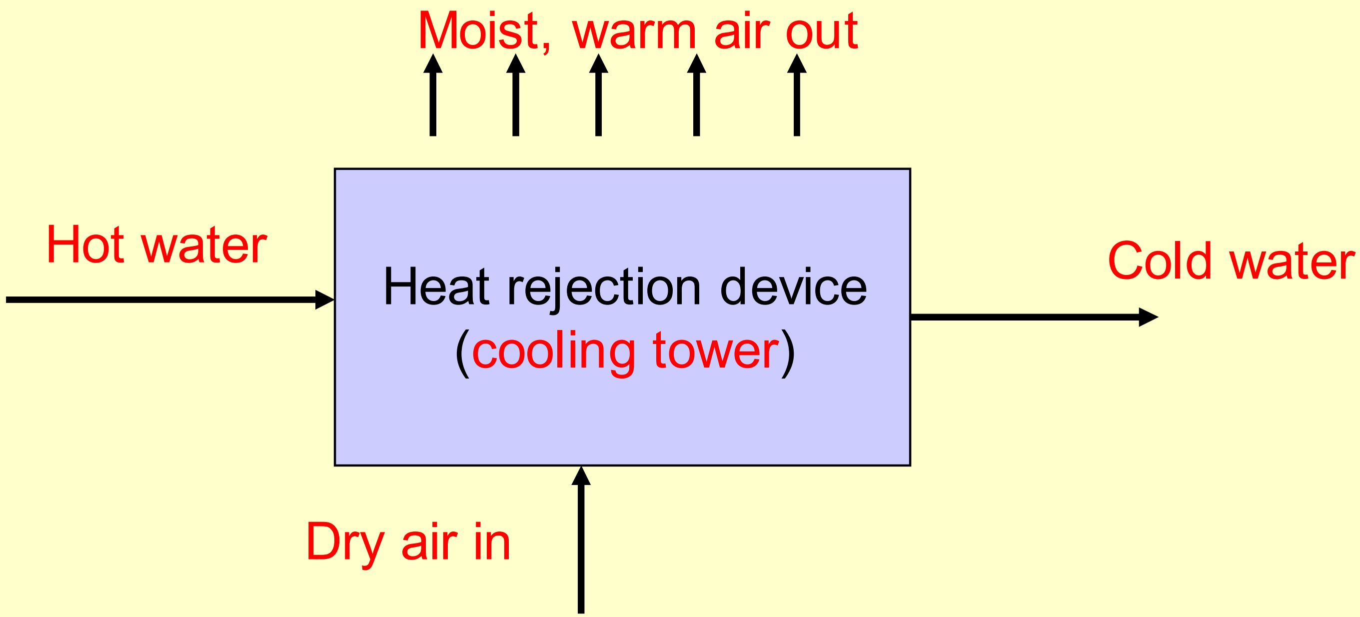
SPD5132 Indoor Environmental and HVAC Systems

http://ibse.hk/SPD5132/



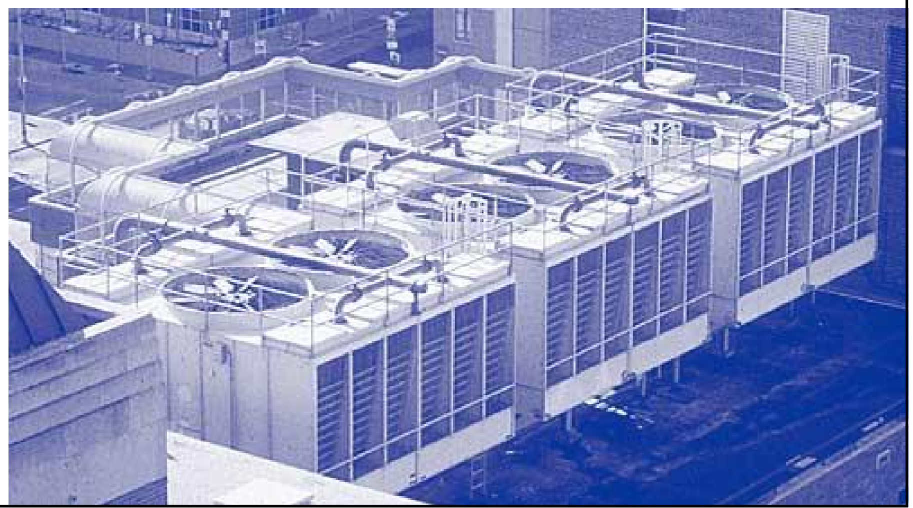
Heat rejection systems

Ir. Dr. Sam C. M. Hui
Faculty of Science and Technology
E-mail: cmhui@vtc.edu.hk

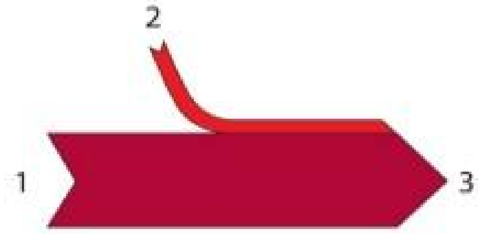
Dec 2016

Contents

- Heat rejection methods
- Cooling towers
- Assessment of cooling towers
- Selecting a cooling tower
- Cooling tower operation

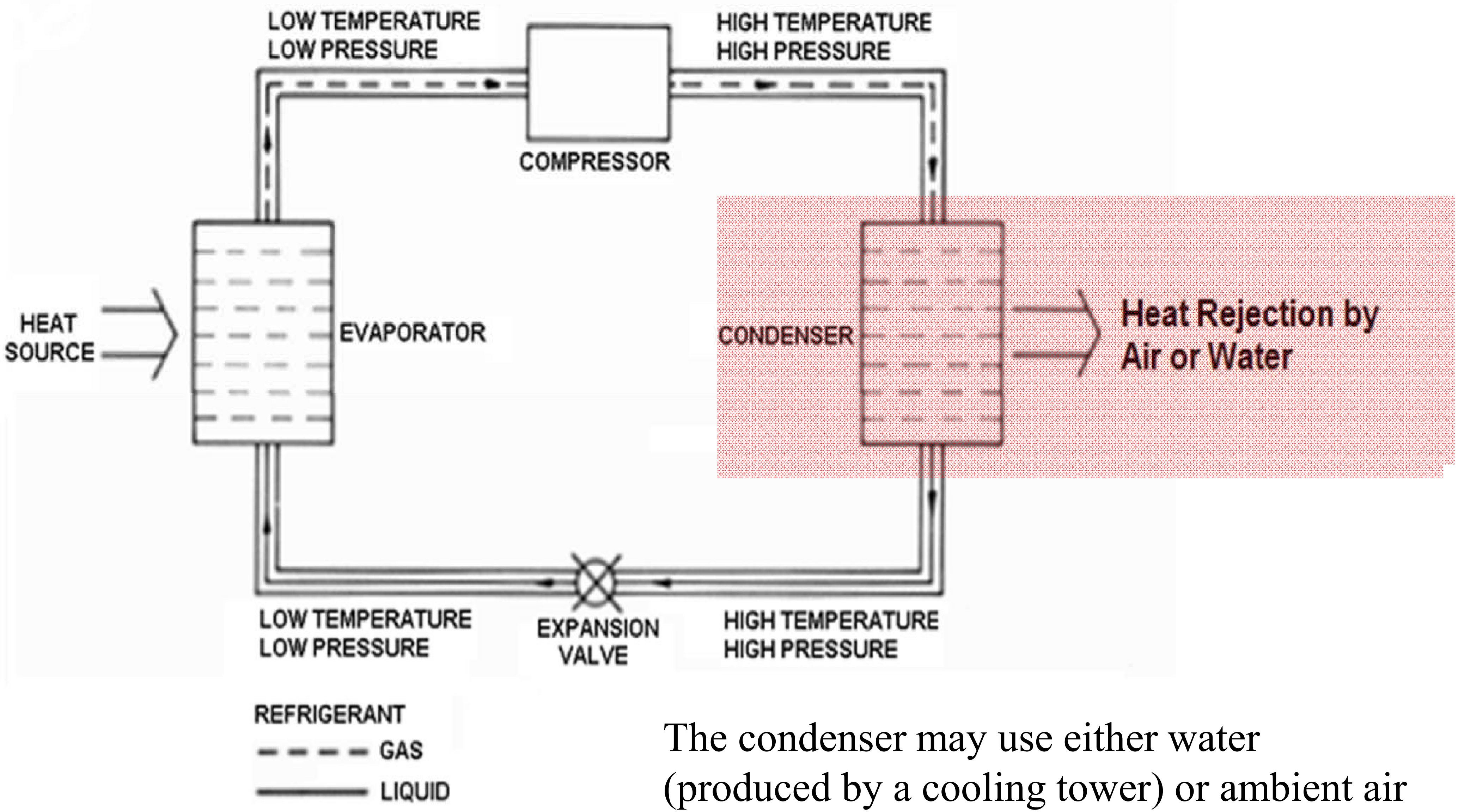


Heat rejection methods



- Heat rejection
  - Discharge of heat to waste or atmosphere or to a system permitting reclaim or recovery
  - Air conditioning systems use refrigeration processes to move heat from the indoor to the outdoor environment
    - The refrigeration cycle absorbs heat by the evaporation of liquid refrigerant in the evaporator (indoor coil), and rejects heat by the condensation of vapour refrigerant in the condenser (outdoor coil)

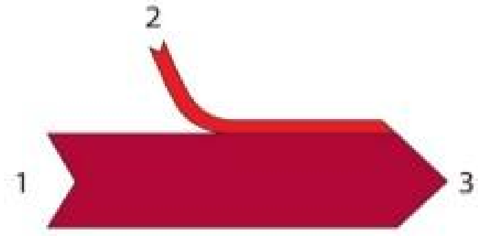
Heat rejection from cooling system to the environment



The condenser may use either water (produced by a cooling tower) or ambient air as the heat rejection medium.

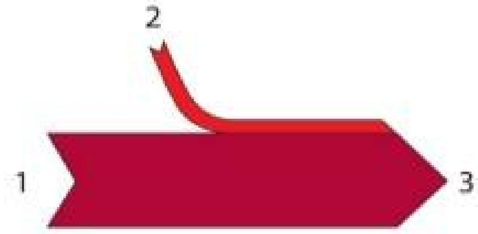
Heat rejection = cooling effect + power input

Heat rejection methods



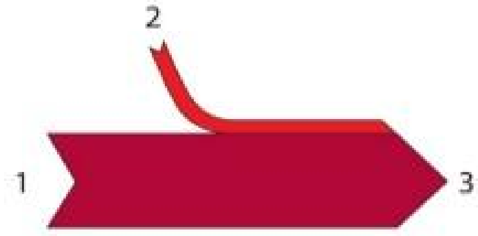
- Three methods for heat rejection:
  - Air Cooled: A process by which air passes over a coil or channel containing fluid. Heat is transferred from the coil directly to the air.
  - Water Cooled: This process utilizes a spray system to pass water over coils or fill media to reject heat to the atmosphere through evaporation. The spray water itself or the fluid contained in the coil can then be used by a cooling system.

Heat rejection methods



- Three methods for heat rejection: (cont'd)
  - Adiabatic: A two stage process that uses a combination of air and water to reject heat.
    - Below a set temperature, the process will run dry. This is similar to an air cooled method where process fluid is run through a coil or micro channel with air flowing over it.
    - When a peak temperature is reached, the air is pre-cooled by pulling it through a pad moistened with a small amount of water. This brings the air close to the ambient wet-bulb temperature, allowing for greater heat rejection when it is blown over the coil. Unlike a water cooled method, the water does not flow directly over the coil.

Heat rejection methods



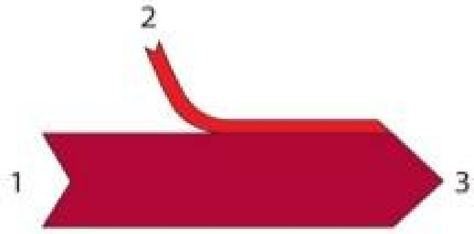
- Air-cooled system
  - Air-cooled condensers use air to cool and condense refrigerant gas to the liquid state
    - These systems normally require 17-25 m^3/min of air per ton of refrigeration
    - Condensing temperatures range from 46 to 60°C, depending on climatic conditions
    - In general, higher condensing temperature will increase the power requirement (fan power) and decrease the cooling system's performance

Examples of air-cooled condensers

Advantages of air-cooled over water-cooled system:

- No problem of water freezing
- No water treatment required
- No condensing water pump required
- Lower initial cost

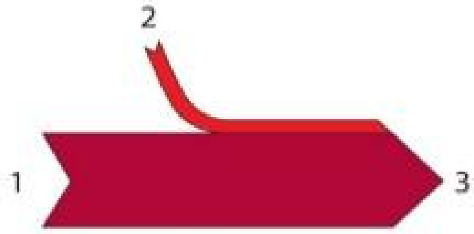
Heat rejection methods



- Water-cooled system
  - Sources of condensing water include spray ponds, domestic supply water, wells, surface water, sea water, and cooling towers
    - Water from these sources is lower in temperature than air is during the summer. Lower condensing temperatures allow higher refrigeration efficiency, and water is generally preferred to air on this basis
    - Water-cooled air-conditioning systems (WACS) have a higher COP (Coefficient of Performance) than air-cooled air-conditioning systems (AACS)*

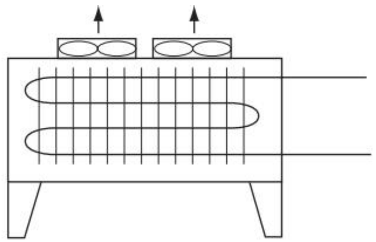
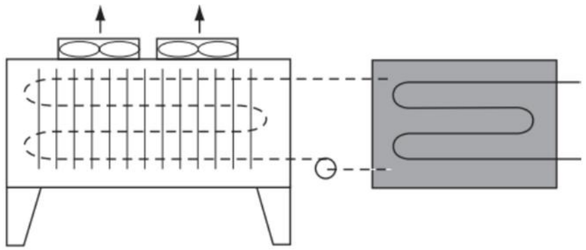
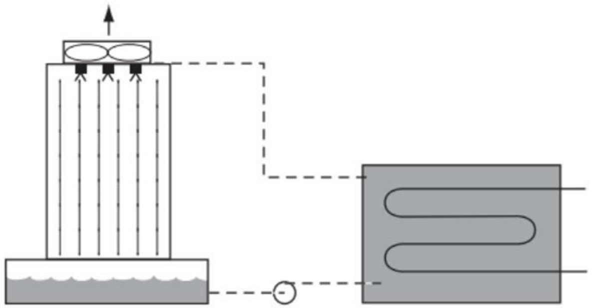
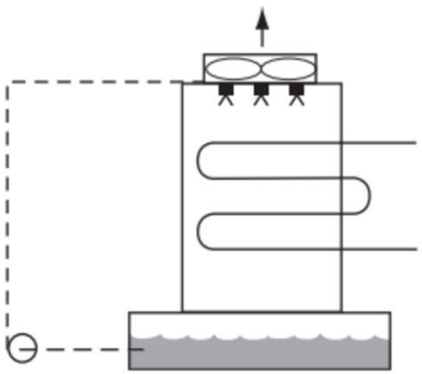
(See also: Water-cooled Air-Conditioning System http://www.energyland.emsd.gov.hk/en/building/water_cooled_sys/)

Heat rejection methods



- Types of heat rejection system:
  - 1. Air cooled condenser
  - 2. Dry air cooler
  - 3. Cooling tower
  - 4. Evaporative condenser

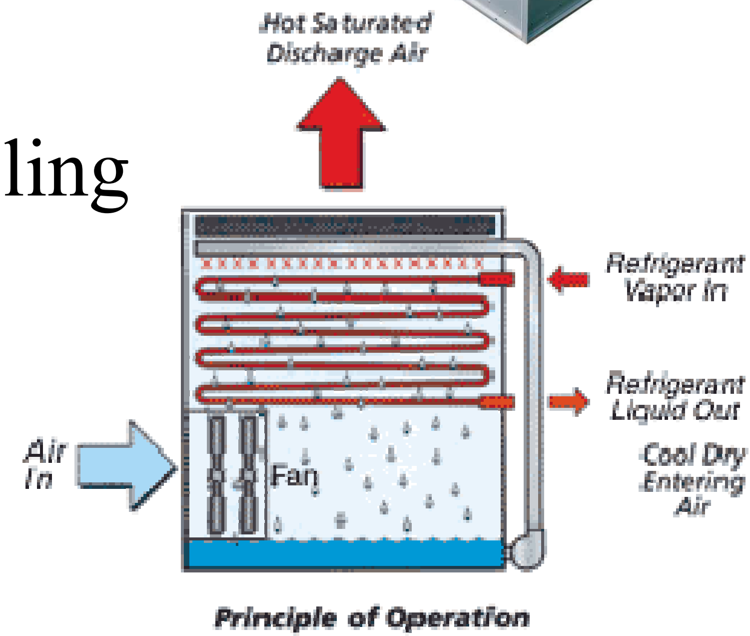
Types of heat rejection system

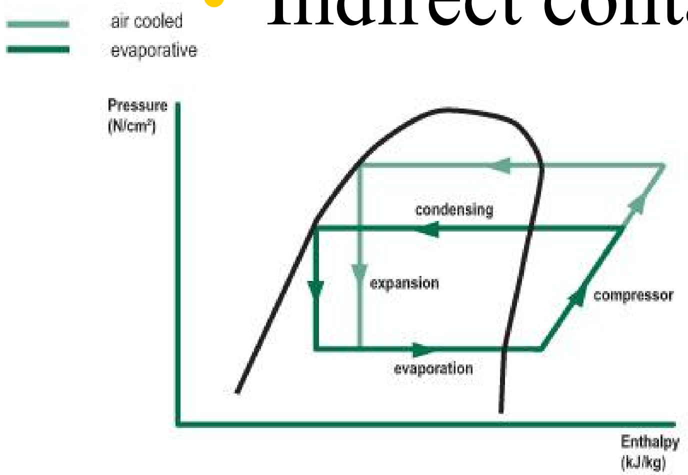
(a) Air cooled condenser	Fans induce air flow over finned tubing in which refrigerant condenses.		Convenient and common for chillers up to a few 100 k W. Free of hygiene risks and do not require water piping. Can be adapted to provide free cooling with thermosiphon systems.
(b) Dry air cooler	Similar to (a) but aqueous glycol solution of water is passed through the tubes instead of refrigerant.		Less efficient than (a) because an additional heat transfer process, and pumps, are required to reject heat from a refrigeration plant. May cool water sufficiently in winter to avoid need to operate a refrigeration plant – 'free cooling'.
(c) Cooling tower	Water is sprayed over a packing material. Airflow over the packing evaporates some of the water causing the water to be cooled.		More efficient than (a) or (b) because less air is required because less air is required and water is cooled to a few degrees above the wet bulb temperature. May cool water sufficiently to avoid need to operate a refrigeration plant – 'free cooling'. High maintenance requirement.
(d) Evaporative condenser	Water is sprayed over tubing in which refrigerant condenses. Airflow across the tubing evaporates some of the water causing the water and the tubes to be cooled.		Most efficient method of rejecting heat from a refrigeration plant. Similar maintenance requirements as (c). Can be adapted to provide free cooling with thermosiphon systems.

(Source: CIBSE, 2003. *Refrigeration and Heat Rejection*, CIBSE Guide B4, Chartered Institution of Building Services Engineers, London.)

Heat rejection methods

- Evaporative condensers
  - Uses both air and water
  - Air flows over the refrigerant coil
  - Water flows over the coil when needed
  - Water remains in the condenser
  - Indirect contact evaporative cooling



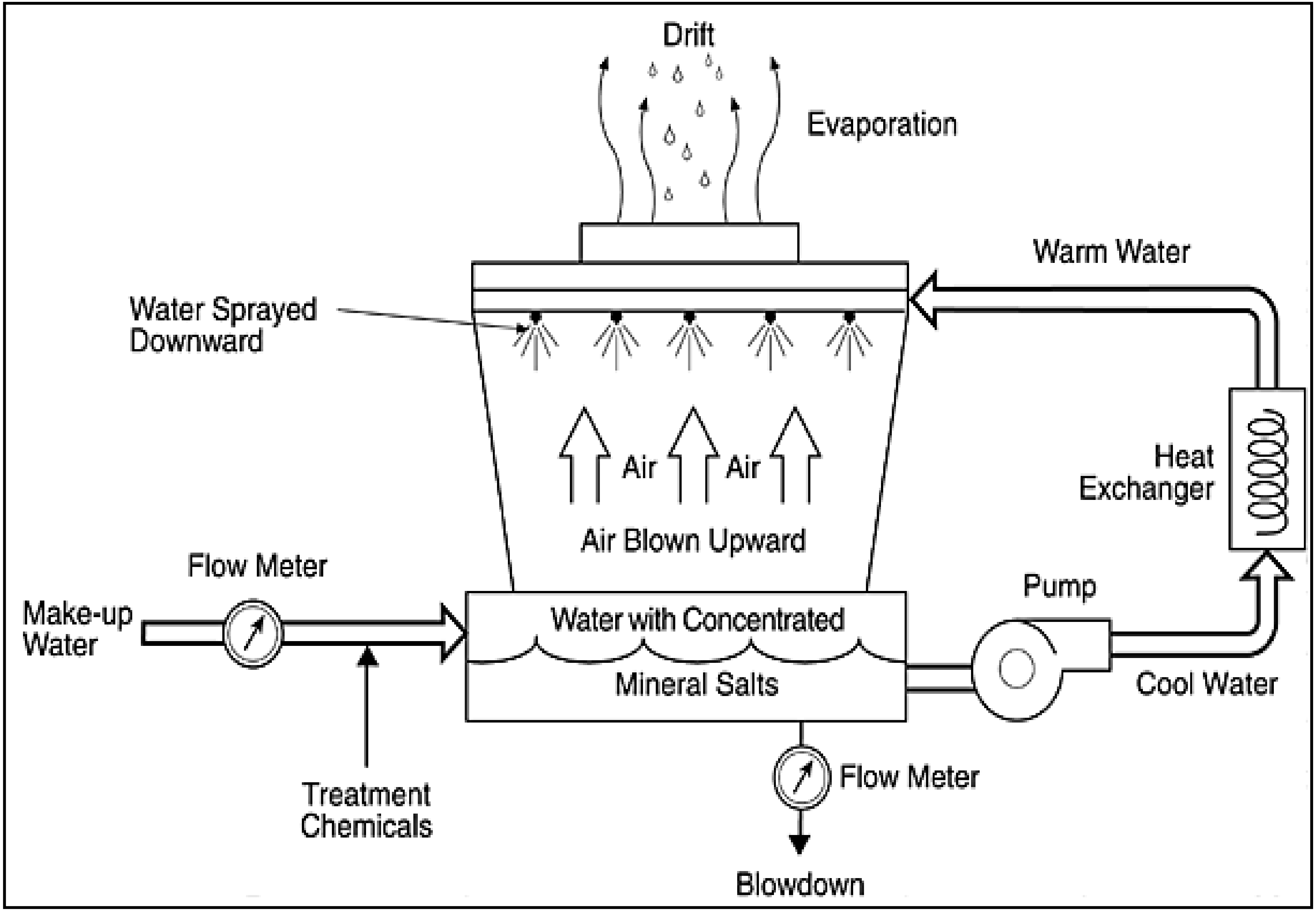


Cooling towers

- A cooling tower is a specialized heat exchanger in which air and water are brought into direct contact with each other in order to reduce the water's temperature
  - A small volume of water is evaporated, creating a cooling action (latent heat exchange)
  - The cooled water is then pumped back to the condenser or process equipment where it absorbs heat

(See also: What Is A Cooling Tower? http://spxcooling.com/coolingtowers)

Main features of cooling towers



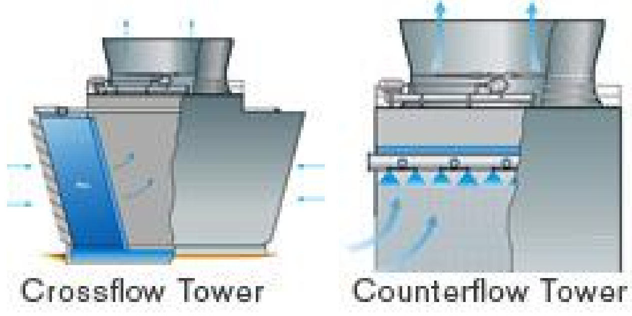
(Source: Pacific Northwest National Library, 2001)

Cooling towers

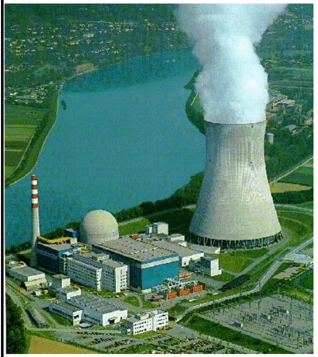
- Make-up – the amount of water required to replace normal losses caused by bleed, drift and evaporation
- Drift – the water entrained in the exit air flow and discharged to the atmosphere – not including evaporation
- Bleed – water that is discharged to waste to help keep the dissolved solids concentration below a certain limit

Cooling towers

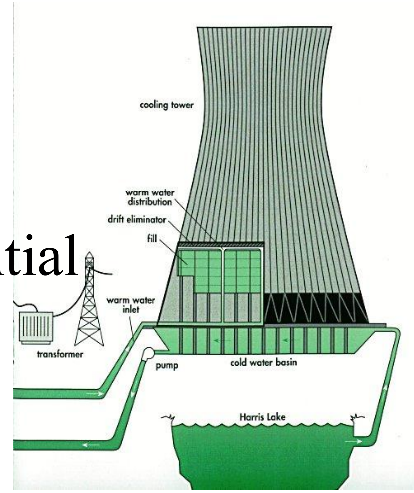
- Classification of cooling towers
  - By direction of air flow



    - Cross flow (airflow is horizontal)
    - Counter flow (airflow is vertical)
  - By how the air flow is produced

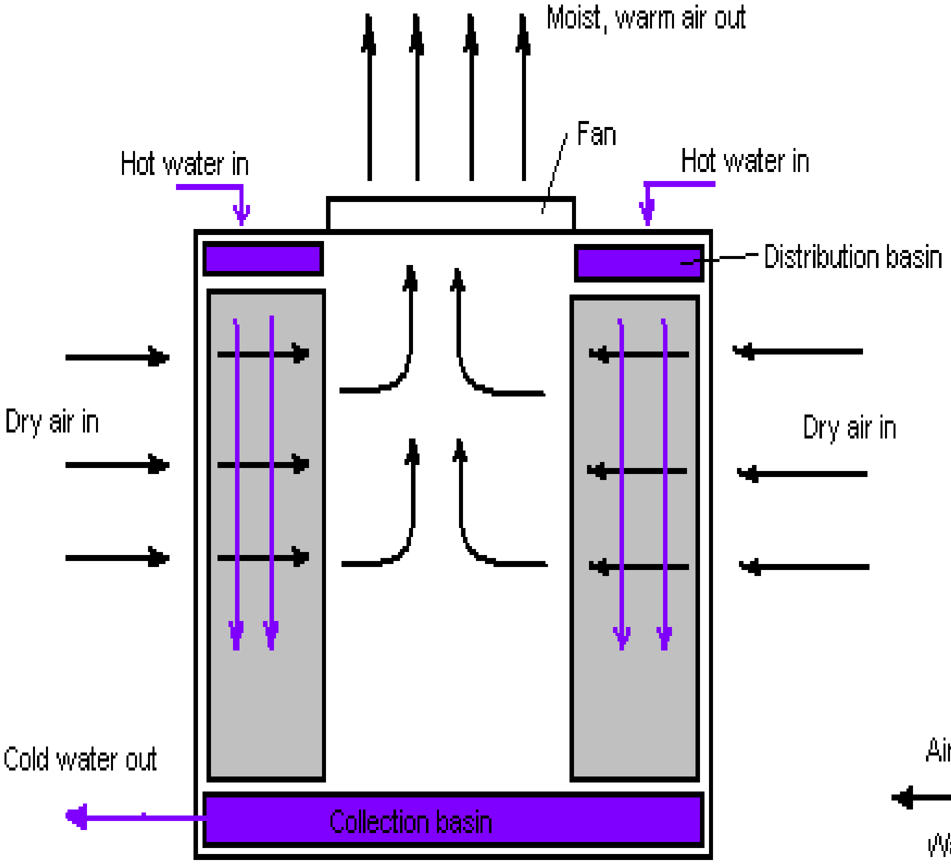


    - Naturally (hyperbolic or chimney towers)
      - Warm air naturally rises due to the density differential

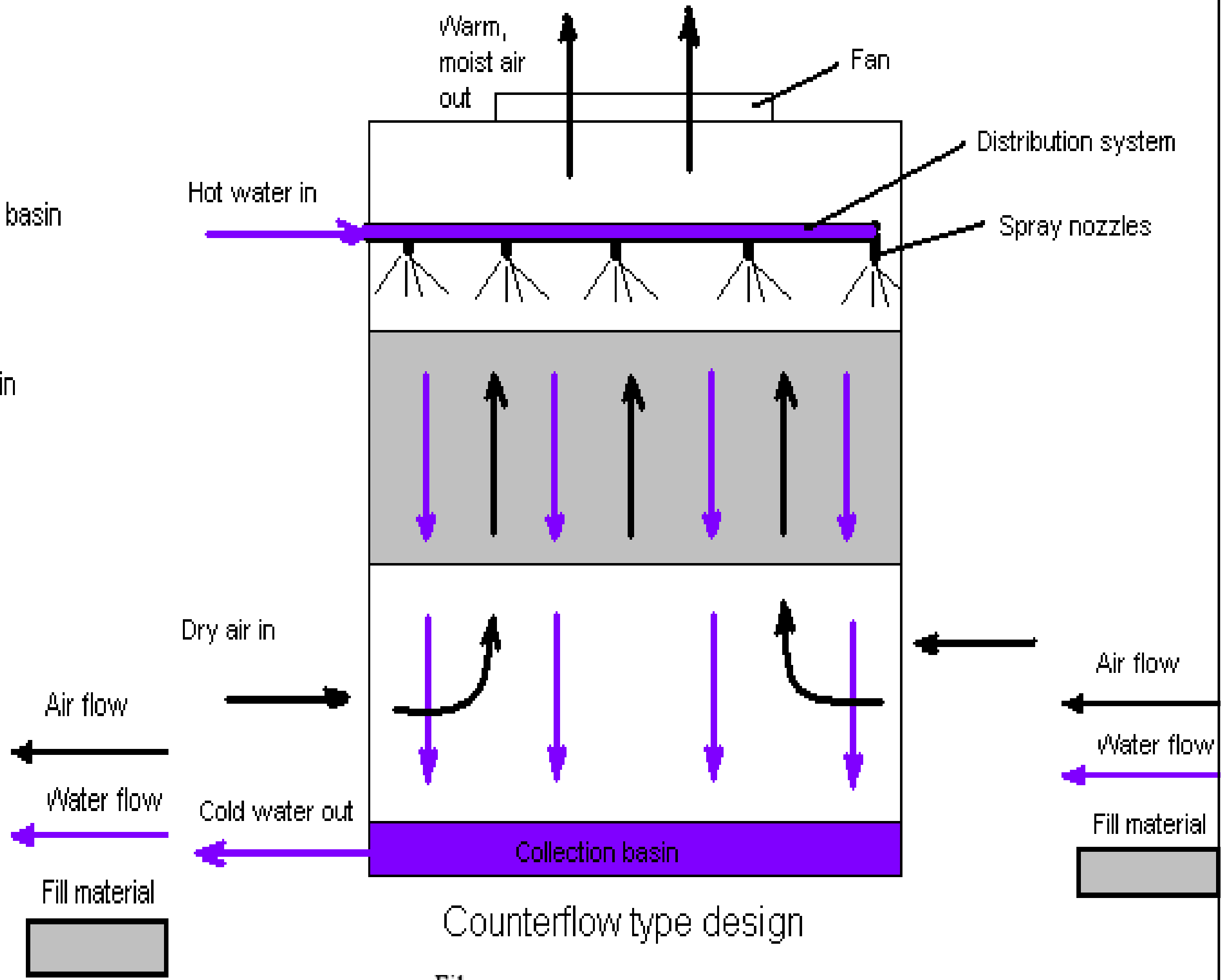


    - Mechanically (forced draft or induced draft)
      - A fan induces airflow through a tower
  - By construction: field-erected, factory assembled

Cross flow and counter flow cooling towers

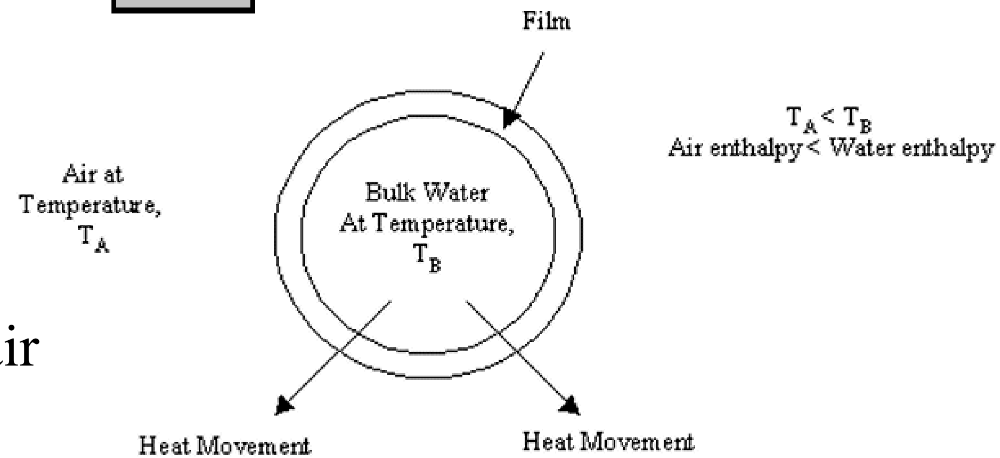


Crossflow type design

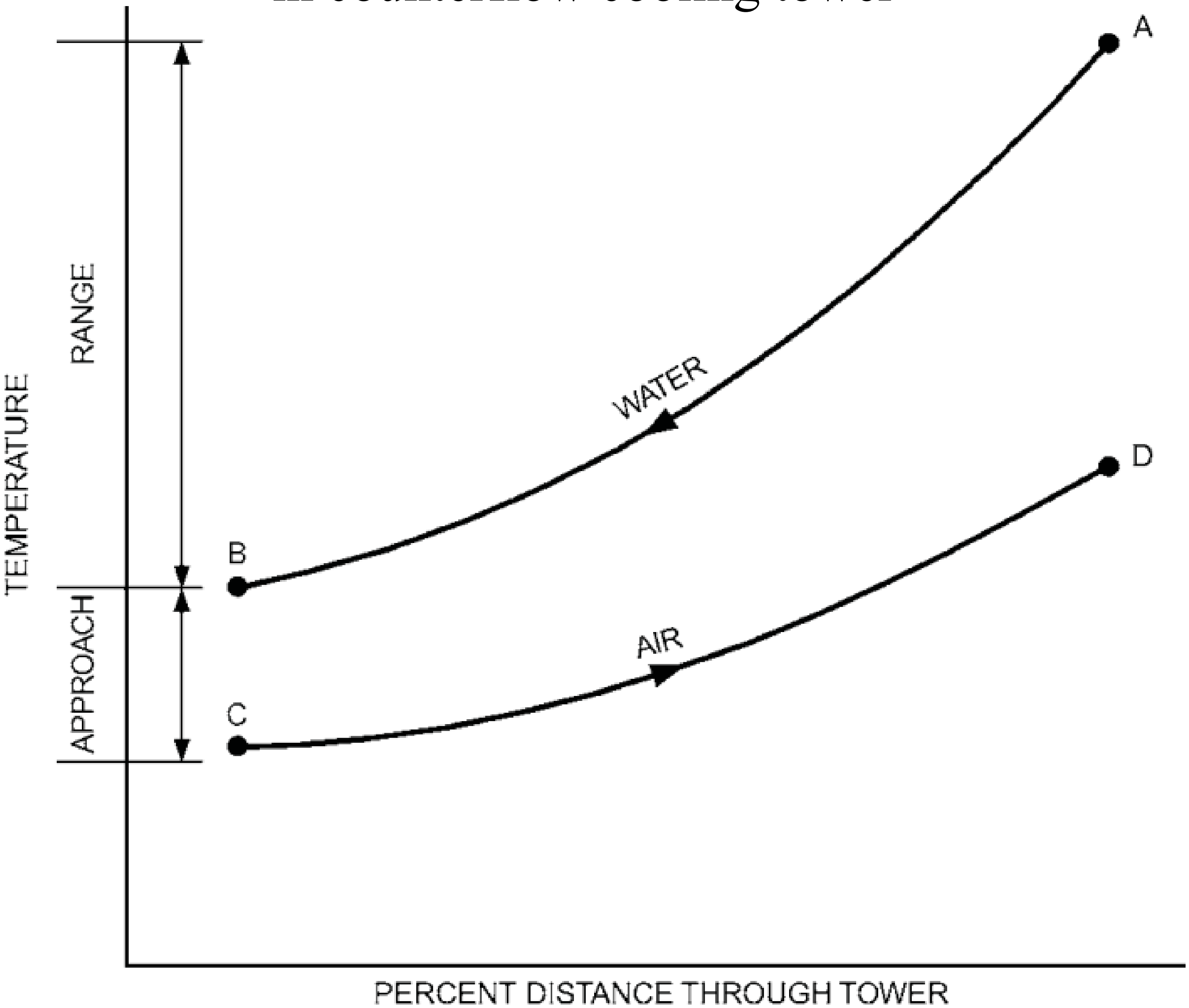


Counterflow type design

Heat and mass transfer relationships between water, interfacial film, and air



Temperature relationship between water and air in counterflow cooling tower



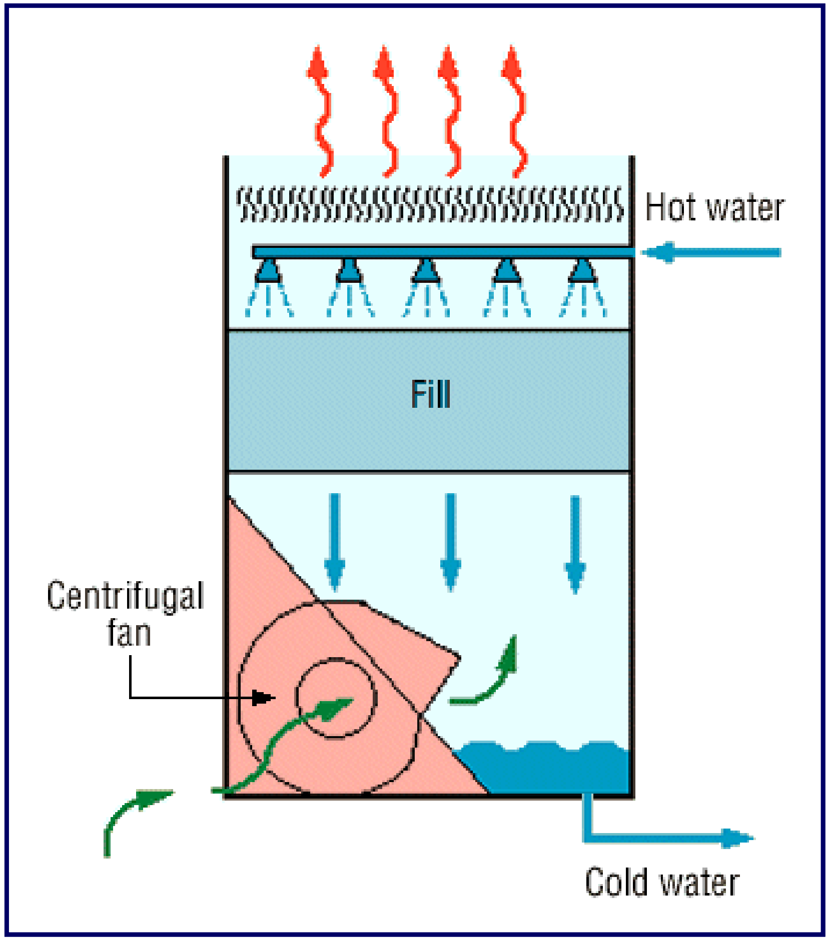
(Source: *ASHRAE 2016 Handbook – HVAC Systems and Equipment*, Chapter 40)

Cooling towers

- Mechanical draft cooling towers
  - Large fans to force air through circulated water
  - Water falls over fill surfaces: enhance heat transfer
  - Large range of capacities
  - Can be grouped, e.g. 8-cell tower
- 3 types of mechanical draft cooling towers
  - Forced draft
  - Induced draft cross flow
  - Induced draft counter flow

Cooling towers

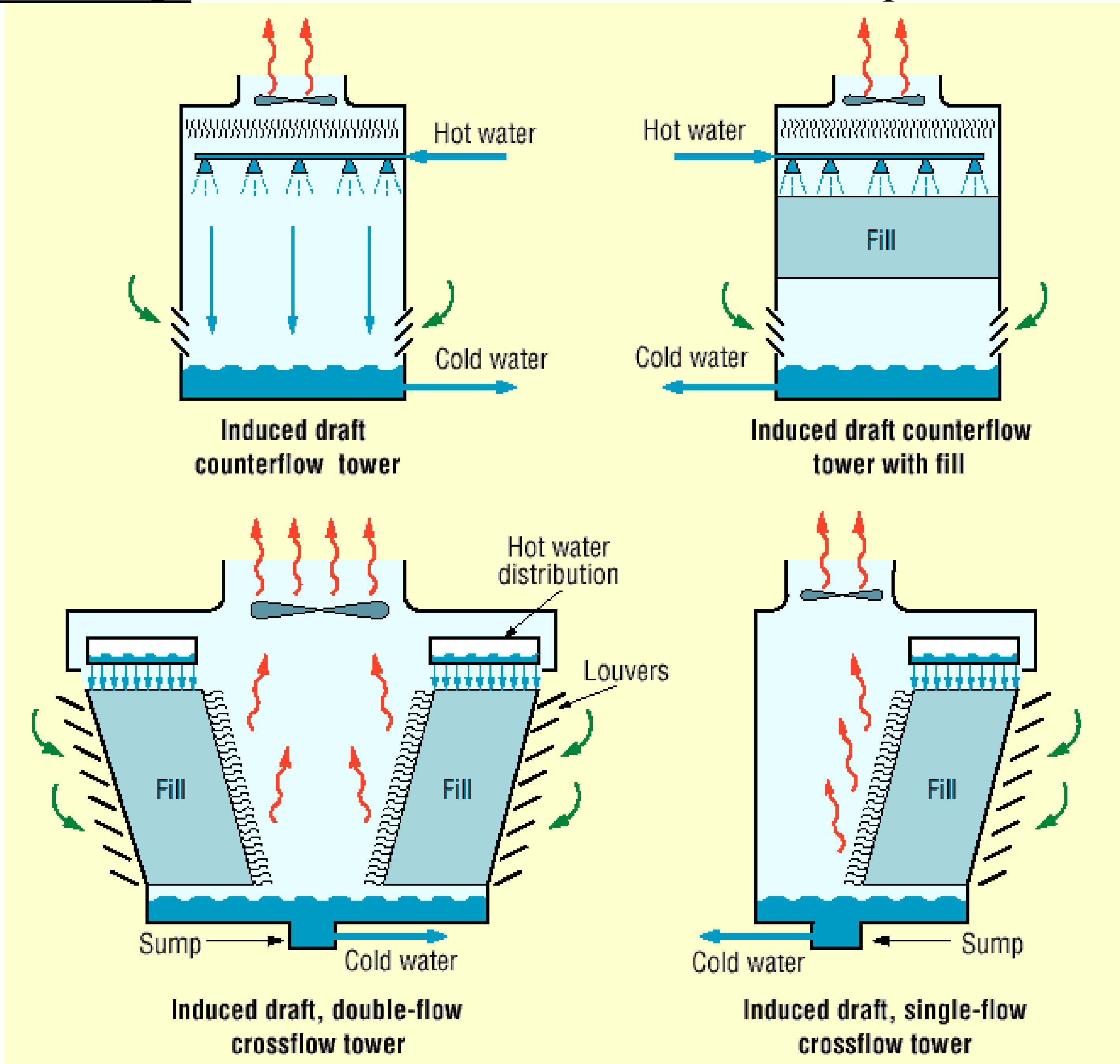
- Forced draft cooling towers
  - Air blown through tower by centrifugal fan at air inlet
  - Advantages: suited for high air resistance & fans are relatively quiet
  - Disadvantages: recirculation due to high air-entry and low air-exit velocities



Induced draft cooling towers

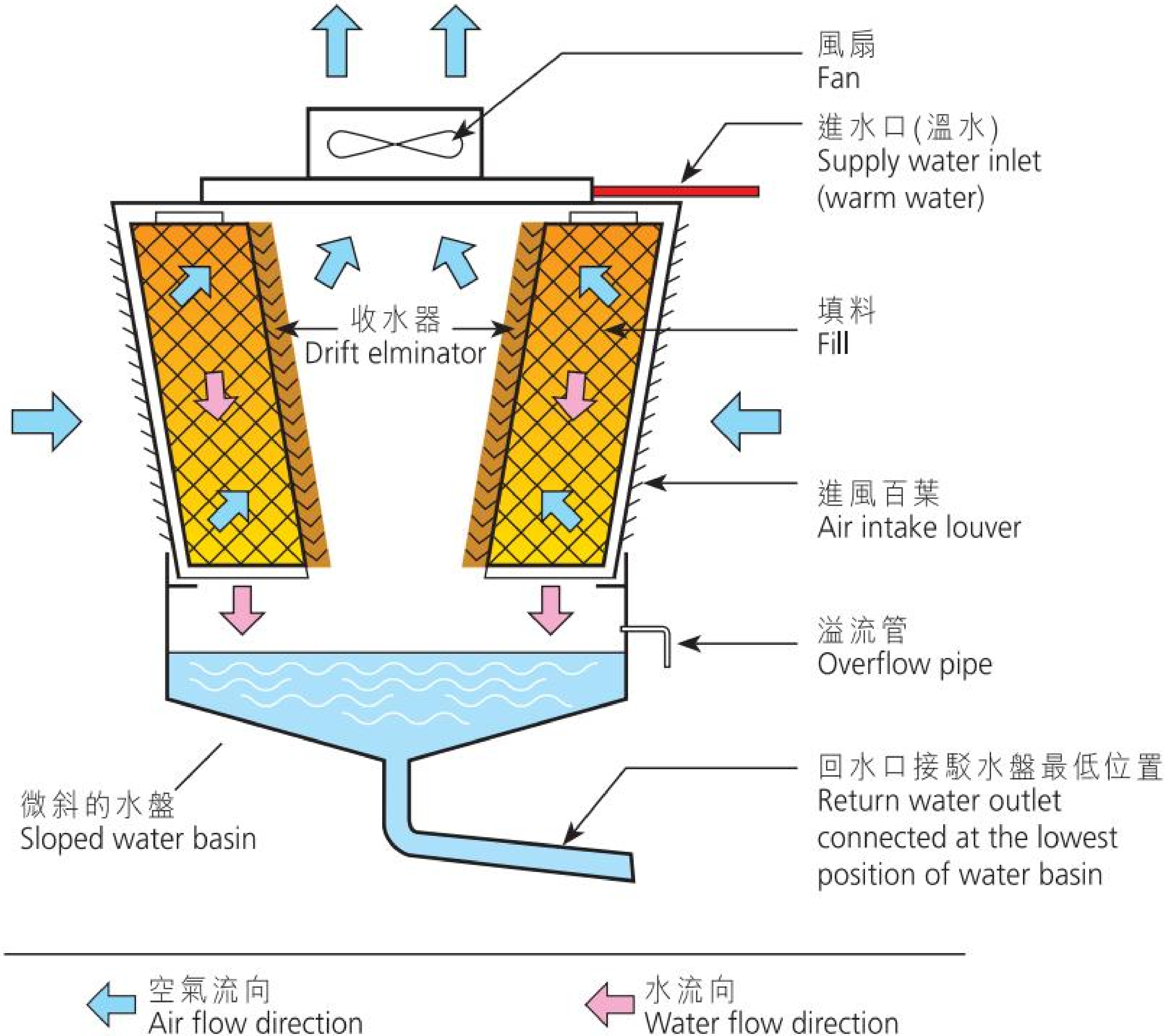
Advantage: less recirculation than forced draft towers

Disadvantage: fans and motor drive mechanism require weather-proofing



Structure of an induced draft, counterflow cooling tower

A typical cooling tower configuration



(Source: EMSD)

Cooling towers

- Basic components of cooling tower
  - Frame and casing: support exterior enclosures
  - Water distribution system: include header which sprays water from top of the tower over splash bars
  - Fan: induced/forced draft towers use fans to push/pull air
  - Air intake louvers: louvers on side of towers which direct air into tower

(See also: Water Distribution http://spxcooling.com/parts/list/cooling/water-distribution, Mechanical Equipment http://spxcooling.com/parts/list/cooling/fans-and-drives)

Cooling towers

- Basic components of cooling tower (cont'd)
  - Fill: material inside a tower which redirects air flow and water
  - Water basin: collects water at bottom of tower
  - Column: wooden/metal post which supports tower
  - Stack: hyperbolic towers and chimney towers have huge stacks located at top
  - Splash bars: used to redirect the downward flow of water

(See also: Fill http://spxcooling.com/parts/list/cooling/fill)

Cooling towers

- Other components of cooling tower
  - Drift eliminators: designed to remove water droplets from the discharged air and reduce loss of process water
    - They cause the air and droplets to make sudden changes in direction. This causes the drops of water to be separated from the air and deposited back into the tower
  - Biomedia: products specially designed to work together for waste water treatment applications

(See also: Drift Eliminator http://spxcooling.com/parts/xcelplus-eliminators, Biomedia http://spxcooling.com/parts/list/cooling/biomedia)

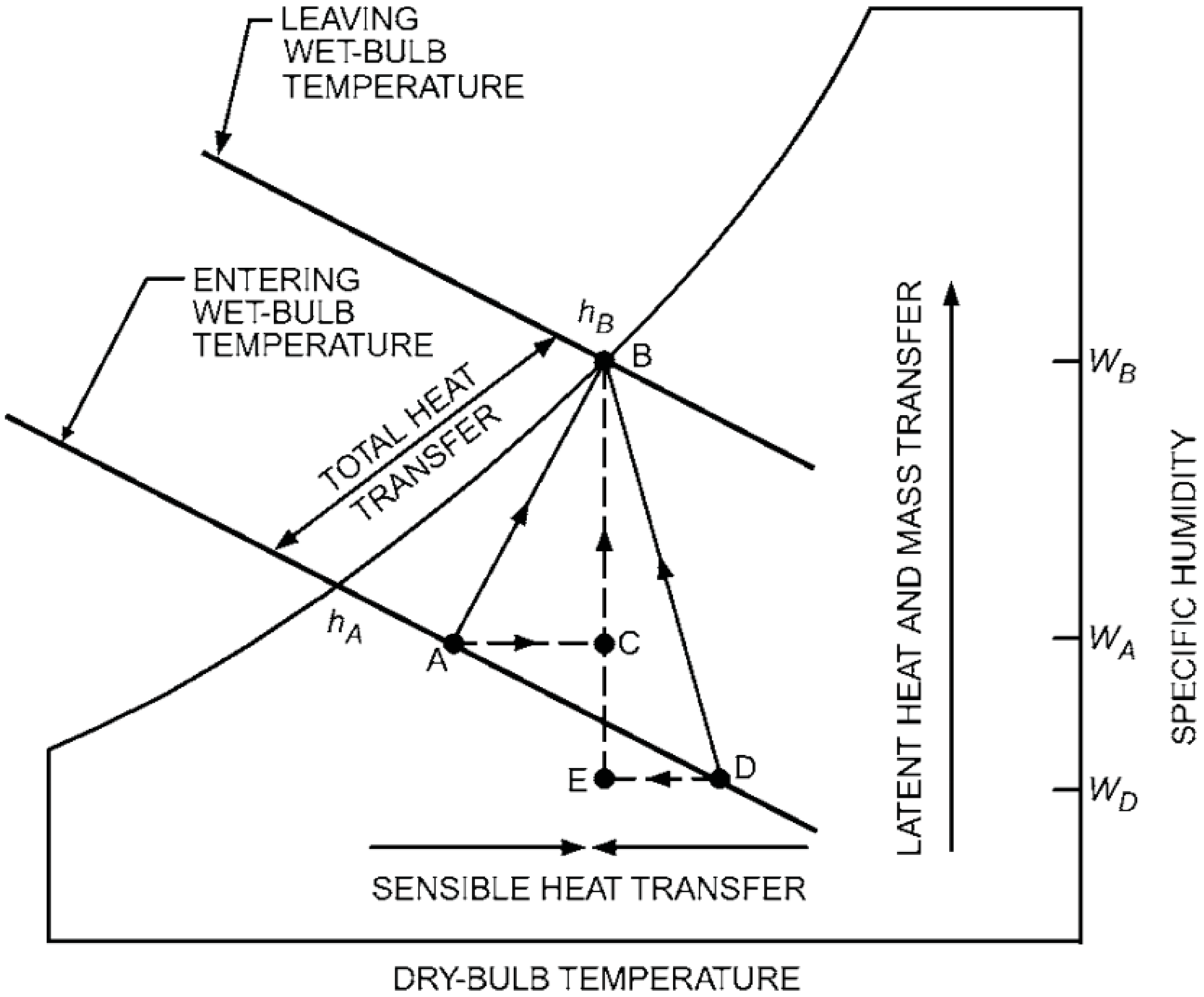
Assessment of cooling towers

- Operating conditions of cooling tower
  - 10-20% of heat (sensible heat) removed from contact between water and air
  - 80-90% of heat removed following evaporation
  - Evaporation is most critical factor affecting tower efficiency
- Factors affecting cooling tower performance
  - Relative humidity, temperature, wind velocity
  - Tower design, water quality, equipment problems

Assessment of cooling towers

- Cooling rate (and temperature) depends upon evaporation rate
  - The minimum temperature to which water can be cooled is the wet bulb temperature of the air
- Factors affecting evaporation rate
  - Wet bulb temperature of incoming air
  - Water surface area
  - Water-air ratio (water flow rate/air flow rate)
  - Contact time

Psychrometric analysis of air passing through cooling tower



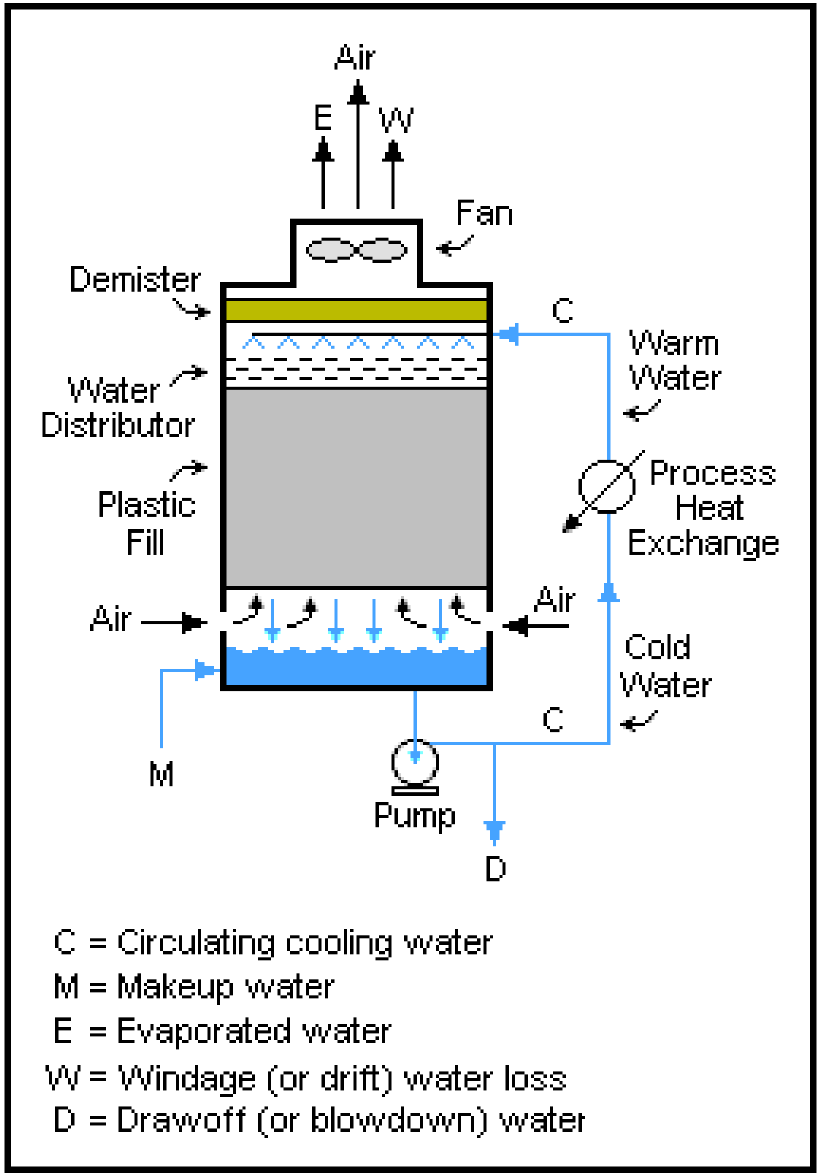
(Source: *ASHRAE 2016 Handbook – HVAC Systems and Equipment*, Chapter 40)

Assessment of cooling towers

- Measured parameters
  - Wet bulb temperature of air
  - Dry bulb temperature of air
  - Cooling tower inlet water temperature
  - Cooling tower outlet water temperature
  - Exhaust air temperature
  - Electrical readings of pump and fan motors
  - Water flow rate
  - Air flow rate

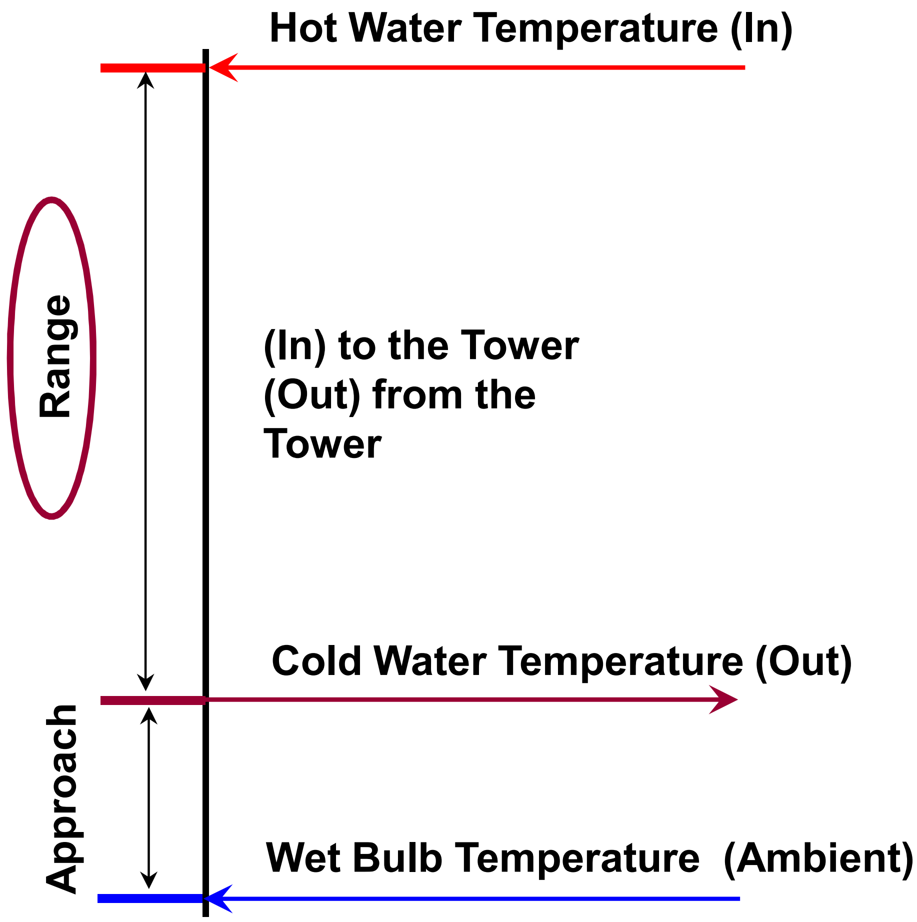
Assessment of cooling towers

- Performance parameters
  - 1. Range
  - 2. Approach
  - 3. Effectiveness
  - 4. Cooling capacity
  - 5. Evaporation loss
  - 6. Cycles of concentration
  - 7. Blow down losses
  - 8. Liquid / Gas ratio



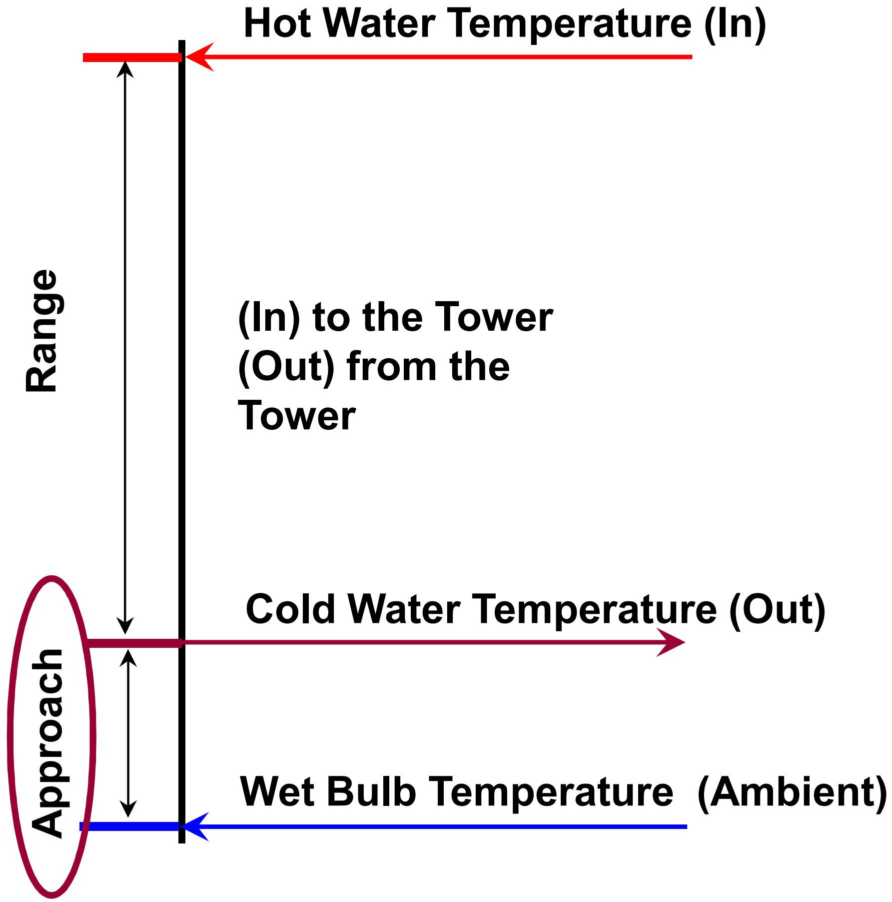
Assessment of cooling towers

- 1. Range
  - Difference between cooling water (CW) inlet and outlet temperature:
  - Range (°C) = CW inlet temp – CW outlet temp
  - High range = good performance



Assessment of cooling towers

- 2. Approach
  - Difference between cooling tower outlet cold water temp. and ambient wet bulb temp.:
  - Approach (°C) = CW outlet temp – Wet bulb temp
  - Low approach = good performance



Assessment of cooling towers

- 3. Effectiveness (in %)
  - = Range / (Range + Approach)
  - = 100 x (CW in temp – CW out temp) / (CW in temp – Wet bulb temp)
  - High effectiveness = good performance
- 4. Cooling capacity
  - Heat rejected in tons of refrigeration (TR)
    - = mass flow rate of water x specific heat x ΔTemp
  - High cooling capacity = good performance

Assessment of cooling towers

- 5. Evaporation loss
  - Water quantity (m^3/hr) evaporated for cooling duty
  - = theoretically, 1.8 m^3 for every 10,000,000 kCal heat rejected
  - = 0.00085 x 1.8 x circulation rate (m^3/hr) x (T_1-T_2)
    - where T_1-T_2 = Temp. difference between inlet and outlet water (°C)
- 6. Cycles of concentration (C.O.C.)
  - Ratio of dissolved solids in circulating water to the dissolved solids in make up water

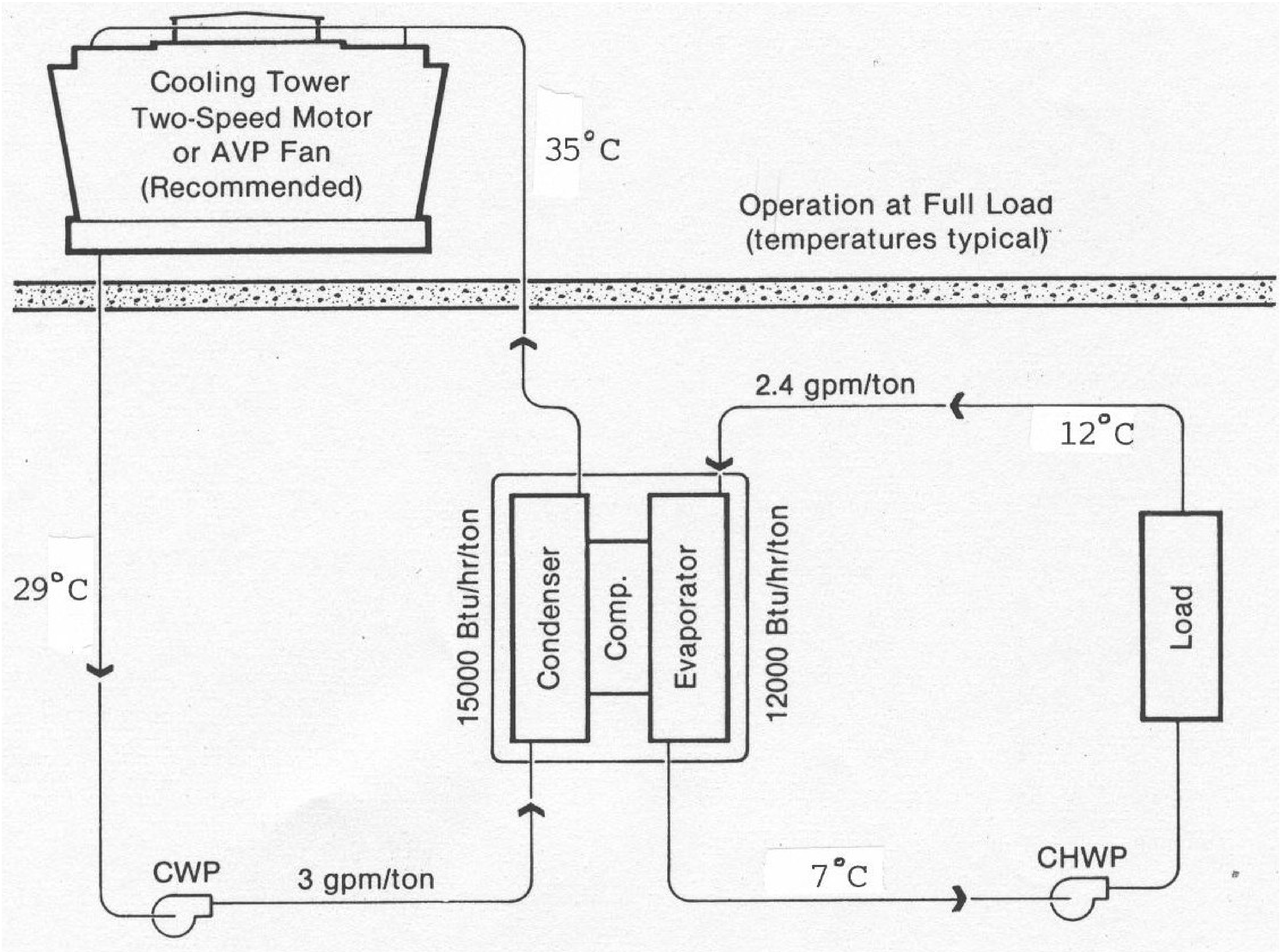
Assessment of cooling towers

- 7. Blow down losses
  - Blow Down = Evaporation Loss / (C.O.C. – 1)
- 8. Liquid gas (L/G) ratio
  - Ratio between water and air mass flow rates
    - Heat removed from the water must be equal to the heat absorbed by the surrounding air
    - $L/G = (h_2 - h_1) / (T_1 - T_2)$
      - T_1, T_2 = hot and cold water temp (°C)
      - Enthalpy of air water vapor mixture at inlet wet bulb temp (h_1) and outlet wet bulb temp (h_2)

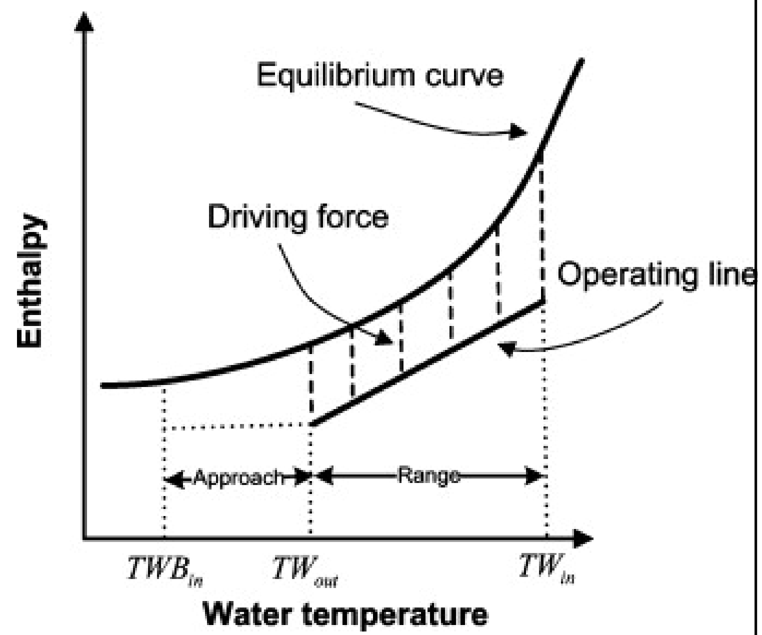
Selecting a cooling tower

- Basic considerations
  - Cooling duty, economics, required services
  - Environmental conditions
  - Maintenance requirements
  - Aesthetics
- Selection factors:
  - Height, length, width, volume of airflow, fan and pump energy consumption, materials of construction, water quality and availability

Design of cooling tower for typical air conditioning system



Selecting a cooling tower



- Capacity
  - Heat dissipation (kCal/hour)
  - Circulated flow rate (m^3/hr)
  - Other factors (e.g. height)
- Range:
  - Determined by process, not by system
- Approach:
  - Closer to the wet bulb temperature
  - = Bigger size cooling tower = More expensive

Selecting a cooling tower

- Heat load
  - Determined by process
  - Required cooling is controlled by the desired operating temperature
  - High heat load = large size & cost of cooling tower
- Materials of construction
  - To meet the expected water quality and atmospheric conditions, e.g.
    - Wood, metals, plastics, graphite composites, concrete, masonry, and tile

Selecting a cooling tower

- Wet bulb temperature – considerations:
  - Water is cooled to temp higher than wet bulb temp
  - Conditions at tower site
  - Not to exceed 5% of design wet bulb temp
  - Is wet bulb temp specified as ambient (preferred) or inlet?
  - Can tower deal with increased wet bulb temp?
  - Cold water to exchange heat

Selecting a cooling tower

- Relationship: range, flow and heat load
  - Range increases with increased
    - Amount circulated water (flow)
    - Heat load
  - Causes of range increase
    - Inlet water temperature increases
    - Exit water temperature decreases
  - Consequence = larger tower

Selecting a cooling tower

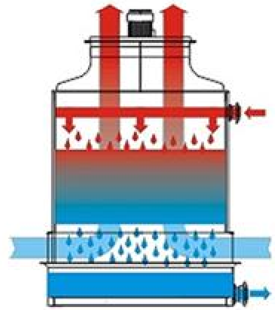
- Relationship: approach and wet bulb temp
  - If approach stays the same (e.g. 4.45 °C)
  - Higher wet bulb temperature (26.67 °C)
    - = more heat picked up (15.5 kCal/kg air)
    - = smaller tower needed
  - Lower wet bulb temperature (21.11 °C)
    - = less heat picked up (12.1 kCal/kg air)
    - = larger tower needed

Selecting a cooling tower

- Fill media impacts electricity use
  - Efficiently designed fill media reduces pumping costs
  - Fill media influences heat exchange: surface area, duration of contact, turbulence
  - Comparing 3 fill media: film fill more efficient

	Splash Fill	*Film Fill*	*Low Clog Film Fill*
Possible L/G Ratio	**1.1 – 1.5**	**1.5 – 2.0**	**1.4 – 1.8**
Effective Heat Exchange Area	**30 – 45 m^2/m^3**	**150 m^2/m^3**	**85 - 100 m^2/m^3**
Fill Height Required	**5 – 10 m**	**1.2 – 1.5 m**	**1.5 – 1.8 m**
Pumping Head Requirement	**9 – 12 m**	**5 – 8 m**	**6 – 9 m**
Quantity of Air Required	**High**	**Much Low**	**Low**

Cooling tower operation

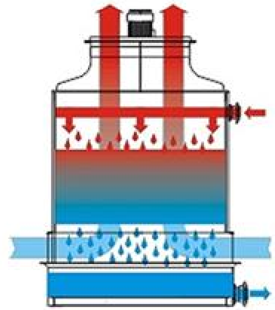


- Operation and maintenance (O&M) work mainly comprise routine checking and upkeeping of conditions of components (e.g. water basin and drift eliminator) and associated equipment (e.g. pumps and valves), water treatment, and cleaning, desludging and disinfection of cooling towers
  - Fresh water cooling towers could be sources of spreading Legionnaires' disease 退伍軍人症

Examples of maintenance service for cooling tower

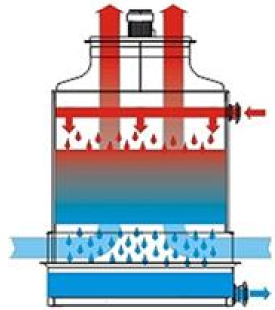
Type of Service	Monthly	Quarterly	Start-Up	Shutdown	Annually
Inspect General Condition of Tower	X		X		
Inspect and Clean as Necessary:					
A) Cold Water and Hot Water Basins	X		X	X	
Flush Cold Water Basin to Remove Silt		X			
B) Optional BALANCE CLEAN® Chamber Inlet Strainer	X		X	X	
C) Air Inlet Louvers	X		X	X	
Check and Adjust Water Level in:					
Cold Water Basin/ Hot Water Basin ·	X		X		
Check Operation of Make-Up Valve	X		X		
Check Bleed Rate and Adjust	X		X		
Power Train:					
A) Check Condition of Belt	X		X		
B) Readjust Tension on Belt		X			
C) Drive Alignment					X
Lubricate Fan Shaft Bearings		X	X	X	
Lubricate Motor Base Adjusting Screw		X	X	X	
Clean Outside of Fan Motor		X	X	X	
Inspect Protective Finish					X

Cooling tower operation



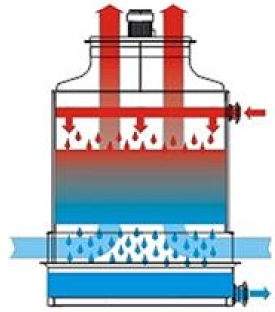
- Troubleshooting of cooling towers
  - Water dissolves many things (especially hot water)
  - Water is cooled and results in deposits in tower
  - Solid concentrate in cooling tower basin
- Problems faced by operators
  - Scale formation – suspended solids from deposits
  - Corrosion – electrochemical reactions with metals
  - Fouling – due to sit, debris, algae
  - Wood decay - fungi

Cooling tower operation



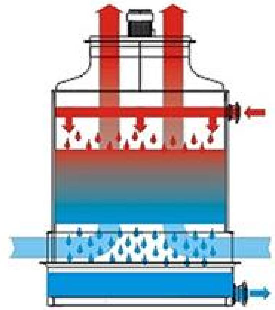
- Water composition control
  - Suspended solids levels checked by operators
  - Measured values compared to make-up water
  - Problem controlled by “blowdown” (i.e. old water replaced with new)
  - Scale formation
    - Remove scale forming solids with softening agents
    - Prevent scale forming materials by addition of chemicals
    - Precipitate scale for removal

Cooling tower operation



- Water composition control (cont'd)
  - Corrosion
    - Add chemical inhibitors (adds thin film to metal)
  - Fouling
    - Use filtering devices
    - Use dispersants with filtering devices
  - Wood decay
    - Use biocides (chlorine or bromine)

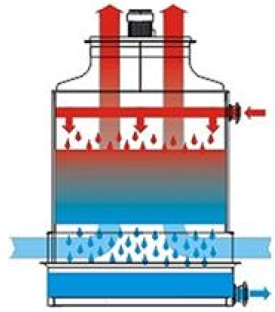
Cooling tower operation



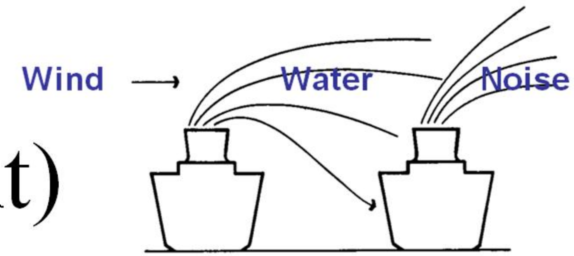
- Free cooling mode with cooling tower
  - Under suitable conditions of weather and heat load, the cooling tower can act as the source of chilled water (i.e. can turn off the chiller)
  - Three design factors to control:
    - Design chilled water temperature
    - Heat exchanger capacity (for an indirect system)
    - Selected cooling tower capacity
  - Two significant variables: load profile and local weather patterns

(See also: Free Cooling http://spxcooling.com/featured/free-cooling/)

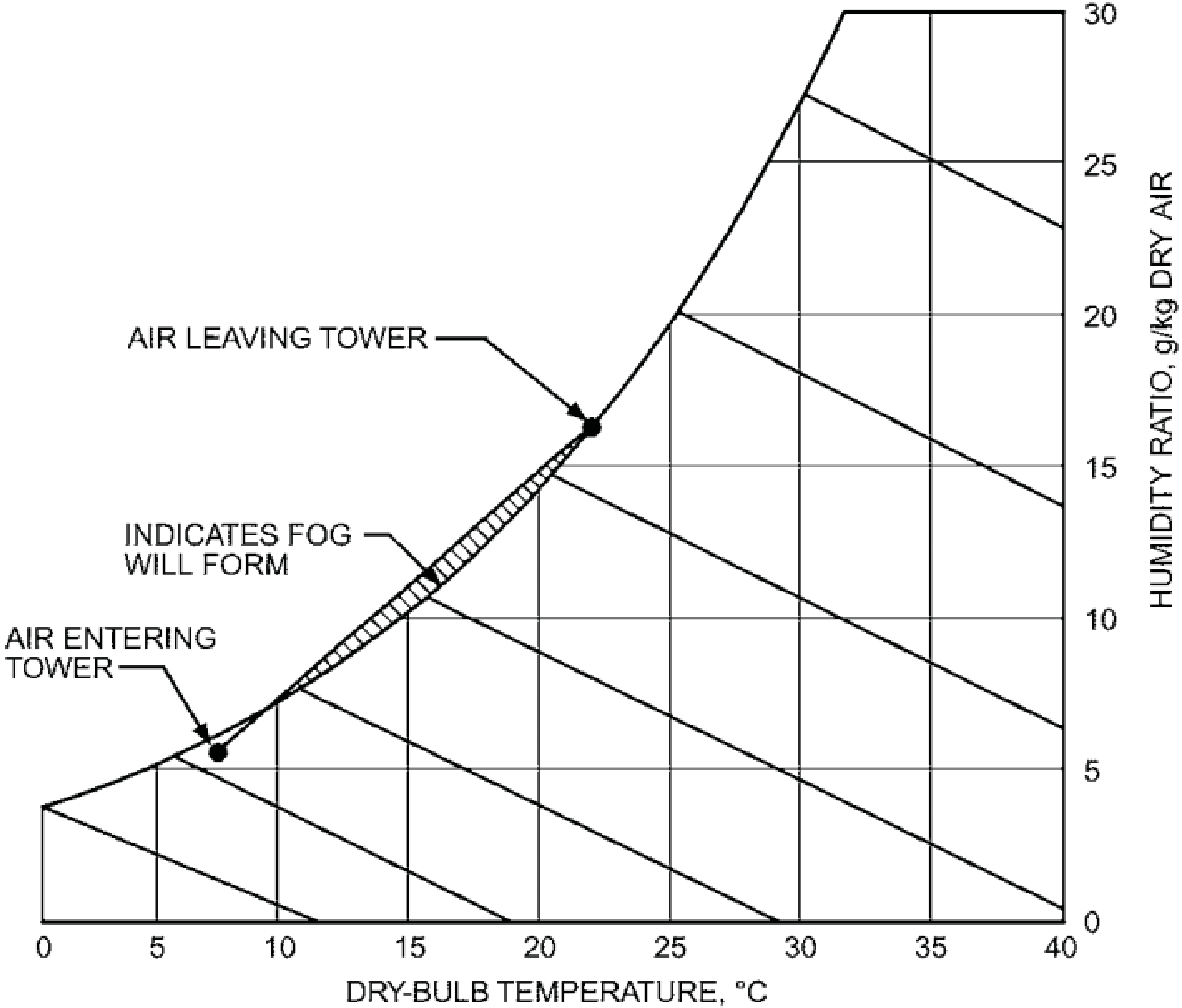
Cooling tower operation



- Sound and noise control
  - Should be considered in the early design stage
  - Put them away from sound-sensitive areas
  - Estimate the sound levels generated by the tower at the critical area; if needed, apply sound barrier, attenuators, lower fan speed
- Drift and fogging (plume abatement)
  - Consider discharge position & drift eliminator
  - Fog prediction and reduction measures

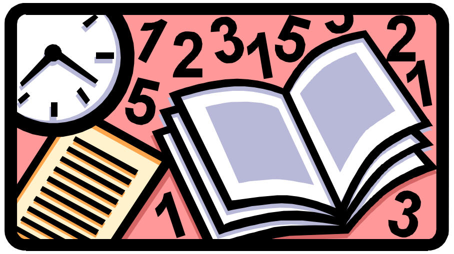


Fog prediction using psychrometric chart

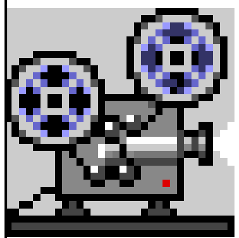


(Source: *ASHRAE 2016 Handbook – HVAC Systems and Equipment*, Chapter 40)

Further Reading

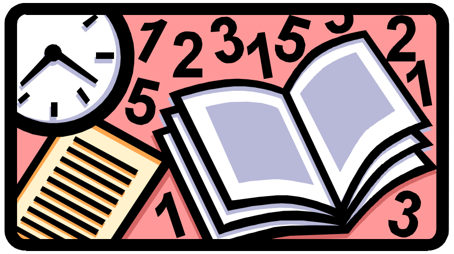


- What Is A Cooling Tower?
  - http://spxcooling.com/coolingtowers
- What is a (wet, atmospheric) cooling tower?
  - http://www.cti.org/whatis/coolingtower.shtml
- Videos:



  - Cooling Tower Basic Operation (2:08) http://www.youtube.com/watch?v=pXaK8_F8dn0
  - How Cooling Towers Work (12:59) http://www.youtube.com/watch?v=UzHJWNL2OtM
  - Cooling Towers Training (22:11) http://www.youtube.com/watch?v=ZpBIDjHAA-k
  - Three Common Cooling Tower Problems (4:53) http://www.youtube.com/watch?v=wVM6_9f-mbg

References



- CIBSE, 2003. *Refrigeration and Heat Rejection*, CIBSE Guide B4, Chartered Institution of Building Services Engineers, London.
- Comparison of Heat Rejection Methods
  - http://www.baltimoreaircoil.com/english/resource-library/file/1481
- Cooling Tower Fundamentals
  - http://spxcooling.com/library/detail/cooling-tower-fundamentals
- Good operation and maintenance practice of fresh water cooling towers for air-conditioning systems
  - http://www.emsd.gov.hk/filemanager/tc/content_296/Good_OnM_Practice_of_Fresh_Water_Cooling_Towers_for_Air-conditioning_Systems.pdf