MARLEY thermal science

Cold Weather Operation of Cooling Towers

ASSOCIATED WITH WATER COOLED CHILLER SYSTEMS

Forward

The purpose of this paper is primarily to address the cold weather operation of open-circuit cooling towers associated with water cooled chiller systems, including those with waterside economizers. Closed-circuit cooling towers and evaporative condensers have special requirements that are not covered in this paper.

Water-cooled systems offer the lowest energy option for most cooling duties. Many buildings require cooling year round and utilize either air-side or waterside economizers to further reduce energy. Indeed, ASHRAE Standard 90.1-2013 expanded the use of economization in more climate zones. For those buildings that utilize water economizers, the cooling towers must operate year-round as would more process-oriented buildings, such as data centers.

In colder climates, many designers and operators are concerned with operating cooling towers in subfreezing temperatures. By following some simple operating guidelines, cooling towers can and have been successfully operated in very cold climates (-15°C / 5°F) as shown in the photograph at right.

Sustained freezing conditions, such as more than 24 hours without wet bulb temperatures going above 32°F, can be considered "sustained freezing conditions" as no daily freeze-thaw cycle will exist. Wind speeds and other factors should also be considered. In general, when the weather report has a wind chill factor forecasted below 32°F for more than a day, operators should implement their freezing operation strategy. Preferably the strategy is built into the design, automated and in use at all times.

In comparison to comfort cooling, data centers may operate year-round with a high load factor, resulting in the cooling tower size being driven by the economizer duty in cold weather. This can result in the cooling tower being oversized for summer duty. Cooling towers operating in economizer mode must produce water temperatures that are at least equal to, or lower than the chilled water temperatures that would otherwise be produced during conventional chiller operation. Note also, that when such data centers are lightly loaded, which is typical in the early years of operation, a potential impact exists due to the larger cooling tower size under freezing conditions.

Cooling tower operation at -15°C — slight visible ice

Cold Weather Operation of Cooling Towers – General

Cooling towers have been operated successfully in some of the most severe freezing conditions around the world. The colder the weather, the more important that relatively simple protocols be followed and precautions taken to avoid operational issues. Fully-loaded data centers are actually ideal candidates for waterside economization in freezing climates thanks to high year-round heat load.

Basic Cold Weather Operation Principles

- Do not operate cooling towers without a heat load and do not operate unattended in multi-day periods of continuously subfreezing cold weather.
- Maintain design minimum or greater water flow rate over the cooling tower heat exchange media (fill) at all times.
- For any flow rate desired by the operator, care must be taken to maintain at least the cooling tower manufacturer's minimum

water flow rate per individual fan cell. The number of cells receiving water must be adjusted to maintain the minimum flow per cell required by the cooling tower manufacturer. Cooling tower cells must be designed to accommodate a 50% turndown of water flow rate, although some designs may be capable of more turndown.

- If desired system condenser water flow is reduced below minimum, the number of cells must be reduced at the same time so the flow is greater than or equal to the minimum flow per cell.
- A cooling tower manufacturer may be able to extend the minimum flow percentage to a lower value by using internal cell water distribution design provisions that accommodate low flow by appropriately reducing active plan area (such as hot water basin dams or overflow cups on a crossflow cooling tower) while keeping the cooling tower interior moist and heated.
- Manage the airflow to maintain above freezing water temperatures in all sections of the fill within all operating cooling tower cells.

Maintain Heat Load. Without a heat load, water flowing over a cooling tower will end up either at the air wet-bulb temperature or as ice, whichever occurs first, as shown in **Figure 1**. This will happen quickly with fans running — more slowly if they're off. Note that the wet bulb temperature drives evaporative heat transfer and is an equal or *lower* temperature than the dry bulb. For example, at 35°F dry bulb, above commonly assumed freezing conditions, the wet bulb temperature can often be less than 32°F — and the water flowing over a cooling tower can freeze without proper operation.

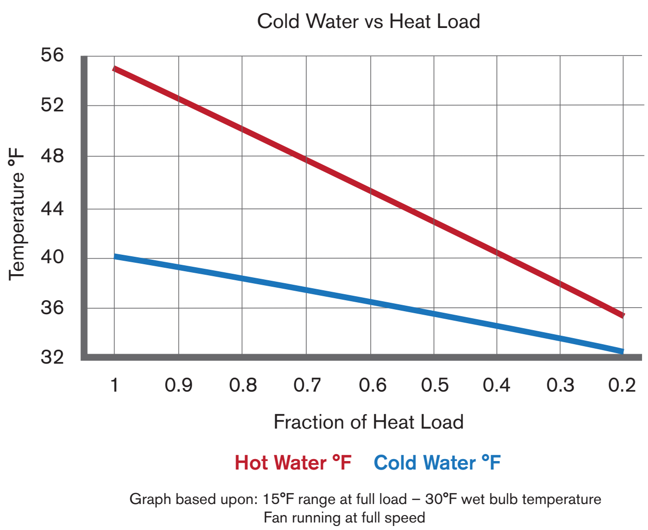

FIGURE 1 *Water temperatures approach the freezing point as heat load is reduced.*

Maintain Vigilance. No matter how automated your cooling tower operation, check the cooling tower regularly in sustained freezing conditions. Perhaps once a shift is enough — perhaps not — only experience will tell for a specific site. Observations can often be accomplished with remote cameras fed back to the control room. The colder the weather, the more often you should observe the cooling tower in person which is counterintuitive as operators naturally oppose going outside when it's cold.

Bypass When Needed. If the heat load drops too low, to prevent icing in cold climates, bypass all of the operating water flow directly to the cold water basin(s). Do not direct flow over the cooling tower until warmed to the target hot water temperature. Do not modulate the bypass water flow or the fill can easily freeze in low flow areas. Size and locate the bypass with help from the cooling tower manufacturer, or purchase it as an option for a new cooling tower. See **Figure 2.**

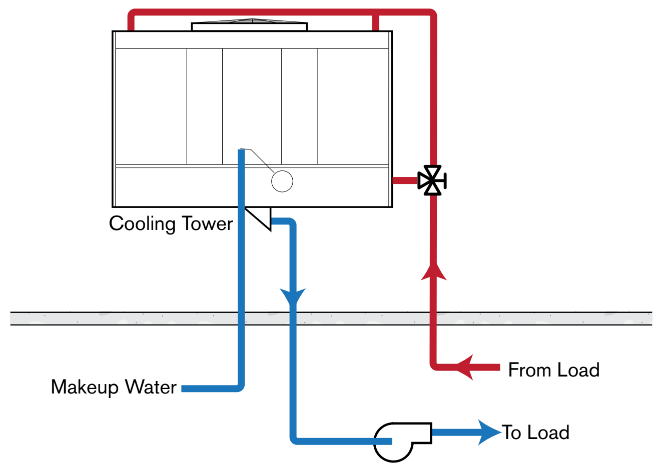

FIGURE 2 *Bypass directly to the cold water basin when water temperature falls below manufacturer's stated minimum in freezing conditions and fans are already off.*

Manage Airflow Appropriately

Fans of multicell cooling towers are sometimes cycled sequentially: All On, One Off, Two Off … etc. However, the following figures indicate that this can lead to a potential for freezing in individual cells using a 30°F wet bulb temperature in the example.

Water temperatures with fans running in all three cells are equal as shown in **Figure 3**.

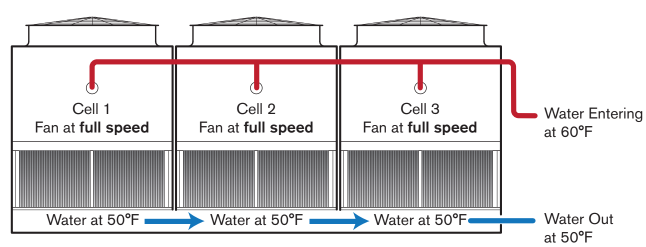

FIGURE 3 *Even discharge temperatures from cell to cell with all fans running at the same fan speed.*

Water temperatures with fans running in two cells are shown in **Figure 4**. Temperatures leaving two of the cells are below the return temperature back to the chiller.

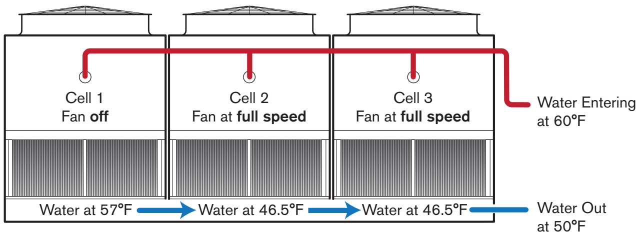

FIGURE 4 *Cell with single fan off has higher leaving cold water temperature than the other two.*

Water temperatures with the fan running in only one cell are shown in **Figure 5**. Water could be freezing in areas within Cell 3 as will be shown later in this paper even though the average discharge from the cell is 40° F, while the average temperature back to the chiller — and likely the only temperature monitored — is 50° F.

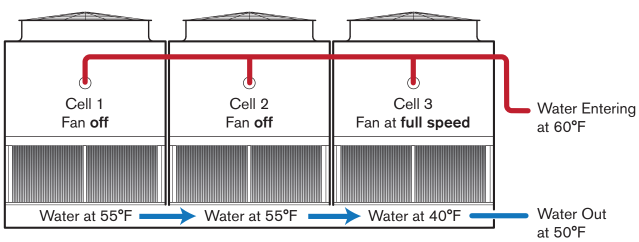

FIGURE 5 *Single cell with fan running has substantially lower leaving cold water temperature than the other two.*

While fan cycling and/or two-speed motors have been used in the past, VFDs (variable frequency drives) can eliminate the cell-to-cell temperature gradients, and are preferred for many reasons but especially when operating cooling towers in sustained freezing conditions. Each cell should be equipped with a VFD drive, and each should operate at the same set point temperature. VFDs are the most energy efficient method of operation as well. For the most energy efficient operation and also the best freezing resistant operation of fans, ASHRAE 90.1-2013 (paragraph 6.5.5.2.2b) requires ramping the speed of VFDs up and down on all cells together.

Types of Cooling Towers

Crossflow and counterflow cooling tower designs have differences in cold weather operation characteristics. The two basic cooling tower configurations are shown in **Figure 6** Crossflow and **Figure 7** Counterflow.

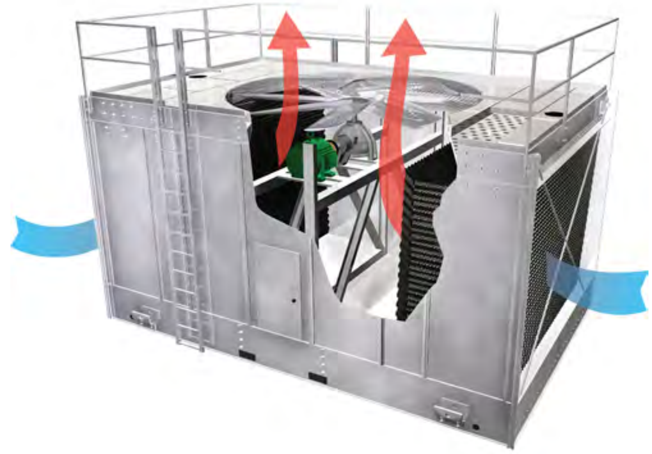

FIGURE 6 *Crossflow – water flows down through the fill from the hot water basin on top, air flows horizontally across the water path.*

Some issues common to both types are:

- A need to avoid cold air contact with very light water loading areas.
- A need to prevent water drops from going outside the cooling tower.
- Operation without enough heat load in freezing conditions is an obvious problem for either design.
- Some icing on cooling towers during subfreezing weather is normal and typically not a concern for operation. Ice will form first at any of the air/water interfaces in the cooling tower, such as the inlet louver area.
- The goal is to prevent excessive icing that can result in cooling tower damage.

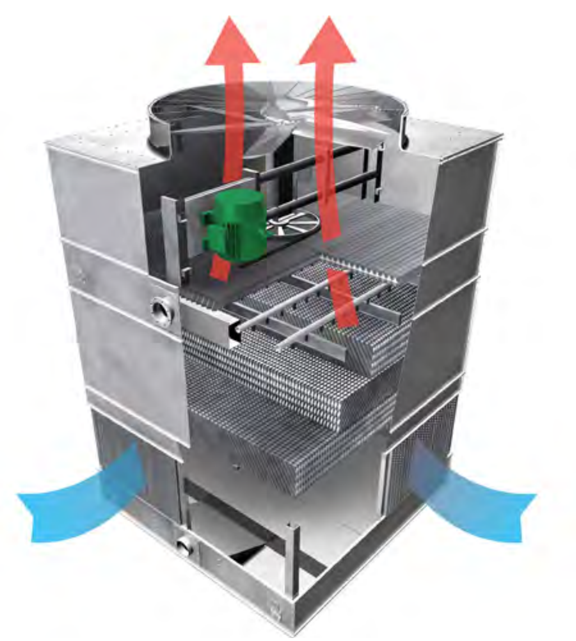

FIGURE 7 *Counterflow – water sprays downward, flows downward through the fill and air flows in from the sides and up through the fill. Water flow is counter to the air flow.*

Icing Control – Crossflow. **Figure 8** shows lines of constant temperature in crossflow cooling tower fill. This typifies what must occur in Cell 3 (**Figure 5**) in order to produce 40°F cold water with 60°F water entering. Water flows downward between fill sheets by gravity. The temperature at the bottom of the air inlet face is about 32°F, at freezing, even though the average is 40°F leaving the cell.

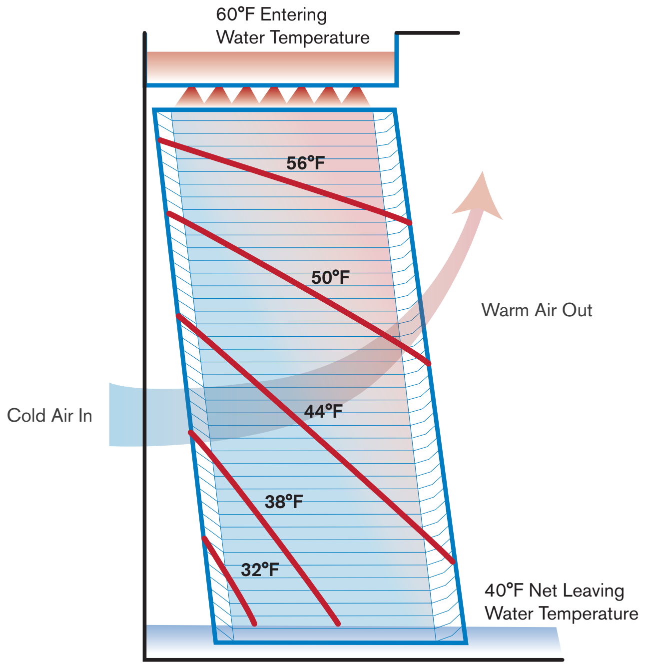

FIGURE 8 *Temperature gradient in a crossflow fill cooling tower showing freezing temperatures at the bottom of the air inlet face.*

Water flow slants in the direction of the airflow, as shown in **Figure 8**. Crossflow fills are designed to slope at an angle compatible with the pull-back of water toward the air discharge face. Water is thus contained evenly between the louvers and eliminators. When fans are off, the water falls straight down, causing heavy water flow on the louver face as shown in **Figure 9**. This heavy warm water flow can effectively deice the louvers under most conditions.

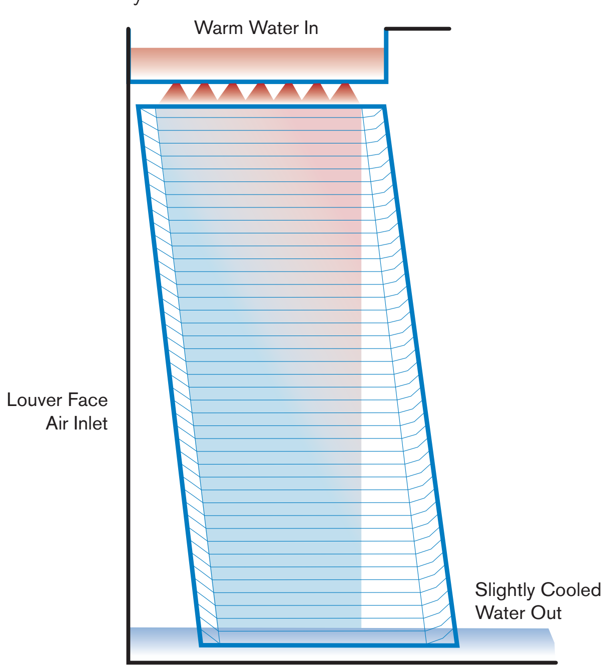

FIGURE 9 *Water washing the louver face with the fan off.*

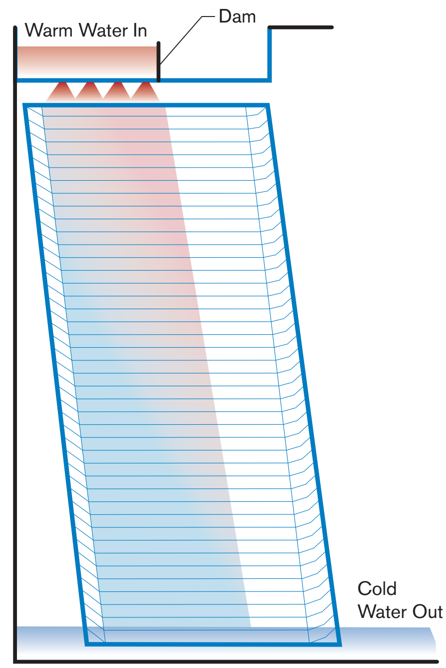

FIGURE 10 *Cell running at reduced water flow with water delivered only to the outboard portion due to a low flow dam or the use of overflow nozzle cups on the inboard nozzles.*

With basin weir dams or overflow cups, water at reduced flow rate is concentrated in the outboard fill areas. At reduced flow, water doesn't overflow the dams or cups on the interior side and stays in the outboard half of the hot water basin, as shown in **Figure 10**. The interior portion of the fill is kept damp and warm by the heated air from the outboard portion of the fill. At full flow, water overflows the weir dam or cups to cover the entire fill area.

Icing Control – Counterflow. Counterflow cooling towers have slightly less cold water gradient at the bottom of the fill than crossflow cooling towers, but the gradient is similar to crossflow at the bottom of the rain zone between the underside of the fill and the water level in the cold water basin as shown in **Figure 11**.

With 40°F average water temperature at the cold water basin level, the temperature at the lowest air inlet face level in the rain zone below the fill can be 32°F as with the crossflow example, increasing to around 43°F at the center of the cooling tower. A counterflow cooling tower with no louvers (common on large field-erected cooling towers), and a structurally clean air inlet is more resistant to icing as fewer locations exist to generate or catch escaping water droplets. Water drops outside the heated air and water zones generate ice buildup.

Typically louvers are necessary in most HVAC counterflow cooling towers, including factory-assembled cooling towers, where

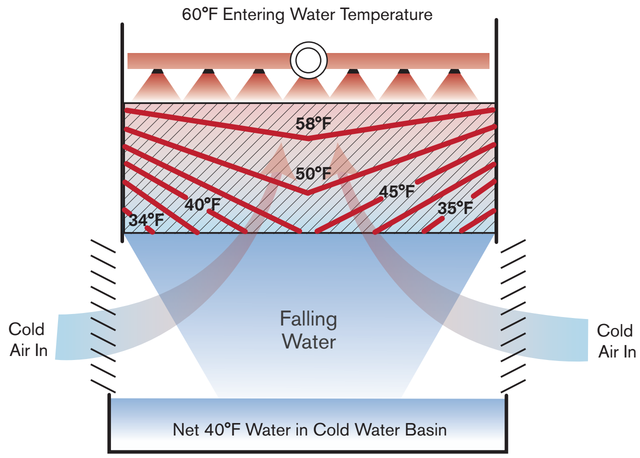

FIGURE 11 *Temperature gradient in a counterflow fill cooling tower showing lower temperature at the perimeter and higher temperature at the center.*

adequate distance between the cooling tower and the basin curb is not practical. Note that with louvers in place, icing may not be visible in or under the fill of a counterflow cooling tower as ice forms on the louvers from the inside out. Multiple spray system designs are sometimes used in counterflow cooling towers to accommodate low water flow rates, but these can be problematic. A counterflow cooling tower does not lend itself to segmented area distribution for reduced flow within a given cell. Individual cells are typically isolated to maintain the minimum flow.

With fans at full airflow on a counterflow cooling tower, the water is pulled back from the air inlet, or louver face, as shown in **Figure 12**.

With fans off, there is a slight negative airflow due to the drag force of the water in the spray chamber and below the fill, so water

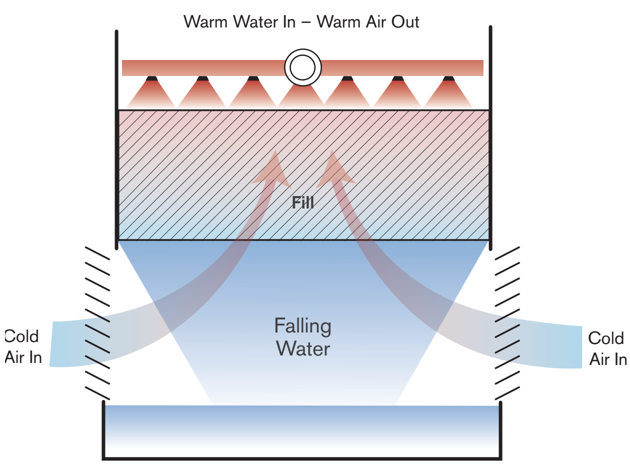

FIGURE 12 *Water pull-back with fans operating on a counterflow cooling tower.*

goes slightly outside the vertical perimeter of the fill. This force is usually a strong enough effect to overcome the natural draft effect caused by the heating of air by the warm water from the heat load on the tower. Air goes in reverse at a low velocity, out of the air inlet, as shown in **Figure 13**. This tends to add to any icing on the louvers in very cold weather.

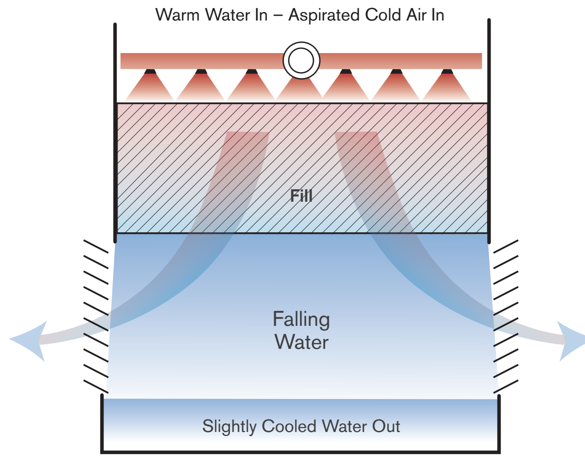

FIGURE 13 *Water outside the fill perimeter on a counterflow cooling tower, fans not running. Basin as shown is wider than the fill plan area to contain the water.*

Reversed fan operation. The goal is to avoid icing, but when ice develops, a first option is to shut off fans cell by cell and let warm water melt ice in that cell for a period of time. For more persistent icing, reverse fans at reduced speed (typically 30% speed or less with VFDs) for a short period of time to deice the inlet louvers. This is another advantage of utilizing a VFD on cooling towers operating in cold weather. Fan reversal sends some water outside the cooling tower, and can also draw freezing air down over the fan equipment. Operations staff needs to monitor deicing by fan reversal closely and keep the duration of reversal to the minimum possible.

Cold Weather Operation

Cooling Towers with "Dry Basin" Systems. A dry basin, or remote sump system gives automatic protection from freezing of cold water basins and exposed drain piping as shown in **Figure 14**. All of the cooling water drains to the tank by gravity. Cooling tower drain-down volume is readily available from the manufacturer to assist in sizing such remote sumps. The volume of the system above the tank overflow level must be added to determine the necessary tank volume.

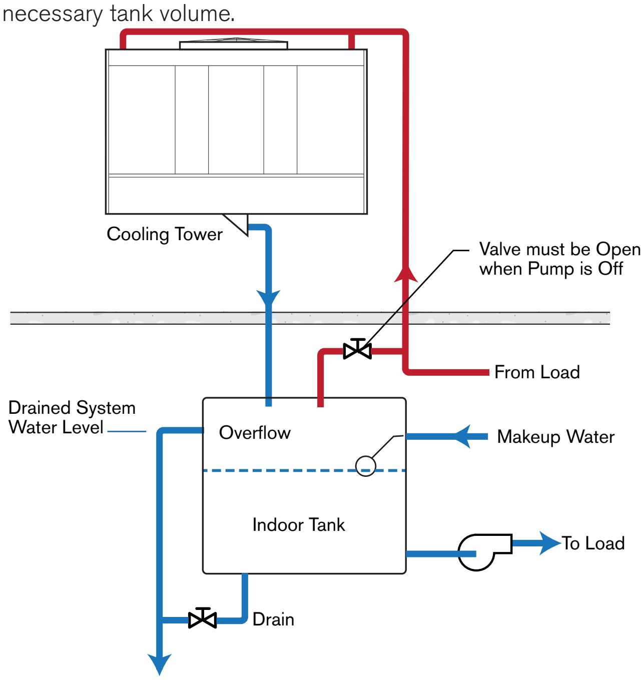

FIGURE 14 *Dry basin system schematic with indoor water storage tank.*

Cooling Towers without Dry Basin Systems. Without a dry basin at shutdown, the heat load is gone, and water is motionless at the level shown. All of the areas full of water in a sufficiently cold condition are subject to freezing, as shown in **Figure 15**.

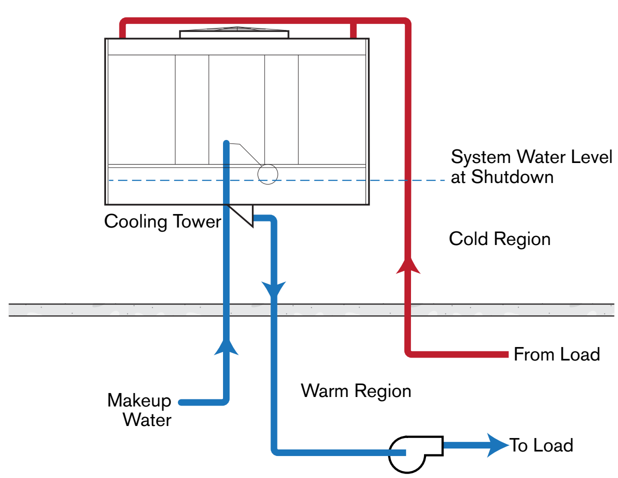

FIGURE 15 *System without dry basin – water left in the cooling tower and piping could be an issue at shutdown.*

If a system is shut down for the winter, drain the cooling tower and all exposed piping as shown in **Figure 16**. Make sure makeup water to the cooling tower is turned off and the line is drained.

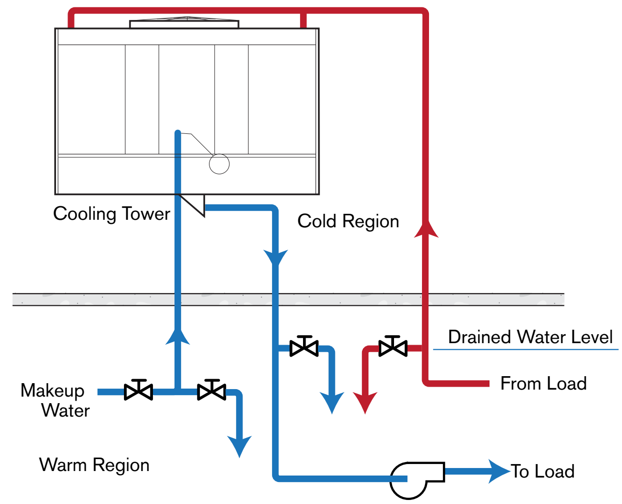

FIGURE 16 *Draining provisions to prevent icing in cooling tower shutdown without a dry basin system.*

If a system is shut down without draining, heat must be added in exposed areas as shown in **Figure 17**. Determine heat load needed from the cooling tower manufacturer. Basin heaters must be controlled to work only when the system flow is off and water is in the cold water basin. Basin heating systems are typically available as an option on new cooling towers, and may be available for retrofit to existing cooling towers. The heaters must not be allowed to energize if not fully covered with water. A thermostat should maintain basin water temperature above 40°F at the specified outdoor temperature. External heat source (steam or hot water) systems are also typically available as an option. Heat trace any lines filled with water exposed to subfreezing ambients as shown in **Figure 17**. The makeup line falls into this category (usually much smaller than cooling water piping and thus quicker to freeze).

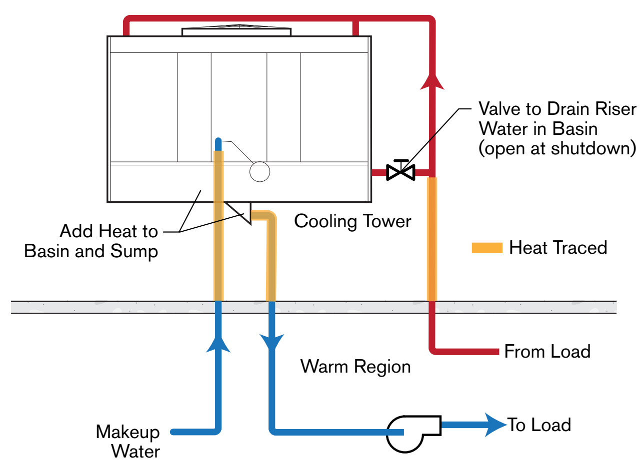

FIGURE 17 *Locations which require heat tracing to protect from freezing in shutdown conditions without draining.*

Other Guidelines. Watch for icing around cooling towers, especially on walkways and ladders, which can present a safety hazard. Use vibration cut-out switches on fans to prevent icing issues on fans during start up or when operating in severe cold conditions at light heat loads.

Waterside Economizers – Free Cooling

The water flow to be recirculated and the cooling range (hot water temperature minus cold water temperature) must be carefully considered for economizer operation. Reducing the water flow rate increases the cooling range at constant heat load. The examples in **Figure 8** and **Figure 11** show that with a 20°F range, a 40°F cold water temperature leaving a cell can yield freezing water temperatures at the bottom of the air inlet, or louver face. A lower cooling range at a higher water flow rate produces a smaller gradient. In other words, operation with twice the flow rate and a 10°F cooling range with the same 40°F cold water temperature has a higher water temperature at the bottom of the air inlet face, and is thus less prone to freezing at the bottom of the louver face. The lowest temperature at the bottom of the air inlet face may be 36°F instead of 32°F with a 20°F range.

Reducing flow and increasing range for the low cold water temperatures desired from an economizer does not provide for freeze protection. Keep the water flow rate up and cycle VFD-controlled fans from the minimum speed to OFF when needed to keep the system at the highest possible average temperature in the fill when in the economizer mode. Obviously, the higher the set point for the economizer, the lower the freezing risk. A 45°F or higher set point at the highest water flow rate that can be maintained will result in less freezing potential in economizer mode.

Integrated Economizers. The use of integrated economizers for data centers or other applications is perceived as a benefit for operation of cooling towers in general, but in particular for freezing conditions. It allows gradual transitions in either direction from economizer operation to full chiller operation. For best control in freezing conditions, this is a good strategy and is required by ASHRAE Standard 90.1-2013.

Summary

Cooling towers can be operated successfully in all climate conditions, including freezing environments. Attention to some basic principles and to key system design characteristics is necessary for success. Use of VFDs on systems of all sizes reduces freezing risk. Systems in severe freezing climates should consider remote sump designs. Owners and designers of projects in freezing climates can confidently take advantage of the significant energy-saving benefits of water cooled chillers with cooling towers, and also with waterside economizers also known as “free cooling”.

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