Loop Cooling Towers

	Parameters	**Description**
	Water Use	Significant water loss due to evaporation.
	Water Quality	Susceptible to contamination from airborne impurities, algae, and scale formation.
	Legionella Risk	Can harbour Legionella bacteria if not properly maintained.
	Environmental Impact	Discharge water into the atmosphere via evaporation, drift, and blowdown, making them subject to strict environmental regulations.
	Operational Control	Less control over water temperature due to dependence on ambient conditions.
	Noise Pollution	Can generate noise due to water circulation and air movement.
	Drift	Water droplets can be carried out of the tower by the air, leading to water loss and potential damage to surrounding areas.
	Maintenance	Have a large water volume and water treatment making them more difficult to maintain and clean compared to closed loop cooling towers.

4.2 Dry Type Closed Loop Cooling Towers

Dry cooling towers employ a heat exchanger through which condenser water circulates and is cooled by secondary sprayed water. Because the condenser water circulates in a closed-loop heat exchanger, it is not exposed to the atmosphere and is therefore not subject to water loss or contamination. They're however less efficient than wet towers and are good choice for humid climates.

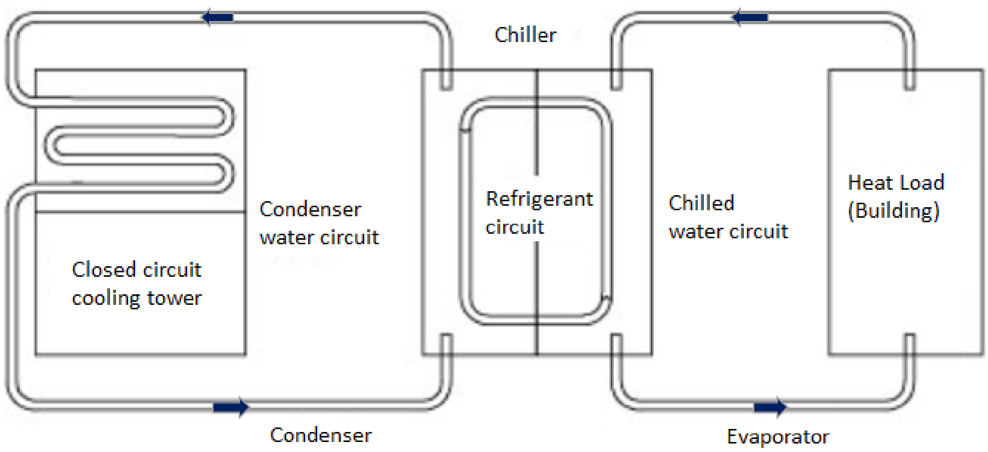


Figure 10. Closed Loop Cooling Tower Schematic

Table 27. Advantages of Closed Loop Cooling Towers

	Parameters	Description
👍	Water Quality	Protects process fluid from contamination by keeping it isolated from the atmosphere.
👍	Maintenance	Simpler system with fewer components requiring maintenance.
👍	Operational Flexibility	Can operate in various modes (dry, free cooling, variable pumping) for energy efficiency.
👍	Water Consumption	Low water loss through evaporation compared to open loop systems. It requires approximately 0.26 to 0.33 GPM/ton by evaporation plus 0.008 to 0.01 GPM/ton for blowdown water.
👍	Chemical Treatment	Less need for water treatment chemicals due to closed loop design.
👍	Freezing Protection	Can be equipped with glycol to prevent freezing in cold climates.
👍	Energy Efficiency	Can achieve higher thermal efficiency through various operating modes.
👍	Environmental Impact	Reduced water consumption and lower chemical usage contribute to a smaller environmental impact.

Table 28. Drawbacks of Closed Loop Cooling Towers

	Parameters	Description
	Initial Cost	Higher as complexity adds due to additional heat exchangers, piping, and controls.
	Fouling	Heat exchangers can experience fouling and scaling, reducing efficiency.
	Cooling Efficiency	Generally, less efficient than open loop systems due to additional heat transfer steps.
	Freezing Risk	Susceptible to freezing in cold climates if not properly protected.
	Footprint	May require larger space due to additional equipment.

4.3 Hybrid Cooling Towers

Hybrid type cooling towers combine elements of both wet and dry cooling to optimize efficiency and minimize water consumption and quality issues. In some cases, it can be a combination of an indirect cooling exchanger with outside water spray. In others it can be a wet-type tower used to cool the refrigerant loop for a large chiller system. In either case, it combines the methodologies of both wet and dry types to achieve the required cooling. Applications include heavily urbanized areas where the vapor plume is undesirable or arid environments where only a small amount of evaporative cooling is needed to reach the cold-water temperature.

Here are some golden rules to help choose between an open loop and closed loop cooling tower:

Table 29. Open vs. Closed Loop Cooling Towers – Key Differences

	Factor	Open Cooling Tower	Closed Cooling Tower
	Heat Transfer Mechanism	Evaporative cooling. Dependent on ambient wet-bulb temperature (WBT).	Utilizes secondary heat exchanger. Performance dependent on ambient dry-bulb temperature (DBT).
	Initial Cost	Lower	Higher (2.5 to 5 times more than open towers).
	Space Requirements	Larger footprint	Smaller footprint
	Water Consumption	High (evaporation)	Low
	Water Quality Management	Requires regular treatment to prevent scaling and biological growth	Better control over water quality

	Factor	Open Cooling Tower	Closed Cooling Tower
	Maintenance	More maintenance required due to exposure to the environment.	Less frequent maintenance needed.
	Energy Efficiency	Generally lower due to direct contact between water and air.	Higher, due to higher pumping pressure for heat exchanger.
	Environmental Impact	Higher due to drift, potential chemical usage, and water loss.	Lower, with reduced chemical usage and water loss. More environmentally friendly.
	Operational Costs	Higher due to water treatment and makeup water.	Lower due to closed circuit cooling and negligible chemical usage.
	Corrosion Control	Higher risk due to exposure to the environment.	Lower risk as water is contained within a closed system.
	Application Suitability	Where water is abundant and inexpensive and/or treatment is manageable.	Where water is scarce or expensive where water quality is critical. Choose closed towers if there are strict regulations on water discharge.

Key Takeaways….

The choice between open and closed-circuit cooling towers depends on factors such as water availability, environmental regulations, cooling requirements, and initial and operating costs.

a. Open loop wet type cooling towers provide higher cooling efficiency with lower approach temperatures.
b. Closed loop dry type cooling tower conserve water but have lower cooling efficiency and higher initial costs compared to wet evaporative cooling towers.
c. Hybrid cooling towers offer a balance of efficiency and water conservation.

4.4 Cooling Tower Classification by Airflow Generation Method

Open loop wet cooling towers are versatile heat rejection systems widely employed in HVAC applications, ranging from small commercial buildings to expansive industrial complexes. This section delves into the intricacies of these towers. They can be further classified based on the method used to move air through the tower structure.

4.5 Natural Draft Cooling Towers

These rely on the natural buoyancy of warm, moist air rising through a tall, hyperboloid-shaped structure to create airflow. They are efficient but require significant space.

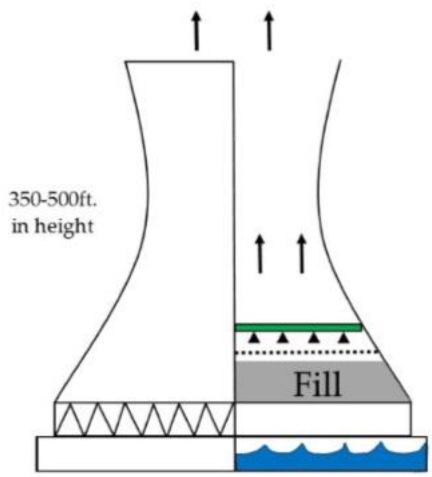


Figure 11. Hyperbolic Natural Draft Cooling Tower Schematic

4.6 Mechanical Draft Cooling Towers

These utilize fans to force or induce airflow through the tower. They are more compact and offer greater control over cooling performance. They are further divided into forced draft and induced draft.

4.7 Forced Draft Cooling Towers

Forced draft towers have the fan placed at the base of the cooling tower, which pushes air upwards through the water distribution system. Their use is limited due to water distribution challenges, high horsepower fans, and the possibility of re-circulation. These are often used in indoor applications where high static pressure is a concern.

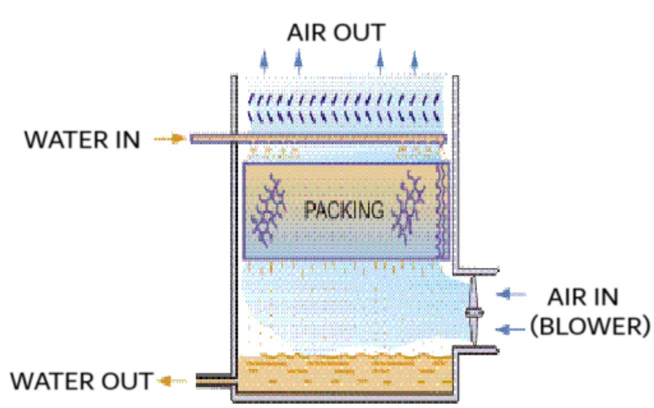


Figure 12. Forced Draft Cooling Tower Schematic

4.8 Induced Draft Cooling Towers

Induced draft cooling towers have fan/s mounted at the top that pull air through the tower and release it at high velocity, reducing re-circulation. Induced draft tower are widely used in HVAC applications and are available in counterflow and crossflow types.

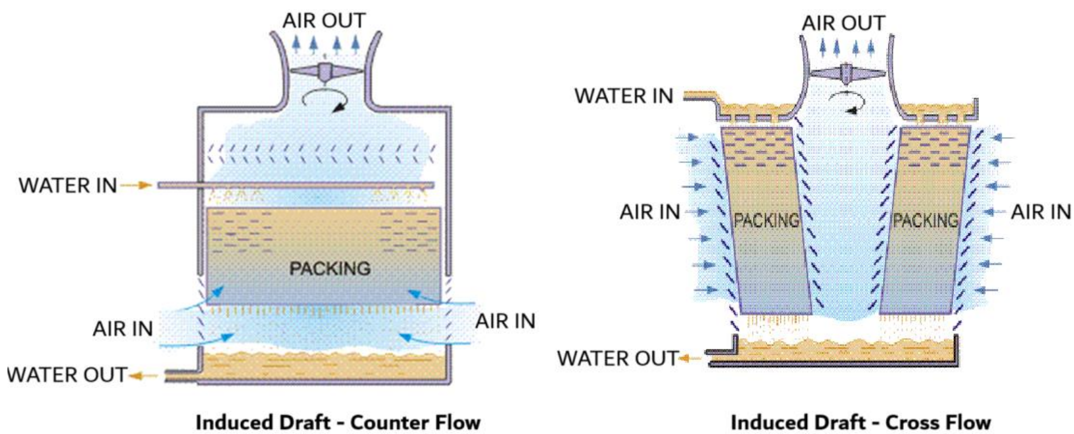


Figure 13. Counterflow vs. Crossflow Cooling Tower Schematic

4.9 Counter- Flow Cooling Towers

Counterflow cooling towers distribute water from the top of the tower thru pressurized spray nozzles and air moves upwards in opposing direction (counter-current) to the flow of water. Air is drawn from the bottom of the cooling tower, passing over the fill surface and exiting out the top.

4.10 Crossflow Cooling Towers

Crossflow cooling tower allows the air to flow horizontally through the fill and the tower's structure into an open plenum area. Hot water flows downward from distribution basins.

The choice between counterflow and crossflow design depends on factors like cooling capacity, budget, space constraints, environmental conditions, and water availability. Understanding the key differences make you make an informed decision for your specific needs.

Table 30. Crossflow vs. Counterflow Cooling Towers: Key Differences

	Parameters	Counterflow	Crossflow
	Space	Requires less ground space.	Needs more space.
	Airflow	Higher air-water contact time, less air required.	Lower air-water contact time, more air required.
	Energy & Water	Higher pumping head, lower fan power.	Lower pumping head, higher fan power.
	Recirculation	Less recirculation	More recirculation
	Fill Pack	Splash/film fill	Splash fill
	Hot Water Basin	No hot water basin. Pressurized distribution.	Hot water basin present. Gravity distribution.
	Power & Pumping	Higher pumping head but lower fan power.	Lower pumping head but higher fan power.
	Inspection & Access	Limited access, requires external platform.	Easier access, internal platform available.
	Noise	Higher noise due to falling water.	Lower noise levels with gravity distribution.
	Costs	Higher initial cost	Lower initial cost
	Safety	Adhere to OSHA standards. Std. 1910.28 requires fall protection for ladders over 24 feet.	Adhere to OSHA standards. Std. 1910.28 requires fall protection for ladders over 24 feet.

Key Takeaway….

Choose counterflow for space constraints, crossflow for better accessibility for inspection and maintenance.

CHAPTER – 5: COOLING TOWER CONSTRUCTION

Cooling towers can be field-erected and factory-assembled.

5.1 Field Erected Cooling Towers

Field-erected cooling towers are constructed on-site. They are custom-designed and built to meet specific project requirements.

a. Applications: Suitable for large industrial and commercial applications where high capacity and custom specifications are needed.
b. Nominal Capacity Range: Typically ranges from 1,000 to 200,000 TR (tons of refrigeration).
c. Material: Often constructed from durable materials like concrete, fiberglass, engineered HDPE or treated wood to withstand environmental conditions.

5.2 Factor Assembled Cooling Towers

Factory-assembled cooling towers, also known as package cooling towers, are pre-engineered and assembled at the factory before being shipped to the site.

a. Applications: Ideal for smaller commercial HVAC applications, or where quick installation and lower initial cost are priorities.
b. Nominal Capacity Range: Typically ranges from 10 to 2,500 TR.
c. Materials: Fiberglass, metal (steel).

Other factors such as shape (square, rectangular or round), and airflow pattern (induced draft, forced draft, or natural draft) can further categorize cooling towers. However, these classifications are often based on operational characteristics rather than the construction method.

Key Guidelines….

Choose factory assembled cooling towers up to 2500 tons of cooling and use multiples if the requirement exceeds this capacity. Use field erected towers only when the capacity exceeds 5000 tons subject to life cycle cost analysis.

5.3 Cooling Tower Materials

The cooling tower's materials should be corrosion resistant and able to withstand the operating conditions of the system. The choice of material for a cooling tower significantly impacts its performance, lifespan, and maintenance costs. Here's a breakdown of common materials:

Galvanized Iron (GI)

Durable and cost effective but lower life span and heavier.

a. Capacity Range: Typically, up to 5000 tons of cooling.
b. Costs: Low compared to other alternatives.
c. Expected Life: 10-15 years with proper maintenance and protective coatings, sealants, and more.
d. Pros: Durable, cost-effective for initial investment, easy to fabricate.
e. Cons: Susceptible to corrosion over time, especially in harsh environments, heavy weight.
f. Applications: G-235 hot-dip galvanized steel is suitable for installations where cost is a primary concern.

Stainless Steel (SS)

Durable but often more expensive and heavier.

a. Capacity Range: Typically, up to 5000 tons of cooling.
b. Costs: High compared to other alternatives.
c. Expected Life: 15-20 years.
d. Pros: Excellent corrosion resistance, durable and long-lasting.
e. Cons: High initial cost, heavy weight may require more robust structural support.
f. Applications: Ideal for environments with high corrosion potential (e.g., coastal or industrial areas). Consider the long-term savings in maintenance when evaluating cost.

Wood

Traditionally used but with limitations due to maintenance requirements.

a. Capacity Range: Can be built to any size.
b. Costs: Moderate initial cost.
c. Expected Life: 15-20 years.
d. Pros: Good thermal conductivity, natural insulation, aesthetic appeal for certain architectural requirements.
e. Cons: Susceptible to biological decay, mold, and termite damage. Requires regular treatment and maintenance.
f. Applications: Suitable for areas with low humidity and providing aesthetic appeal for certain architectural requirements.

Fiberglass

Often used for its corrosion resistance and lightweight properties.

a. Capacity Range: Typically, up to 1500 tons of cooling.
b. Costs: Moderate to high compared to GI.
c. Expected Life: 15-20 years.
d. Pros: Lightweight, corrosion-resistant, high strength-to-weight ratio.
e. Cons: Susceptible to cracks and damage from impact, UV radiation, and chemicals.
f. Applications: Ideal for various climates, requires careful handling. Easier installation, especially on rooftops.

Engineered Plastic (HDPE)

Modern alternative with specific advantages and drawbacks.

a. Capacity Range: Up to 2500 tons of cooling.
b. Costs: Moderate initial cost.
c. Expected Life: 20-25 years.
d. Pros: Lightweight, resistant to corrosion, chemicals, and biological growth, high strength, easy to clean.
e. Cons: Susceptible to UV degradation, may not be suitable for extremely cold climates.
f. Rules of Thumb: Ideal for corrosive environments and applications requiring low maintenance. Easier installation, especially on rooftops.

Table 31. Key Guidelines on Selecting Cooling Tower Materials

	Characteristics for Material	Rules of Thumb
	Cost economics	Consider GI or wood, but account for higher maintenance.
	Corrosive environments	Stainless steel, fiberglass or HDPE are preferable despite the higher initial cost.
	Aesthetic or natural environments	Wood may be suitable with proper treatment.
	Installation	FRP and HDPE are lightweight, offer excellent performance with reduced structural requirements.

When selecting cooling tower materials for HVAC applications, it is essential to balance the initial and operational costs, expected lifespan, maintenance requirements, and specific environmental conditions.

Plastic materials such as fiberglass and HDPE weigh as much as 40% less than a steel tower while being 5-10 times thicker. They can be combined in a cluster to provide faster and easier installation. Below are some general guidelines:

5.4 Key Components

A cooling tower is a complex system comprised of various components, each playing a critical role in the system's overall functionality. These components can be broadly categorized into:

a. Structural components
b. Mechanical components
c. Electrical components
d. Other ancillary components

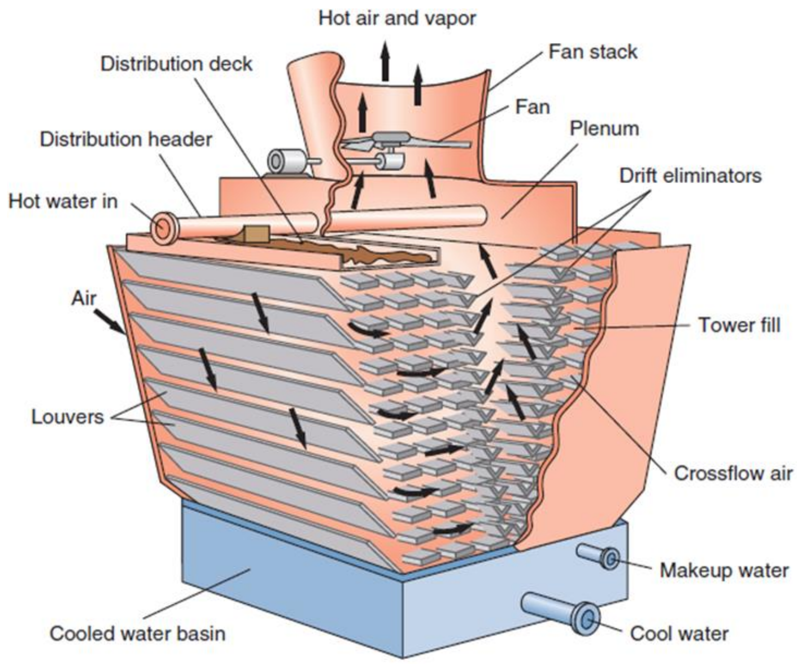


Figure 14. Cooling Tower Components

Table 32. Structural Components of Cooling Tower

Component	Function	Importance
Cold-Water Basin	Collects cooled water after exiting the fill	Provides reservoir for cooled water and allows for pump suction
Tower Framework	Supports the entire cooling tower structure	Ensures structural stability and transmits loads to the foundation
Water Distribution System	Delivers hot water evenly over the fill media	Optimizes water flow for efficient heat transfer and cooling performance
Fan Deck	Supports the fan cylinders and transmits loads	Provides structural support for the fan system
Fan Cylinders	Encase the fan blades and	Create the air movement necessary for heat

Component	Function	Importance
	direct airflow through the tower	exchange
Fill	Increases surface area for air-water contact	Maximizes evaporation rate for efficient heat transfer
Drift Eliminators	Capture large water droplets entrained in the air stream	Minimizes water loss and conserves makeup water
Casing	Encloses the internal components of the cooling tower	Protects internal components from weather, debris, and accidental contact
Louvers	Regulate airflow into the tower and block unwanted elements	Control air intake, minimize sunlight penetration, prevent water splash-out, and reduce noise
Access and Safety Components	Ladders| Safety cages	Provide safe access to different levels of the tower.
Access and Safety Components	Platforms| Walkways| Guardrails	Offer safe work areas for maintenance activities.

Table 33. Mechanical Components of Cooling Tower

Component	Function	Importance
Fans	Create airflow. Made of FRP or Aluminium for corrosion resistance.	Essential for airflow, cooling, and evaporation. Typically designed as 50-60 CFM/TR (airflow rate), 1-2 in WG (static pressure), 200-400 RPM (speed).
Drive Shafts	Transfer power from the motor to rotate the fan blades.	Transmit torque from the motor to the fan.
Gearbox (Reducer)	Increases torque from the motor to the fan (optional).	Enables the use of smaller, lighter motors for large fans, potentially reducing energy consumption.
Belt Drives	Alternative method to transmit power from the motor to the fan.	Can be a simpler and less expensive option compared to gearboxes for some applications.
Safety Guard	Provides a barrier around rotating components (fans, drives).	Protects personnel from accidental contact with moving parts and prevents injuries.
Safety Equipment	Shutoff valves	Isolate sections of the water system for maintenance.
Safety Equipment	Vibration monitoring systems	Detect excessive vibration in fans or motors, allowing for preventive maintenance and avoiding potential breakdowns.
Safety Equipment	Fall arrest systems	Provide additional safety measures for workers at high points.

Table 34. Electrical Components of Cooling Tower

Component	Function	Importance
Motors	Provide power to drive the fans.	Essential for creating airflow through the tower.
Motor Controls	Regulate motor operation (start, stop, speed).	Allow for control of fan speed based on cooling requirements and optimize energy usage.
Variable Frequency Drives (VFDs)	Electronically control the frequency and voltage of the power supplied to the motor (if applicable).	Enable efficient motor operation at variable speeds, leading to significant energy savings compared to traditional on/off controls.
Lighting	Illuminates the cooling tower.	Provides illumination for safe nighttime operation and maintenance.
Wiring Systems	Connect electrical components and transmit power throughout the tower.	Ensure proper power distribution for motor operation, controls, and other electrical equipment.
Control Instruments	Monitor and regulate various operating parameters (temperature, pressure, water level, etc.).	Provide critical data for efficient cooling tower operation and allow for adjustments to optimize performance.

Table 35. Ancillary Equipment's in Cooling Tower

Component	Function	Importance
Supporting Structure (Pad, Legs)	Transfers weight of the cooling tower to the foundation	Provides a stable base for the entire cooling tower structure.
Access Walkways/Ladders	Allow safe access to different levels of the tower for maintenance	Facilitate safe movement and work at various points within the tower.
Piping	Conveys water throughout the cooling tower system	Enables circulation of hot water to the fill and cooled water back to the process.
Utilities	Provides power and other essential services to the cooling tower	Delivers electricity to operate motors, controls, and other electrical equipment.
Tower Water Pump	Circulates water through the cooling tower system	Ensures continuous flow of hot water over the fill media for heat exchange and cooling.

Each of the items above need to be thoughtfully spec'd and budgeted for—as well as planned for maintenance and repair activities. It is important to understand what a supplier has included in their price and what you will need to furnish in addition.

CHAPTER - 6: COOLING TOWER LAYOUT

The space required for a cooling tower is influenced by plan area and height. The plan area of a cooling tower refers to the amount of space it occupies on the ground. This is different from the footprint area.

6.1 Cooling Tower Plan Area

The plan area is the area occupied by the cooling tower, including any supporting structures whereas the footprint area is typically determined by the size of the tower, as well as any auxiliary equipment or structures that may be required for its operation. For example, a cooling tower may need to have a motor room, pump room, or other ancillary equipment, which will take up additional space. Standard industry guidelines for estimating space are:

a. 50TR cooling tower: 10-12 feet diameter or 10' x 10' to 12' x 12' plan area.
b. 100TR cooling tower: 14-16 feet diameter or 14' x 14' to 16' x 16' plan area.
c. 500TR cooling tower: 30-40 feet diameter or 30' x 30' to 40’ x 40’ plan area.

Note that the length and width dimensions of a cooling tower are also determined based on the specific design requirements, such as the number of cells, the type of fill material used, and other factors. The dimensions can vary widely based on these factors, and there is no typical range for length and width dimensions.

	Parameters	Rules of Thumb
👍	Cooling Tower Plan Area	The area occupied by the tower, including supporting structures.
👍	Footprint Area Considerations	Include space for auxiliary equipment like motor or pump rooms.
👍	Total Space Estimation	Reserve 2-3 square feet per TR of cooling tower capacity.

Cooling Tower Height

The height of a cooling tower is typically determined by the pressure drop that is required to move the air through the tower. A larger base with lower profile or a smaller base with taller structure can both impact the overall space requirements and cooling efficiency. As a rule, taller cooling towers can handle higher cooling loads and provide better heat transfer efficiency, but they may also require more energy to operate.

6.2 Cooling Tower Location and Layout

Efficient cooling tower operation relies on proper airflow and intake. Poor air circulation can draw moist, warm or contaminated air degrading its performance. The location and layout of a cooling tower are therefore critical for achieving optimal performance and ensuring safety. Key layout considerations include:

a. Space: Ensure enough room for airflow and maintenance.
b. Layout: Position to minimize air recirculation and short-circuiting.
c. Proximity: Place near equipment to reduce piping costs and heat loss.
d. Airflow: Consider wind direction and obstructions.
e. Air velocity: Design inlets to block hot, humid air.
f. Maintenance Access: Ensure easy access for upkeep.
g. Noise Control: Minimize noise transmission.
h. Safety: Prioritize Legionella risk prevention.
i. Structural: Design to handle environmental forces like wind and earthquakes.

The following table provides benchmark values and rules of thumb for cooling tower placement.

Table 36. Cooling Tower Layout Considerations

	Parameters	Rules of Thumb
	Clearance	Maintain at least one tower height distance from obstructions.
	Proximity	Locate near the cooling load (preferably within 100 feet).
	Wind	Consider windbreaks or louvers for high-wind areas.
	Air Velocity	Less than 600 feet per minute (FPM) on 50% louvers opening.
	Safety Distance	Maintain 15 -25 feet from air intakes and occupied spaces.
	Noise	Target noise level of 85 dBA at 3 feet. Use sound attenuation measures.
	Aesthetics	Enhance appearance with screening, landscaping, or finishes.
	Regulations	Adhere to local building, environmental, and water use regulations.

6.3 Cooling Tower at Ground Level

When cooling towers are located at the ground level, provide fully paved area around the entire installation, and provide a perimeter fence for security and to keep windblown debris from fouling the equipment.

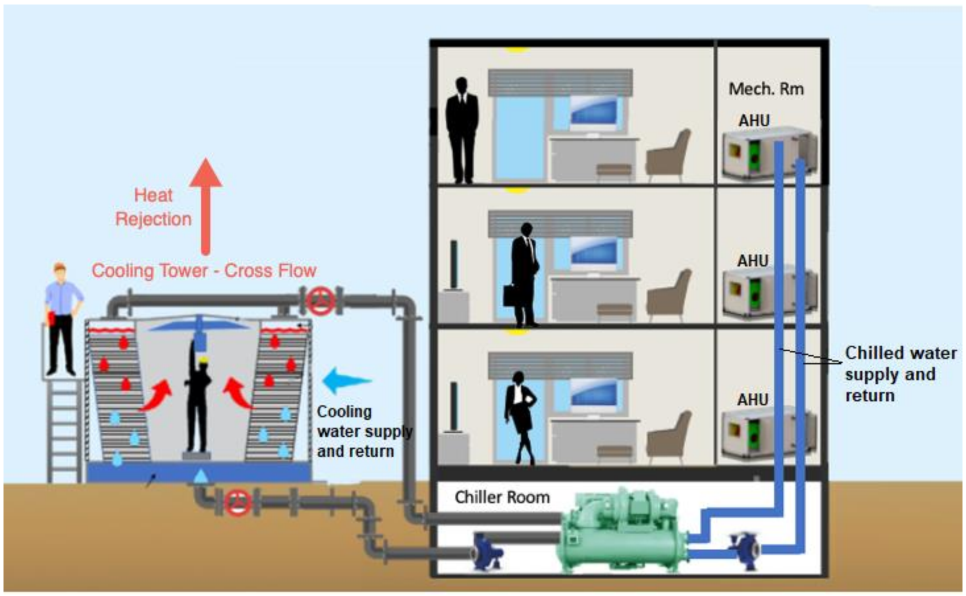


Figure 15. Chiller at Basement Level and Cooling Tower at Ground Floor

6.4 Cooling Tower at Roof Level

The decision to locate a cooling tower on a rooftop versus a ground-level or other location will depend on the specific needs and constraints of the site, as well as the preferences of the owner or operator.

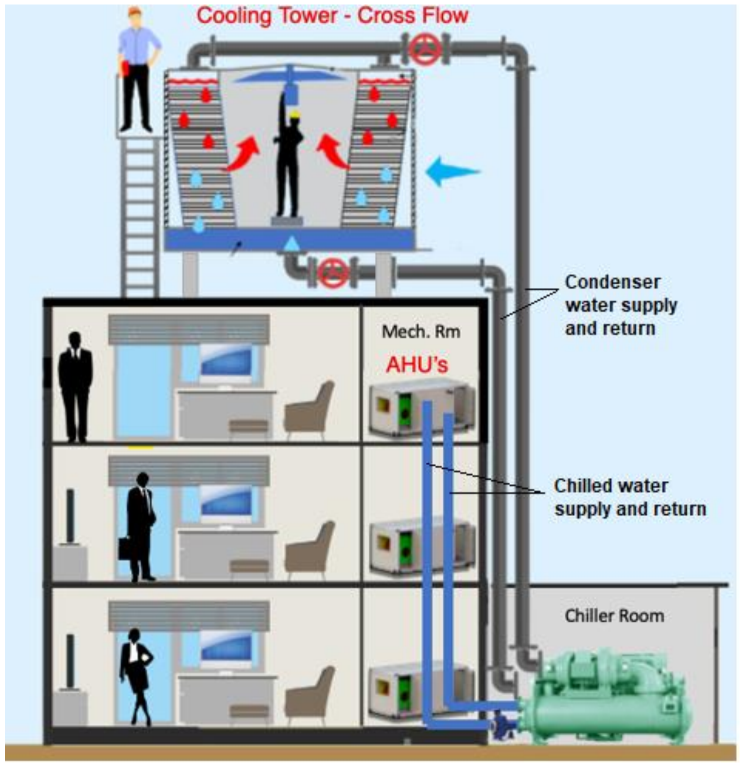


Figure 16. Chiller at Ground Level and Cooling Tower at Roof Level

Advantages of rooftop cooling towers include:

a. Space-saving: Rooftop cooling towers can be an efficient use of space, particularly in urban or densely populated areas where ground-level space may be limited.
b. Reduced noise: A rooftop cooling tower may generate less noise compared to a ground-level installation, which can be a benefit for nearby residents or businesses.
c. Improved aesthetics: Depending on the surrounding area, a rooftop cooling tower may be less visible and potentially more attractive compared to a ground-level installation.

Disadvantages of rooftop cooling towers include:

a. Accessibility: Rooftop cooling towers may be more difficult to access for maintenance and repairs compared to ground-level installations.
b. Structural support: The roof of a building may need to be reinforced or modified to support the weight of a cooling tower, which can increase the cost of installation.
c. Safety: Installing a cooling tower on a roof may present safety concerns for workers, as they may be required to work at heights.

6.5 Air-Intake Separation Distances

The intake and exhaust distances of a cooling tower refer to the distance between the cooling tower and the nearest obstacles that could potentially block or redirect the airflow. Refer to the guidelines below:

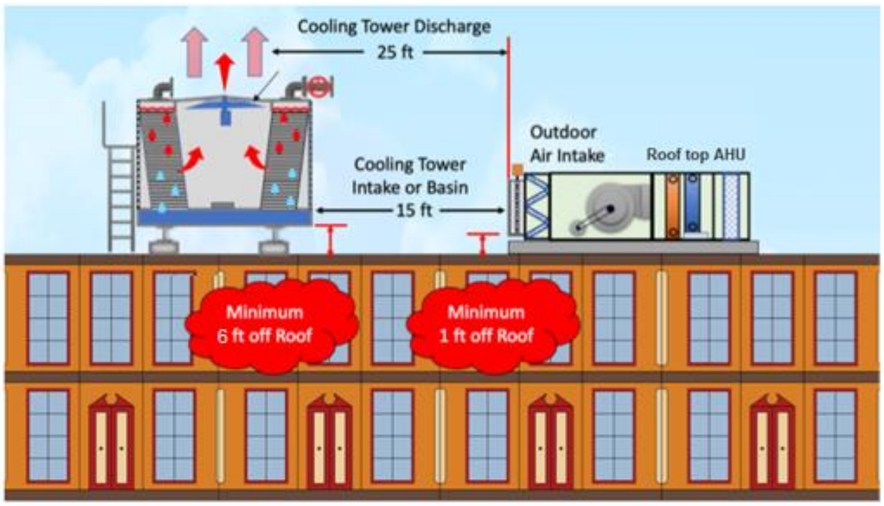


Figure 17. Cooling Tower Separation Distances

Table 37. Cooling Tower Location Guidelines

	Cooling Tower Location	**Rules of Thumb**
	Air Inlet Location	15 feet away from building ventilation air intakes
	Air Exhaust Location	25 feet away from building ventilation air intakes
	Outlet Air Discharge	3 feet above roof or nearby obstructions
	Clearance from Overhead Obstructions	5 feet between top of tower and overhead obstructions
	Clearance from Ground	6 feet between bottom of tower and ground

Location of Air Intakes w.r.t Nearby Obstructions

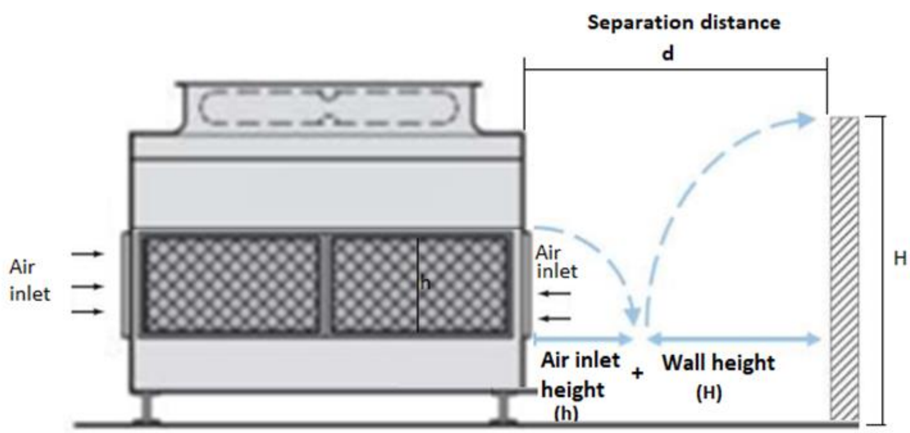


Figure 18. Cooling Tower Separation Distance form Nearby Obstructions

Table 38. Location of Air-Intakes w.r.t Nearby Obstructions

	Parameters	**Rules of Thumb**
👍	Minimum Distance from Structural Walls and Obstructions	Maintain a minimum of 10 feet to ensure proper airflow and prevent turbulence.
👍	Optimum Separation Distance (d)	The ideal separation distance (d) from inlet to solid wall is calculated as: d = h + H (air inlet height + wall height). Recirculation impact is minimal. No additional correction required.

Note: These rules of thumb ensure proper airflow and prevent turbulence by providing guidelines for locating cooling tower air inlets and exhaust outlets away from structural walls and other obstructions.

6.6 Air-Intake Configurations

The different air intake configurations for cooling towers are:

a. Single Air Inlet
b. Dual Air Inlet
c. Four-Side Air Inlet

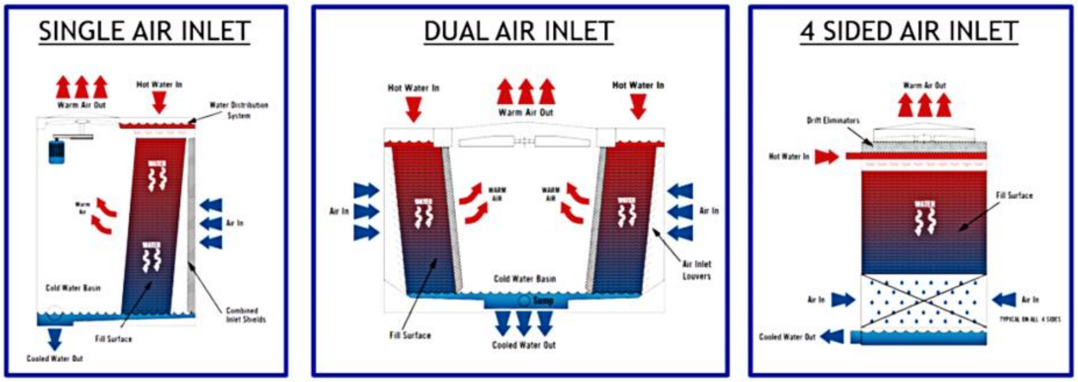


Figure 19. Cooling Tower Air Inlet Design

Table 39. Cooling Tower Air Inlet Design

Design Type	Description	Pros	Cons
Single Air Inlet	One air inlet on one side of the tower, drawing air from one direction.	Simple design, low cost, minimal pressure drop.	Limited air flow control, poor air mixing, increased risk of hot air recirculation.
Dual Air Inlet	Two air inlets on opposite sides of the tower, drawing air from two directions.	Improved air flow control, better air mixing, reduced risk of hot air recirculation.	Higher cost, increased pressure drop, more complex design.
Four-Side Air Inlet	Air inlets on all four sides, drawing air from all directions.	Excellent air flow control, optimal air mixing, minimal risk of hot air recirculation.	High cost, significant pressure drop, complex design, requires more perimeter space.

Note: Four-side air inlet design is typically used in large cooling towers where air flow control and air mixing are critical.

CHAPTER - 7: TECHNICAL ADVANCEMENTS & OPTIONS

In the field of cooling towers, there have been significant advancements in recent years that aim to improve their performance, efficiency, and environmental impact. Some essential features and technical options include the following:

7.1 Capacity Control Features

The following methods can be employed for capacity control and energy optimization in cooling towers:

a. Fan Cycling: This straightforward method involves cycling the tower fan on and off to control capacity, commonly used in multi-cell installations to manage load effectively.
b. Two-Speed Motors: Two-speed fan motors can operate at lower RPMs under reduced load conditions. Alternatively, a low-horsepower pony motor can be utilized as a more cost-effective option to a two-speed motor.
c. Variable Fan Speed: Variable Frequency Drives (VFDs) adjust the cooling tower fan speed based on demand. By modulating fan speed, VFDs help to reduce energy consumption and minimize wear on mechanical components.
d. Multi-Cell Cooling Tower: Designing a multi-cell cooling tower allows for one or more cells to be placed on standby during off-hours or periods of low demand, enhancing energy efficiency.
e. Fluid Bypass: A fluid bypass system provides a parallel path to divert some condenser water around the cooling tower during part-load conditions, optimizing performance.
f. Automatic Control: Modern cooling towers are equipped with advanced Building Management Systems (BMS) or Direct Digital Control (DDC) systems, automating operations by monitoring temperature, flow rates, and water quality to make real-time adjustments for optimal performance.
g. Remote Monitoring and IoT Integration: IoT-enabled sensors continuously monitor cooling tower performance, with data sent to cloud-based platforms for remote access, allowing for predictive maintenance and real-time optimization.

7.2 Energy Efficiency Features

With rising energy costs and a growing focus on sustainability, it's important to design, build, install, and maintain cooling towers to minimize energy use. Here are some methods to enhance efficiency:

a. Fan Speed Control: Per ASHRAE 90.1-2022 standards, cooling tower fan speed should be controlled in proportion to the leaving fluid temperature or condensing temperature/pressure. This can be achieved using two-speed motors or variable speed drive (VSD) technology, applicable to both new and existing systems.
b. Advanced Fan Designs: Modern cooling towers feature axial or centrifugal fans with optimized blade designs to boost airflow efficiency while reducing energy consumption. Some designs even incorporate fan stacking for improved performance.
c. High-Efficiency Motors: Utilizing high-efficiency motors that meet or exceed NEMA Premium standards can cut energy consumption by up to 10% compared to standard motors.
d. Thermal Storage Integration: Integrating thermal storage systems allows cooling towers to operate during off-peak hours, storing cooling energy in chilled water tanks. This strategy reduces peak energy demand and enhances overall energy efficiency.

7.3 Water Conservation Features

Cooling towers incorporate several water-saving features, including:

a. Drift Eliminators: High-efficiency drift eliminators prevent water droplets from escaping the cooling tower, significantly reducing water loss.
b. Low Flow Nozzles: These nozzles create smaller water droplets, enhancing cooling efficiency and reducing water consumption by up to 20%.
c. Level Controls: Water level controls help prevent overflows and water waste by ensuring the cooling tower is not overfilled.
d. Water Treatment: Advanced water treatment systems, including chemical and chemical-free options like UV or ozone treatment, prevent scaling and fouling. This reduces water consumption and decreases the need for blowdown.
e. Auto-Blowdown: Automated blowdown systems optimize water use by adjusting the frequency and volume of blowdown based on water quality, minimizing waste.

7.4 Fill Material and Size Considerations

The fill material and size of a cooling tower are vital components that significantly impact its performance. By selecting the appropriate fill material and size, you can enhance heat transfer and increase the contact time between air and water, leading to improved cooling efficiency. The following recommendations are important:

a. Fill Media: High-efficiency fill materials, such as cross-fluted film, offer an optimal contact time of 1.5 to 2 minutes while minimizing pressure drop. This ensures an efficient cooling process.
b. Fill Options: For clean water systems, film fill is ideal, while splash fill is recommended for systems with high levels of suspended solids. Splash fill is typically used in industrial applications and for high-temperature water, whereas film fill is better suited for HVAC systems and lower-temperature water.

7.5 Noise Control

You have an option to select a) standard fan, b) low sound fan and c) whisper quiet fan.

a. Standard Fan: Baseline option, offering a balance between performance and cost.
b. Low Sound Fan: Optimized blade geometry and materials reduce noise levels while maintaining efficiency.
c. Whisper Quiet Fan: Premium option, designed for maximum noise reduction in critical environments.

Additionally, you can add intake sound attenuation louvers, enclosures, barriers and water splash mats to reduce noise transmission to surrounding areas, meeting stringent noise regulations.

7.6 Safety Features

Cooling towers now incorporate advanced safety features to minimize risks and ensure a secure environment for personnel and equipment.

a. Anti-Legionella Measures: Advanced water treatment and disinfection systems, including UV sterilizers and ozone generators, effectively reduce the risk of Legionella bacteria growth, promoting a safer environment.
b. Slip-Resistant Access and Fall Protection: Non-slip walkways and OSHA-compliant railings provide maintenance personnel with secure access, reducing the risk of accidents and injuries.
c. Emergency Response: State-of-the-art emergency shutoff systems can detect abnormal conditions, such as high vibration or temperature, and automatically trigger shutdowns to protect both equipment and personnel from potential harm.

These enhanced safety features demonstrate a commitment to prioritizing safety in cooling tower design and operation, ensuring a secure working environment and minimizing risks.

7.7 Technological Advancements in Cooling Towers

a. Sweeper System: Automated sweeper system uses pressurized water streams to prevent sediment buildup at the tower's bottom, reducing water waste and improving efficiency.
b. Side Stream Filtration: Removes suspended solids and contaminants from circulating water, improving water quality and reducing blowdown frequency. Recommended features:
    - Minimum filtration capacity: 50 microns.
    - Minimum filtration flow: entire system volume every hour.
    - Disc filter recommended; avoid centrifugal separators and sand filters due to inadequate filtration and excessive backwash water usage.
c. Vibration Monitoring: Vibration sensors on critical components detect excessive vibrations, indicating mechanical issues. Integrates with predictive maintenance systems for proactive action.
d. Vibration Isolation: Isolation pads and mounts for motors and fans reduce vibration-induced noise, enhancing operational quietness.
e. Real-Time Alerts: IoT-based monitoring systems provide instant alerts and data analytics, enabling prompt action against unusual vibrations and preventing costly downtime.
f. Corrosion-Resistant Materials: Advanced materials like HDPE, FRP, and stainless steel extend cooling tower lifespan, reducing maintenance costs and environmental impact.

These innovative features demonstrate the industry's commitment to improving energy efficiency, water conservation, operational safety, and overall performance of HVAC cooling towers. Implementing these technologies can lead to significant cost savings, reduced environmental impact, and improved system reliability.

7.8 Cooling Tower Specifications Criteria

The cooling tower shall be selected to fit within the available footprint and height constraints. The engineer shall consider and address in the design all the following:

a. Cross flow or counter flow towers
b. Multi cell versus single cell towers
c. Gear drive, belt-drive, or variable speed fans
d. Concrete basin or stainless-steel basin
e. Spray nozzles and fill arrangement
f. Davit for fan and motor service
g. Stairs and ladder safety cage, with locked access.
h. Walking platform for complete safe access to fan, fan motor, and hot water deck and nozzles.

i. Tower Loading and Supporting Structure
j. Basin Heating System
k. Drain down issues on remote basins
l. Basin equalizer piping / weirs and drain, overflow and bleed down connections.
m. Sanitary connection to completely drain the basins.
n. Cooling tower location to mitigate noise and IAQ (Legionella) issues.
o. Controls for water level and freeze protection.

7.9 Minimum Performance Requirements

ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers) 90.1 standards established minimum efficiency standards for cooling towers with either axial or centrifugal fans.

Table 40. ASHRAE 90.1 Minimum Performance Requirements

	Category	ASHRAE 90.1 Minimum Performance Requirements
	Axial Fan Cooling Towers	Must achieve greater than 40.2 GPM/hp efficiency at 95°F entering water, 85°F leaving water, and 75°F wet bulb temperature.
	Centrifugal Fan Cooling Towers	Must achieve greater than 20.0 GPM/hp efficiency at 95°F entering water, 85°F leaving water, and 75°F wet bulb temperature.

Performance Requirements for Open and Closed Cooling Towers —Minimum Efficiency Requirements per AHSRAE 90.1, 2019, Table 6.8.1-7

Table 41. ASHRAE 90.1, Minimum Efficiency Requirements

Equipment Type	Rated Capacity	Subcategory or Rating Condition	Performance Required	Test Procedure
Propeller or axial fan open-circuit cooling towers	All	95°F entering water 85°F leaving water 75°F entering WBT	≥40.2 GPM/hp	CTI ATC-105 and CTI STD-201 RS
Centrifugal fan open-circuit cooling towers	All	95°F entering water 85°F leaving water 75°F entering WBT	≥20.0 GPM/hp	CTI ATC-105 and CTI STD-201 RS
Propeller or axial fan closed-circuit cooling towers	All	102°F entering water 90°F leaving water 75°F entering WBT	≥16.1 GPM/hp	CTI ATC-105S and CTI STD-201 RS
Centrifugal closed-	All	102°F entering water	≥7.0 GPM/hp	CTI ATC-

circuit cooling towers		90°F leaving water 75°F entering WBT		105S and CTI STD-201 RS

7.10 Cooling Tower Certification

The Cooling Technology Institute (CTI) verifies that a cooling tower performance matches manufacturer's claims and certifies that cooling tower operates as specified.

Table 42. Cooling Tower Testing Requirements

Test Type	**Description**	**Standard**
Drift Emissions	Measures particulate matter (PM) to assess environmental impact.	Environmental Protection Agency (EPA) considers cooling towers as a source of drift and requires that they meet local area permit standards.
Particle Size	Determines particle size (in microns) to assess water chemistry and distribution.	EPA. The size of particles can range from 7 microns up to several thousand microns but are invisible to the naked eye.
Sound Testing	Evaluates noise levels for compliance with regulations.	CTI ATC-128
Thermal Certification	Verifies thermal performance through qualifying and annual tests.	CTI STD-201, CTI ATC-105
Plume and Abatement	Assesses visible plume production and evaluates plume abatement performance.	CTI ATC-150

Note: CTI stands for Cooling Technology Institute, and the mentioned standards are specific guidelines for cooling tower testing and certification.

CHAPTER - 8: WATER TREATMENT ESSENTIALS

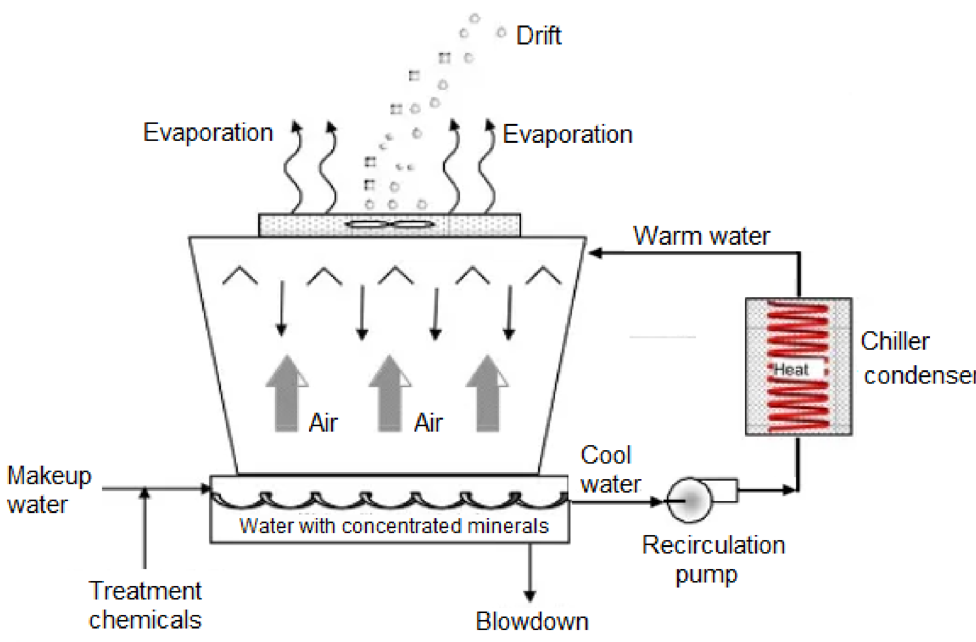
In cooling towers, water evaporates to dissipate heat, causing minerals and impurities in the makeup water to become more concentrated over time. If not managed through bleed-off, these solids can reduce efficiency and harm downstream equipment like heat exchangers. Cooling tower performance depends on two key factors:

a. Water Quality Maintenance: Regularly monitor and control water chemistry to prevent corrosion, scaling, and microbial growth.
b. Recirculated Water Management: Manage blowdown effectively to remove concentrated dissolved solids and maintain water balance.

Before discussing water quality, let's first understand cooling tower water balance and blowdown management.

8.1 Cooling Tower Water Balance

Water leaves a cooling tower system in one of four ways – Evaporation, Drift, Blowdown and Basin Leaks/Overflows.



Cooling Tower Water Balance

Figure 20. Cooling Tower Water Balance

Table 43. Cooling Tower Water Losses

	Water Losses	Description
	Evaporation	Water loss due to water turning into vapor when it is exposed to air and heat. It impacts the tower's water balance and efficiency.
	Drift	Small water loss as mist or droplets; minimized with drift eliminators and baffles. It is an environmental issue, as the discharged water may contain impurities and other contaminants that can impact the quality of the surrounding air and water.
	Blowdown	An intentional discharge of water to control dissolved solids concentration and prevent scale formation and corrosion. It is compensated by make-up water.
	Basin Leaks/Overflows	Preventable water loss due to improper operation, float control, or valve maintenance. So not considered in water balance.
	Water Balance Formula	Make-Up = Evaporation + Blowdown + Drift The water losses should be estimated to find your makeup water calculation. Influencing factor is the size of cooling tower and the water circulation rate.
	Total Water Loss	1.3 to 1.5% of total water circulation rate for induced draft towers.

Table 44. Quantum of Evaporation Losses

	Parameters	Rules of Thumb
	Heat Removal	For every pound of water evaporated, approximately 1000 BTUs are removed from the remaining water.
	Evaporation Loss	Approximately 1% of water circulation per 10°F cooling range.
	Evaporation Calculation	Evaporation (GPM) = 0.01 x Water circulation (GPM) for 10°F temperature range.
	Cooling Tower Flowrate and Evaporation Loss	Water circulation = 3 GPM/Ton for 10°F temperature range. Therefore, Evaporation = 0.01 x 3 GPM/Ton = 0.03 GPM/Ton

Table 45. Drift or Windage Losses

	Parameters	Rules of Thumb
	Drift Loss Formula	Drift = %Windage x Recirculation rate

	Parameters	**Rules of Thumb**
	Typical Drift Loss	0.1 to 0.3% of water circulation
	Natural Draft Tower	Drift loss (D) = 0.3 to 1.0% of circulating water (C)
	Induced Draft Tower	Drift loss (D) = 0.1 to 0.2% of circulating water (C)
	High-Efficiency Drift Eliminators	Drift loss (D) = 0.0005 to <0.001% of circulating water (C)

Note: These rules of thumb provide estimates for drift loss in cooling towers, but actual values may vary depending on specific conditions and equipment efficiency.

Table 46. Blowdown Losses

	Parameters	**Rules of Thumb**
	Typical Blowdown Loss	0.2 to 0.3% of water circulation
	Blowdown Calculation	Blowdown (GPM) = 0.002 x Water circulation (GPM)
	Typical Value for HVAC	Cooling tower circulation rate = 3 GPM/Ton per 10°F range. Blowdown = 0.002 x 3 GPM/Ton = 0.006 GPM/Ton OR 6 GPM per 1,000 Tons of cooling
	Monitoring	Careful monitoring and control of blowdown quantity provides the most significant opportunity to conserve water in cooling tower operations.

Note: These rules of thumb provide estimates for blowdown in cooling towers, but actual values may vary depending on specific conditions, water chemistry, and equipment efficiency.

8.2 Makeup Water

The purpose of makeup water is to replace water lost due to evaporation, blowdown, windage, and leaks. It is determined by adding all the water losses from the system.

Table 47. Makeup Water

	Parameters	**Rules of Thumb**
	Makeup Water Formula	Makeup = Evaporation + Blowdown + Drift

	Evaporation Loss	1% of circulation for every 10°F of cooling range
	Blowdown Loss	0.2 - 0.3% of circulation (to prevent excessive salt buildup)
	Windage/Drift Loss	0.1-0.3% of circulation (mechanical draft towers)
	Makeup Water Calculation	Total makeup water = (Evaporation% + Blowdown% + Drift%) x circulation rate (GPM) Total makeup water = (1% + 0.2% + 0.1%) x circulation rate (GPM) Total makeup water = 1.3% x circulation rate (GPM)
	Typical makeup rate for HVAC applications	Cooling tower circulation rate = 3 GPM/Ton per 10°F range. Makeup = 1.3% x 3 GPM/Ton = 0.039 GPM/Ton OR 39 GPM per 1000 tons of refrigeration

Note: These rules of thumb provide estimates for makeup water in cooling towers, but actual values may vary depending on specific conditions, water chemistry, and equipment efficiency.

8.3 Cycles of Concentration (COC)

Cycle of Concentration (COC) measures the ratio of dissolved solids in blowdown water to make-up water. It represents the efficiency of water use in a cooling tower. Maximizing COC reduces blowdown and make-up water needs, but higher COC can lead to scaling and corrosion. Proper management is essential to balance efficiency and water chemistry.

Table 48. Cycles of Concentration

	Parameters	**Rules of Thumb**
	COC Calculation	Ratio of dissolved solids in blowdown water to makeup water, or Ratio of makeup water volume to blowdown water volume.
	COC Goal	Maximize COC to minimize blowdown water quantity and reduce makeup water demand.
	Recommended COC	Typically, 3 to 5, but may vary depending on cooling tower type, makeup water quality, and water treatment level.
	High COC	Reduces the blowdown but increases the risks of scale buildup and corrosion due to concentrated minerals.
	Low COC	Increases blowdown leading to higher water usage and chemical treatment costs.

Equation 10. Relationships between COC, Blowdown, Makeup and Evaporation Rate

The blowdown rate is related to evaporation rate, makeup rate and COC by following equations:

$$\text{Blowdown} = \frac{\text{Evaporation rate}}{\text{COC} - 1}$$

$$\text{Blowdown} = \frac{\text{Make up rate}}{\text{COC}}$$

The makeup rate can also be estimated by rearranging the blowdown and cycles of concentration equations identified previously. Some useful formulas are:

$$\text{Makeup} = \text{Evaporation} + \frac{\text{Make up}}{\text{COC}}$$

$$\text{Makeup} = \text{Evaporation} + \frac{\text{Evaporation}}{(\text{COC} - 1)}$$

$$\text{Makeup} = \frac{\text{COC x Evaporation}}{(\text{COC} - 1)}$$

Table 49. Blowdown Rate and COC Relationship

	COC (Cycles of Concentration)	Blowdown Rate
	Increasing COC	Decreases blowdown rate and reduces make-up water demand.
	Decreasing COC	Increases blowdown rate and raises make-up water demand.

This table summarizes the impact of COC adjustments on blowdown and make-up water usage.

8.4 Water Treatment Indicators

Two commonly used indicators of scaling or corrosive tendency of the recirculating water are:

a. Langelier Saturation Index (LSI)
b. Ryznar Saturation Index (RSI)

Both these indices indicate whether water will precipitate, dissolve, or be in equilibrium with calcium carbonate. These can be applied as below.

a. Langelier Index: Suitable for high alkalinity water (>100 ppm) at high temperatures (>120°F/49°C). Used in industrial process cooling towers and power plants.

b. Ryznar Index: Suitable for low to moderate alkalinity waters (<100 ppm), low to moderate pH (<7.5), and temperatures (<120°F/49°C). Used in commercial cooling towers and HVAC systems.

Table 50. Water Treatment Indicators

	Water Indicators	Rules of Thumb
	Langelier Index	Langelier Index may be positive or negative. • Positive values indicate scaling conditions. • Negative values indicate corrosive and non-scaling conditions.
	Ryznar Index	The Ryznar index value is always positive. • Values < 6 indicate calcium carbonate precipitation (scaling). • Values > 6 indicate corrosive water (dissolving calcium carbonate).

In either case, the objective is to set the bleed off rate to limit the cycles of concentration such that the cooling water chemistry is maintained on the non-scaling side of the index.

8.5 Cooling Water Quality

Water quality includes factors such as pH, hardness, dissolved and suspended solids, scaling tendency, chloride content, chlorination practices, and possible contaminants. Elevated temperatures will generally increase both the propensity for corrosion and scaling.

Some important parameters that must be considered for exposure of a material to a cooling water environment include:

Table 51. Maintaining Water Chemistry

	Water Chemistry	Rules of Thumb
	pH	The pH is a measure of how acidic or alkaline a solution is, and the pH of water is expressed in scale of 0 to 14. • Neutral: 7 • Acidic: <7 (corrosion risk)

		• Basic: >7 (scaling risk)
	Hardness	Refers to the concentration of calcium and magnesium ions in the water, which can cause scaling in pipes and heat exchangers. • ≥200 ppm: High scaling risk
	TDS (Total Dissolved Solids)	Refers to the total concentration of dissolved solids in the water, including minerals, salts, and organic compounds. High TDS: Scaling and corrosion risk • ≥500 ppm: High scaling risk
	Total Alkalinity	Refers to the ability of the water to neutralize acids, and is related to the presence of bicarbonate, carbonate, and hydroxide ions. • ≥200 ppm: High scaling risk
	TSS (Total Suspended Solids)	Refers to the concentration of suspended particles in the water, such as dirt, debris, and microorganisms. Affects system efficiency. • ≥50 ppm: High risk
	Chlorides	Precursor to corrosion and scaling. • ≥500 ppm: High risk
	Biological Parameters	Presence of microorganisms such as bacteria, algae, and fungi, which can lead to biofouling, corrosion, and reduced system efficiency. Regular monitoring and control necessary.

8.6 Cooling Water Treatment

Proper cooling water treatment is essential for chillers and cooling towers because these systems rely on water to transfer heat from the process or building to the environment. Without treatment, water impurities can cause scaling, corrosion and microbial growth.

8.7 Scale Control

Hard deposits form on the internal surfaces of water-cooled condensers, insulating the heat transfer surface and increasing condensing temperatures. The principal reason of scale formation is the hardness of makeup water.

Table 52. Key Indicators of Scale Formation

	Scale Types	Characteristics
	Calcium Carbonate	Most common type of scale deposit with waters high in calcium hardness and total alkalinity. Same composition as limestone.
	Calcium Phosphate	Dense deposit, removable by acid cleaning.
	Calcium Sulphate (Gypsum)	More soluble than calcium carbonate, but difficult to remove. Clean with sulfuric acid and maintaining pH control.
	Silica	Glass-like coating, difficult to remove. Forms in high-temperature, high-pH conditions.

Table 53. Energy Penalty due to Scaling

Just 1/32 of an inch of scale (0.03-inch scale) corresponds to an increase in energy costs of over 30% and can add nearly $52000 to the cost of operating a 500-ton chiller. Refer below an example:

	Equipment	KW/ton	Load factor	Operating hours	KWH/rate	Energy cost
	500-ton chiller	x 0.65	x 100%	x 6570	$0.09	= $192173

Table 54. Energy costs vs. Scale Thickness

	Deposit Thickness (inches)	% Efficiency Loss	Increased Energy Cost
	0.01	9%	$17296
	0.02	18%	$34609
	0.03	27%	$51887
	0.04	36%	$69182
	0.05	45%	$86478

Energy Savings vs. Chemical Cleaning Costs

Energy savings = $51887.00

Estimated chemical cleaning cost = $ 900.00

Annual net savings = 51887 – 900 = $ 50987.00

Scale can be removed only by using chemicals or physical scrubbing.

Table 55. Impacts of Scale Thickness

	Scale Thickness	Impact
	1/64"	15% decrease in condenser performance.
	1/64"	3.5% increase in compressor BHP.
	1/64"	0.5% decrease in compressor capacity.

Table 56. Controlled Parameters for Scale Prevention

	Parameters	Rules of Thumb
	pH Control	Between 7.2 and 8.5.
	Hardness Limit	Below 200 ppm.
	Alkalinity Limit	Below 200 ppm.
	TDS Limit	Below 500 ppm.
	Silica Limit	Below 150 ppm to guard against Calcium Sulphate deposits.
	Cleaning Schedule	Establish a regular cleaning schedule to remove scale deposits.

8.8 Corrosion Control

Corrosion is a reaction between a metal and its environment. Heat exchange equipment in cooling systems is made from various metals such as steel, copper, galvanized steel, and stainless steel. If not properly protected, these metals will corrode when exposed to air and water.

Table 57. Methods for Corrosion Monitoring

	Aspect	**Details**
	Corrosion Monitoring Method	Using corrosion coupons.
	Corrosion Rates	Carbon Steel: <0.05 mm/year Copper Alloys: <0.02 mm/year

8.9 Key Indicators for Corrosion

The key indicators for corrosion are:

a. The pH of less than 7 is acidic and is responsible for corrosion of metal parts.
b. High conductivity of condenser water.
c. High levels of dissolved oxygen in condenser cooling water.
d. High levels of the total dissolved solids (TDS).
e. The presence of corrosive gases, such as chlorine.

Since the water in an open recirculating cooling system is saturated with oxygen, an ongoing water treatment is required to minimize corrosion and prolong the useful life of plant equipment.

Table 58. Controlling Parameters for Corrosion Prevention

	Parameters	**Rules of Thumb**
	pH Control	Between 7.2 and 8.5.
	Conductivity Limit	Below 1000 µS/cm.
	Dissolved Oxygen Limit	Below 2 ppm.
	TDS Limit	Below 500 ppm.
	Corrosive Gas Control	Monitor and control corrosive gases like chlorine.
	Ongoing Water Treatment	Use corrosion inhibitors as needed.

8.10 Microbial Growth and Fouling

It's the build-up of deposits in heat surfaces of cooling towers and the tube surfaces of the condenser. Dirt and debris scrubbed from the air and particulate matter entering through the makeup water are the prime source of foulants. Internally, the rusty by-products of corrosion contribute to fouling deposits. As these impurities accumulate, they tend to form large deposits that foul pumps, screens, heat exchangers and other system components.

8.11 Key Indicators of Equipment Fouling

The warm, moist environment of cooling towers promotes bacterial and microbial growth, posing health risks and decreasing system efficiency. The key indicators that can be used to check fouling of heat exchangers (e.g., condenser) are:

a. High Pressure Drop: Across the condenser.
b. Low Temperature Difference: Between entering/leaving side of condenser.
c. Reduced Cooling Capacity: Failure to achieve minimum capacity.
d. Low Flowrate: Below minimum flowrate.

These indicators suggest fouling, which can reduce efficiency and damage equipment.

Table 59. Controlling Parameters for Microbial Growth

	Parameters	Rules of Thumb
	Free Chlorine Level	Between 0.5 and 1.5 ppm.
	Microbial Growth and Bacterial Count	The total bacterial count in cooling tower water should be less than 1,000 colony-forming units (CFU) per millilitre (mL) of water, and the concentration of Legionella bacteria should be less than 10 CFU per mL of water.
	Ongoing Water Treatment	Regularly clean and disinfect the cooling tower.

8.12 Water Treatment Equipment

Water treatment equipment in HVAC applications is essential for maintaining system efficiency, preventing corrosion, scaling, and biological growth in cooling towers, boilers, and chilled water systems. Common water treatment systems include filtration units, chemical dosing systems, water softeners, and corrosion inhibitors. These systems help control water quality by removing impurities, regulating pH levels, and minimizing the buildup of minerals and contaminants that can reduce heat transfer and damage system components.

Table 60. Water Treatment Equipment

	Equipment	Rules of Thumb
	Chemical dosing system	Delivers chemicals into the cooling water via chemical storage tanks, metering pumps, and control instruments.

	Equipment	Rules of Thumb
	Filtration system	Removes particulate matter and microorganisms from the cooling water to prevent fouling and reduce the load on downstream treatment equipment.
	Reverse osmosis (RO)	Removes total dissolved solids (TDS) from the cooling water, reducing scaling potential and improving water quality.
	Softening system	Removes hardness-causing minerals from the water, reducing scaling potential and improving water quality.
	Biological control system	Uses biocides or other treatments to control bacterial growth in the cooling water, preventing biofouling and relate.
	UV Sterilizers	Uses ultraviolet light for disinfection.
	Ozone Generator	Disinfects and oxidizes organic matter

8.13 Water Treatment Chemicals and Inhibitors

Chemical dosing systems utilize specialty chemicals, inhibitors, and adjusters to adjust the water chemistry.

Table 61. Common Water Dosing Chemicals

	Parameters	Chemicals/Inhibitors	Function
	pH Control	Sodium Hydroxide (NaOH)	Raises pH
	pH Control	Sulfuric Acid (H_2SO_4)	Lowers pH
	Scale Control	Phosphonates, Polyacrylates, Polyacrylic Acid, Polymaleic Acid	Inhibits scale formation. Work by binding to the calcium and magnesium ions in the water.
	Corrosion Control	Zinc Phosphates, Molybdates, Nitrite	Inhibits corrosion. Work by forming a protective film on the metal surfaces.
	Biofouling Control	Chlorine, Bromine, Ozone	Disinfectant (oxidizing biocide). Work by killing or inhibiting the growth of bacteria, algae, and other microorganisms
	Biofouling Control	Quaternary Ammonium Compounds, Isothiazolinones	Disinfectant (non-oxidizing biocide)

Notes:

a. The selection of chemicals and inhibitors depends on specific water quality and system conditions.
b. Dosage rates and application methods should be optimized for effective treatment.
c. Regular monitoring and testing are necessary to ensure treatment efficacy and system safety.

Consult a water treatment expert for specific recommendations, proprietary chemicals and dosage requirements.

8.14 Physical Cleaning Methods

Physical cleaning methods for scale removal involve the use of mechanical force to physically dislodge or dissolve mineral scale deposits from surfaces.

Table 62. Physical Cleaning Methods for Scale Removal

	Cleaning Methods	**Rules of Thumb**
👍	High-Pressure Water Jetting	Use high-pressure water jet to dislodge mineral scale deposits from the surface. Typically, 10,000-40,000 psi pressure required to dislodge hard scale deposits.
👍	Scrubbing and Brushing	Use mechanical scrubbing or brushing. Effective for removing soft and loose scale deposits.
👍	Acid Cleaning	Use an acid solution to dissolve mineral scale deposits. Recommended dilute hydrochloric or sulfamic acid to dissolve hard resistant scale deposits.
👍	Ultrasonic Cleaning	Use high-frequency sound waves to create small cavitation bubbles that dislodge mineral scale deposits from surfaces. Effective in removing scale from hard-to-reach areas and delicate equipment.

Physical cleaning methods are often used in combination with chemical cleaning methods to achieve the best results. It is important to use appropriate protective equipment and follow proper safety procedures when using physical cleaning methods for scale removal.

8.15 Zero Discharge Environmental Regulations

Zero discharge regulations aim to eliminate or minimize the release of pollutants and wastewater into the environment, promoting sustainable industrial practices. In cooling systems, zero discharge means all wastewater is either recycled or treated and reused. The following regulations set standards in USA.

US Agencies and Regulations

a. Environmental Protection Agency (EPA)
b. Clean Water Act (CWA): Regulates wastewater discharge into waters of the US
c. Resource Conservation and Recovery Act (RCRA): Regulates hazardous waste management
d. National Pollutant Discharge Elimination System (NPDES): Regulates point source pollution
e. Occupational Safety and Health Administration (OSHA)

International Agencies:

a. United Nations Environment Programme (UNEP)
b. European Environment Agency (EEA)
c. World Health Organization (WHO)

Table 63. Environmental Limits for Zero Discharge

	Environmental Limits	Benchmark Values
	Effluent discharge limits	US: varies by industry and pollutant (e.g., 10 ppm for BOD, 1 ppm for heavy metals). International: varies by country and pollutant (e.g., EU: 25 mg/L for COD).
	Water reuse and recycling targets	US: 50% water reuse in industrial processes. International: varies by country (e.g., EU: 20% water reuse by 2025).

Strategies for Zero Discharge

a. Implement water conservation measures to reduce wastewater generation.
b. Use treatment technologies like membrane bioreactors, advanced oxidation, and nanofiltration.
c. Implement closed-loop systems for water reuse and recycling.
d. Conduct regular monitoring and reporting to ensure compliance.
e. Adopt best management practices (BMPs) for pollution prevention.

8.16 Water Conservation Opportunities

Besides water treatment and controlling blowdown, consider these water-saving strategies:

a. Drift Eliminators: Install drift eliminators to minimize water loss due to drift.

b. High-Efficiency Nozzles: Use high-efficiency nozzles to reduce water consumption.
c. Variable Frequency Drives: Install variable frequency drives to optimize fan and pump operation.
d. Air Flow Optimization: Optimize air flow to reduce water usage.
e. Cooling Tower Upgrades: Upgrade to more efficient cooling towers or modify existing ones.
f. Water Recycling: Explore water recycling or from using alternate sources of make-up water such as air handler condensate (water that collects when warm, moist air passes over the cooling coils in air handler units). This reuse is particularly appropriate because the condensate has a low mineral content and is typically generated in greatest quantities when cooling tower loads are the highest.
g. Leak Detection and Repair: Regularly detect and repair leaks to minimize water loss.
h. Optimize Cooling Tower Size: Ensure the cooling tower is properly sized for the application.
i. Regular Maintenance: Regularly maintain the cooling tower to prevent inefficiencies and water waste.

Implementing these strategies can significantly reduce water consumption in cooling tower operation.

CHAPTER - 9: WATER COOLED CONDENSERS

Water-cooled condensers efficiently reject heat from the refrigerant to the water, allowing for a stable and reliable cooling process. They can achieve higher energy efficiency compared to air-cooled condensers and can handle high cooling capacities, making them suitable for large commercial and industrial applications.

9.1 Chiller Evaporator Vs. Condenser

The condenser is always bigger than the evaporator.

a. Evaporator Sizing: The size or capacity of the evaporator is based on the peak cooling demand of the building or process, representing the nominal capacity of the chiller.
b. Condenser Sizing: The size of condenser is calculated by adding the evaporator's nominal capacity to the extra heat generated by compressor and motor inefficiencies. This additional heat typically increases the size of the condenser by 15-25% compared to the evaporator.

9.2 Total Heat Rejection (THR) and Heat Rejection Factor (HRF)

THR represents the total heat a condenser removes, which includes:

a. Heat absorbed by the refrigerant in the evaporator
b. Work input to the compressor
c. Motor heat (in hermetic chillers)

HRF is the ratio of THR to evaporator load, typically 1.15 to 1.25 for vapor compression chillers. Lower HRF indicates higher efficiency.

Equation 11. Heat Rejection Factor

$$\text{HRF} = \frac{\text{THR}}{\text{Evaporator Load}}$$

The HRF can be influenced by factors such as the refrigerant used, the condenser design, and the operating conditions of the chiller.

9.3 Heat Rejection from Vapor Compression Chillers

Multiply evaporator tons by HRF (usually 1.25 for estimation for vapor compression chillers).

Condenser (tons) = Evaporator (tons) x 1.25

Condenser (tons) = 12000 BTU/hr./ton x 1.25

Condenser (tons) = 15000 BTU/hr./ton

Example: For 100-ton rated chiller capacity, the condenser (and cooling tower) will be sized for 100 x 1.25 = 125 tons.

9.4 Heat Rejection from Absorption Chillers

For absorption chillers, the heat rejection factor is 2.4.

Example: For 100-ton rated vapor absorption machine, the condenser (and cooling tower) will be sized for 100 x 2.4 = 240 tons.

9.5 Types of Water-Cooled Condensers

The main types of water-cooled condensers are:

a. **Shell and Tube Condensers:** These consist of a cylindrical shell containing a tube bundle, where the refrigerant flows through the tubes, and water flows around the shell. The water absorbs heat from the refrigerant, causing it to condense. These condensers are known for their durability, efficiency, and ability to handle high-pressure refrigerants.
b. **Plate Heat Exchanger Condensers:** These use a series of metal plates arranged in a frame, with refrigerant flowing on one side of each plate and water on the other. They are compact, highly efficient in heat transfer, and commonly used in smaller systems where space is limited.
c. **Spiral Coil Condensers:** Feature a spiral coil design enclosed in a welded shell. It can be arranged horizontally or vertically and is generally the most compact and least expensive option. Refrigerant flows through the coil and the water flows around it.
d. **Tube-in-Tube (double tube) Condensers:** These consist of an inner tube carrying refrigerant and an outer tube carrying water, with countercurrent flows to maximize heat transfer efficiency.

9.6 Factors Affecting Condenser Sizing, Selection and Performance

When designing and selecting a water-cooled condenser for an HVAC system, several rules of thumb can guide the process. These rules of thumb provide a starting point, but actual sizing may vary based on specific system requirements and operating conditions.

Table 64. Condenser Capacity

	Parameters	Rules of Thumb
	Condenser Capacity	The size of the condenser should be appropriate for the size of the system it will be used in (i.e., on cooling load + 25% heat of compression). This is about 15,000 BTU/hr. per ton of cooling capacity.

9.7 Condenser Water Flowrate (GPM)

The cooling water flowrate is dependent on the condenser heat load and the temperature range.

Equation 12. Condenser Water Flowrate

$$\text{Water flowrate (GPM)} = \frac{\text{Condenser heat load (Btu/h)}}{500 \text{ x Range (°F)}}$$

We learnt that the condenser heat load is 15000 BTU/hr/Ton due to added heat of compression. Therefore,

$$\text{Water flowrate (GPM/ton)} = \frac{15000 \text{ (Btu/h)}}{500 \text{ x } \Delta\text{T Range (°F)}}$$

Condenser designed for 10°F temperature differential between supply water and return water will have a flowrate of 3 GPM/ton.

$$\text{Water flowrate} = \frac{15000 \text{ (Btu/h)}}{500 \text{ x } 10 \text{ °F}} = \mathbf{3\ GPM/ton}$$

Or the condenser designed for 12°F temperature differential between supply water and return water will have a flowrate of 2.5 GPM/ton.

$$\text{Water flowrate} = \frac{15000 \text{ (Btu/h)}}{500 \text{ x } 12 \text{ °F}} = \mathbf{2.5\ GPM/ton}$$

Quick Estimation:

$$\text{Water flowrate (GPM/ton)} = \frac{15000 \text{ (Btu/h)}}{500 \text{ x } \Delta\text{T Range (°F)}}$$

$$\text{Water flowrate (GPM/ton)} = \frac{30}{\text{Temp. Range (°F)}}$$

This implies:

Higher range will demand lesser flowrate.

12°F range = 2.5 GPM per ton

10°F range = 3 GPM per ton (standard default as per AHRI 550/590).

9.8 Condenser Water Temperatures

The cooling water temperature affects the condenser performance. Lower the entering cooling water temperature (ECWT), higher the condenser performance. ECWT is dependent on the cooling tower approach.

Typically, in 70°F to 85°F range. Lower the better.

As per AHRI 550/590, the performance is based on:

- Entering water temperature = 85°F.
- Leaving water temperature = 95°F
- Condenser Range = 95 – 85 = 10°F

Caution:

While a lower entering condenser water temperature generally improves chiller performance, it's crucial to avoid dropping below 70°F. If the entering condenser water temperature gets too low, the condenser head pressure may decrease, potentially preventing sufficient refrigerant flow through the expansion valve. It may increase the risk of refrigerant flooding, which can damage the compressor. Other issues like ice formation or slugging.

9.9 Condensing Temperature

The condensing temperature is a temperature at which the refrigerant condenses into a liquid at a given pressure. It is also called saturated condenser temperature (SCT) and can be found in refrigerant property tables corresponding to the specific refrigerant pressure.

Higher condensing temperature increases energy consumption, reduces chiller capacity and may lead to compressor overheating and damage.

Table 65. Typical Condensing Temperatures

	Parameters	Rules of Thumb
	Optimal Condensing Temperature	95°F to 100°F
	Typical Condensing Temperature	100°F to 110°F for most chillers.
	Maximum Allowable Condensing Temperature	115°F to 120°F

9.10 Condenser Approach

The condenser approach is typically defined as the difference between the Saturated Condenser Temperature (SCT) and the Leaving Condenser Water Temperature (LCWT). It is typically between 3 to 5°F at full load for new chillers.

A higher approach temperature signifies that the refrigerant is not being cooled properly, which can lead to a reduction in system efficiency and cooling capacity. Higher approach values can be due to:

a. Fouled condenser tubes: Scale, dirt, or other deposits can reduce heat transfer efficiency.
b. Low water flow: Insufficient water flow can limit heat transfer.
c. Air in the refrigerant: Non-condensable gases can reduce the effectiveness of the condenser.
d. Refrigerant charge problems: Undercharge or overcharge can affect performance. It can be due to loss of refrigerant due to leakages or an unbalanced refrigerant distribution in the chiller due to a faulty level sensor or expansion valve.

Table 66. Condenser Approach

	Parameters	Rules of Thumb
	Condenser Approach	A rule of thumb is to have a condenser approach temperature between for 3 to 5°F at full load for new chillers. The condenser approach is influenced by the chiller's age and the load on the chiller. • Water cooled condenser (new chiller): 3°F to 5°F • Water cooled condenser (old chiller): 5°F to 7°F • Air cooled condenser: 10°F to 20°F.

9.11 Condenser Pressure Drop

Pressure drop across a chiller condenser refers to the difference in pressure between the inlet and outlet of the condenser water circuit. This pressure drop occurs as the cooling water flows through the condenser tubes. Larger pressure drop affects the condenser water pump power consumption. Factors affecting pressure drop includes:

a. Condenser Design: The length, diameter, and number of tubes in the condenser affect the pressure drop.
b. Water Flow Rate: Higher flow rates increase the pressure drop due to increased friction within the tubes.
c. Tube Fouling: Accumulation of scale or other deposits inside the tubes increases resistance to flow, leading to a higher pressure drop.

Table 67. Recommended Max. Permissible Condenser Pressure Drop

	Parameters	Rules of Thumb
	Pressure drop across condenser	The pressure drop typically ranges from 10 to 30 feet of water. • Limit pressure drop below 25 feet of water for optimal chiller performance. • Limit pressure drop to 15 feet of water for chillers with low-pressure refrigerants.

9.12 Condensing Heat Transfer Coefficient

The overall heat transfer coefficient (U-value) is a measure of the efficiency of heat transfer between the refrigerant and the water in the condenser. Factors influencing the U-value include the type of condenser (shell and tube, plate heat exchanger, etc.), material of construction (e.g., copper, stainless steel, titanium), water flow rate & velocity, and cleanliness of the heat exchange surfaces. A higher U-value indicates better heat transfer efficiency.

Table 68. Typical Heat Transfer Coefficient for Water-Cooled Condensers

	Type of Condenser	Rules of Thumb
	Water-Cooled Condensers	• Typical U-value: 150-300 Btu/h·ft^2·°F • High-efficiency U-value: 400-600 Btu/h·ft^2·°F
	Shell and Tube Condensers	• Typical U-value: 100-200 Btu/h·ft^2·°F

	Type of Condenser	Rules of Thumb
		• High-efficiency U-value: 250-400 Btu/h·ft^2·°F
	Plate Heat Exchanger (PHE) Condensers:	• Typical U-value: 300-500 Btu/h·ft^2·°F • High-efficiency U-value: 600-800 Btu/h·ft^2·°F
	Air-Cooled Condensers	• Typical U-value: 50-100 Btu/h·ft^2·°F • High-efficiency U-value: 150-250 Btu/h·ft^2·°F

9.13 Fouling Factor

Fouling factor is a measure of the expected reduction in heat transfer efficiency due to the buildup of dirt, sediments, or other deposits on heat exchange surfaces. This factor should be considered during the design phase to ensure that the condenser can maintain performance even with some level of fouling.

Table 69. Typical Fouling Factor for Water-Cooled Condenser

	Parameters	Rules of Thumb
	Fouling Factor	A fouling factor of 0.00025 Btu/hr. ft^2 °F is a reasonable estimate for typical operating conditions.

It is important to note that fouling is a dynamic process and can change over time, so periodic cleaning and maintenance of the condenser is necessary to ensure optimal performance and energy efficiency of the water-cooled condenser.

9.14 Refrigerant Type

Different refrigerants have different properties, and the condenser should be compatible with the refrigerant being used. Ensure the selected refrigerant is compatible with the condenser materials, such as copper, aluminum, or steel.

Table 70. Refrigerant Type

	Type of Refrigerants	Rules of Thumb
	Refrigerants	Choose refrigerants with zero Ozone Depletion Potential (ODP) and low Global Warming Potential (GWP) to minimize climate impact. As a rule of thumb: • CFC and HCFCs compounds are no longer used and replaced with HFOs (Hydro-fluoro-olefins) and natural

		refrigerants. • GWP < 1,000 for medium-term applications • GWP < 100 for long-term applications

9.15 Water Quality

The quality of the cooling water directly affects the condenser's performance and longevity. Impurities in the water, such as dissolved solids, minerals, and microorganisms, can lead to scaling, corrosion, and fouling of the condenser tubes. Proper water treatment, including filtration, chemical dosing, and blowdown management, is essential to maintaining water quality and ensuring efficient heat transfer. Refer to Chapter – 8 for optimum water chemistry.

9.16 Design Features of Shell & Tube Condensers

Shell and tube condensers are the most common type in large HVAC plants.

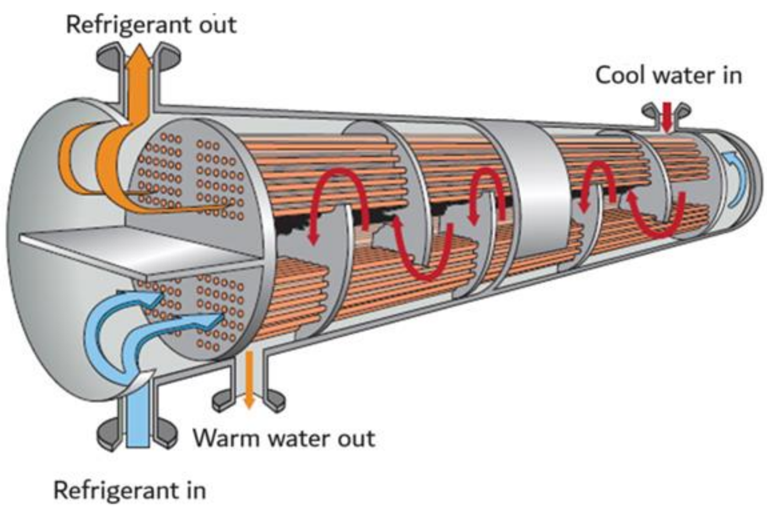


Figure 21. Shell & Tube Condenser

In a typical shell and tube condenser, the refrigerant is in the tubes, and the water is in the shell. The refrigerant flows through the tubes, where it condenses as it releases heat to the water circulating around the tubes in the shell. The condenser is designed to withstand the operating pressures of the system, including any potential pressure spikes. The specific operating pressure of a commercial chiller condenser can vary widely based on the refrigerant, chiller capacity, design, and operating conditions.

Refrigerant Flow Path

Refrigerant can flow in a single pass or multiple passes through the tubes, depending on the condenser design and the desired heat transfer performance. The choice depends on the desired balance between efficiency and pressure drop.

Single-Pass Design

Refrigerant flows through the tubes only once, from inlet to outlet. Typically used for small to medium-sized chillers.

a. Advantages: Simple design, lower cost, and lower pressure drop.
b. Disadvantages: Lower heat transfer efficiency compared to multi-pass.

Multi-Pass Design

Refrigerant flows through the tube's multiple times, with changes in direction. Typically used for larger chillers, where higher efficiency is crucial.

a. Advantages: Higher heat transfer efficiency, smaller overall size, and better temperature control.
b. Disadvantages: More complex design, higher pressure drop, and potential for fluid mixing.

Water Flow Path

The water flows through the shell, surrounding the tubes. The shell is typically designed with baffles to enhance water turbulence and improve heat transfer. Baffles also help to distribute the water flow evenly across the tube bundle.

Typically, water-cooled condensers are connected in a counterflow configuration. In this setup, the water that enters the condenser exchanges heat with the liquid refrigerant exiting the condenser first and then the water leaving the condenser contacts with the refrigerant entering the condenser. This allows the colder refrigerant to be in contact with the coldest water and the warmer refrigerant to be in contact with the warmer water. Consequently, it results in a higher mean temperature difference between the two fluids, leading to a higher rate of heat transfer.

Construction Features

a. Tube Arrangement: Tubes are typically arranged in a triangular or square pitch to maximize heat transfer.
b. Baffles: Baffles are used to direct water flow, prevent short-circuiting, and promote even heat transfer.
c. Support Plates: Support plates hold the tubes in place and maintain even spacing.
d. Insulation: The condenser is typically not insulated as heat within the condenser is unwanted and is just going to be rejected out to atmosphere.
e. Drainage: The condenser is designed to drain condensate and prevent waterlogging.
f. Venting: The condenser is vented to remove air and non-condensable gases.

Table 71. Shell & Tube Condenser Design Parameters

	Component	**Rules of Thumb**
	Material	Shell: Carbon Steel. Tubes: Copper, stainless steel (SS) or titanium. • Copper or copper-nickel alloy tubes is the most used material for its excellent thermal conductivity. • SS is often used in applications where water quality is a concern. Offers superior corrosion resistance. • Titanium is used for seawater or aggressive water environments.
	Tubes	Standard Design Features: Shell Diameter: 2-4 ft (varies with the capacity) Tubes: • Diameter: 3/4 – 1” • Pitch: 1.25 - 1.5x diameter • Length: 6 - 20 feet • Thickness: 16 - 20 gauge • Number: 50 – 200 (varies with the capacity)
	Baffles	Used to increase turbulence and improve heat transfer. Spacing is typically 20 - 30 inches.
	Condenser Water Inlet Temperature	70 - 85°F

	Component	Rules of Thumb
	Condenser Range	10 -12°F
	Condenser Approach	3 to 5°F
	Condenser Water Flowrate	3 GPM/Ton for 10°F range
	Design Pressure	150-300 psi

9.17 Minimum Performance Standards

The Minimum Energy Performance Standards for water-cooled condensers, as outlined in ASHRAE 90.1, establish efficiency requirements to reduce energy consumption in HVAC systems. These standards specify the minimum performance criteria for condenser water temperature, flow rates, and power consumption to optimize heat rejection and improve system efficiency. The standard requires:

a. Minimum water-cooled condenser efficiency: 135 kW/ton (10.6 COP) at full load
b. Minimum condenser water flow rate: 2.5 GPM/ton
c. Maximum condenser pressure drop: 10 psi
d. Requirements for condenser water temperature range (ΔT): 10°F to 20°F

Additionally, ASHRAE 90.1-2019 mandates:

a. Efficiency certifications from third-party organizations (e.g., AHRI)
b. Compliance with ISO 13256-1 for water-cooled condenser testing
c. Installation of flow meters and pressure sensors for condenser water systems

Table 72. ASHRAE 90.1 -2019, Minimum Performance Standards for Energy Efficiency

Chiller Type	Size (Tons)	Minimum Full-Load Efficiency (kW/ton)	Part-Load Efficiency (kW/ton)
Water-Cooled Screw Chillers	150-300	0.543	0.542
	301-600	0.496	0.494
	>600	0.438	0.434
Water-Cooled Centrifugal Chillers	All	0.542	0.525

Key Sections:

- Section 6.4.3: Water-Cooled Condensers

- Section 6.4.4: Condenser Water Systems
- Appendix G: Minimum Efficiency Requirements

Note: This table is only a summary of the ASHRAE 90.1-2019 requirements for water-cooled condenser chillers. It is also important to note that some states or local jurisdictions may have more stringent requirements than the ASHRAE 90.1 standard.

9.18 Chiller Control Sequence

The schematic below depicts the control sequence of a water-cooled chiller.

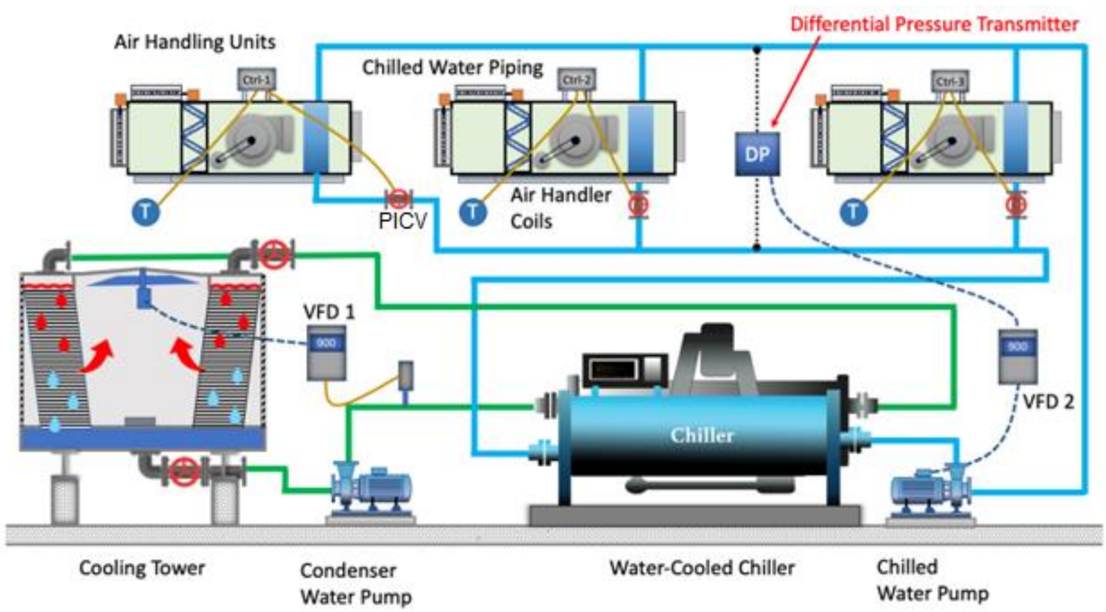


Figure 22. Water-Cooled Chiller Flow Diagram & Control Sequence

The chiller works as below:

a. Chiller transfers heat from space to chilled water through air handling units (AHUs).
b. Chilled water pumps circulate chilled water.
c. Variable frequency drive (VFD) adjusts pump speed to maintain optimal flow rates, pressure conditions, and temperature settings.
d. Pressure independent control valves (PICVs) maintain a constant pressure difference across coils or AHUs, valve, regardless of changes in system pressure. Here's what happens:
    - When the VFDs adjust the chilled water pumps' speed, the flow rate changes.
    - The PICV responds to this change by adjusting its opening to maintain the setpoint pressure difference.

  - This means the flow rate through the PICV will vary, but the pressure difference across the valve remains constant.

e. Piping differential pressure sensors ensure the system operates within a stable pressure range.

f. Condenser water temperature sensor monitors the temperature of cooling tower outlet (which is the entering cooling water to the condenser). If the water becomes too cold, the cooling tower fan will be set at a lower speed.

This control sequence optimizes efficiency, reduces energy consumption, and operating costs. Temperature settings are maintained through coordinated control of the VFD pumps, PICVs, and chillers.

9.19 Verification of Performance

AHRI codes provide standard rating conditions and procedures for testing and certifying HVACR equipment. These codes help ensure that equipment performance and efficiency can be accurately compared across different manufacturers and models.

Table 73. AHRI Codes applicable to water-cooled condenser chillers

	AHRI Codes	Description
	AHRI 550/590	Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle
	AHRI 570/590	Performance Rating of Water-Chilling Packages Using the Vapor Compression Cycle and Electric Motor Driven Compressors
	AHRI 580/590	Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Absorption Cycle

CHAPTER - 10: AIR COOLED CONDENSERS

Air-cooled chillers remove heat from water through a refrigeration cycle and then reject that heat to the atmosphere via an air-cooled condenser or condensing units. Before diving deeper into the subject, let's understand the terms air-cooled condensers and condensing units.

10.1 Key Terminology

Air-cooled refrigeration systems have four main parts: a compressor, evaporator, expansion device, and air-cooled condenser. These parts can be separate units or combined in one machine, with the compressor's location being the main difference.

Figure 23. Air-cooled Condenser vs. Condensing Unit

Air cooled condensers

Air-cooled condensers have a condenser coil and fan(s) in a casing, but no compressor(s) or evaporator. They are often used in split systems with a remote chiller that cools water, or directly with package units for DX cooling.

Air cooled condensing units

Air-cooled condensing units combine the compressor, condenser, and fan(s) in one enclosure, but don't have an evaporator. They are usually used in split systems with DX cooling coils. This is the most common setup. When the condensing unit also has a shell and tube evaporator, it's called an air-cooled chiller.

10.2 Air-Cooled Chiller Units

Air-cooled chillers are the best option where water is scarce or expensive. Listed below are some major pros and cons.

Advantages of Air-cooled Systems

Air-cooled chillers offer several advantages:

a. No water loop required: Ideal for areas with limited water availability.
b. Simpler installation and maintenance: Fewer components and no water treatment needs.
c. Space-saving: No mechanical room space needed, typically located outside the building.
d. Less equipment: Eliminates the need for cooling tower, cooling water pump(s), associated piping, condenser water treatment.
e. Environmental benefits: Zero water usage, no discharge.
f. Reduced health risks: Not prone to Legionella growth, ensuring a safer operation.

Limitations

Air-cooled condensers have some limitations:

a. Lower cooling capacity: Operates at a higher condensing temperature and produce15-20% less cooling compared to water-cooled systems.
b. Higher energy consumption: 1.1-1.2 kW/TR vs 0.6-0.8 kW/TR for water-cooled systems.
c. Noise considerations: Propeller fan(s) can generate significant noise, requiring special attention in certain applications (e.g., residential areas).

10.3 Main Components of Air-Cooled System

The main components of air-cooled chillers units include:

a. Compressor: The chiller's essential component is the compressor, which compresses the refrigerant and elevates its temperature. Positive displacement compressors, including scroll and screw types, are the primary types used in air-cooled condenser systems. Centrifugal compressors are generally not used in air-cooled configuration.
b. Condenser: The condenser facilitates the transfer of heat from the refrigerant to the ambient air, and it comprises fins and tubes that allows the refrigerant to release heat to the surrounding air.

c. Expansion valve: The expansion valve is responsible for regulating the flow of refrigerant into the evaporator, where it absorbs heat from the water or space being cooled.
d. Fans: Fans are used to circulate air over the condenser. They help to remove heat from the refrigerant and transfer it to the surrounding air.
e. Control system: The control system is responsible for monitoring and controlling the operation of the refrigeration machine. It may include sensors, thermostats, and other devices to ensure that the refrigeration machine is operating efficiently and effectively.
f. Refrigerant: The refrigerant absorbs heat from either the water or air in the area being cooled. Air-cooled chillers commonly employ refrigerants such as R-123, R 407 and R-410a. R-132a is not commonly used as a refrigerant in air-cooled condenser chillers.

Table 74. Estimating Chiller Capacity – Rules of Thumb

	Application	**Tonnage**
	Low load (apartments, dormitories etc.)	1 ton per 300 square feet
	Moderate load (offices, restaurants, studios, mercantile etc.)	1 ton per 200 square feet
	Heavy load (data centers, server rooms, high occupancy theaters, auditoriums etc.)	1 ton per 100 square feet

For conceptual purposes, the capacity of chiller should be worked on moderate load option of <u>1 ton per 200 square foot</u> of occupied floor area.

These are just the approximations. The actual capacity should be worked out by cooling load analysis, which largely depend on the geographical location of the building, ambient conditions, building construction and use.

Table 75. Factors Affecting Air-cooled Condenser Sizing and Performance

	Parameters	**Rules of Thumb**
	Nominal Capacity of Condensing Unit	15000 BTU/hr. per ton of refrigeration. Total Heat Rejection (THR) is roughly 15 to 25% higher than the nominal rating of the chiller.
	Effect of Elevation	Higher elevations reduce air density, affecting heat transfer. Increase condenser size by 2 to 3% for every 1000 feet elevation gain.

	Parameters	Rules of Thumb
	Condenser Derating	For every 2°F increase in outdoor temperature above the design temperature (usually 95°F), the unit's capacity is reduced by 1-2%. Some manufacturers recommend derating the unit's capacity by 10-20% for high ambient temperatures (above 104°F).
	Condensing Temperature	The typical condensing temperature for an air-cooled chiller is 120°F to 140°F as compared to 105°F in a comparable water condensed chiller.
	Condenser Approach	The air-cooled condenser approach is typically around 18-27°F above the ambient air temperature. This means that if the ambient air temperature is 95°F, the refrigerant leaving the condenser should be around 113 - 122°F. A higher approach temperature indicates that the condenser is not transferring heat as effectively as it should. This could be due to several factors, such as fouling on the heat exchanger surfaces, insufficient airflow, or an oversized condenser for the given application.
	Refrigerant Pressure	150-300 psi for most applications.
	Energy Consumption	1.1 to 1.3 KW per ton of refrigeration. Air-cooled condenser chillers are less efficient compared to water-cooled chillers.
	Common Refrigerant	R-123 = Good thermodynamic properties and a high cooling capacity. R-132a = Generally, not used in air-cooled chillers. R-410a = High-pressure refrigerant commonly used in newer chiller designs. Less energy-efficient than R-123 in certain operating conditions.
	Refrigerant Charge	2 to 3 lbs. per ton of refrigeration.
	Environmental Impact	Zero water discharge. Choose chillers with a high coefficient of performance (COP) or low KW/TR. Consider refrigerant type with zero ozone depletion potential (ODP) and low global warming potential (GWP).
	Cost	Around $1500/ton below 50-tons chiller capacity.

	Parameters	Rules of Thumb
		Around $1000/ton to $1200/ton between 50 to 300-tons chiller capacity.

Table 76. Compressor Options for Air-Cooled Condensers

The compressors provide the driving force that moves the refrigerant around the system. Opting for high-efficiency chiller compressors can help reduce energy consumption and improve overall system efficiency.

	Type of Compressor	Rules of Thumb
	Screw Compressors	Positive displacement machines, suitable for air-cooled systems in 5 - 80-ton capacity.
	Scroll Compressors	Positive displacement machines, suitable for air-cooled systems in 20 – 500-ton capacity.
	Centrifugal Compressors	Centrifugal chillers are generally not utilized in air-cooled options. Centrifugal compressors are dynamic machines that operate at higher speeds while using low pressure refrigerant. These factors make it difficult to reject heat to the air, leading to reduced performance and efficiency. Centrifugal chillers are better suited for water-cooled applications.

Table 77. Condenser Coil Construction

Air cooled condensers consist of tubes made of copper and aluminium fins that serve in the transfer of heat with the passing air. Listed below are some key characteristics:

	Parameters	Typical Range - Rules of Thumb
	Coil Surface Area	1 to 1.5 sq. ft/ton of refrigeration.
	Coil Tubes	3/8-inch diameter, fewer rows for minimal air resistance.
	Coil Depth	2 - 4 rows deep for optimal heat transfer.
	Fin Spacing	8 - 14 fins per inch (FPI) for good heat transfer efficiency.
	Coil Coating	Protective layer (e.g., Heresite treatment on Aluminium fins) for corrosion resistance.

Table 78. Condenser Fans

The fans move air across the condenser. Condenser fans are often propeller fans directly driven, vertical or horizontally air discharge arrangement with integral current and thermal overload protection. Listed below are some key characteristics:

	Characteristics	Typical Range – Rules of Thumb
	Airflow	600 to 900 CFM of air per ton of refrigeration
	Air velocity	500 and 600 FPM across condenser coil surface.
	Static pressure	0.2 to 0.5-inch water gauge static pressure
	Motor construction	NEMA MG 1, general purpose, continuous duty, Design B.
	Fan power consumption	0.1 to 0.2 HP/ton of cooling

10.4 Head Pressure Control

Head pressure is the pressure created by the refrigerant leaving the compressor and entering the condenser. It is important to maintain the correct head pressure in the chiller system, as too high or too low a pressure can cause performance issues, reduce the chiller's lifespan, and increase energy consumption. Airflow rate through fan needs to be adjusted according to the chiller's demand and to achieve optimum head pressure control.

Table 79. Controlling Condenser Head pressure

	Strategy	Rules of Thumb
	Fan Speed	Run condenser fans at maximum speed during high ambient temperatures.
	Coil Maintenance	Keep air-cooled condenser coils clean and free from debris.
	Refrigerant Charge	Regularly check refrigerant levels to avoid over/undercharging.

Table 80. Fan Control Strategy

Three type of fan control strategies are used at low ambient temperatures. The options are a) on/off (single speed fans), b) two-speed fans or c) variable speed fans.

	Option	Rules of Thumb
	Single Speed Fan	Simple ON/OFF control, less efficient.
	2-Speed Fan	Simple control, better energy performance than single speed, requires sequencing.
	Variable Speed Fan (VFD)	Regulates fan speed for optimal head pressure, lowest energy consumption, required by ASHRAE 90.1 for fans > 5 hp.

10.5 Physical Layout

The size of the air-cooled condenser coil (without compressor) and air-cooled condensing chiller (with compressor) should be considered to plan for the space allocation including clearances for air circulation, maintenance, and servicing. The size and dimensions can vary depending on the manufacturer, model, and specific configuration.

Table 81. Approximate Size of Air-cooled Condensers

	Parameters	Rules of Thumb
	Size of Condenser Coil (without compressor)	1-1.5 sq. ft. of surface area per ton of refrigeration (TR)
	Size of Condensing Unit (with compressor)	Footprint of approximately 2 times the nominal rating in square feet. Typical Dimensions (L x W x H): • 100 TR = 18' x 8' x 8' to 20' x 10' x 10' • 200 TR = 25' x 10' x 10' to 30' x 12' x 12' • 300 TR = 30' x 12' x 12' to 35' x 15' x 15' • 500 TR = 35' x 15' x 15' to 40' x 20' x 20'
	Floor Loading	Approximately 40 - 70 pounds per ton of refrigeration
	Noise Level	Less than 70 dBA at 10 ft (3 m) distance

10.6 Air-Cooled Units – Layout and Separation Criteria

Air-cooled condensing units configured as split arrangement with the evaporators should be installed with shortest possible refrigerant piping to avoid pressure losses in the pipework and prevent any risk of stagnant oil in the piping that may damage the compressor.

Air-cooled condensers should be installed in such a way that air can circulate freely without being recirculated. Adequate space should be provided around the chiller to allow for maintenance and servicing.

The separation distance between evaporator and condensing units should be as short as possible. Recommended guidelines are:

- < 150 ft. for chillers and variable refrigerant volume (VRV) units.
- <50 ft. for small units less than 5 tons of refrigeration (refer to manufacturer's guidelines).

Table 82. Separation from Walls or Obstructions

	Parameters	**Rules of Thumb**
	General Installation	Ensure free air circulation without recirculation.
	Clearance from Walls/Obstructions	Minimum 3 feet or at least one unit width (W).
	Clearance in Front of Control Panel/Access Doors	Minimum 5 feet.
	Installation in Enclosed Areas	Install as described for pit units.

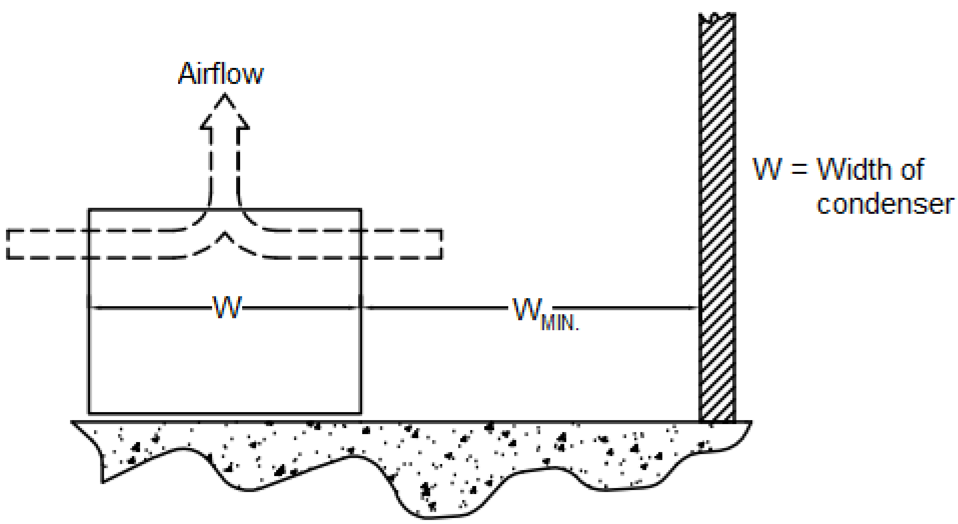


Figure 24. Air-Cooled Condenser – Clearances from Wall or Obstructions

Table 83. Separation Distance between Multiple Units

	Parameters	Rules of Thumb
	Distance from Adjacent Units	Maintain a minimum distance of 2 times the height or width of the unit (whichever is greater) to prevent hot air recirculation.
	End-to-End Placement	Minimum distance between units is 4 feet.

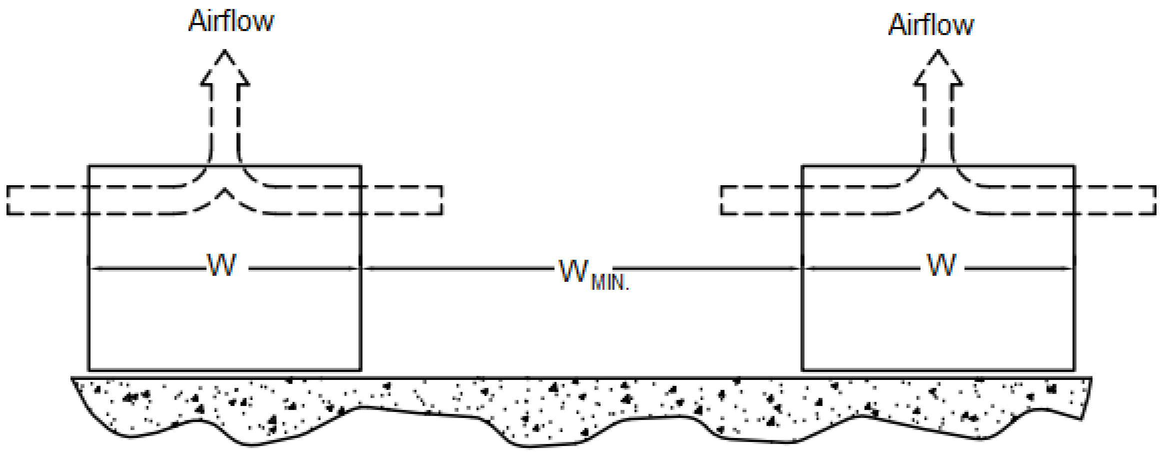


Figure 25. Air-Cooled Condensers – Clearances for Multiple Units

Table 84. Condensers Located in Pits

	Parameters	Rules of Thumb
	Top Level	The unit's top should be level with the top of the pit.
	Side Clearance	Maintain a side distance of at least twice the unit width (2W).
	Discharge Cones/Stacks	Use discharge cones or stacks to raise air discharge to the top of the pit if the unit's top is not level with the pit.

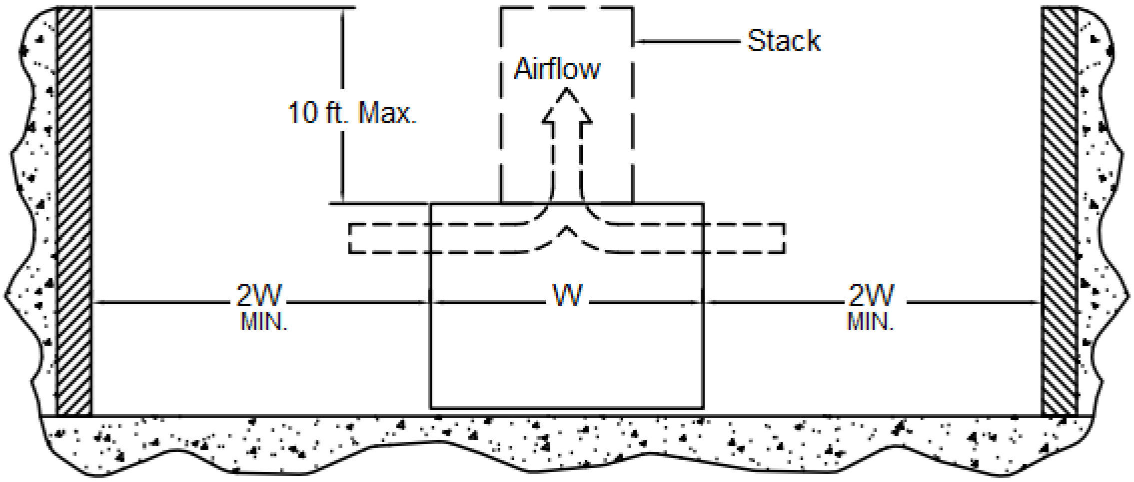


Figure 26. Clearances for Air-Cooled Condensers Located in Pits

Table 85. Decorative Fences or Louvers

For aesthetic reasons, the chillers are often placed behind architectural screens or fences, which can restrict the flow of ambient air to these chillers. Here's the rule of thumb for fencing around units:

	Parameters	**Rules of Thumb**
👍	Fences	Fences must have 50% free area and a 1-foot undercut.
👍	Clearance	Maintain a minimum clearance of "W" (unit width) around the unit.
👍	Fence Height	Fences must not exceed the top of the unit.
👍	Alternative	If these requirements are not met, install the unit as indicated for "Units in pits."

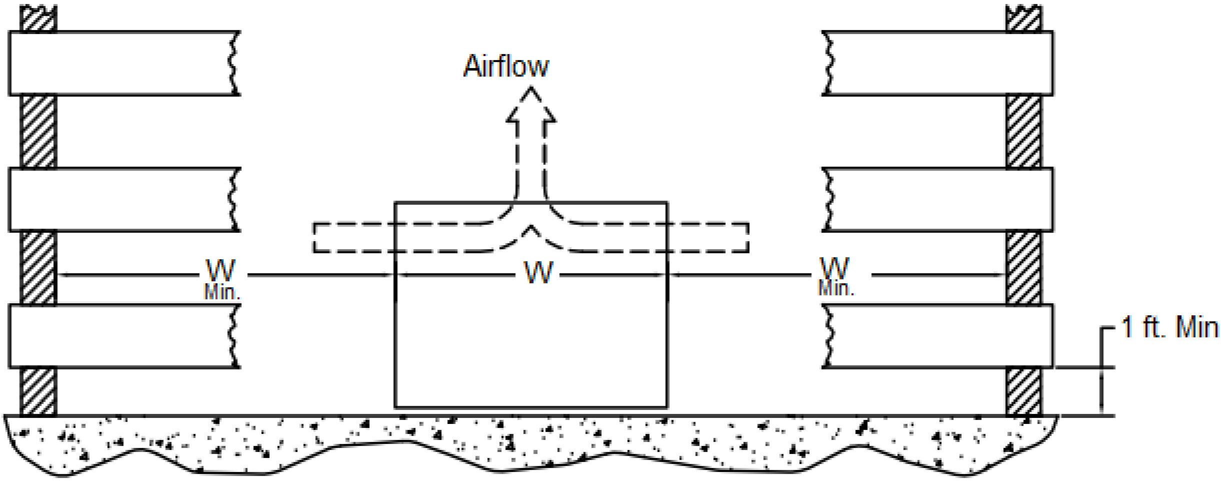


Figure 27. Air-Cooled Condensers – Clearnance for Fence Enclosures

10.7 Standard Installation for Split Systems

The condensing unit must be installed in an open environment, allowing fresh air to flow to the condenser. Therefore, avoid enclosed areas, close to walls, heat sources, or other systems.

	Condenser Location	Considerations
	Below Compressor	Size liquid line to prevent flashing due to pressure drop and elevation change; may need additional sub-cooling.
	Above Compressor	Prevent liquid refrigerant and oil from flowing back into the compressor; install hot gas line to the floor before rising and use a check valve upstream of the condenser.

10.8 Design Considerations for Refrigerant Lines

The proper design of discharge lines involves two objectives:

	Objective	Reason
	Minimize Pressure Loss	Minimize refrigerant pressure loss to reduce compressor horsepower. Reduce compressor horsepower/ton
	Maintain Sufficient Gas Velocity	To ensure oil is carried to condenser coil and receiver at all loading conditions.

The design of the discharge line is very critical, especially, if the condenser is located at a higher elevation, as commonly encountered when the condenser is on a roof and the compressor and receiver are on grade level or in a basement equipment room.

The following recommendations should be adhered to for refrigerant R-404A/R-507 at 105°F condensing temperatures. Refer to manufacturer's guidelines for other refrigerants and correction factors.

Line Size, Type L Copper (OD)	**Discharge Line**			**Drain Line**
	R-404A/R-507 Sat. Suction Temp (°F)			**R-404A/R-507**
	-40	0	40	
1/2	0.56	0.63	0.7	1.5
5/8	1.0	1.2	1.3	2.3
7/8	2.7	3.1	3.4	4.9
1-1/8	5.5	6.3	7.0	8.3
1-3/8	9.6	10.9	12.1	12.6
1-5/8	15.2	17.2	19.1	17.9
2-1/8	31.4	35.6	39.5	31.1
2-5/8	55.3	62.8	69.5	48.0
3-1/8	87.9	99.8	110.5	68.4
3-5/8	130.5	148.1	164.0	92.6
4-1/8	183.7	208.4	230.9	120.3

Source: ASHRAE Refrigeration Handbook

10.9 Discharge Line Arrangement

If the line is sized for full load conditions, the gas velocity may be too low at reduced loads to carry oil up through the line and condenser coil. Reducing the discharge line size would increase gas velocity at reduced loads but would cause excessive refrigerant pressure drop at full load. To overcome this, one of two solutions can be implemented.

a. Proper sizing of discharge line and installing an oil separator at the bottom of the trap. (refer figure below).
b. Include a double riser discharge line (refer figure below).

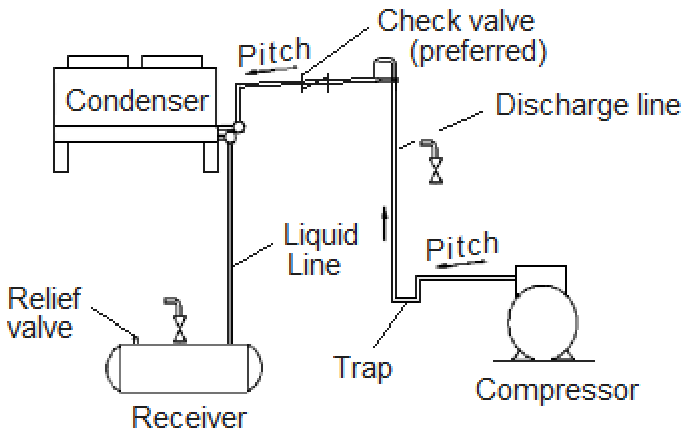


Figure 28. Arrangement with Oil Separator

10.10 Arrangement with Double Riser

Line "A" should be sized to carry the oil at minimum load conditions and the line "B" should be sized so that at the full load conditions both lines would have sufficient flow velocity to carry the oil to the condenser.

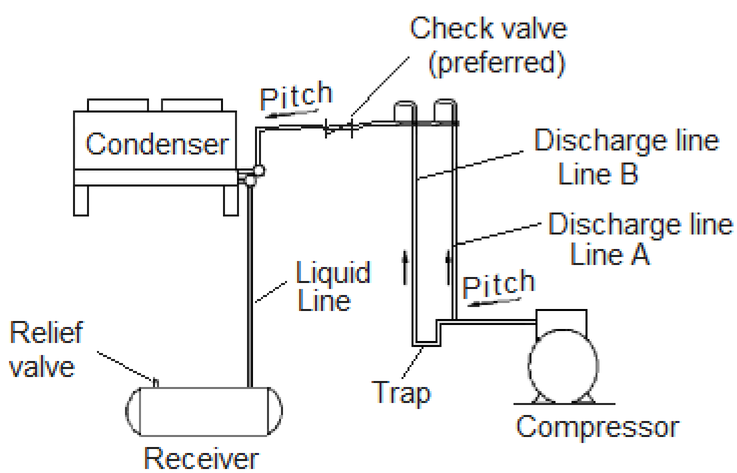


Figure 29. Condenser Arrangement with Double Riser

For more complete information, refer to the ASHRAE Handbook on Systems.

10.11 Minimum Performance Requirements

Performance Requirements for Evaporative and Air-cooled Condensers—Minimum Efficiency Requirements per ASHRAE 90.1, Table 6.8.1-7

Table 86. ASHRAE 90.1 – Min. Performance & Testing Requirements

Equipment Type	Test Fluid	Rated Conditions	Performance Required	Test Procedure
Propeller/Axial Fan Evaporative Condenser	R-507A	165°F (Entering Gas Temp.) /105°F (Condensing Temp.)/75°F (WBT)	≥157,000 Btu/h-hp	CTI ATC-106
Propeller/Axial Fan Evaporative Condenser	Ammonia	140°F (Entering Gas Temp.) /96.3°F (Condensing Temp.)/75°F (WBT)	≥134,000 Btu/h-hp	CTI ATC-106
Centrifugal Fan Evaporative Condenser	R-507A	165°F (Entering Gas Temp.) /105°F (Condensing Temp.)/75°F (WBT)	≥135,000 Btu/h-hp	CTI ATC-106
Centrifugal Fan Evaporative Condenser	Ammonia	140°F (Entering Gas Temp.) /96.3°F (Condensing Temp.)/75°F (WBT)	≥110,000 Btu/h-hp	CTI ATC-106
Air Cooled Condenser	All	125°F (Condensing Temp.)/190°F (Entering Gas Temp.)/15°F (Subcooling)/95°F (DBT)	≥176,000 Btu/h-hp	AHRI 460

10.12 Air-Cooled Chiller Control Sequence

The schematic below depicts the control sequence of an air-cooled chiller.

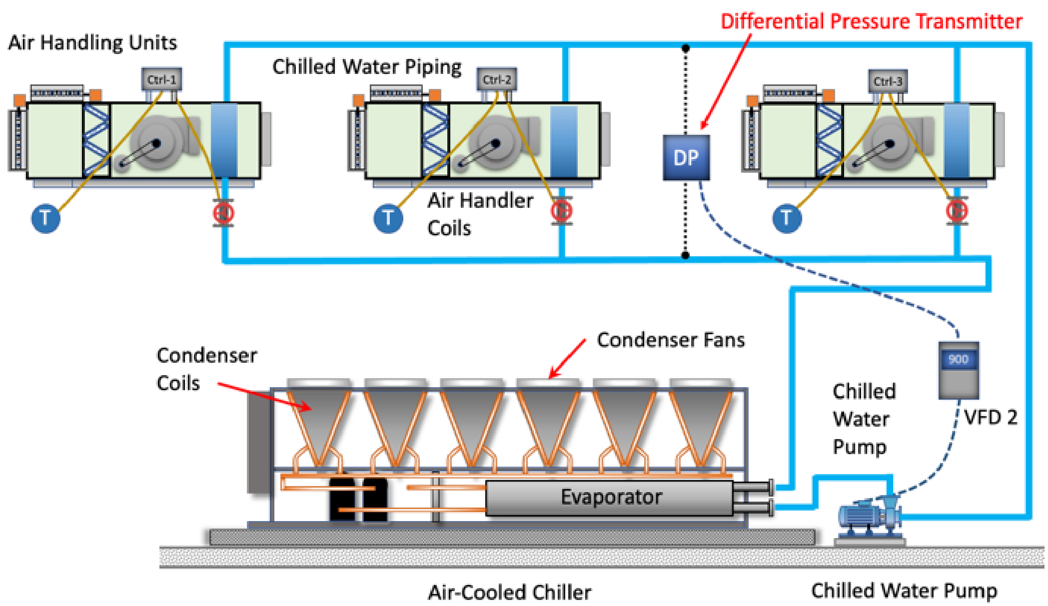


Figure 30. Air-Cooled Chiller Flow Diagramd & Controls Sequence

Chilled Water Side:

a. Pressure Independent Control Valves (PICVs) dynamically balance water network in response to zone demands.
b. Variable speed chilled water pumps controlled by variable frequency drive (VFD) maintain required flow via DPS sensors.

Condenser Side:

a. Fan staging responds to chiller load and ambient temperature

Result:

a. Efficient chiller operation
b. Reduced energy consumption
c. Lower operating costs

Table 87. Verification of Performance

	Unit Size	Standard
	< 135,000 Btu/h	AHRI 210/240
	≥ 135,000 Btu/h	AHRI 340/360
	Sound Power Level	AHRI 270

Course Summary

This course provided an extensive understanding of essential principles and practical tips for designing, operating, and maintaining heat rejection equipment in HVAC applications, including cooling towers, water-cooled condensers, and air-cooled condensers.

The course delved into the different types of cooling tower and condenser technologies, including natural draft, mechanical draft, induced draft, and forced draft systems, and how their performance and efficiency are affected by factors such as temperature, humidity, airflow rate, and water quality. Additionally, the course covered the key design considerations for selecting the appropriate cooling tower and condensers for a specific application, such as location, capacity, noise, and environmental factors.

The course also emphasized the cooling water issues and importance of proper water treatment to prevent corrosion, scaling, and biological fouling in cooling systems. Furthermore, the course provided practical tips and rules of thumbs for design sizing and selection of heat rejection systems in HVAC applications. Readers learned about the importance of considering factors such as load calculations, space requirements, and system efficiency when selecting a cooling system for a specific HVAC application.

Important Note: This course module (#10) focuses on heat rejection systems. In addition, there are two more modules (#8 and #9) that provide an in-depth look at the type of chiller and chilled water distribution, offering a comprehensive understanding of the entire chilled water system design process. Together, these modules will equip you with comprehensive knowledge of chilled water systems, crucial for designing and optimizing your building's cooling infrastructure.

References

1. ASHRAE Handbook: HVAC Applications, Chapter 37 - Cooling Towers.
2. ASHRAE Handbook: HVAC Systems and Equipment, Chapter 26 - Water Treatment.
3. Cooling Technology Institute (CTI) Standard 201: Acceptance Test Code for Water-Cooling Towers.
4. EVAPCO, Inc. "Evaporative Cooling Towers: Selection, Application and Performance." White Paper.
5. SPX Cooling Technologies, Inc. "Cooling Tower Fundamentals: The Basis for Performance and Reliability."
6. Baltimore Aircoil Company. "Cooling Tower Fundamentals."
7. Carrier Corporation. "Water-Cooled Liquid Chillers Technical Development Program."
8. Daikin Applied. "Pathfinder Air-Cooled Screw Chiller."
9. McQuay International. "Air-Cooled Screw Chillers AGS Series."
10. Marley Engineered Products. "Cooling Tower Fundamentals."
11. Delta Cooling Towers, Inc. "Cooling Tower Sizing Guide."
12. Nalco Water. "Cooling Water Treatment Fundamentals."
13. GE Water & Process Technologies. "Cooling Water Treatment Fundamentals."

ANNEXURE - 1: KEY RULES OF THUMB

Heat Dissipation Equipment

	Chiller Types	Rules of Thumb
👍	Water-Cooled Chillers	Cooling towers are required for dissipating heat.
👍	Air-Cooled Chillers	Utilize finned tube condenser coil. No water, no cooling tower, no condenser water pumps and water treatment.

Understanding Cooling Tower Parameters

	Parameters	Rules of Thumb
👍	Chiller Heat Load	1 cooling tower ton = 15,000 BTU/hr.
👍	Cooling Tower Capacity	Size 15-25% larger than chiller capacity
👍	Water Flow Rate	3 GPM/ton of refrigeration for a 10°F range. Higher range will require lesser flow rate.
👍	Wet Bulb Temperature (WBT)	Higher WBT requires larger cooling tower. Use a wet bulb temperature that represents the local climate conditions, often in the range of 75°F to 85°F.
👍	Cooling Range	The difference between the hot water entering the cooling tower and the cooled water exiting the tower. Cooling tower range follows the condenser design range.
👍	Approach Temperature	The difference between the cooled water temperature and the wet bulb temperature of the entering air. Aim for an approach temperature of 5°F to 7°F.
👍	Lowest Achievable Water Temperature	Ambient WBT + Approach
👍	Tower Size	Size the cooling tower to handle 3 GPM/ton of cooling load (when designed for 10°F range).
👍	Tower Size (Fill Area)	For every ton of cooling, allocate approximately 1.5 square feet of tower fill area.
👍	Heat Load	The cooling tower must be capable of rejecting approximately 15,000 BTU/hr. per ton of refrigeration.
👍	Air Flow Rate	Provide 1,000 to 1,200 cubic feet per minute (CFM) of air per ton of cooling load.
👍	Fan Power	Allocate 0.1 to 0.2 horsepower (HP) per ton of cooling load for the cooling tower fans.
👍	Evaporation Loss	≈ 1% of water circulation for 10°F cooling range.

	Parameters	**Rules of Thumb**
👍	Typical Drift Loss	≈ 0.1 to 0.3% of water circulation
👍	Typical Blowdown Loss	≈ 0.2 to 0.3% of water circulation
👍	Total Water Loss	≈ 1.2 to 1.5% of total water circulation rate for induced draft towers.
👍	Make-Up Water	≈ 1.5 to 2.0 GPM per ton of cooling load, considering evaporation, drift, and blowdown losses.
👍	Piping Size	≈ 2.5-inch piping for up to 100 tons, 4-inch piping for 200 to 300 tons, and 6-inch piping for 600 tons or more.
👍	Water Treatment	Regular water treatment is essential to prevent scaling, corrosion, and biological growth; monitor water quality regularly.

Cooling Tower - Design and Performance

	Parameters	**Rules of Thumb**
👍	Classification	Cooling towers are classified by how they remove heat into three classifications: Wet type, Dry type and Hybrid type.
👍	Wet Type Cooling Towers	Utilize the evaporation of water to dissipate heat, making them highly efficient but susceptible to water loss and quality issues.
👍	Dry Type Cooling Towers	Employ a heat exchanger to cool water without direct exposure to the atmosphere, thus avoiding water loss and contamination but generally less efficient than wet types.
👍	Hybrid Cooling Towers	Combine elements of both wet and dry cooling to optimize efficiency and minimize water consumption and quality issues.
👍	Wet Evaporative Cooling Towers	These are most common for HVAC applications. These come in 4 designs: • Natural Draft (relies on buoyancy) • Mechanical Draft (uses fans) • Induced Draft (fans at the top pull air) • Forced Draft (fans at the base push air)
👍	Capacity	Maximum cooling load + 15 to 25% heat of compression. 1 cooling tower ton = 15,000 BTU/hr. @ 1.25 heat rejection of compressor.
👍	Cooling Tower Sizing	The cooling tower size depends on a) Heat load, b) ambient wet bulb temperature (WBT), c) approach and d) range.

	Heat Load	Amount of heat to be removed and directly influence the size of the tower. It is dependent on the cooling water flow rate and the desired temperature range. Heat load (BTU/hr.) = 500 x Flow rate (GPM) x Temp. Range (°F)
	Wet Bulb Temperature (WBT)	Cooling tower size varies inversely with WBT. A higher wet bulb temperature means higher humidity levels that will reduce the rate of evaporation and may require a larger cooling tower.
	Approach	Difference between cold water leaving tower and air WBT. Ideal: 5 to 7°F. A smaller approach means cooler water but bigger and costlier tower. Cooling tower performance is defined by approach, not range.
	Lowest Achievable Water Temperature	Ambient WBT + Approach.
	Range	Difference between the hot water entering the cooling tower and the cooled water exiting the tower. Higher range = lower flow rate, reduced pump energy but increased chiller kW consumption.
	Water flow rate	≈3 GPM/ton for 10°F range, 2.5 GPM/ton for 12°F range.

Cooling Tower - Energy and Efficiency

	Parameters	**Rules of Thumb**
	Energy Requirement	1,000 BTUs to evaporate 1 pound of water.
	Evaporation Rate	≈ 0.1% of water evaporates per 1°F cooling range
	Temperature Drop	≈1°F for every pound of water evaporated.
	Thermal efficiency	≈75% to 80% is considered a good target.
	Fan Sizing	600 to 900 CFM per ton with 1-2 in WG static pressure.
	Fan speed	200-400 RPM.
	Fan Motor Power	0.2 Watts per CFM per 1 inch-WG static pressure.

👍	Pump Sizing	3 GPM/TR for 10°F Range and 60 feet head (Typical design)
👍	Pump Power	20 Watts per GPM @ 60 feet head, 70% pump efficiency, 85% motor efficiency.
👍	Energy Efficiency	Use VFDs to allow fans to operate at variable speeds, reducing energy consumption during low cooling demand.

Cooling Tower - Construction, Materials and Key Components

	Parameters	Rules of Thumb
👍	Field-Erected Cooling Towers	Suitable for projects over 5,000 TR. Consider life cycle cost analysis.
👍	Factory-Assembled Cooling Towers	Ideal for capacities up to 2,500 TR. Use multiple units for higher capacities.
👍	Cooling Tower Cells	Available capacity: 5-100 TR, 1 cell 100-500 TR, 2-4 cells 500-1000 TR or more, 4-6 cells
👍	Material Selection	Galvanized iron (GI) for cost-effective solutions; stainless steel (SS) for corrosive environments; fiberglass/HDPE for weight savings.
👍	Life Expectancy	GI: 10-15 years, SS: 15-20 years, Fiberglass/HDPE: 15-25 years.
👍	Structural Components	Cold-Water Basin, Tower Framework, Water Distribution System, Fan Deck, Fan Cylinders, Fill, Drift Eliminators, Casing, Louvers, Access and Safety Components.
👍	Mechanical Components	Fans, Drive Shafts, Gearbox, Belt Drives, Safety Guard, Safety Equipment.
👍	Electrical Components	Motors, Motor Controls, VFDs, Lighting, Wiring Systems, Control Instruments.
👍	Ancillary Equipment	Supporting Structure, Access Walkways/Ladders, Piping, Utilities, Tower Water Pump.
👍	Tower Size (Fill Area)	For every ton of cooling, allocate approximately 1.5 square feet of tower fill area.
👍	Piping	Use 2.5-inch piping for up to 100 tons, 4-inch piping for 200 to 300 tons, and 6-inch piping for 600 tons or more. Fluid velocity 6 feet per second (fps).
👍	Vendors	Some options include Baltimore Aircoil, Delta, Evapco, Marley and SPX Cooling Technologies.

Cooling Tower - Safety and Industry Standards

	Parameters	Rules of Thumb
👍	Safety Components	Include safety guards and fall protection systems
👍	Industry Standard Metrics	95°F entering water, 85°F leaving water, 78°F WBT, 10°F range, 7°F approach.

Cooling Tower - Costs Per Ton

	Type of Cooling Tower	Rules of Thumb
👍	Induced Draft	$120 - $200 per ton
👍	Forced Draft	$100 - $180 per ton
👍	Closed-Circuit	2.5 to 5 times the cost of open circuit towers

Counterflow vs. Crossflow Cooling Towers

Counter-flow towers: A counterflow type requires less space and provides easier access to the internal components and maintenance.

Crossflow towers: A crossflow tower tends to be quieter and is less prone to scaling and is more suitable for areas with hard water.

	Parameters	Counterflow	Crossflow
👍	Space	Requires less ground space	Needs more space
👍	Airflow	Higher air-water contact time	Lower air-water contact time
👍	Energy & Water	Higher pumping head, lower fan power	Lower pumping head, higher fan power
👍	Recirculation	Less recirculation	More recirculation
👍	Fill Pack	Splash/film fill	Splash fill
👍	Hot Water Basin	No hot water basin	Hot water basin present
👍	Power & Pumping	Higher pumping head but lower fan power	Lower pumping head but higher fan power
👍	Inspection & Access	Limited access	Easier access

	Parameters	**Counterflow**	**Crossflow**
	Noise	Higher noise due to falling water	Lower noise levels
	Costs	Higher initial cost	Lower initial cost

Cooling Tower Layout

	Parameters	**Rules of Thumb**
	Ground Space	Adequate space for airflow and maintenance. Reserve 2-3 square feet per TR of cooling tower capacity. Fully paved area around the tower with a perimeter fence for security and protection from debris.
	Tower Height	Determined by pressure drop required to move air through the tower.
	Layout	Minimize air recirculation and short-circuiting
	Clearance	Maintain at least one tower height distance from obstructions.
	Proximity	Locate near the cooling load (within 100 feet) to reduce piping costs and heat loss.
	Air Velocity	Less than 600 FPM on 50% louvers opening.
	Noise	Target 65 dBA or lower at a distance of 10 feet from the fan.
	Cooling Tower Separation	At least 15 -25 feet away from the building ventilation air intakes.
	Regulations	Adhere to local building, environmental, and water use regulations.

Cooling Tower Water Losses

	Parameters	**Rules of Thumb**
	Total Water Loss	1.3 to 1.5% of total water circulation rate. Average value ≈ 4 GPM per 100 tons of cooling.
	Evaporation Loss	1% of water circulation per 10°F cooling range. Average value ≈ 3 GPM per 100 tons of cooling.
	Evaporation Calculation	Evaporation (GPM) = 0.01 x Water circulation (GPM) for 10°F temperature range.
	Drift Loss	0.1 to 0.3% of circulating water, controlled by baffles and drift eliminators.
	Drift Loss Formula	Drift = %Windage x Recirculation rate

	Parameters	Rules of Thumb
	Blowdown Loss	0.2 to 0.3% of water circulation, used to control dissolved solids.
	Cycles of Concentration (COC)	Recommended range is typically between 3 and 5.

Water-Cooled Condensers

	Parameters	Rules of Thumb
	Types	Shell and Tube - Cylindrical shell with tube bundle Plate Heat Exchanger - Series of metal plates Spiral Coil - Spiral coil enclosed in a welded shell Tube-in-Tube - Inner tube with refrigerant, outer tube with water.
	Condenser Load and Capacity	Sized approximately 25% higher than chiller nominal rating. 1 ton of condenser load ≈ 15,000 Btu/hr.
	Condenser Water Temperature	Condenser entering water temperature (EWT) = 85°F and Condenser leaving air temperature (LWT) = 95°F (AHRI Standard 550/590).
	Temperature Range	≈10°F difference between LWT and EWT (Typical Design).
	Condenser Water Flowrate	≈3 GPM/ton for 10°F range, 2.5 GPM/ton for 12°F range.
	Condensing Temperature	Optimal: 95-100°F, Typical: 100-110°F, Max: 115-120°F.
	Condenser Approach	3°F to 5°F (new), 5°F to 7°F (old).
	Pressure Drop	10 to 30 feet of water.
	Heat Transfer Coefficient (U-value)	Water-cooled: 150-300 Btu/h·ft²·°F.
	Fouling Factor	0.00025 Btu/h·ft²·°F.
	Refrigerant Type	Zero ODP, Low GWP (GWP < 1,000 for medium-term, GWP < 100 for long-term).
	Refrigerant Charge	1 to 1.5 lbs./ton.
	Water Quality	Maintain to prevent scaling, corrosion, and fouling.

	Parameters	Rules of Thumb
	Water-cooled Chiller Space Requirements	A typical water-cooled chiller has the following dimensions for its footprint: • A 200-ton chiller is typically around 10 to 14 feet long, 4 to 5 feet wide, and 6 to 8 feet tall. • A 300-to-500-ton chiller is usually around 12 to 16 feet long, 5 to 6 feet wide, and 7 to 8 feet tall. • A 600-to-1000-ton chiller is usually around 18 to 22 feet long, 6 to 7 feet wide, and 8 to 10 feet tall.
	Water-cooled Chiller Availability	Scroll type: 10 to 80 tons; Screw type: 40 to 300 tons; Centrifugal type: 150 to 4000+ tons.

Air-Cooled Condenser and Condensing Unit

	Parameters	Rules of Thumb
	Type	Air-cooled condenser with copper tubes, aluminum fins, and fan(s); Condensing unit includes condenser and compressor.
	Nominal Capacity	15,000 BTU/hr. per ton for 25% heat rejection by compressor and motor inefficiencies.
	Climatic Conditions	Effective operation below 95°F ambient temperature.
	Condenser Derating	Capacity reduces by 1-2% per 2°F increase above 95°F. Increase size.
	Power & Outdoor Temp Impact	Power increases by 1-2% per 1°F rise above 95°F.
	Elevation Impact	Capacity reduces by 2-3% per 1,000 feet elevation. Increase size.
	Condensing Temperature	120°F to 140°F for air-cooled systems, compared to 105°F for water-cooled condensers.
	Airflow Rate	600 to 900 CFM per ton.
	Specific Energy Consumption	1.1-1.3 kW/TR (compressors: 1.0-1.2 kW/ton, fans: 0.1-0.2 HP/ton).
	Number of Fans	One fan for up to 10 TR heat dissipation.
	Fan Speed Control	Single-speed, 2-speed, or variable speed for efficiency.
	Air Velocity	500-600 FPM for heat transfer.
	Condenser Coil Face Area	1 to 1.5 sq. ft. per ton.

	Parameters	Rules of Thumb
	Noise Level	Below 65 dB at 10 feet.
	Clearance from Walls	Minimum 3 feet or unit width.
	Clearance in Front of Panel	Minimum 5 feet.
	Distance Between Two Condenser Units	2 times height or width, end-to-end: Minimum 4 feet.
	Refrigerant Line Sizing	Follow ASHRAE guidelines.
	Floor Loading	40-70 pounds per ton.
	Refrigerant Type	Commonly R-123, R-134a, R-410a with zero ODP
	Refrigerant Charge	2-3 lbs./ton for compact air-cooled chillers.
	Environmental Impact	No blowdown waste concerns.
	Compressor Type	Scroll: 10-80 TR; Screw: 50-500 TR; Centrifugal: Not used in air-cooled.

Cooling Water Quality

	Parameters	Rules of Thumb
	Scaling Indicators	pH >7, Hardness > 200 ppm, alkalinity >200 ppm, and TDS > 500 ppm promote scale formation.
	Corrosion Indicators	pH< 7, conductivity >1000 µS/cm, chlorides >500 ppm, dissolved oxygen >2 ppm accelerate corrosion.
	Microbial Growth	Free chlorine: 0.5 - 1.5 ppm; Bacteria count: <1,000 CFU/mL, Legionella: <10 CFU/mL CFU: Colony Forming Units
	Water Treatment Chemicals	Use pH adjusters, scale/corrosion inhibitors, and biocides for control.

Ideal Water Quality

	Parameters	Rules of Thumb
	pH	7.2-8.5
	Hardness	<200 ppm

	Parameters	Rules of Thumb
	TDS	<500 ppm
	Total Alkalinity	<200 ppm
	Silica	<150 ppm
	Chlorides	<500 ppm
	TSS	<50 ppm
	Conductivity	<1000 µS/cm
	Dissolved Oxygen	<2 ppm
	Free Chlorine	0.5-1.5 ppm
	Microbial Growth/Bacterial Count	<1000 CFU/mL

Chemical Treatment

	Parameters	Chemicals/Inhibitors & Function
	pH Control	Sodium Hydroxide (NaOH) - Raises pH, Sulfuric Acid (H_2SO_4) - lowers pH
	Scale Control	Phosphonates, Polyacrylates, Polymaleic Acid - inhibits scale formation
	Corrosion Control	Zinc Phosphates, Molybdates, Nitrite - forms protective film, inhibits corrosion
	Biofouling Control	Chlorine, Bromine, Ozone - Oxidizing biocide, kills microorganisms

Disclaimer: The rules, metrics, and guidelines in this course are based on the author's experience and established engineering practices. These are not universal benchmarks, and specific values may vary depending on operating conditions and other factors. Proper design and engineering analysis based on manufacturer recommendations are essential for desired results. This document is a live resource and will be updated as new information becomes available.