TECHNICAL FEATURE

Cooling tower operation at –15°C (5°F) in Montreal, slight visible ice.

PHOTO COURTESY OF JEFF CLARKE, ENVIROAIR INDUSTRIES

Cold Weather Operation Of Cooling Towers

BY PAUL LINDAHL, MEMBER ASHRAE

The purpose of this article is to address primarily the cold weather operation of open circuit cooling towers associated with water-cooled chiller systems, including those with water side economizers. While similar in many ways with regard to freeze protection of the recirculating water in contact with cooling air outside the process coils, closed-circuit cooling towers and evaporative condensers have special requirements that are not covered in this article.

As mentioned in "Saving Energy With Cooling Towers" by Frank Morrison in the February issue, water-cooled systems offer the lowest energy option for most cooling duties. Many buildings require cooling year-round and use either airside 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 use 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 even in very cold climates, as shown in *Figure 1,* at –15°C (5°F) in Montreal. More than 24 hours without wet-bulb temperatures going above 32°F (0°C) 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 (0°C) for more than a day, operators should be thinking about freezing operation strategy. Preferably the strategy is built into the design, automated and in use all of the time.

In comparison to comfort cooling, data centers may operate year-round with a high load factor, resulting in the cooling tower sizing being driven by the economizer duty in cold weather. This can result in the cooling tower being oversized for the 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. However, when such data centers are lightly loaded, which is typical in the early years of operation,

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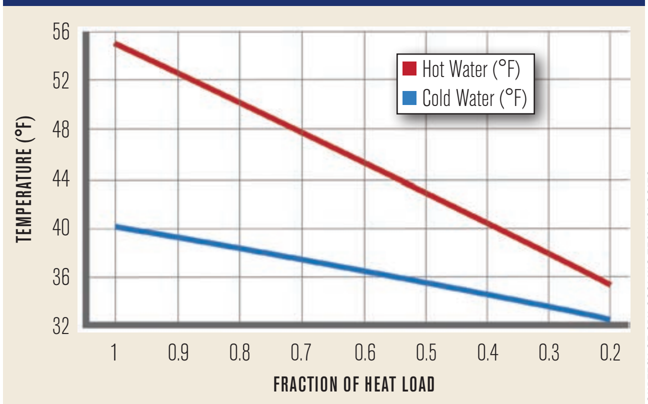
FIGURE 1 Water temperatures approaching the freezing point as heat load is reduced. (Graph based on 15°F range at full load, 30°F wet-bulb temperature and fan running at full speed.)



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a potential impact exists due to the larger cooling tower sizing under freezing conditions.

Cold Weather Operation of Cooling Towers

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

The sidebar, "Basic Cold Weather Operation," lists operating guidelines and the next section discusses each of these in more detail.

Maintaining 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 wet-bulb temperature drives evaporative heat transfer, and is an equal or *lower* temperature than the dry bulb. For example, at 35°F (1.6°C) dry bulb, above commonly assumed freezing conditions, the wet-bulb temperature often can be less than 32°F (0°C) wet bulb—and the water flowing over a cooling tower can freeze without proper operation.

Maintaining Vigilance. No matter how automated your cooling tower operation, visit the cooling tower regularly in sustained freezing conditions. Perhaps once a shift is enough—perhaps not—only experience will determine what is best for a specific site. Remote cameras fed back to the control room can be used for observation. The colder the weather, the more often you should observe the cooling tower in person. This can be counterintuitive because operators naturally trend the opposite way, going out less as the temperature drops.

Basic Cold Weather Operation

Do not operate cooling towers without a heat load.

Do not operate cooling towers unattended in multi-day periods of continuously sub-freezing 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 manufacturer's minimum water flow rate per individual fan cell. The number of cells receiving water must adjusted to maintain the minimum flow per cell required by the manufacturer as noted in "Saving Energy With Cooling Towers" by Frank Morrison in the February issue, Standard 90.1-2013 (Paragraph 6.5.5.4) requires that cooling tower cells be designed to accommodate a 50% turndown of water flow rate, but some designs may be capable of more turn-down.
- 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 use of internal cell water distribution design provisions that can 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 through operating cells to maintain above freezing water temperatures in all sections of the operating fill within all of those cells.

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 flow the water back over the cooling tower until it warms up to the target hot water temperature. Do not modulate the bypass water flow because 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 (*Figure 2*).

Manage Airflow Appropriately. Fans of multi-cell cooling towers are sometimes cycled sequentially: all on, one off, two off, etc. However, the following figures indicate that

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.

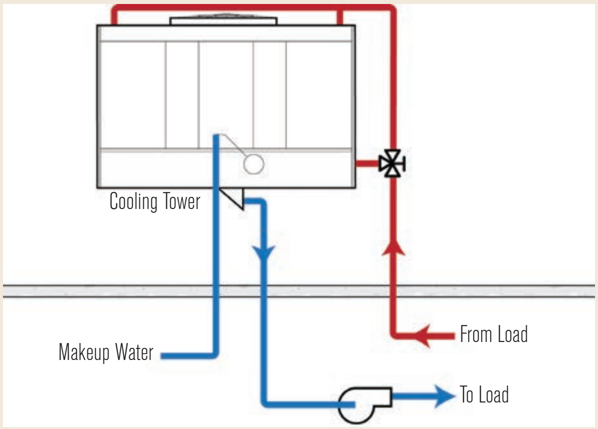

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FIGURE 3 Even discharge temperatures from cell to cell with all fans running at the same fan speed.

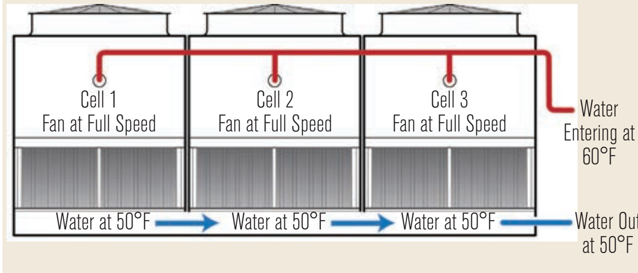

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FIGURE 4 Cell with single fan off has higher leaving cold water temperature than the other two.

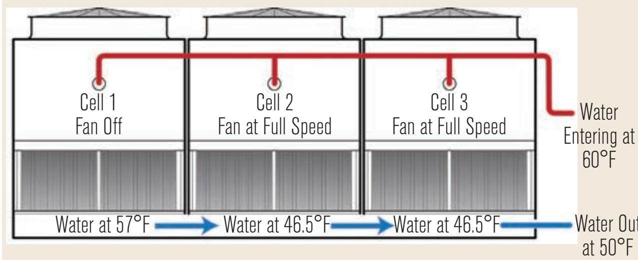

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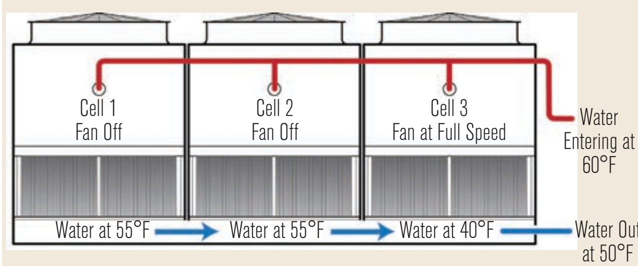
FIGURE 5 Single cell with fan running has substantially lower leaving cold water temperature than the other two.



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this cycling can lead to a potential for freezing in individual cells, using a 30°F wet-bulb temperature in the example.

Water temperatures with fans in all three cells running are equal as shown in *Figure 3*. Water temperatures with fans in two cells on are shown in *Figure 4*. Temperatures leaving two of the cells are below the return temperature back to the chiller.

Water temperatures with only the fan in one cell running are shown in *Figure 5*. Water could be freezing in areas within Cell 3 as will be shown later even though the average discharge from the cell is 40°F (4°C), while the average temperature back to the chiller, and likely the only temperature monitored, is 50°F (10°C).

While fan cycling and/or two-speed motors have been used in the past, variable frequency drives (VFDs) can eliminate the cell-to-cell temperature gradients, and are preferred especially when operating cooling towers in sustained freezing conditions. Each cell should be equipped with a VFD, and they should all operate at the same setpoint temperature. VFDs are the most energy-efficient method of operation as well, as discussed in last month's article. Standard 90.1-2013 (Paragraph 6.5.5.2.2b) requires ramping up and down the speed of VFDs on all cells together for the most energy-efficient operation, which is also the best freezing resistant operation of fans.

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

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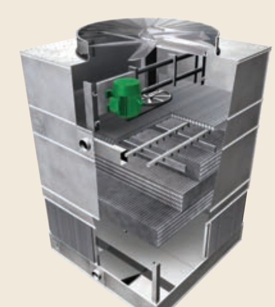
FIGURE 7 Counterflow; water sprays downward, flows downward through the fill, and air flows in from sides and up through the fill. Water flow is counter to airflow.



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Types of Cooling Towers. Some differences in cold weather operation characteristics exist between crossflow and counterflow cooling tower designs. The two basic cooling tower configurations are shown in *Figures 6* and *7*.

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

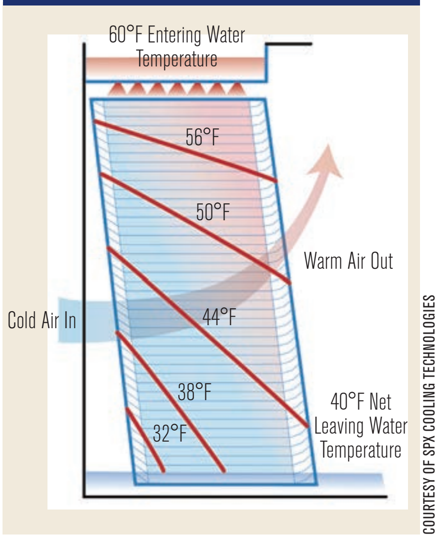


FIGURE 9 Water washing the louver face with fan turned off.

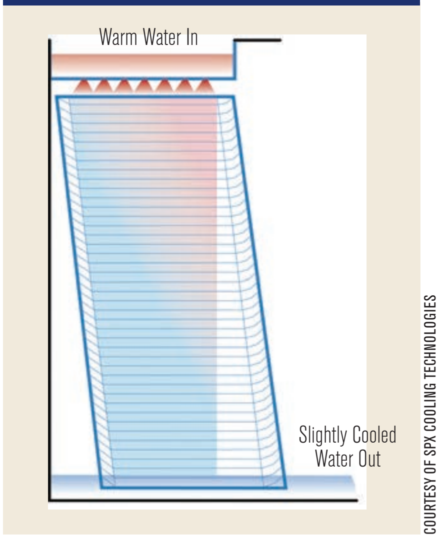
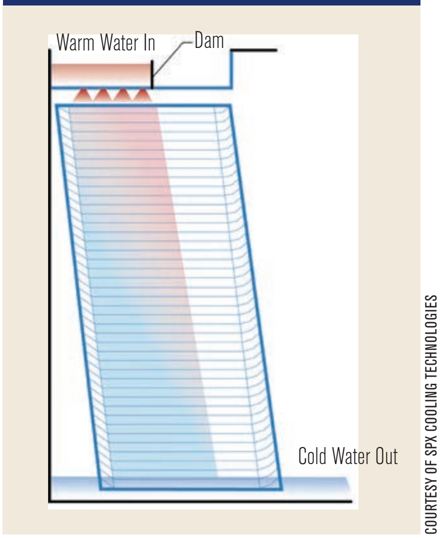


FIGURE 10 Cell running at reduced water flow with water delivered only to the outboard portion due to a low flow dam or use of overflow cups on the inboard nozzles.



Issues common to both types include a need to avoid cold air contact with very light water loading areas and a need to prevent water drops from going outside the cooling tower. In addition, operating 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 the operation of the cooling tower. 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

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FIGURE 11 Temperature gradient in a counterflow film filled cooling tower, showing lower temperature at the perimeter and higher temperature at the center.

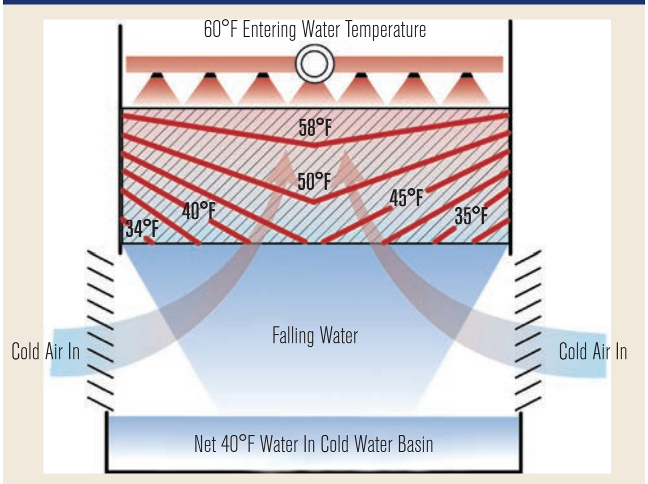

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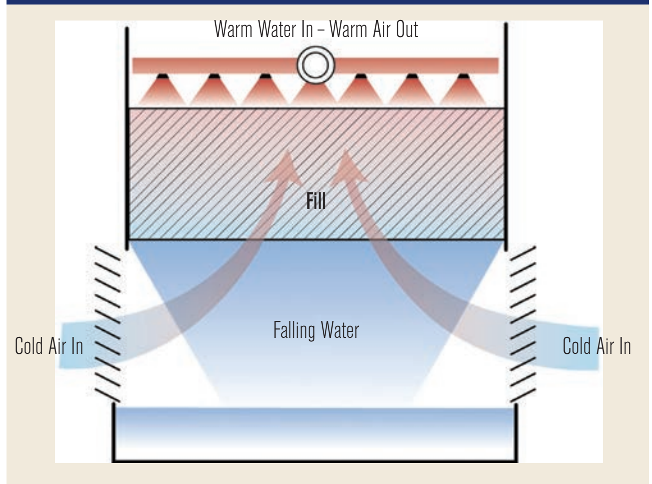
FIGURE 12 Water pull-back with fans operating on a counterflow.



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prevent excessive icing that can result in cooling tower damage.

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*, Page 28) 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 (0°C), at freezing, even though the average is 40°F (4°C) leaving the cell.

Water flow slants in the direction of airflow, as shown in *Figure 8,* sloping along with the fill. Crossflow film fills are designed to slope at an angle compatible with the pull-back of water toward the air discharge face. Water is

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

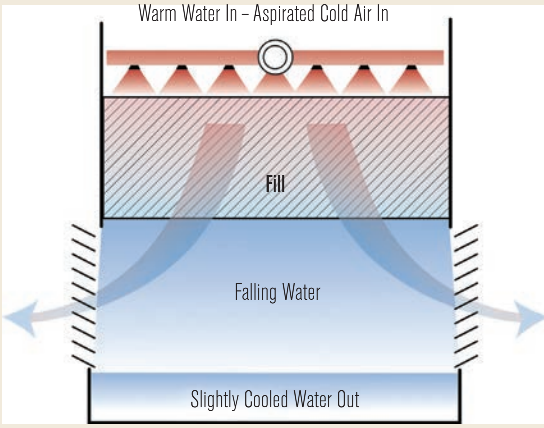

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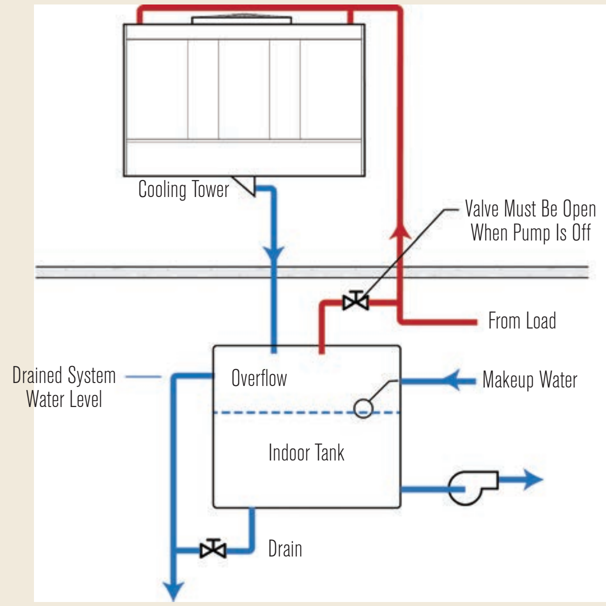
FIGURE 14 Dry basin system schematic, with indoor water storage tank.



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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* (Page 29). This heavy warm water flow can effectively de-ice the louvers under most conditions.

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* (Page 29). 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 has slightly less cold water gradient at the bottom of fill than crossflow, 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 (*Figure 11*, Page 30). With 40°F (4°C) average temperature for the water at the cold water basin level, the temperature at the lowest air inlet face level in the rain zone below the fill can be at 32°F (0°C) (as with the crossflow example), increasing to around 43°F (6°C) at the center of the cooling tower. A counterflow with no louvers (common on 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 generate ice buildup. But, louvers are necessary in most HVAC applications, including factory-assembled cooling towers, where 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 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 and are not common. Counterflow 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 over the cooling towers.

With fans at full airflow on a counterflow, the water is pulled back from the air inlet, or louver face, as shown in *Figure 12* (Page 30).

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 goes slightly outside the vertical perimeter of the fill. This is usually a large 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.

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 de-ice the inlet louvers. This is another advantage of using 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

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

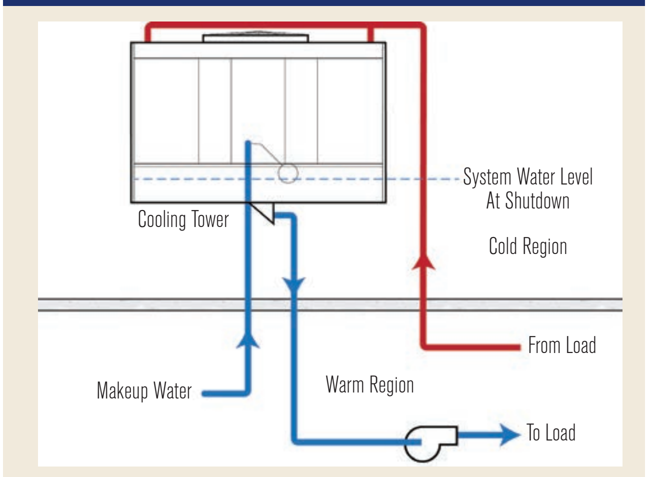

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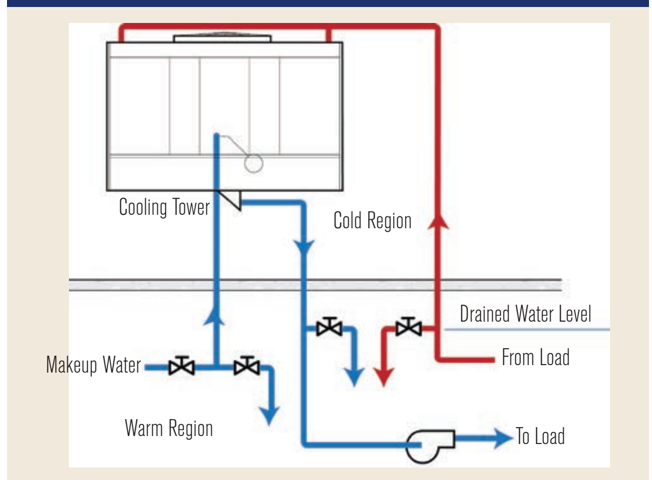
FIGURE 16 Draining provisions to prevent icing in shut down cooling tower without a dry basin system.



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the fan equipment. Operations staff needs to monitor de-icing by fan reversal closely, and keep the duration of reversal to the minimum possible.

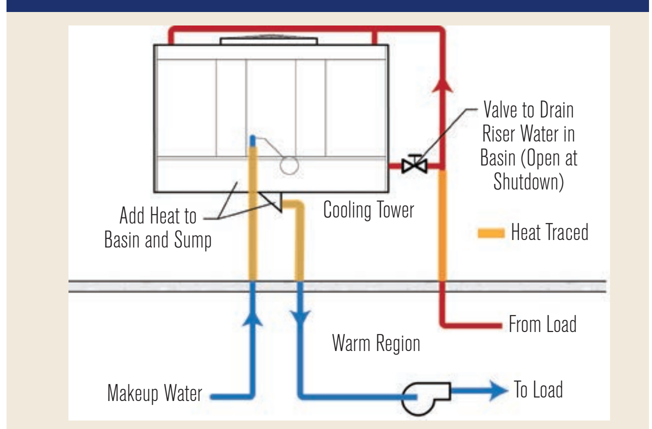
Cold Weather Operation of Cooling Towers with "Dry Basin" Systems. A "dry basin," or remote sump system, gives automatic protection from freezing of cold water basins and exposed drain piping as shown in *Figure 14*. All of the cooling water drains to the tank by gravity. Cooling tower drain down volume 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.

Cold Weather Operation of 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*.

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.

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 tower sales, 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 (4°C) at the specified outdoor temperature. External heat

FIGURE 17 Locations that require heat tracing to protect from freezing in shut down conditions without draining.



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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, therefore, quicker to freeze).

Other Guidelines for Cold Weather Operation of Cooling Towers. 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 issues with icing on fans when started up or when operating in severe cold conditions at light heat loads.

Cold Weather Operation of Cooling Towers with Waterside Economizers. 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 *Figures 8* and *11* (Pages 29, 30) show that with a 20°F (11°C) range, a 40°F (4°C) 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 (5.5°C) cooling range with the same 40°F (4°C) cold water temperature has a higher water temperature at the bottom of the air inlet face, and is 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 (2°C), instead of 32°F (0°C) with a 20°F (11°C) range.

Reducing flow and increasing range for the low cold water temperatures desired from an economizer is going in the wrong direction 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 setpoint for the economizer operation that can be used, the lower the freezing risk. A 45°F (7°C) or higher setpoint 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 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 with projects in freezing climates can take advantage with confidence of the significant energy saving benefits of water-cooled chillers with cooling towers, and also with water-side economizers (aka, “free cooling”). ■

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