2016 ASHRAE Handbook—HVAC Systems and Equipment

Chapter 40

(COOLING TOWER) Page 354 – 356

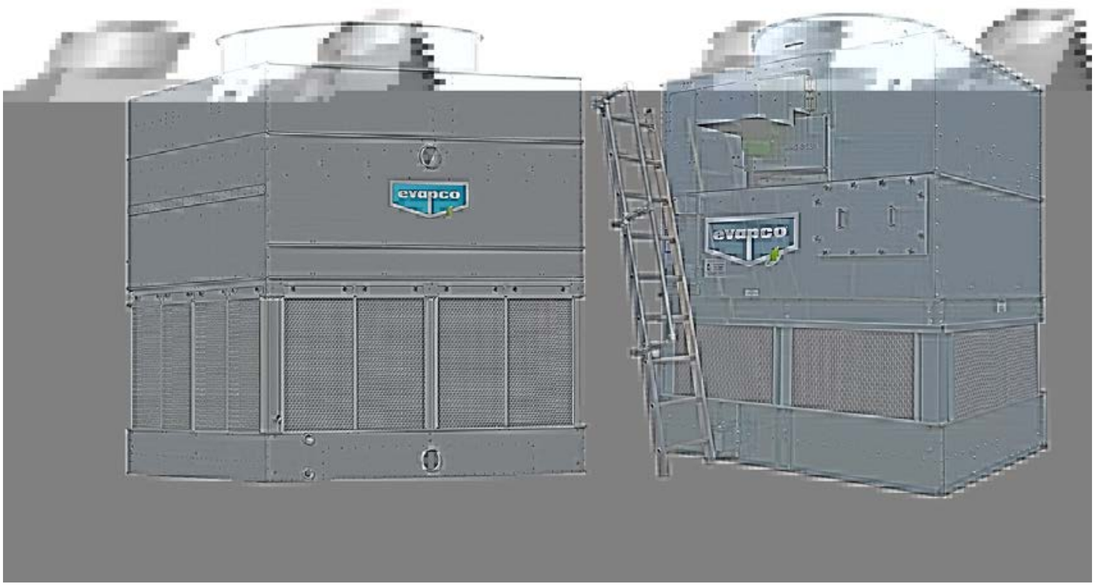

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Table of Contents

NOTE: All information or details that are mentioned here in this document have already been extracted from the ASHRAE Handbook Equipment.

INTRODUCTION

- The purpose of cooling tower is remove the heat from the building or condensers to get the higher efficiency for refrigeration cycle.

- Cooling towers overcome most of these problems and therefore are commonly used to dissipate heat from refrigeration, air conditioning, and industrial process systems.

- The water consumption rate of a cooling tower system is only about 5% of that of a once through system, making it the least expensive system to operate with purchased water supplies.

- Lastly, cooling towers can cool water to within 2 to 3 K of the ambient wet-bulb temperature, which is always lower than the ambient dry-bulb, or approximately 20 K lower than can air cooled systems of reasonable size (in the 880 to 1760 kW range). This lower temperature improves the efficiency of the overall system, thereby reducing energy use significantly and increasing process output.

1. PRINCIPLE OF OPERATION

- **A cooling tower cools water by a** combination of heat and mass transfer. Water to be cooled is distributed in the tower by spray nozzles, splash bars, or film-type fill, which exposes a very large water surface area to atmospheric air.

- **Atmospheric air is circulated** by (1) fans, (2) convective currents, (3) natural wind currents, or (4) induction effect from sprays

- A portion of the water absorbs heat to change from a liquid to a vapour at constant pressure. This heat of vaporization at atmospheric pressure is transferred from the water remaining in the liquid state into the airstream.

- Figure 1 shows the temperature relationship between water and air as they pass through a counter flow cooling tower.

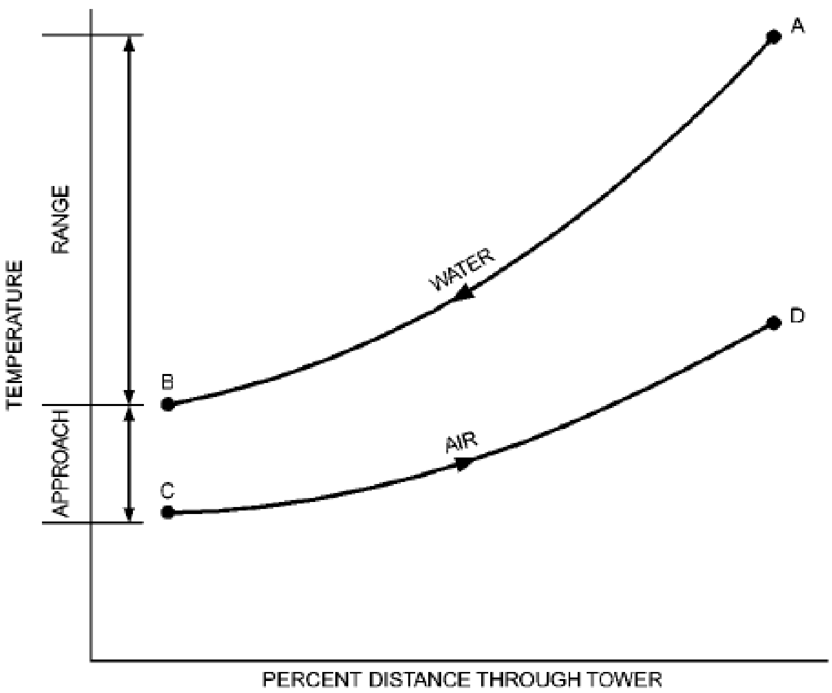

Fig. 1 Temperature Relationship Between Water and Air in Counterflow Cooling Tower

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- The curves indicate the drop in water temperature (A to B) and the rise in the air wet-bulb temperature (C to D) in their respective passages through the tower.

- The temperature difference between the water entering and leaving the cooling tower (A minus B) is the range.

- **For a steady-state system**, **the range** is the same as the water temperature rise through the load heat exchanger, provided the flow rate through the cooling tower and heat exchanger are the same. **Accordingly, the range is determined by the heat load and water flow rate, not by the size or thermal capability of the cooling tower.**

- The difference between the leaving water temperature and entering air wet-bulb temperature (B minus C) in Figure 1 is the approach to the wet-bulb or simply the approach of the cooling tower.

- **The approach is** a function of cooling tower capability.

- **Thermal performance of a cooling tower depends mainly on the entering air wet-bulb temperature.** The entering air dry-bulb temperature and relative humidity, taken independently, have an insignificant effect on thermal performance of mechanical-draft cooling towers, but do affect the rate of water evaporation in the cooling tower.

- A psychometric analysis of the air passing through a cooling tower illustrates this effect (Figure 2).

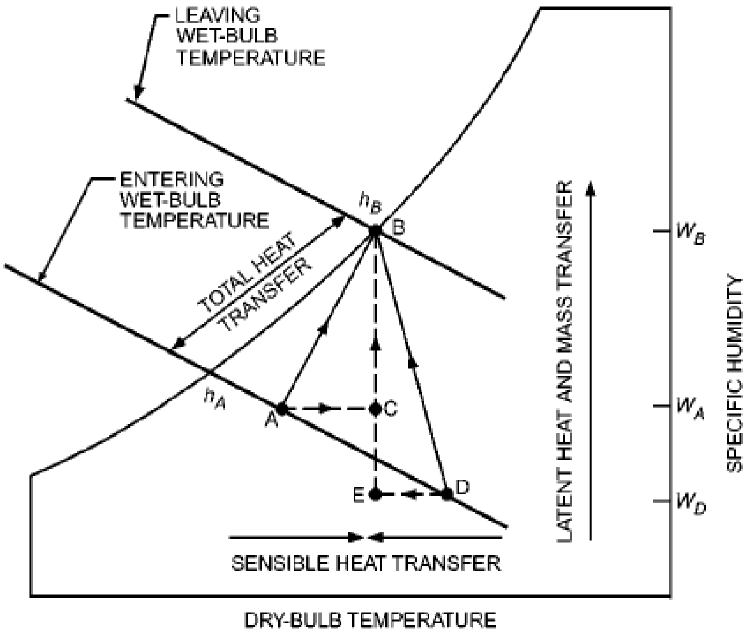

Fig. 2 Psychrometric Analysis of Air Passing Through Cooling Tower

- The evaporation rate at typical design conditions is approximately 1% of the water flow rate for each 7 K of water temperature range; however, the average evaporation rate over the operating season is less than the design rate because the sensible component of total heat transfer increases as entering air temperature decreases.

2. DESIGN CONDITIONS

The thermal capability of any cooling tower may be defined by the following parameters:

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- Entering and leaving water temperatures.
- Entering air wet-bulb (and sometimes dry-bulb) temperatures.
- Water flow rate.

- **The entering air dry-bulb temperature affects the amount of water evaporated from any evaporative cooling tower.** It also affects airflow through hyperbolic towers and directly establishes thermal capability in any indirect contact cooling tower component operating in a dry mode.

- The thermal capability of a cooling tower used for air conditioning may be expressed in nominal capacity, which is based on heat dissipation of 1.25 kW per kilowatt of evaporator cooling.

- Nominal cooling capacity is defined as cooling 54 mL/s of water from 35°C to 29.4°C at a 25.6°C entering air wet-bulb temperature. **At these conditions, the cooling tower rejects 1.25 kW per kilowatt of evaporator capacity.**

3. TYPES OF COOLING TOWERS

- Two basic types of evaporative cooling devices are used. The **direct-contact** or **open cooling tower** (Figure 3), exposes water directly to the cooling atmosphere, thereby transferring the source heat load directly to the air.

- A **closed-circuit cooling tower**, involves **indirect contact** between heated fluid and atmosphere (Figure 4), essentially combining a heat exchanger and cooling tower into one relatively compact device.

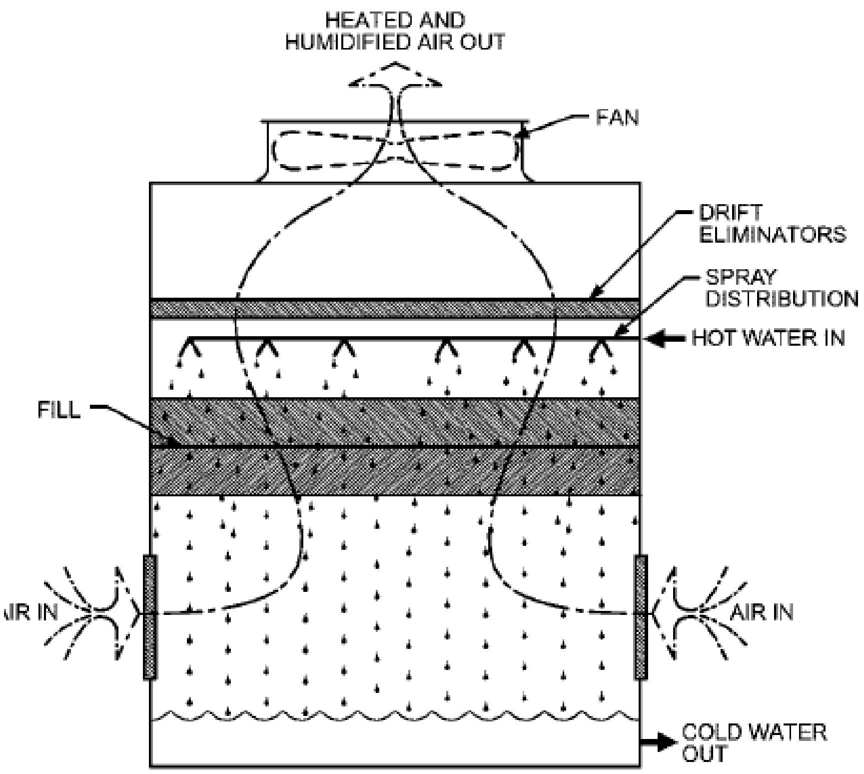

Fig. 3 Direct-Contact or Open Evaporative Cooling Tower

- **Of the direct-contact devices,** the most rudimentary is a spray filled cooling tower that exposes water to the air without any heat transfer medium or fill. In this device, the amount of water surface exposed to the air depends on the spray efficiency, and the time of contact depends on the elevation and pressure of the water distribution system.

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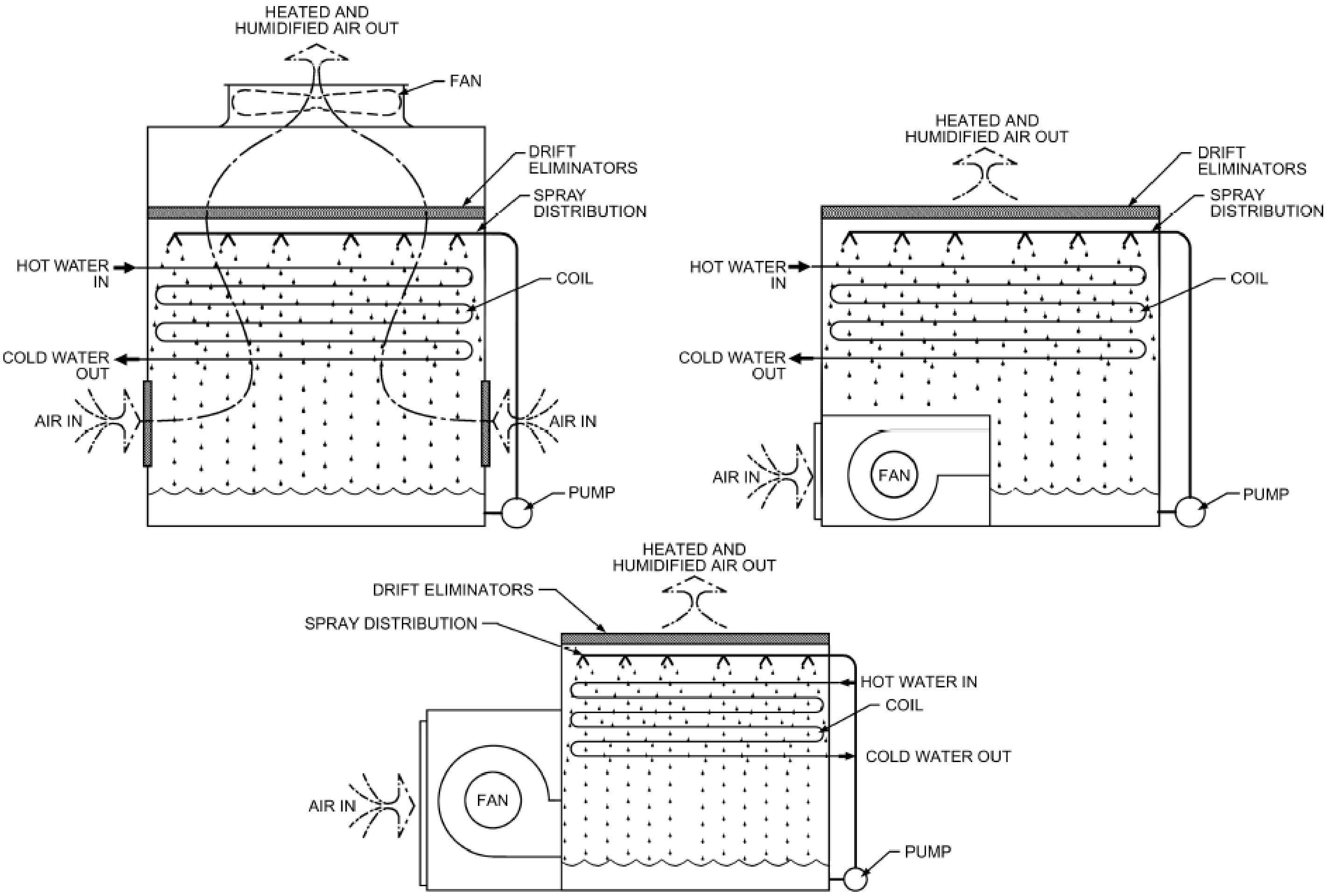

Fig. 4 Indirect-Contact or Closed-Circuit Evaporative Cooling Towers

- **To increase contact surfaces as well as time of exposure,** a heat transfer medium, or fill, is installed below the water distribution system, in the path of the air.

- The two types of fill in use are splash type and film-type (Figure 5A). Splash-type fill maximizes contact area and time by forcing the water to cascade through successive elevations of splash bars arranged in staggered rows. Film-type fill achieves the same effect by causing the water to flow in a thin layer over closely spaced sheets.

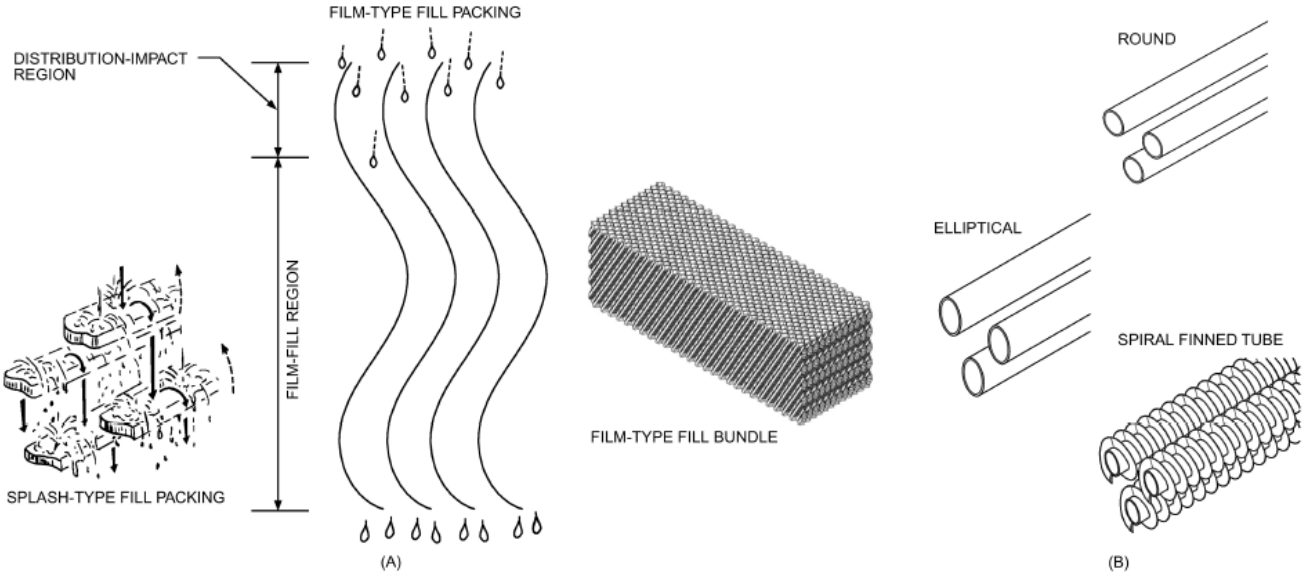

Fig. 5 Types of (A) Fill and (B) Coils

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- Either type of fill can be used in counterflow and cross-flow cooling towers.

- **For thermal performance levels** typically encountered in air conditioning and refrigeration, a tower with film-type fill is usually more compact.

- **However, splash-type fill is less sensitive to initial air and water distribution and, along with specially configured, more widely spaced film-type fills**, is preferred for applications that may be subjected to blockage by scale, silt, or biological fouling.

- **Some closed-circuit cooling tower** designs include cooling tower fill to augment heat exchange in the coil (Figure 6).

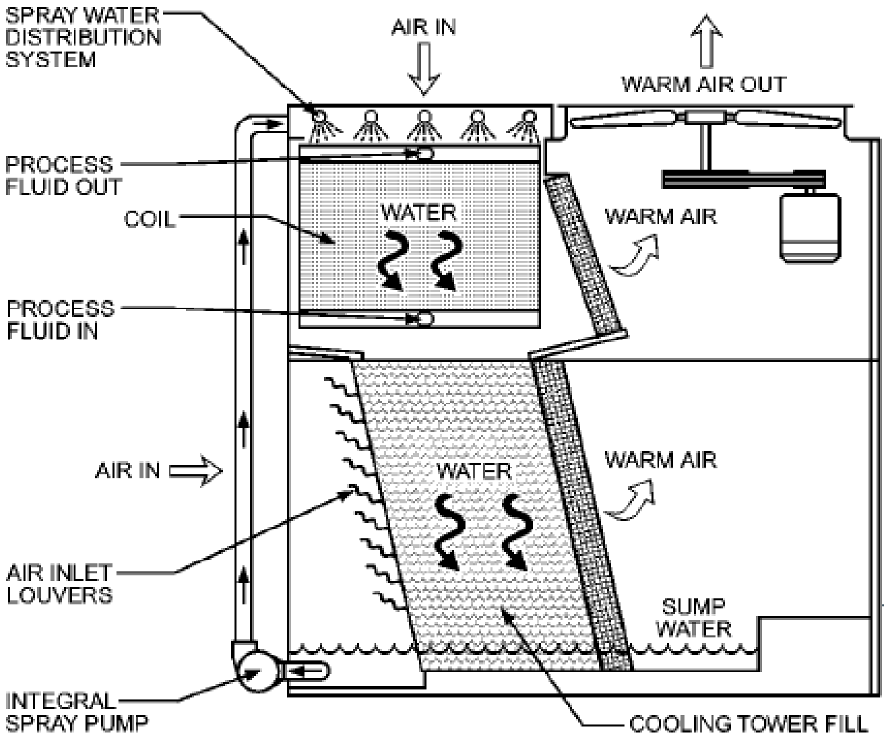

Fig. 6 Combined Flow Coil/Fill Evaporative Cooling Tower

- **Coil shed cooling towers** usually consist of isolated coil sections (nonventilated) located beneath a conventional cooling tower (Figure 7).

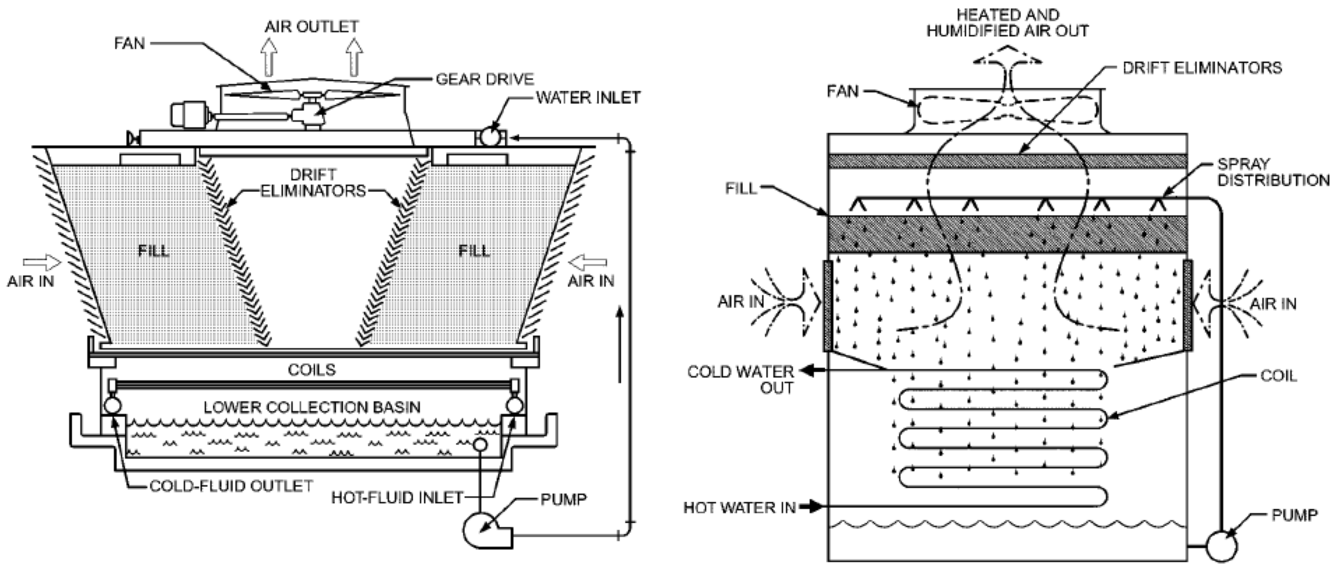

Fig. 7 Coil Shed Cooling Tower

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2.1. Direct-Contact Cooling Towers

- **Non-Mechanical-Draft Cooling Towers.** Aspirated by sprays or a differential in air density, these towers do not contain fill and do not use a mechanical air-moving device. The aspirating effect of the water spray, either vertical (Figure 8) or horizontal (Figure 9), induces airflow through the cooling tower in a parallel flow pattern. Because air velocities for the vertical spray tower (both entering and leaving) are relatively low.

- **Some horizontal spray cooling towers** (Figure 9) use high-pressure sprays to induce large air quantities and improve air/ water contact. Multispeed or staged pumping systems are normally recommended to reduce energy use in periods of reduced load and ambient conditions.

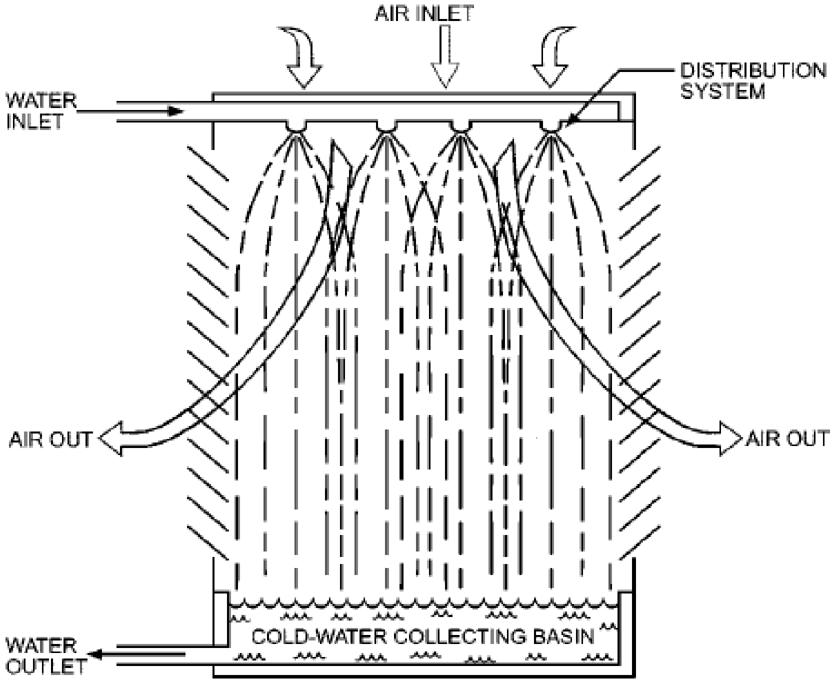

Fig. 8 Vertical Spray Cooling Tower

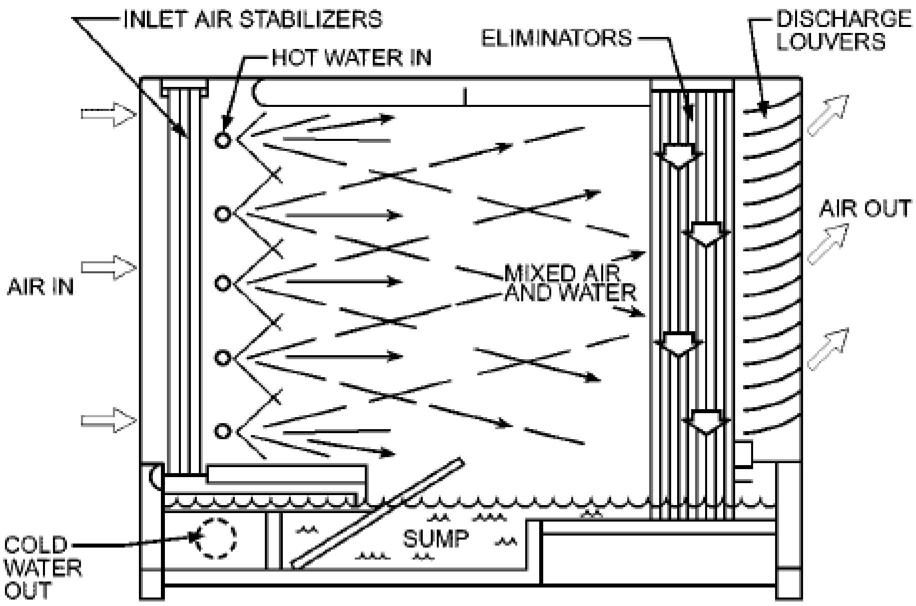

Fig. 9 Horizontal Spray Cooling Tower

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- **Chimney (hyperbolic) towers** have been used primarily for large power installations, but may be of generic interest (Figure 10). The heat transfer mode may be counterflow, cross-flow, or parallel flow. *Air is induced through the cooling tower* by the air density differentials that exist between the lighter, heat-humidified chimney air and the outdoor atmosphere. **Fill can be splash or film type.**

- **Materials used in chimney construction have been** primarily steel-reinforced concrete; early timber structures had size limitations.

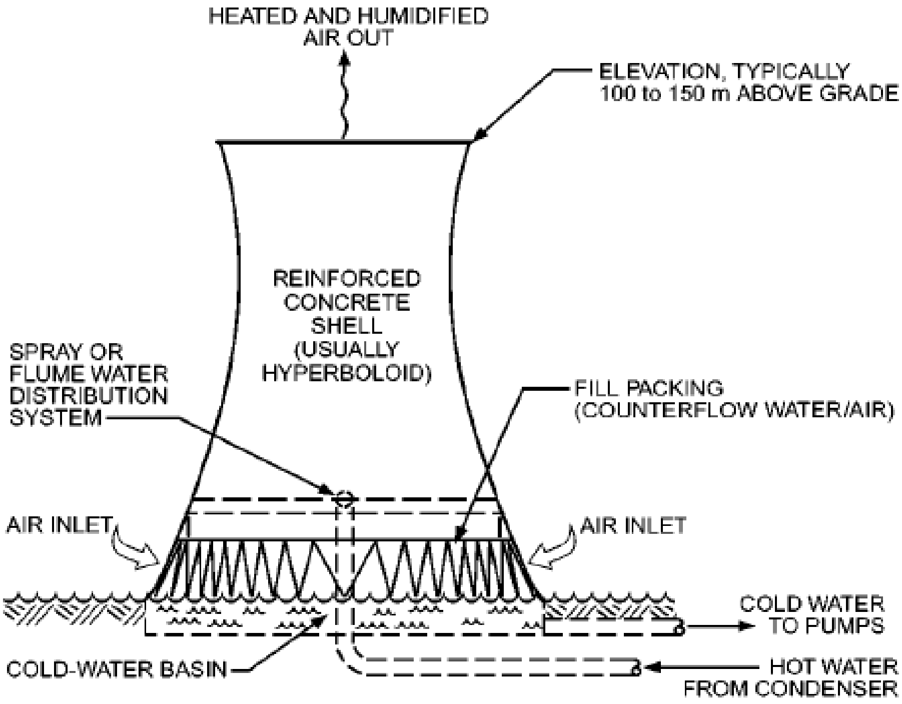

Fig. 10 Hyperbolic Tower

- **Mechanical-Draft Cooling Towers.** Figure 11 shows five different designs for mechanical-draft (conventional) cooling towers. *Fans may be on the inlet air side (forced-draft) or the exit air side (induceddraft).* **The type of fan selected, either centrifugal or axial, depends on external pressure needs, permissible sound levels, and energy usage requirements.** Water is downflow; the air may be upflow (counterflow heat transfer) or horizontal flow (cross-flow heat transfer). Air entry may be through one, two, three, or all four sides of the tower. All four combinations (i.e., forced-draft counterflow, induced-draft counterflow, forced-draft cross-flow, and induced-draft cross-flow) have been produced in various sizes and configurations.

- **Cooling towers are typically classified as either** factory-assembled (Figure 12), where the entire cooling tower or a few large components are factory-assembled and shipped to the site for installation, or field erected (Figure 13), where the tower is constructed completely on site.

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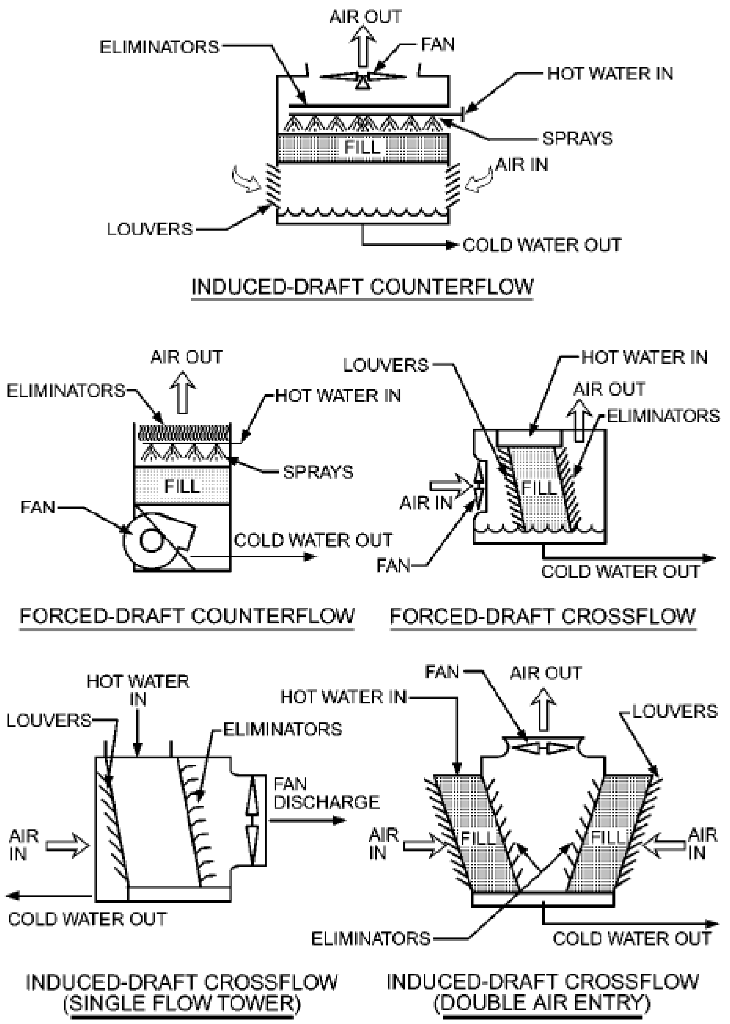

Fig. 11 Conventional Mechanical-Draft Cooling Towers

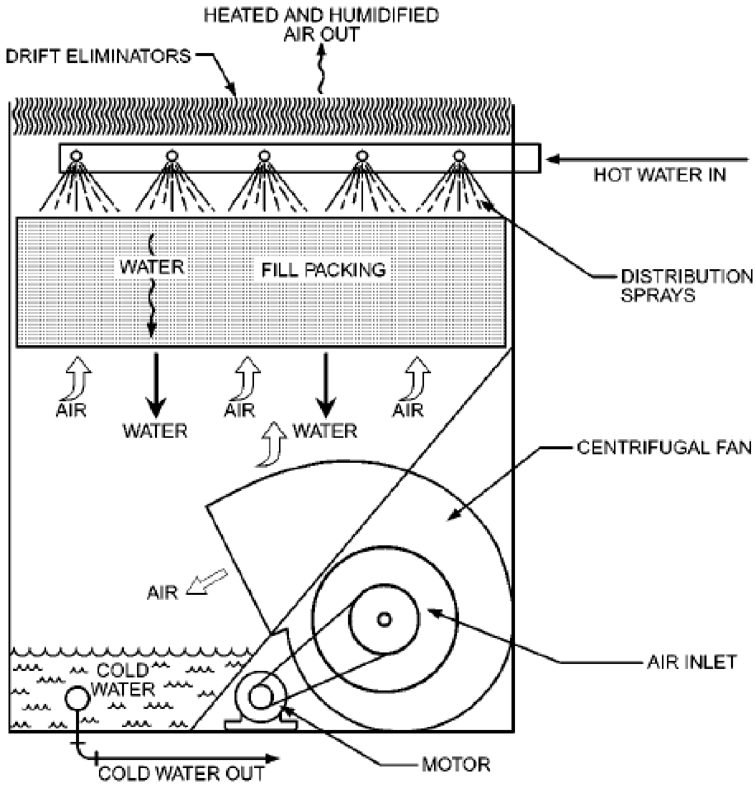

Fig. 12 Factory-Assembled Counterflow Forced-Draft Cooling Tower

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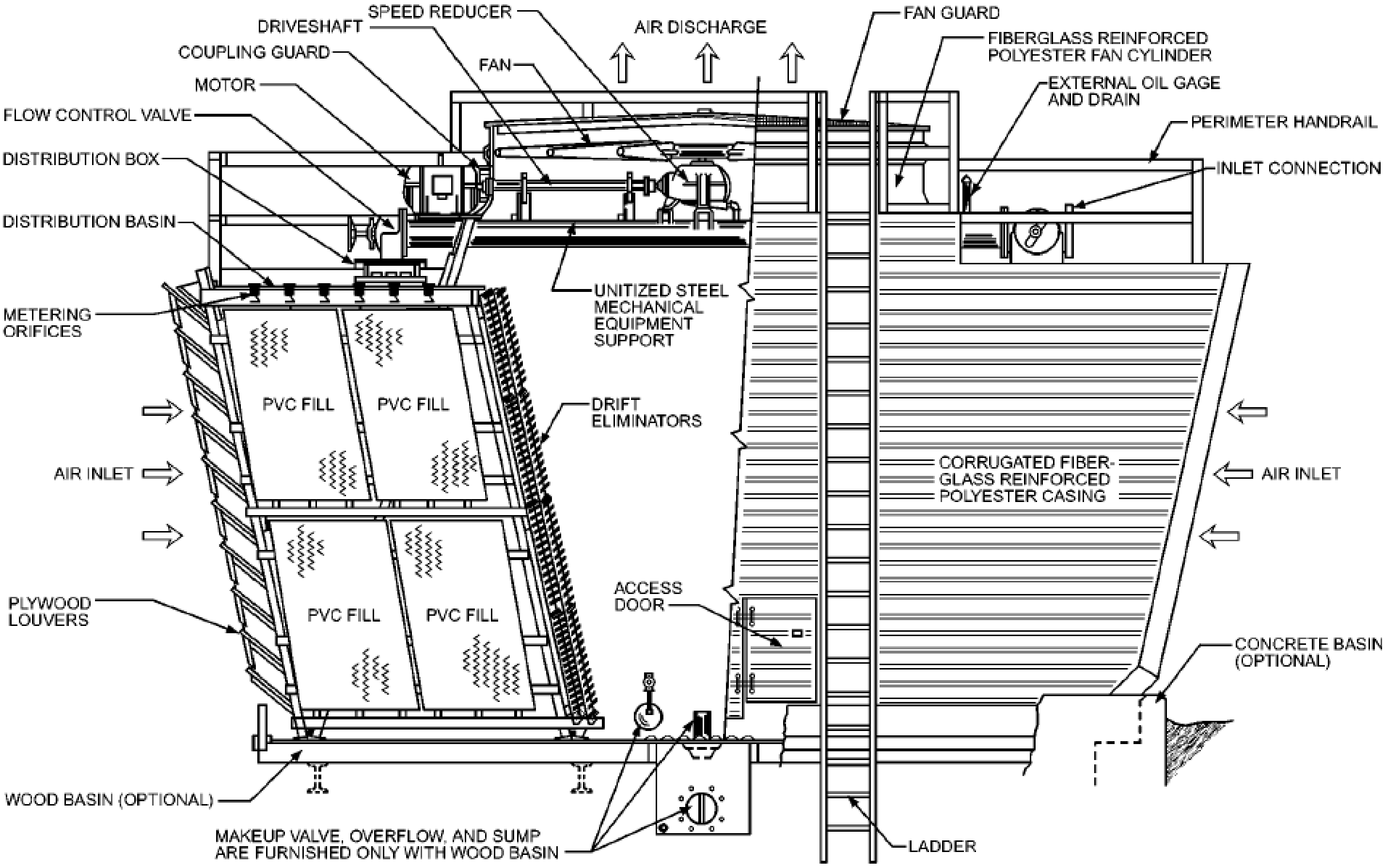

Fig. 13 Field-Erected Cross-Flow Mechanical-Draft Cooling Tower

- **Special-purpose cooling towers** containing a conventional mechanical-draft unit in combination with an air-cooled (finnedtube) heat exchanger are wet/dry cooling towers (Figure 14). They are used for either vapor plume reduction or water conservation. The hot, moist plumes discharged from cooling towers are especially dense in cooler weather. **On some installations, limited abatement of these plumes is required to avoid restricted visibility on roadways, on bridges, and around buildings.**

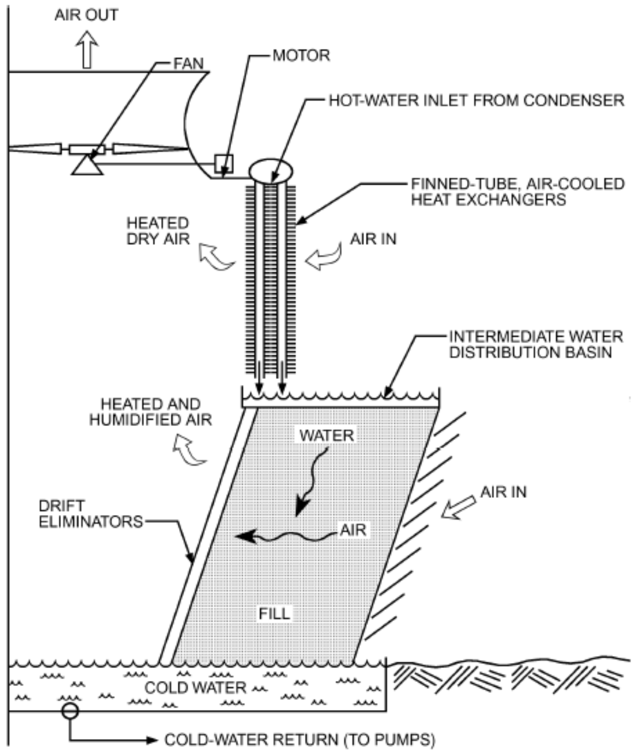

Fig. 14 Combination Wet/Dry Cooling Tower

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- **A variant of the wet/dry cooling tower is an evaporatively precooled/ air-cooled heat exchanger**. It uses an adiabatic saturator (air precooler/humidifier) to enhance summer performance of an aircooled exchanger, thus conserving water compared to conventional cooling towers (annualized) (Figure 15). Evaporative fill sections usually operate only during specified summer periods, whereas full dry operation is expected below 10 to 20°C dry-bulb ambient conditions. Integral water pumps return the lower basin water to the upper distribution systems of the adiabatic saturators in a manner similar to closed-circuit fluid cooler and evaporative condenser products.

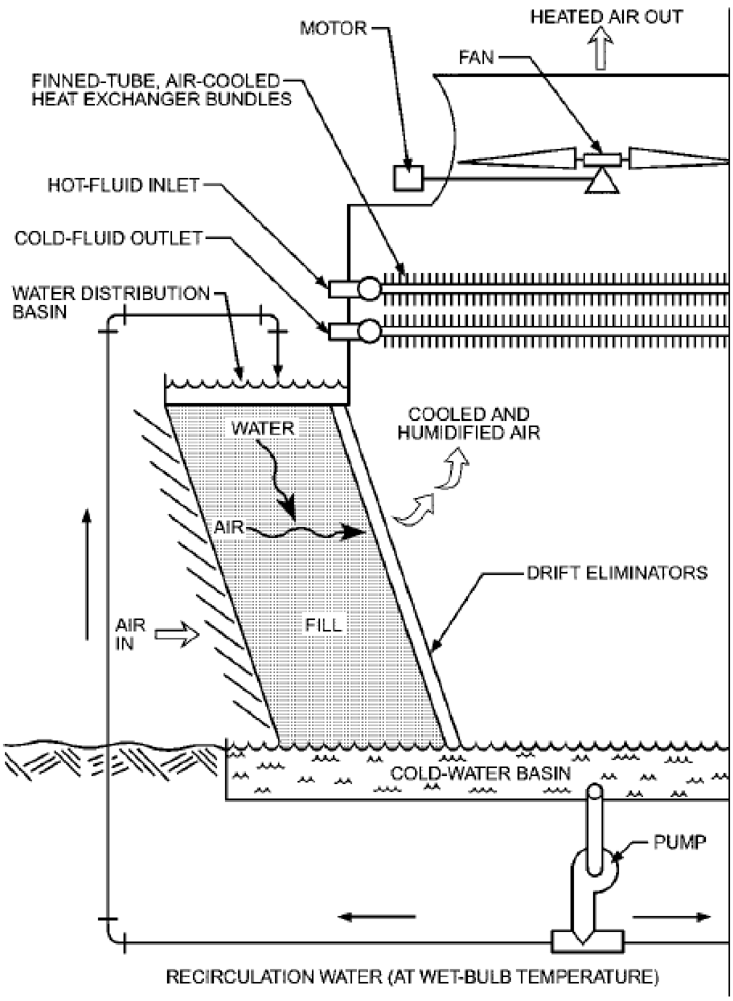

Fig. 15 Adiabatically Saturated Air-Cooled Heat Exchanger

2.2. Indirect-Contact Cooling Towers

- **Closed-Circuit Cooling Towers (Mechanical Draft).** Both counterflow and cross-flow arrangements are used in forced- and induced draft fan arrangements.

- The tubular heat exchangers are typically serpentine bundles, usually arranged for free gravity internal drainage.

- **Pumps** are integrated in the product to transport water from the lower collection basin to upper distribution basins or sprays.

- **Indirect-contact cooling towers** (see Figure 4) require a closed circuit heat exchanger (usually tubular serpentine coil bundles) that is exposed to air/water cascades similar to the fill of a cooling tower.

- **Some types include** supplemental film or splash fill sections to augment the external heat exchange surface area. In Figure 6, air flows down over the coil, parallel to the recirculating water, and exits

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horizontally into the fan plenum, Recirculating water then flows over cooling tower fill, where it is further cooled by a second airstream before being reintroduced over the coil.

- **Open- and closed-circuit cooling tower capacities are not directly comparable** because of the intermediate step of heat transfer in the closed-circuit design.

- Closed-circuit cooling towers are more readily comparable to a combination of an open-circuit cooling tower and liquid-to-liquid heat exchanger, such as a plate-and-frame heat exchanger (see Figure 22).

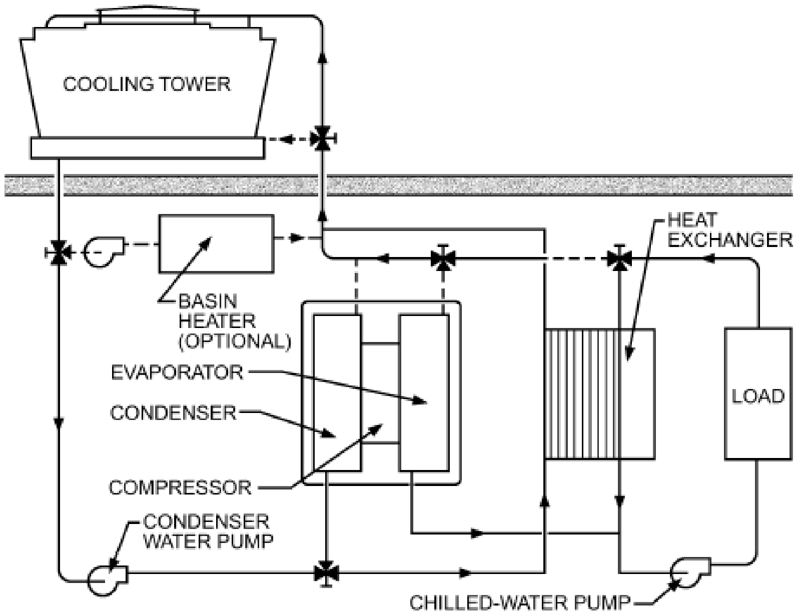

Fig. 22 Free Cooling by Auxiliary Heat Exchanger

2.3. Hybrid Cooling Towers

- **Hybrid cooling towers** combine sensible, adiabatic, and evaporative cooling to reduce water and energy requirements compared to conventional cooling equipment.

- **Water savings are** achieved through different operational combinations of these cooling types. When more adiabatic, direct evaporative, or indirect evaporative cooling is used, less energy is consumed at the expense of using more water.

- **Conversely**, when more direct sensible cooling is used, less water is consumed at the expense of using more energy.

- The following operational modes can be used singly or in combination:

Wet Mode (**Figure 16**). This mode uses only evaporative cooling during elevated temperature or load conditions. It optimizes fan energy and/or process fluid temperatures with increased water consumption from evaporation.

Dry/Wet Mode (**Figure 17**). The dry/wet mode simultaneously uses evaporative and sensible cooling when allowed by moderate temperature or load conditions. This mode meets load requirements while reducing water consumption from evaporation through increased fan energy consumption or modulating flow through the evaporative coil. It may also reduce plumes.

Adiabatic Mode (**Figure 18**). This mode rejects heat through the dry coil, and the recirculating spray water merely serves to saturate and adiabatically precool incoming outdoor air. Adiabatic cooling of the incoming air results in lower air temperatures, which increases the rate of sensible heat transfer. Visible plume and water consumption are greatly reduced.

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Dry Mode (Figure 19). The dry mode uses sensible cooling when allowed by reduced load and/or ambient temperatures. This mode eliminates water consumption from evaporation while meeting load requirements through increased fan energy. Plume is avoided with this mode.

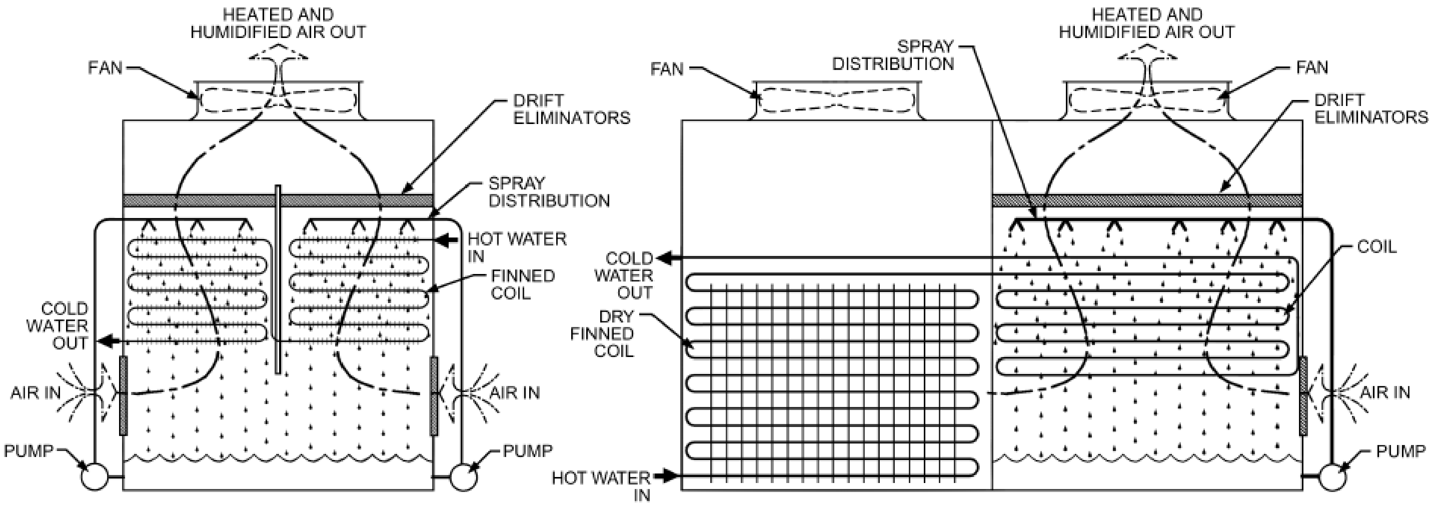
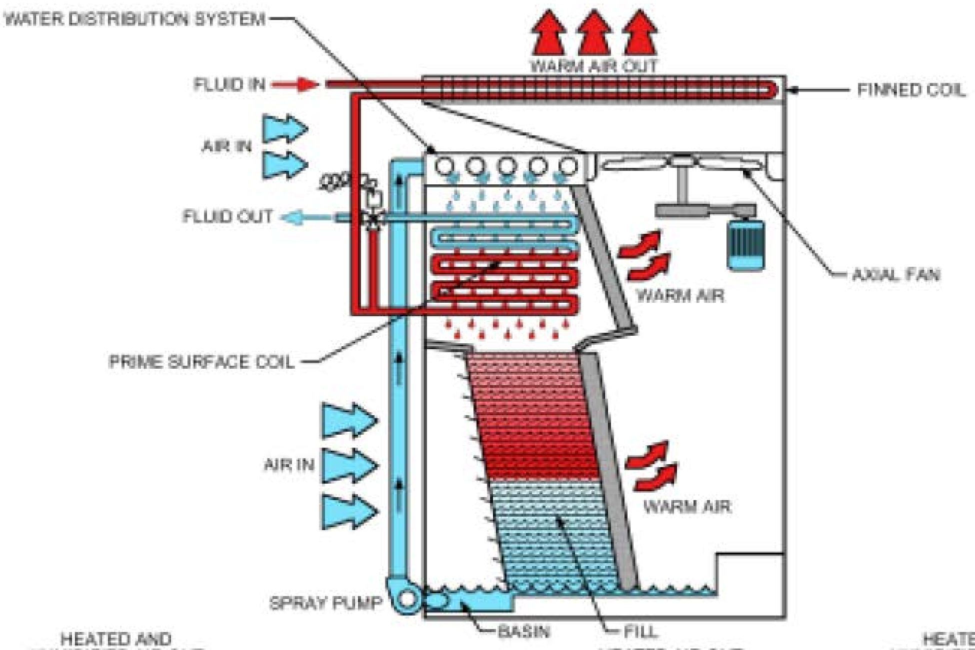


Fig. 16 Hybrid Cooling Towers in Wet Operational Mode



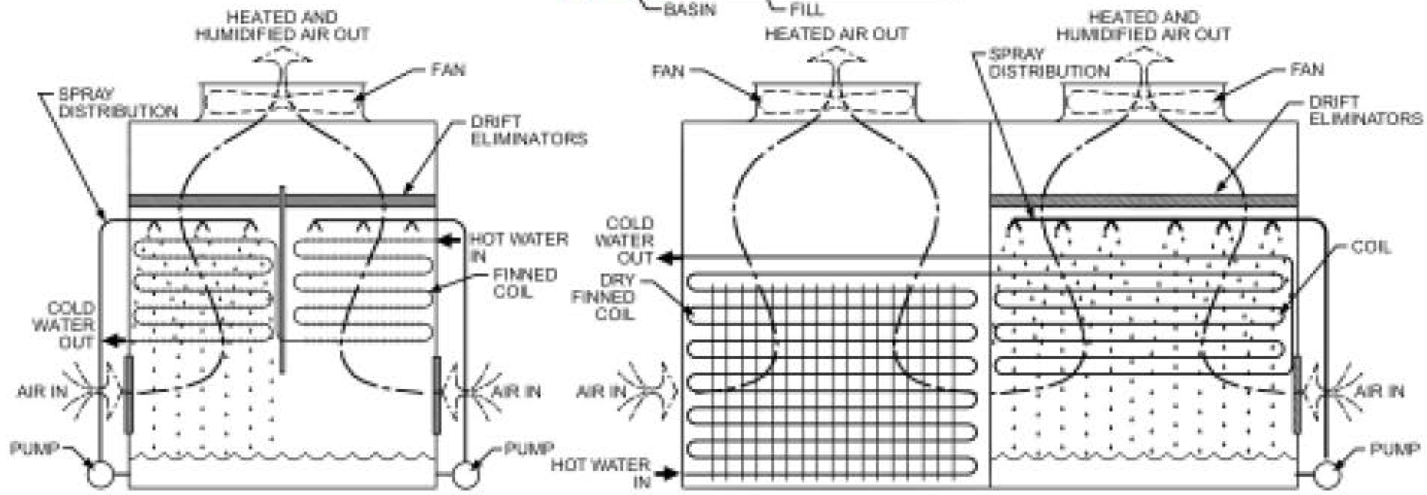


Fig. 17 Hybrid Cooling Towers in Dry/Wet Operational Mode

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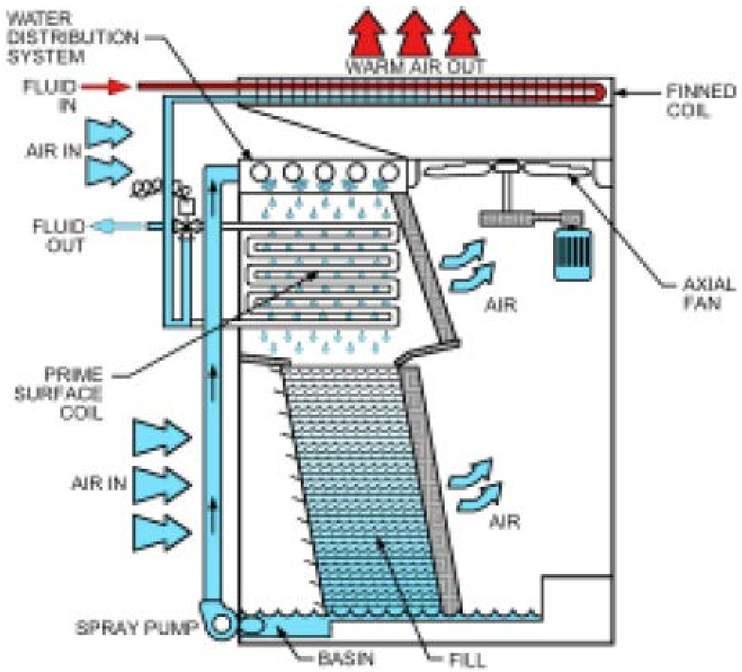

Fig. 18 Hybrid Cooling Tower in Adiabatic Operational Mode

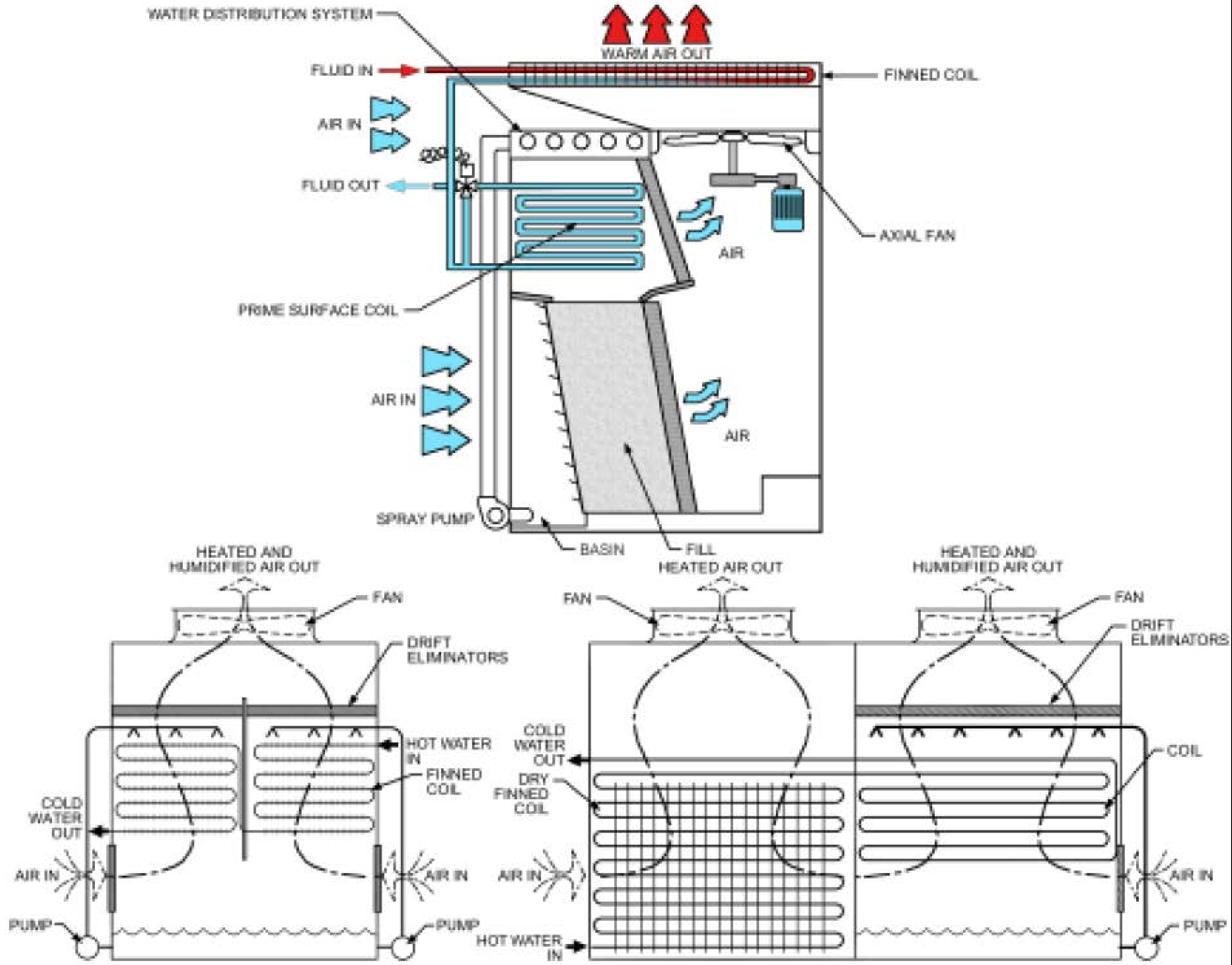

Fig. 19 Hybrid Cooling Towers in Dry Operational Mode

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4. MATERIALS OF CONSTRUCTION

- Materials for cooling tower construction are usually selected to meet the expected water quality and atmospheric conditions:

- Wood.
- Metals.
- Plastics.
- Graphite Composites.
- Concrete, Masonry, and Tile.

5. SELECTION CONSIDERATIONS

- **Selecting the proper water-cooling equipment** for a specific application requires consideration of cooling duty, economics, required services, environmental conditions, maintenance requirements, and aesthetics. **Many of these factors are interrelated, but they should be evaluated individually.** Because a wide variety of water-cooling equipment may meet the required cooling duty, factors such as height, length, width, volume of airflow, fan and pump energy consumption, materials of construction, water quality, and availability influence final equipment selection.

- The optimum choice is generally made after an economic evaluation.

- **Chapter 37 of the 2015 ASHRAE Handbook—HVAC Applications describes two common methods of economic evaluation:** life-cycle costing and payback analysis. Each of these procedures compares equipment on the basis of total owning, operating, and maintenance costs.

- Initial-cost comparisons consider the following factors:

- Erected cost of equipment.
- Costs of interface with other subsystems, which include items such as.
- Basin grillage and value of the space occupied.
- Pumps and prime movers.
- Electrical wiring to pump and fan motors.
- Electrical controls and switchgear.
- Piping to and from the cooling tower (some designs require more inlet and discharge connections than others, thus affecting the cost of piping).
- Cooling tower basin, basin screens, overflow piping, and makeup lines, if not furnished by the manufacturer.
- Shutoff and control valves, if not furnished by the manufacturer.
- Walkways, ladders, etc., providing access to the tower, if not furnished by the manufacturer.
- Fire protection sprinkler system.

- In evaluating owning and maintenance costs, consider the following major items:

- System energy costs (fans, pumps, etc.) on the basis of operating hours per year.
- Energy demand charges.
- Expected equipment life.
- Maintenance and repair costs.
- Money costs.
- Life-cycle cost.
- Water availability.

- **Other factors are** (1) safety features and safety codes; (2) conformity to building codes; (3) general design and rigidity of structures; (4) relative effects of corrosion, scale, or deterioration on service life; (5) availability of spare parts; (6) experience and reliability of manufacturers; (7) independent certification of thermal ratings; and (8) operating flexibility for economical operation at varying loads or during seasonal changes. In addition, equipment vibration, sound levels, acoustical attenuation, and compatibility with the architectural design are important. **The following section details many of these more important considerations.**

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6. APPLICATION

This section describes some of the major design considerations, **but the cooling tower manufacturer should be consulted for more detailed recommendations.**

6.1. Siting

When a cooling tower can be located in an open space with free air motion and unimpeded air supply, siting is normally not an obstacle to satisfactory installation. However, cooling towers are often situated indoors, against walls, or in enclosures. **In such cases, the following factors must be considered:**

- Sufficient free and unobstructed space **should be provided around the unit to ensure an adequate air supply to the fans and to allow proper servicing.**
- **Cooling tower discharge air should not be deflected in any way that might promote recirculation [a portion of the warm, moist discharge air re-entering the cooling tower** (Figure 20)]. **Recirculation raises the entering wet-bulb temperature, causing increased hot water and cold water temperatures, and, during cold weather operation,** can promote the icing of air intake areas. **The possibility of air recirculation should be considered, particularly on multiple tower installations.**

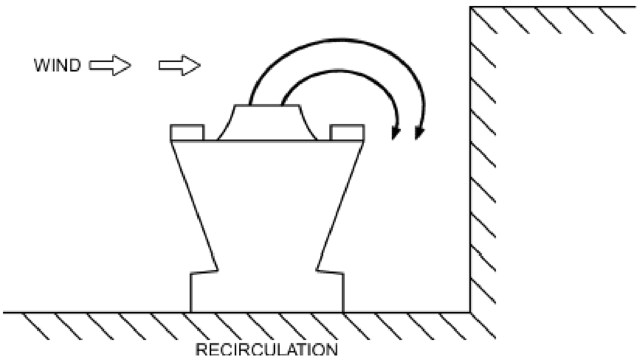

Fig. 20 Discharge Air Reentering Cooling Tower

- Additionally, **cooling towers should be located to prevent introducing the warm discharge air and any associated drift, which may contain chemical and/or biological contaminants, into the fresh air intake of the building that the tower is serving or into those of adjacent buildings.**
- **Location of the cooling tower is usually determined by one or more of the following:**

1- Structural support requirements,
2- Rigging limitations.
3- Local codes and ordinances.
4- Cost of bringing auxiliary services to the cooling tower and architectural compatibility.
5- Sound, plume, and drift considerations are also best handled by proper site selection during the planning stage.

For additional information on seismic and wind restraint, see **Chapter 55 of the 2015 *ASHRAE Handbook—HVAC Applications*.**

6.2. Piping

- **Piping should be adequately sized according to standard commercial practice.**
- **All piping should be designed to allow expansion and contraction.**
- **If the cooling tower has more than one inlet connection, balancing valves should be installed to balance the flow to each cell properly.**

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- **Positive shutoff valves should be used, if necessary, to isolate individual cells for servicing.**

- **When two or more cooling towers operate in parallel**, **an equalizer line between the cooling tower basins handles imbalances in the piping to and from the units and changing flow rates that arise from obstructions such as clogged orifices and strainers**.

- **All heat exchangers, and as much tower piping as possible**, **should be installed below the operating water level in the cooling tower to prevent overflowing of the cooling tower at shutdown and to ensure satisfactory pump operation during start-up.**

- **Cooling tower basins must carry the proper amount of water during operation to prevent air entrainment into the water suction line.**

- **Basins should also have enough reserve volume between the operating and overflow levels to fill riser and water distribution lines on start-up and to fulfil the water-in suspension requirement of the cooling tower.**

- **Unlike open cooling towers, closed-circuit cooling towers can be installed anywhere, even below the heat exchangers, as the fluid to be cooled is contained in a closed loop; the external spray water is self-contained within the closed-circuit cooling tower.**

6.3. Capacity Control

- Most cooling towers encounter substantial changes in ambient wet-bulb temperature and load during the normal operating season. Accordingly, some form of capacity control may be required to maintain prescribed system temperatures or process conditions.

- **Frequency-modulating controls for fan motor speed can provide virtually infinite capacity control and energy management**. *Previously, automatic, variable-pitch propeller fans were the only way to do this.* However, these mechanically complex drive systems are more expensive and have higher sound levels, because they operate at full design speed only. They have been replaced by variable frequency drives (VFDs) coupled with a standard fixed-pitch fan, thereby saving more fan energy and operating significantly more quietly than cycling fans, especially at less than full load.

- ***Variable-frequency fan drives are*** economical and can save considerable energy as well as extend the life of the motor, fan, and drive (gearbox or V-belt) assembly compared to fan cycling or two speed control. **However, the following special considerations must be discussed with the cooling tower manufacturer and the supplier of the VFD:**

1- **Care must be taken to avoid operating the fan system at a critical speed or a multiple thereof**. **Critical speeds** *are fan operating speeds identical to one of the natural frequencies of the fan assembly and/or supporting structure*. At these speeds, fan resonance occurs, resulting in excessive vibration and possibly fan system failure, sometimes very quickly. **Consult the tower manufacturer on what speeds (if any) must be avoided**. **Alternatively**, *the tower can be tested at start-up using an accelerometer to identify critical frequencies throughout the full speed range, though this is generally not necessary with pre-engineered, factory-assemble units.* **Critical frequencies, identified either by the manufacturer or through actual testing, must be locked out in the VFD skip frequency program.**

2- **Some VFDs, particularly pulse-width modulating (PWM) drives**, create overvoltage at the motor that can cause motor and bearing failures. The magnitude of these overvoltage increases significantly with the length of cable between the controller and the motor, **so lead lengths should be kept as short as possible.** *Special motors, filters, or other corrective measures may be necessary to ensure dependable operation.* **Consult the cooling tower manufacturer and/or the VFD supplier**. Chapter 45 also has more information on variable-frequency drives.

3- **A VFD-compatible motor should be specified on all cooling towers with variable-frequency drive.**

4- *Most VFDs can modulate down to 10% or less of full motor speed.* However, a given cooling tower may have special limits below 25% speed. **If operating below 25% speed, consult the cooling tower manufacturer on the possible limits of their equipment.**

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- **Two-speed fan motors or additional lower-power pony motors,** in conjunction with fan cycling, can double the number of steps of capacity control compared to fan cycling alone. This is particularly useful on single-fan motor units, which would have only one step of capacity control by fan cycling. **Two-speed fan motors provide the added advantage of reduced energy consumption at reduced load.** *Pony motors, which are typically sized for 1/3 of the power of the main motor, provide redundancy in case one motor fails in addition to energy savings.*

- **It is more economical to operate all fans at the same speed than to operate one fan at full speed before starting the next.** *For example,* two cells operating at half speed (12.5% of full-speed power) have similar cooling capacity as one cell operating at full speed and one cell with the fan off. However, two cells operating at half speed use one-fourth the power (12.5% + 12.5%) of the one cell operating at full speed (100%). Figure 21 compares cooling tower fan power versus speed for single-, two-, and variable-speed fan motors.

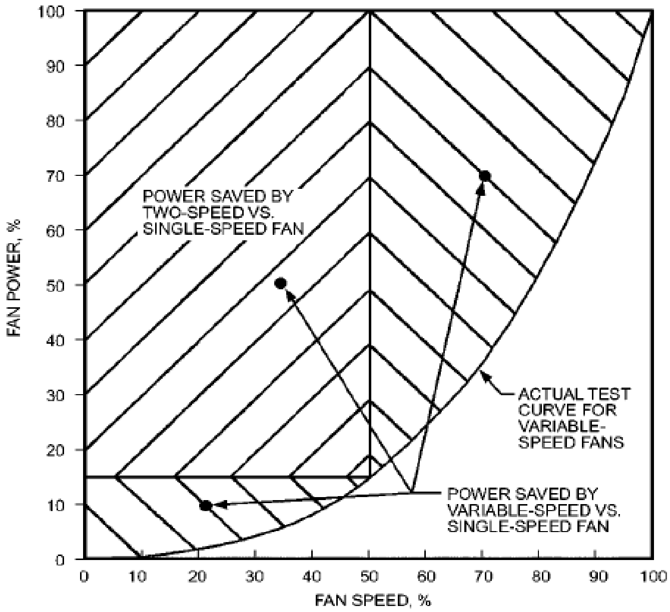

Fig. 21 Cooling Tower Fan Power Versus Speed
(White 1994)

- **Modulating dampers in the discharge of centrifugal blower fans are also used for cooling tower capacity control, as well as for energy management.** In some cases, modulating dampers may be used with two-speed motors. **Note that modulating dampers have been replaced by variable-frequency drives for these purposes.**

- **Cooling towers that inject water to induce airflow through the cooling tower have various pumping arrangements for capacity control. Multiple pumps in series or two-speed pumping provide capacity control and also reduce energy consumption.**

- **Modulating water bypasses for capacity control should be used only after consultation with the cooling tower manufacturer. This is particularly important at low ambient conditions in which the reduced water flow can promote freezing within the cooling tower.**

6.4. Water-Side Economizer (Free Cooling)

- *With an appropriately equipped and piped system, using the cooling tower for free cooling during reduced load and/or reduced ambient conditions* **can significantly reduce system energy consumption**. Because the cooling tower's cold-water temperature drops as the load and ambient temperature drop, the water temperature will eventually be low enough to serve the load directly, allowing the energy-intensive chiller to be shut off. Figures 22 to 24 outline three methods of free cooling but do not show all of the piping, valving, and controls that may be necessary for the functioning of a specific system.

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- **Indirect Free Cooling.** *This type of cooling separates the condenser-water and chilled-water circuits* and may be accomplished in the following ways:

1- A separate heat exchanger in the system (usually plate-and frame) allows heat to transfer from the chilled-water circuit to the condenser-water circuit by total bypass of the chiller system (Figure 22).

2- An indirect-contact, closed-circuit evaporative cooling tower (Figures 4, 6, and 7) also allows indirect free cooling and eliminates the need for an additional heat exchanger. Its use is covered in the following section on Direct Free Cooling.

3- In vapour migration system (Figure 23), bypasses between the evaporator and condenser allow migratory flow of refrigerant vapour to the condenser; they also allow gravity flow of liquid refrigerant back to the evaporator without compressor operation. Not all chiller systems are adaptable to this arrangement, and those that are may offer limited load capability under this mode. In some cases, auxiliary pumps enhance refrigerant flow and, therefore, load capability.

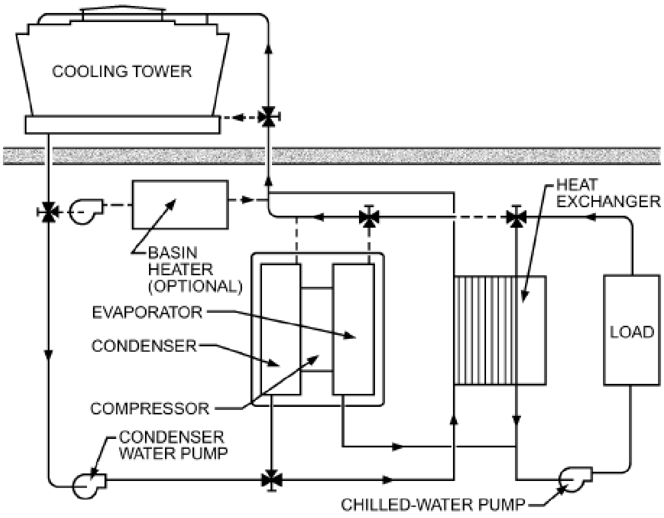

Fig. 22 Free Cooling by Auxiliary Heat Exchanger

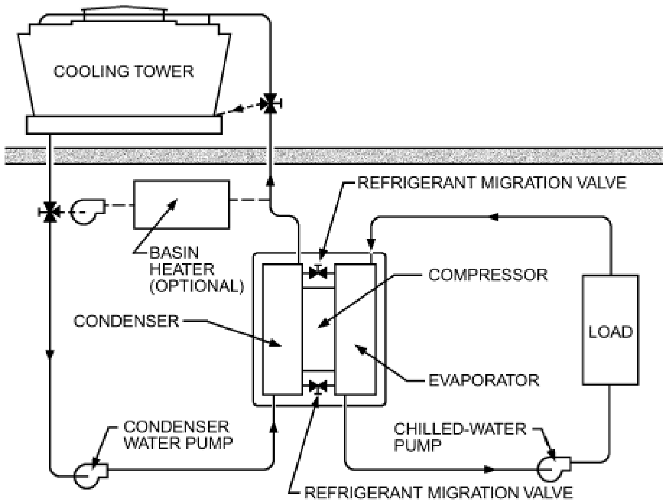

Fig. 23 Free Cooling by Refrigerant Vapor Migration

- **Direct Free Cooling.** *This type of cooling involves interconnecting the condenser-water and chilled-water circuits so the cooling tower water serves the load directly* (Figure 24). In this case, the chilled-water pump is normally bypassed so design water flow can be maintained to the cooling tower. **The primary disadvantage of the direct free-cooling system is that it allows the relatively dirty condenser water to contaminate the clean chilled-water system. Although filtration systems (either side-stream or full-flow) minimize this contamination, many specifiers consider it to be an overriding concern. Using a closed-circuit (indirect-contact) cooling tower eliminates this contamination**. During summer, water from the cooling tower is circulated in a closed loop through the condenser. During winter, water from the cooling tower is circulated in a closed loop directly through the chilled-water circuit.

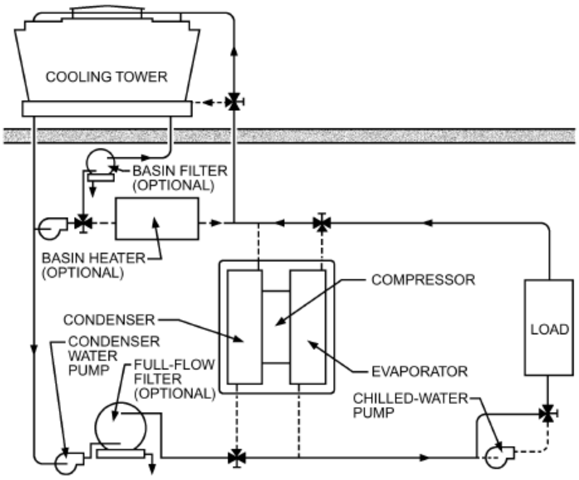

Fig. 24 Free Cooling by Interconnection of Water Circuits

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6.5. Winter Operation

- **When a cooling tower is to be used in freezing climates,** the following design and operating considerations are necessary.

6.5.1. Open Circulating Water.

- *Direct-contact cooling towers can be winterized by a suitable method of capacity control that maintains the temperature of water leaving the cooling tower well above freezing*. **In addition, during cold weather, regular visual inspections of the cooling tower should be made to ensure all controls are operating properly.**

- **On induced-draft axial fan cooling towers**, fans may be periodically operated in reverse, usually at low speed, to deice the air intake areas. Using fan cycling or (preferably) variable-frequency drives minimizes the possibility of icing by matching cooling tower capability with the load. *Some icing can be expected at the cold air/water interface.* **Good operating practice includes frequent inspections of the cooling tower, especially during extremely cold weather.**

- Recirculation of moist discharge air on forced-draft equipment can cause ice formation on inlet air screens and fans. Installing vibration cut out switches can minimize the risk of damage from ice formation on rotating equipment.

6.5.2. Closed Circulating Water

- When system design allows, the best protection is to use an antifreeze solution. *When this is not possible*, **supplemental heat must be provided to the heat exchanger, and the manufacturer should be consulted about the amount of heat input required.**

- **Positive-closure damper hoods** are also available from many manufacturers to reduce heat loss from the coil section and thus reduce the amount of heat input required.

- **All exposed piping to and from the closed-circuit cooling tower should be insulated and heat traced**.

- **In case of a power failure** during freezing weather and where water is used in the system, the heat exchanger should include an emergency draining system.

6.5.3. Basin Water

- **Freeze protection for basin water** *in an idle cooling tower or closed-circuit cooling tower can be obtained by various means.* **A good method is to use** an auxiliary sump tank located in a heated space. When a remote sump is impractical, auxiliary heat must be supplied to the cooling tower basin to prevent freezing.

- Common sources are electric immersion heaters and steam and hot water coils.

- **Towers that do not operate in the winter should be cleaned and drained**.

- **Consult the cooling tower manufacturer for the exact heat requirements to prevent freezing at design winter temperatures**.

- Using dry cooling on closed-circuit cooling towers during winter operation eliminates the potential for ice build-up on air inlet louvers and may allow the basin water to be drained.

- **All exposed water lines susceptible to freezing should be protected by electric heat tape or cable and insulation.** This precaution applies to all lines or portions of lines that have water in them when the cooling tower is shut down.

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6.6. Sound

- Sound has become an important consideration in the selection and siting of outdoor equipment such as cooling towers and other evaporative cooling devices.

- ***Many communities*** *have enacted legislation that limits allowable sound levels of outdoor equipment.* Even if legislation does not exist, people who live and work near a cooling tower installation may object if the sound intrudes on their environment. Because the cost of correcting a sound problem may exceed the original cost of the cooling tower, **sound should be considered in the early stages of system design.**

- **To determine the acceptability of cooling tower sound levels in a given environment:**

    - **The first step** is to establish a noise criterion for the area of concern. This may be an existing or pending code or an estimate of sound levels that will be acceptable to those living or working in the area.

    - **The second step** is to estimate the sound levels generated by the tower at the critical area, taking into account the effects of the cooling tower installation geometry and the distance from the tower to the critical area.

    - **Often, the cooling tower manufacturer can supply sound rating data on a specific unit that serve as the basis for this estimate.**

    - **Lastly,** *the noise criterion is compared to the estimated tower sound levels to determine the acceptability of the installation.*

- **VFDs can also be programmed to run at lower speeds during light-load periods**, *such as at night, if these correspond to critical sound-sensitive periods.*

- **In critical situations,** effective solutions may include barrier walls between the cooling tower and the sound-sensitive area, acoustical treatment of the cooling tower, or using low-sound fans.

- **Attenuators specifically designed for the tower are available from most manufacturers.** It may also be practical to install a cooling tower larger than would normally be required and lower the sound levels by operating the unit at reduced fan speed. This also has the advantage of saving energy because of the smaller fan motor(s), which can quickly pay for the added investment in the larger cooling tower.

- For additional information on sound control, s**ee Chapter 48 of the 2015 *ASHRAE Handbook—HVAC Applications*.**

6.7. Drift

- Water droplets become entrained in the airstream as it passes through the cooling tower. Although eliminators strip most of this water from the discharge airstream, some discharges from the tower as drift.

- *The rate of drift loss from a cooling tower is a function of cooling tower configuration,* eliminator design, airflow rat through the tower, and water loading.

- **Generally**, an efficient eliminator design reduces maximum drift loss to between 0.001 and 0.005% of the water circulation rate.

- Because drift contains the minerals of the makeup water (which may be concentrated three to five times) and often contains water treatment chemicals, **cooling towers should not be placed near parking areas, large windowed areas, or architectural surfaces sensitive to staining or scale deposits.**

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6.8. Fogging (Cooling Tower Plume)

- **Cooling tower plumes** *form when water vapour generated in the cooling tower mixes with the colder ambient air as it leaves the tower and condenses.* They are often seen at power plants, chemical plants, data centres and commercial buildings.

- **Fog persistence depends** on its original intensity and on the degree of mechanical and convective mixing with ambient air that dissipates the fog.

- **Methods of reducing or preventing fogging have taken many forms,** including heating the cooling tower exhaust with natural gas burners or hot-water or steam coils, installing precipitators, and spraying chemicals at the tower exhaust. **However**, **such solutions are generally costly to operate and are not always effective. The simplest solution is to allow the leaving water temperature to drop below design, which helps reduce the temperature difference between the water and the ambient air. This can reduce the density of the plume, making it less objectionable or, depending on the specific conditions, eliminating it.**

- **Hybrid closed-circuit cooling towers operating in dry/wet or dry mode** can minimize or prevent fogging.

- **Often, however, the most practical solution to tower fogging is to locate the cooling tower where visible plumes, should they form, will not be objectionable. Accordingly, when selecting cooling tower sites, the potential for fogging and its effect on tower surroundings, such as large windowed areas or traffic arteries, should be considered.**

6.9. Maintenance

- *Usually, the cooling tower manufacturer furnishes operating and maintenance manuals that include recommendations for procedures and intervals as well as parts lists for the specific unit.* **These recommendations should be followed when formulating the maintenance program for the cooling tower.**

- Efficient operation and thermal performance of a cooling tower depend not only on mechanical maintenance, but also on cleanliness. **Accordingly, cooling tower owners should incorporate the following as a basic part of their maintenance program**:

    - Periodic inspection of mechanical equipment, fill, and both hot and cold-water basins to ensure that they are maintained in a good state of repair.

    - Periodic draining and cleaning of wetted surfaces and areas of alternate wetting and drying to prevent accumulation of dirt, scale, or biological organisms, such as algae and slime, in which bacteria may develop.

    - Proper treatment of circulating water for biological control and corrosion, in accordance with accepted industry practice.
    - Systematic documentation of operating and maintenance functions. This is extremely important because without it, no policing can be done to determine whether an individual has actually adhered to a maintenance policy.

6.10.Inspections

The following should be checked daily (no less than weekly) in an informal walk-through inspection:

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Maintenance

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- Proper treatment of circulating water for biological control and corrosion, in accordance with accepted industry practice.
- Systematic documentation of operating and maintenance functions. This is extremely important because without it, no policing can be done to determine whether an individual has actually adhered to a maintenance policy.

Inspections

The following should be checked daily (no less than weekly) in an informal walk-through inspection. Areas requiring attention have been loosely grouped for clarity, although category distinctions are often hazy because the areas are interdependent.

Performance. Optimum performance and safety depend on the operation of each individual component at its designed capability. A single blocked strainer, for instance, can adversely affect the capacity and efficiency of the entire system. Operators should always be alert to any degradation in performance, as this usually is the first sign of a problem and is invaluable in pinpointing minor problems before they become major. Consult the equipment manufacturers to obtain specific information on each piece of equipment (for both maintenance and technical characteristics), and keep manuals handy for quick reference.

Check and record all water and refrigerant temperatures, pump pressures, outdoor conditions, and pressure drops (differential pressure) across condensers, heat exchangers and filtration devices. This record helps operators become familiar with the equipment as it operates under various load conditions and provides a permanent record that can be used to calculate flow rates, assess equipment efficiency, expedite diagnostic procedures, and adjust maintenance and water treatment regimens to obtain maximum performance from the system.

For those units with water-side economizers using plate heat exchangers, check temperature and pressure differentials daily for evidence of clogging or fouling.

Major Mechanical Components. During cooling tower inspections, be alert for any unusual noise or vibration from pumps, motors, fans, and other mechanical equipment. This is often the first sign of mechanical trouble. Operators thoroughly familiar with their equipment generally have little trouble recognizing unusual conditions. Also listen for cavitation noises from pumps, which can indicate blocked strainers.

Check the cooling tower fan and drive system assembly for loose mounting hardware, condition of fasteners, grease and oil leaks, and noticeable vibration or wobble when the fan is running. Excessive vibration can rapidly deteriorate the tower.

Observe at least one fan start and stop each week. If a fan has a serious problem, lock it out of operation and call for expert assistance. To be safe, do not take chances by running defective fans.

Fan and drive systems should be professionally checked for dynamic balance, alignment, proper fan pitch (if adjustable), and vibration whenever major repair work is performed on the fan or if unusual noises or vibrations are present. It is good practice to have these items checked at least once every third year on all but the smallest cooling towers. Any vibration switches should be checked for proper operation at least annually.

Verify calibration of the fan thermostat periodically to prevent excessive cycling and to ensure that the most economical temperature to the chiller is maintained.

Cooling Tower Structure. Check the tower structure and casing for water and air leaks as well as deterioration. Inspect louvers, fill, and drift eliminators for clogging, excessive scale, or algal growth. Clean as necessary, using high-pressure water and taking care not to damage fragile fill and eliminator components.

Watch for excessive drift (water carryover), and take corrective action as required. Drift is the primary means of *Legionella* transmittal by cooling towers and evaporative condensers (see ASHRAE *Standard* 188 and *Guideline* 12 for recommendations on control of *Legionella*). Deteriorated drift eliminators should be replaced. Many older cooling towers have drift eliminators that contain asbestos. In the United States, deteriorated asbestos-type eliminators should as a rule be designated friable material and be handled and disposed of in a manner approved by the Environment Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA).

Check the cooling tower basin, structural members and supports, fasteners, safety rails, and ladders for corrosion or other deterioration and repair as necessary. Replace deteriorated cooling tower components as required.

Water Distribution and Quality. Check the hot-water distribution system frequently, and clear clogged nozzles as required. Water distribution should be evenly balanced when the system is at rated flow and should be rechecked periodically. Cooling towers with open distribution pans benefit from covers, which retard algal growth. Pressurized water distribution systems "shaded" by eliminators also slow growth of algae.

The basin water level should be within the manufacturer's range for normal operating level, and high enough to allow most solids to settle out, thereby improving water quality to the equipment served by the cooling tower.

Cooling tower water should be clear, and the surface should not have an oily film, excessive foaming, or scum. Oil inhibits heat transfer in cooling towers, condensers, and other heat exchangers and should not be present in cooling tower water. Foam and scum can indicate excess organic material that can provide nutrients to bacteria (Rosa 1992). If such conditions are encountered, contact the water treatment specialist, who will take steps to correct the problem.

Check the cold-water basin in several places for corrosion, accumulated deposits, and excessive algae, because sediments and corrosion may not be uniformly distributed. Corrosion and microbiological activity often occur under sediments. Cooling tower outlet strainers should be in place and free of clogging.

Do not neglect the strainers in the system. In-line strainers may be the single most neglected component in the average installation. They should be inspected and, if necessary, cleaned each time the cooling tower is cleaned. Pay particular attention to the small, fine strainers used on auxiliary equipment such as computer cooling units and blowdown lines.

Blow down chilled-water risers frequently, particularly on systems using direct free cooling. Exercise all valves in the system periodically by opening and closing them fully.

For systems with water-side economizers, maintaining good water quality is paramount to prevent fouling of the heat exchanger or chilled-water system, depending on the type of economizer used.

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6.11. Water Treatment

- **The quality of water circulating through an evaporative cooling system significantly affects the overall system efficiency, degree of maintenance required, and useful life of system components**. Because the water is cooled primarily by evaporation of a portion of the circulating water, the concentration of dissolved solids and other impurities in the water can increase rapidly. Also, appreciable quantities of airborne impurities, such as dust and gases, may enter during operation. Depending on the nature of the impurities, they can cause scaling, corrosion, and/or silt deposits.

- Simple blowdown (discharge of a small portion of recirculating water to a drain) may be adequate to control scale and corrosion on sites with good-quality makeup water, but it will not control biological contaminants, including *Legionella pneumophila.*

- **All cooling tower systems should be treated to restrict biological growth, and many benefit from treatment to control scale and corrosion.**

- **For a complete and detailed description of water treatment,** see Chapter 49 of the 2015 *ASHRAE Handbook—HVAC Applications.* ASHRAE *Standard* 188 and *Guideline* 12 **should also be consulted for recommendations regarding control of *Legionella*.**

- **Specific recommendations on water treatment, including control of biological contaminants, can be obtained from any qualified water treatment supplier.**

6.12. White Rust (IMPORTANT)

- *A common material of construction for factory assembled cooling towers is galvanized steel*. Galvanizing is a process by which steel substrate is protected by a zinc coating for corrosion protection. The zinc coating is applied in a process that alloys the protective coating directly with the steel substrate, providing a mechanical barrier to the environment as well as electrochemical resistance to corrosion. If the zinc coating is breached, the zinc becomes a sacrificial anode providing cathodic corrosion protection of the steel.

- **Protective zinc surfaces must be treated to form a protective surface layer that reduces chemical activity (passivation) to maintain corrosion protection.**

- **Specific water conditions must be met to develop and maintain a passive zinc surface, including pH control, preventing mechanical abrasion by solids, corrosion inhibitors, moderate hardness, and moderate alkalinity.**

- **Additional information is available from** *manufacturers or position papers from organizations such as the Cooling Technology Institute (CTI) and Association of Water Technologies (AWT)*.

7. PERFORMANCE CURVES

The combination of flow rate and heat load dictates the range a cooling tower must accommodate. The entering air wet-bulb temperature and required system temperature level combine with cooling tower size to balance the heat rejected at a specified approach. **The performance curves in this section are typical and may vary from project to project. Computerized selection and rating programs are also available from many manufacturers to generate performance ratings and curves for their equipment**.

The curves produce accurate comparisons within the scope of the information presented but should not be extrapolated outside the field of data given. **Also, the curves are based on a typical mechanical-draft, film-filled, cross-flow, medium-sized, air-conditioning cooling tower.**

Other types and sizes of cooling towers produce somewhat different balance points of temperature level. **However, the curves may be used to evaluate a tower for year-round or seasonal use if they are restricted to the general operating characteristics described.** (See specific manufacturer's data for maximum accuracy when planning for test or critical temperature needs.)

A cooling tower selected for a specified design condition will operate at other temperature levels when the

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ambient temperature is off-design or when heat load or flow rate varies from the design condition. When flow rate is held constant, range falls as heat load falls, causing temperature levels to fall to a closer approach. Hot- and cold water temperatures fall when the ambient wet bulb falls at constant heat load, range, and flow rate. As water loading to a particular tower falls at constant ambient wet bulb and range, the tower cools the water to a lower temperature level or closer approach to the wet bulb.

A means of evaluating the typical performance of a cooling tower used for a typical air-conditioning system is shown in Figures 26 to 29. The example tower was selected for a flow rate of 54 mL/s per kilowatt when cooling water from 32.5 to 27.5°C at 24°C entering wet-bulb temperature (Figure 26).

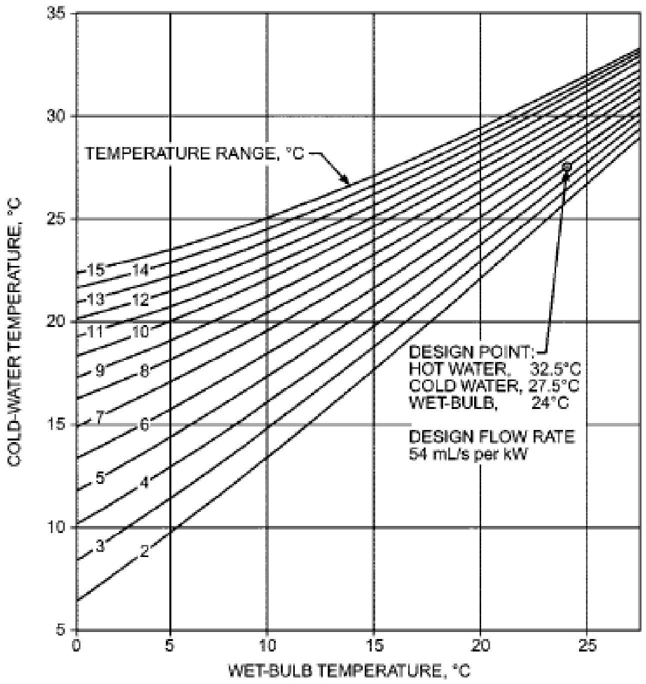

Fig. 26 Cooling Tower Performance—100% Design Flow

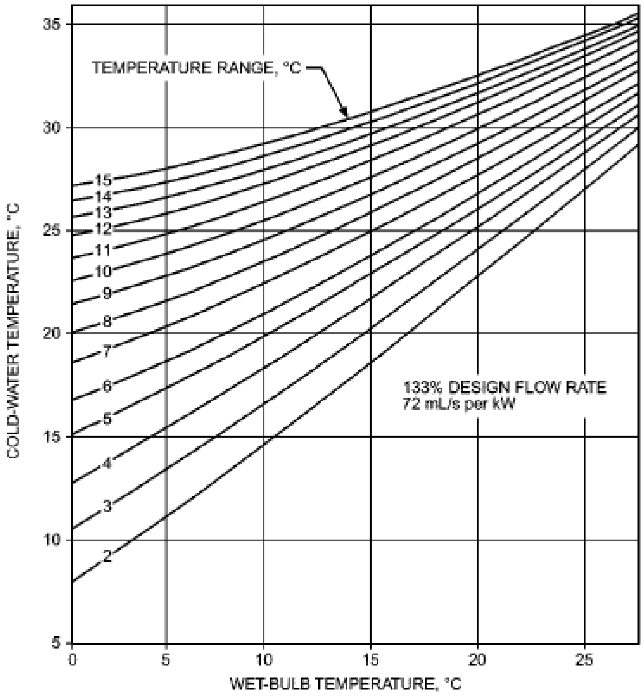

Fig. 28 Cooling Tower Performance—133% Design Flow

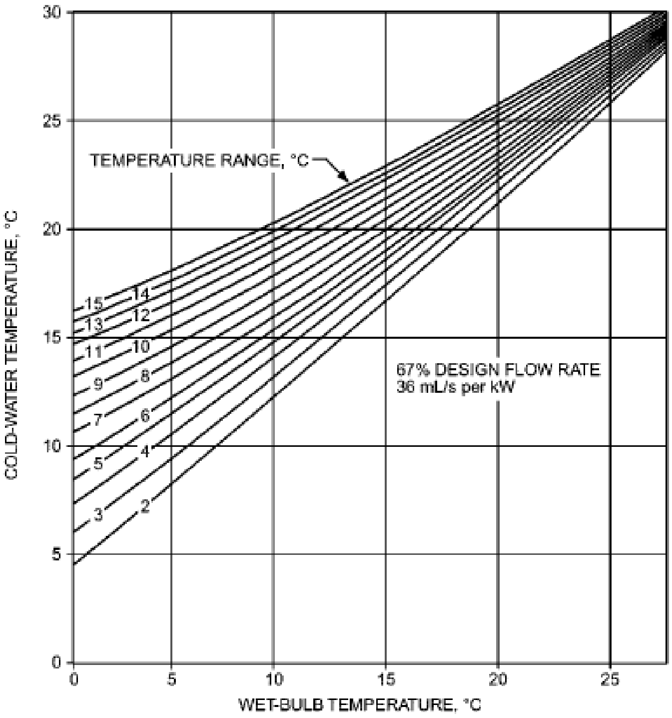

Fig. 27 Cooling Tower Performance—67% Design Flow

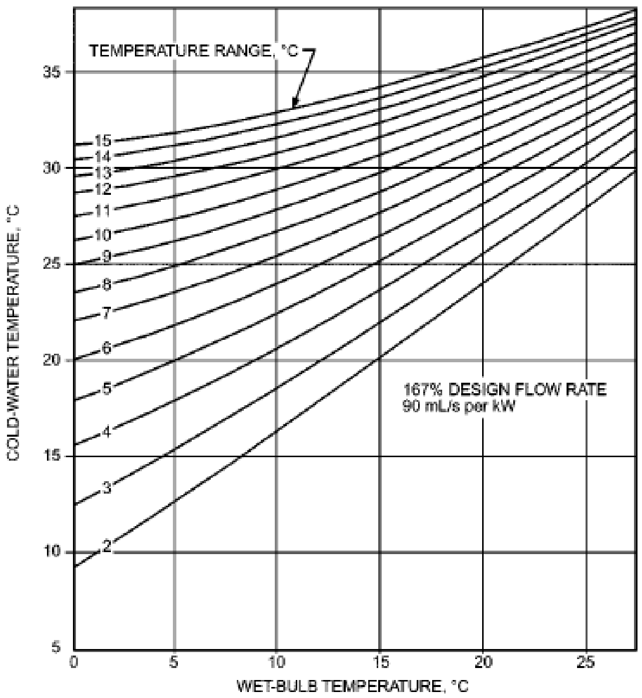

Fig. 29 Cooling Tower Performance—167% Design Flow

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8. COOLING TOWER THERMAL PERFORMANCE

8. COOLING TOWER THERMAL PERFORMANCE

Three basic alternatives are available to a purchaser/designer seeking assurance that a cooling tower will perform as specified: (1) certification of performance by an independent third party such as CTI, (2) an acceptance test performed at the site after the unit is installed, or (3) a performance bond. Codes and standards that pertain to performance certification and field testing of cooling towers are listed in Chapter 52.

Certification. The thermal performance of many commercially available cooling tower lines, both open- and closed-circuit, is certified by CTI in accordance with their *Standard* STD-201, which applies to mechanical-draft, open- and closed-circuit water cooling towers. It is based on entering wet-bulb temperature and certifies cooling tower performance when operating in an open, unrestricted environment. Independent performance certification eliminates the need for field acceptance tests and performance bonds.

Field Acceptance Test. As an alternative to certification, tower performance can be verified after installation by conducting a field acceptance test in accordance with one of the two available test standards. Of the two standards, CTI *Standard* ATC-105 is more commonly used, although American Society of Mechanical Engineers (ASME) *Standard* PTC-23 is also used. CTI *Standard* ATC-105S is used for thermal performance testing of closed-circuit cooling towers. These standards are similar in their requirements, and both base the performance evaluation on entering wet-bulb temperature. ASME *Standard* PTC-23, however, provides an alternative for evaluation based on ambient wet-bulb temperature as well.

With either procedure, the test consists of measuring the hot-water temperature in the inlet piping to the cooling tower or in the hot-water distribution basin. Preferably, the cold-water temperature is measured at the discharge of the circulating pump, where there is much less chance for temperature stratification. The wet-bulb temperature is measured by an array of mechanically aspirated psychrometers. The recirculating water flow rate is measured by any of several approved methods, usually a pitot-tube traverse of the piping leading to the cooling tower. Recently calibrated instruments should be used for all measurements, and electronic data acquisition is recommended for all but the smallest installations.

For an accurate test, the tower should be running under a steady heat load combined with a steady flow of recirculating water, both as near design as possible. Weather conditions should be reasonably stable, with prevailing winds of 4.5 m/s or less. The cooling tower should be clean and adjusted for proper water distribution, with all fans operating at design speed. Both CTI and ASME standards specify maximum recommended deviations from design operating conditions of range, flow, wet-bulb temperature, heat load, and fan power.

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