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Free Cooling Considerations

Optimizing system components for free cooling operation

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TABLE 1—Cooling coil selections. (Information obtained using Heatcraft coil selection program.)								
			Winter					
Coil data	Summer		100 percent		80 percent		70 percent	
Summer EWT, F	42	44	42	44	42	44	42	44
Coil size, sq ft	40		40		40		40	
Velocity, fpm	500		500		400		350	
Air PD, in. WG	0.69	0.82	0.57	0.69	0.40	0.48	0.32	0.38
EAT (DB/WB), F	77/64.5		70.5/54.3		69.4/53.8		69/53.6	
LAT (DB), F	53.1	52.9	53.1	53	53	53.1	53.1	53.1
LAT (WB), F	52.5	52.6	53.1	53	53	53.1	53.1	53.1
Total MBtuh	706	700	380	382	287	286	243	243
Percentage of summer MBtuh	100	100	53.8	54.6	40.7	40.9	34.4	34.7
EWT, F	42	44	48	48.5	49	49.5	49	50
LWT, F	58.4	60.3	58	60	58	60	59	60
gpm	86	86	76	66.5	63.5	54.5	48.5	48.5
Water PD, ft	12.5	14.4	10.0	9.1	7.2	6.4	4.5	5.2

This is a discussion of the application of water-side free cooling utilizing plate-and-frame heat exchangers (HX). Free cooling is the production of chilled water without the use of chillers. The heat removed from the building's cooling coils is transferred through the HX to the cooling towers for rejection to the atmosphere. Free cooling is not really free; even though the chiller is off, chilled and tower water pumps and cooling tower fan(s) are required to operate.

This article is broken into three sections that present considerations on how to design the building's cooling system(s) to get the most out of free cooling, considerations for the chilled water side of the free cooling system, and considerations for the cooling tower water side of the system.

Cooling system

The first step is to design the building's cooling system to optimize use of free cooling. A limitation of free cooling is that 39 to 40 F is about the lowest temperature water that can be delivered from the cooling towers before freezing problems become difficult to avoid.

A second limitation is the approach temperature of the heat exchanger. The approach temperature is the difference between the temperatures of the entering water on the cold side of the HX (tower side) and the leaving chilled water on the warm side. This approach temperature can be as low as 1.5 to 2 F; however, due to the higher cost for smaller approach temperatures, 2.5 to 3 F provides for a more economical HX selection. This results in a minimum free cooling chilled water temperature of 41 to 43 F.

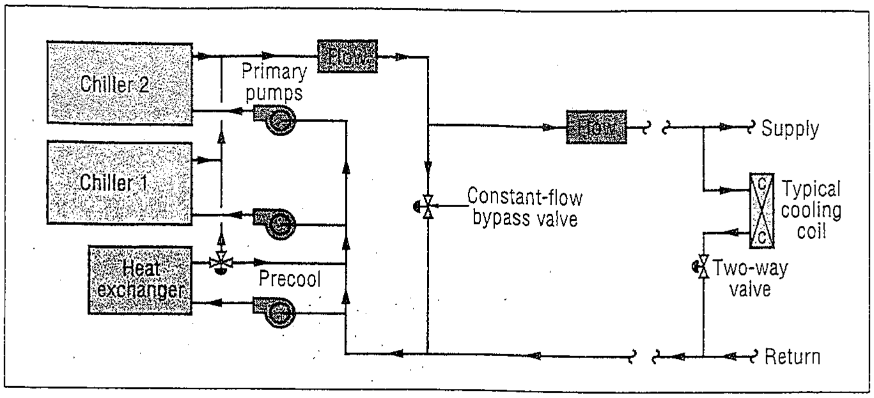
The water temperature supplied by the cooling towers is variable depending on the actual cooling load and the outdoor air conditions. If the chilled water temperature can be allowed to rise by 5 to 7 F in the free cooling season (generally late fall, winter, and early spring), free cooling will be available with warmer entering air temperatures to the cooling tower, and the system will be able to operate for up to 1100 additional hr of free cooling (depending on location). This can increase the savings of the free cooling system by 60 percent or more.

Free cooling

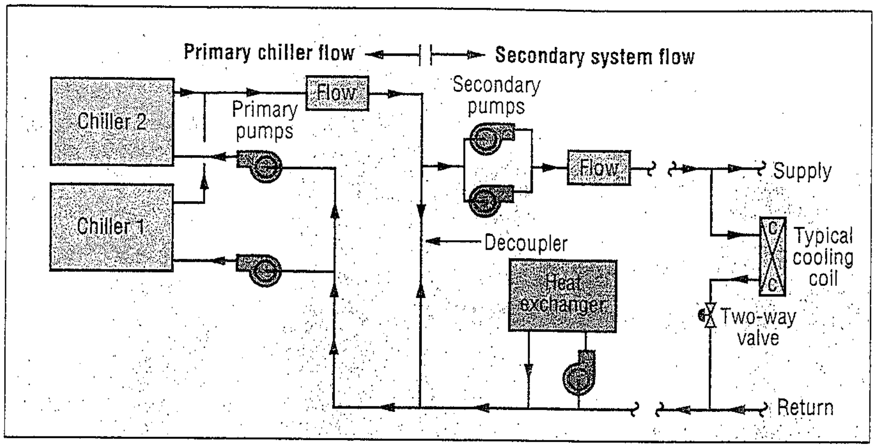
This sounds good, but can 46 to 50 F chilled water do any cooling? And what about dehumidification? The answers to these questions depend on the types of cooling systems in the building, but for comfort cooling applications, the warmer water can be used for cooling and dehumidification without a problem.

An understanding of how chilled water coils operate at reduced loads helps explain how the warmer water can be used. Since water-side economizer is being considered, this usually means that an air-side economizer cycle (utilizing up to 100 percent outdoor air to provide cooling in cool weather) is not feasible. For example, let's look at a five-story office building that has two 20,000-cfm air-handling units (AHUs) per floor in interior mechanical rooms where only 15 percent fixed outdoor air (3000 cfm) can be supplied to the units. The summer design outdoor air temperature is 88 F DB/76 F WB, and the return air temperature is 75 F DB/62.5 F WB (50 percent relative humidity). For free cooling (winter conditions), 45 F DB/41 F WB is the worst-case outdoor air temperature (above this, the cooling towers will not supply cold enough water), and the return air temperature is 75 F DB/56.7 F WB (30 percent maximum winter relative humidity). The leaving air temperature (LAT) for the AHUs is 55 F. This requires the cooling coils to deliver about 53 F DB (to allow 2 F fan heat on draw-through units).

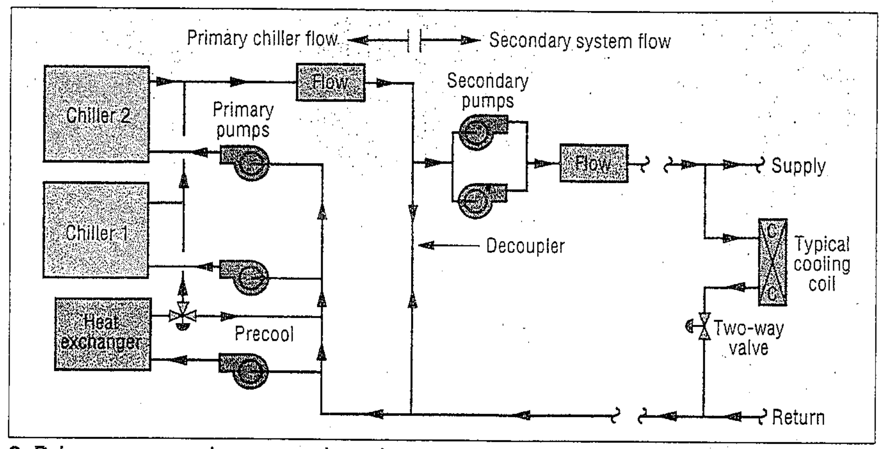
Most chilled water systems are designed to supply chilled water between 42 and 44 F. Table 1 shows cooling coil selections with both 42 and 44 F summer entering water temperatures (EWTs), each with a 16 F temperature rise. The table shows the summer design selection and three additional winter (free cooling) selections with warmer EWTs. The winter selections are at 100 percent air flow (constant-volume system), 80 percent (variable-volume system with typical wall/glass exposure), and 70 percent (variable volume with more wall/glass exposure).



1 Primary-only pumping free cooling heat exchanger location.



2 Primary-secondary pumping preferred heat exchanger location.



3 Primary-secondary pumping alternate heat exchanger location.

As the table shows, the warmer free cooling chilled water can cool the supply air to the same temperature as summer operation. This is due to the reduced winter cooling load. The skin (outdoor exposure—windows, wall, and roof) heat gain may actually be a heat loss in the cooler weather. In addition, the cooler outdoor air precools the return air (as opposed to summer operation where the outdoor air increases the cooling load). Since the same temperature air is supplied to the rooms, dehumidification is not a problem (the cooler/drier outdoor air actually lowers the relative humidity in the building). This results in a winter cooling coil load reduction of about 45 percent for a constant-volume system and 60 to 65 percent for variable-volume systems.

If fan-coil units are used to cool the building, the perimeter units have reduced skin load in the winter and thus should work with warmer chilled water. The interior fan-coil units have a similar cooling load year round, with only a reduction in the dehumidification portion. For these to work with up to 50 F chilled water, one must select units for 45 to 48 F entering chilled water (oversized since the perimeter units are generally selected for 42 to 44 F water). The savings from extended hours of free cooling help justify the slight additional cost for oversized units.

Chilled water

Once the building's cooling system is designed, the next step is to design the building's chilled water system to optimize the use of free cooling. This involves placing the heat exchanger (HX) in the piping loop at a location and configuration that will allow for the greatest use of free cooling.

The HX capacity is maximized when it has the warmest entering chilled water available. In addition, even when the HX can't produce cold enough chilled water to do all the cooling, energy can be saved by using it to precool the chilled water before it is returned to the chiller. This reduces the chiller load.

There are two basic chilled water pumping system arrangements. The first is primary-only pumping, where one pump serves each chiller and is sized to supply

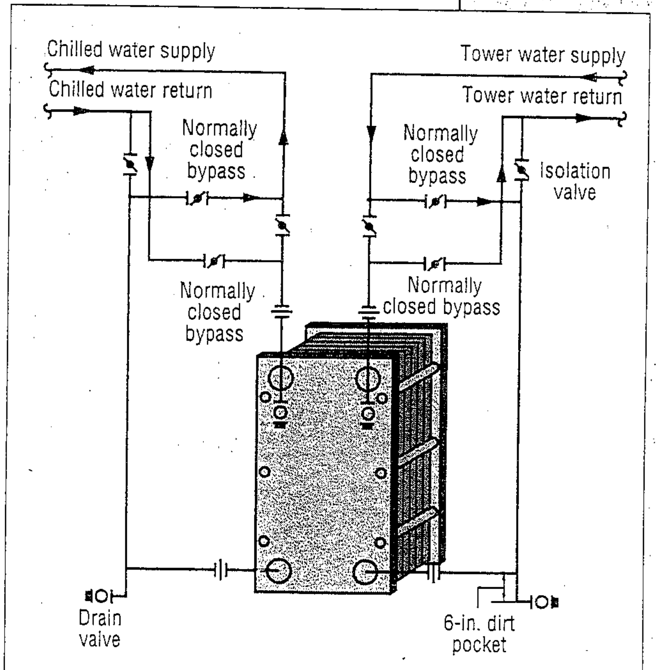
Heat exchanger considerations

Plate-and-frame heat exchangers are usually the type used for free cooling applications. These are capable of a 2 to 3 F approach temperature, which is the difference between the entering water temperature on the cold side of the unit (tower water) and the leaving temperature on the warm side of the unit (chilled water), in a compact and cost-effective package. Tower water flows on one side of each plate while chilled water flows on the other side in the opposite direction. By closely spacing multiple plates side by side, the heat exchanger effectively sandwiches each chilled water flow path with two tower water flow paths (one on each side of the two plates that separate the chilled water from the tower water).

Heat transfer is very high due to the turbulent flow and closeness of the plates. But even here, there are areas of concern. Since these plates are very close together, there is the possibility of fouling or clogging (the manufacturers generally say that the high turbulence decreases the chance of fouling, but experience shows that fouling does happen). Fouling should be accounted for both in the design of the unit (using at least 0.00025 fouling factor) and in the installation details.

Fouling can be reduced by providing strainers for the heat exchanger with a screen size for about 1/8-in. particles (confirm with each heat exchanger selection). A strainer can be located at the heat exchanger, or the strainer at the pumps can be specified with the required screen size. In addition, the piping can be arranged to allow the exchanger to be cleaned by backflushing. This requires bypasses as shown in accompanying figure. Backflushing does not completely clean the unit but does reduce the number of cleanings required. To clean the unit fully, one must separate the plates, clean them, and put them back together (usually with new gasketing).

Another potential problem can occur when there is a large difference in operating pressure (over 40 psi) on the two sides of the plates. This differential pressure can bow the plates outward on the high-pressure side (especially when large plates are used). This decreases the velocity on the high-pressure side, reducing turbulence and increasing fouling. It also decreases the free area for flow on the low-pressure side, thus increasing the pressure drop, which decreases flow and capacity. As long as the heat exchanger schedules or specifications include data on the expected operating pressures, the manufacturer can account for them by using stiffer plates, increasing the number of plates, or a combination of both.



Heat exchanger backflush valving.

the chilled water to all cooling coils. The second is primary-secondary pumping, where a smaller primary pump (one per chiller) is sized to pump through the chiller in a local loop. In this system, the secondary pumps are sized to supply the chilled water from the primary loop to the cooling coils and back to the loop.

The best location of the HX for each of these systems is different. For primary-only pumping systems, the HX is best located closest to the system return, as shown in Fig. 1. With this location, even if full free cooling isn't available (due to a rise in chilled water temperature leaving the HX above maximum design), the HX can still provide some cooling by lowering the chilled water return temperature to the chillers by opening the three-way valve to the precool bypass position, thus lowering the load on the chiller(s).

For primary-secondary pumping systems, the best location is in the secondary chilled water return piping before the decoupler, as shown in Fig. 2. In primary-secondary systems, the controls are usually designed to maintain more primary flow than secondary flow. This prevents the secondary supply water temperature from increasing above design (caused by warm return water bypassing the chillers through the decoupler). Locating the HX as shown in Fig. 2 always ensures that the warmest water is returned to the HX. The pump for the HX is decoupled from the primary and secondary pumps, and no diverting valve is needed for precooling—just turn on a chiller and associated primary pump when the HX can only do precooling.

Alternatively, the HX could be located similarly to Fig. 1 (after the decoupler in the location of the first chiller). This is shown in Fig. 3. This location works equally as well as that in Fig. 2 during periods when the HX can do all of the cooling. However, during precooling operation, the better location is as shown in Fig. 2 because the entering water is almost always warmer. This increases the HX capacity compared to the Fig. 3 location, where the return water is cooled somewhat by the excess primary flow through the decoupler to the return.

One advantage of Fig. 3 over Fig. 2 is that the pump used for the HX may be able to be easily used as a spare primary chilled water pump for the chillers (if the sizing is similar). In Fig. 2, the HX pump is not as easily used as a backup for the chiller pumps.

Tower water

Since operation during free cooling involves tower water supply temperatures around 40 F, some precautions need to be addressed. The items of greatest concern are freezing of the outdoor piping and/or towers, control of temperature, and startup and operation of chillers with cold tower water.

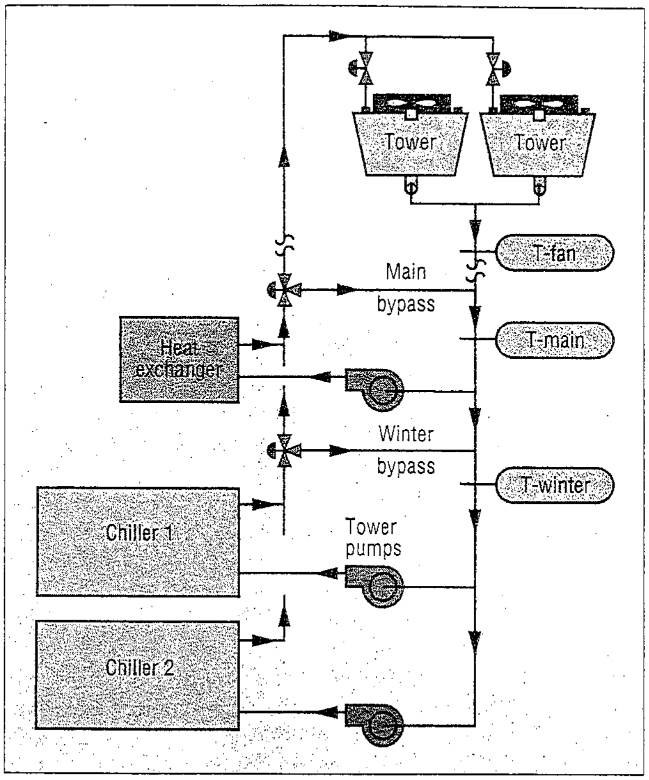
Outdoor piping can be kept from freezing by heat tracing. Since the winter operating temperature is about 40 F, the thermostat for the heat tracing should be set to energize at about 36 F and de-energize at about 38 F so that the heat tracing only operates when needed and does not add a load to the cooling system. The basins of the cooling towers also need protection, accomplished with either electric or steam basin heaters. These should be set to operate at the same temperatures as the piping system heat tracing.

Like most cooling equipment, cooling towers are sized for the hottest, most humid day of the year. Any time the outdoor conditions are less than design, the towers are oversized. This can lead to temperature control problems during free cooling operation. To have better temperature control in subfreezing weather with variable cooling loads, one must use either two-speed or variable-speed fans.

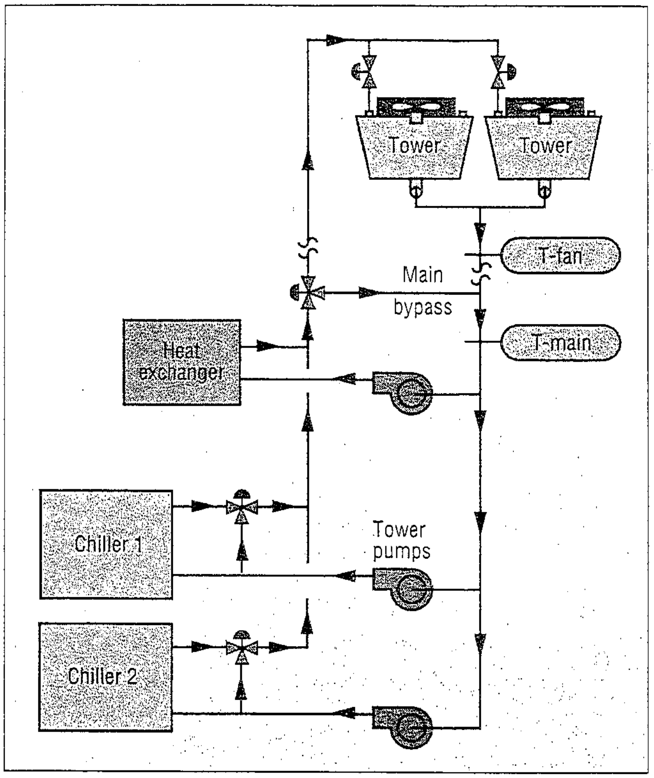
Table 2 shows the approximate outdoor air wet bulb temperatures and fan speeds for summer and winter loads for two 300-ton towers using two-speed fans. The 46 F leaving water temperature (LWT) allows a 3 F approach for the HX to supply 49 F water. The bottom row of the table shows operation with one tower fan at half speed with half of the winter design load. Note the overcooling (drop in LWT to 37 F). This can produce icing on the tower, and to keep the temperature above 40 F, the fan must cycle between half speed and off. As the load drops off, the towers can overcool the water flowing through them by gravity, even with the fans off. If the load drops to much less than half capacity in subfreezing outdoor temperatures, there is a very good chance of ice forming on the cooling towers. Preventive measures include adding isolation valves to each tower so that as the flow is re-

TABLE 2—Approximate outdoor air wet-bulb temperatures and fan speeds for summer and winter loads for two 300-ton towers using two-speed fans. (Information based on data generated by Marley Cooling Tower selection program.)

Outdoor WB temperature, F	Tower capacity	LWT, F	Tower 1 fan	Tower 2 fan
78 (design)	600 tons	85	High speed	High speed
41	2900 MBtuh	46	High speed	High speed
37.5	2900 MBtuh	46	High speed	Low speed
34	2900 MBtuh	46	Low speed	Low speed
15	2900 MBtuh	46	Low speed	Off
20	1450 MBtuh	37	Low speed	Off



4 Tower water bypass control.



5 Tower water head pressure control.

duced and the water temperature drops, cells can be isolated, forcing higher flow through the remaining towers. This higher flow lessens the chance of icing. In addition, a tower bypass valve is needed. The bypass valve should be controlled so that if the water temperature drops below a low limit (say 40 F), the towers are fully bypassed. If the flow to the tower is modulated, the likelihood of icing increases. When the water warms up by about 4 F, the bypass valve can open fully to the towers.

Tower fans should have the capability of being reversed so that they can be used for deicing if tower icing should occur. This should be done after the water has bypassed the tower and warmed to about 44 F. The reversed air flow forces some of the falling water to the perimeter where it comes in contact with the ice and melts it. When the tower is deiced, normal operation can be restored.

A further step to minimize the chance of tower icing is to add variable-speed drives to the tower fans. This allows operation to a minimum speed of 20 to 30 percent (check with tower manufacturer for minimum speed) and provides better free cooling temperature control. This is especially helpful in areas where the outdoor wet-bulb temperature is below 10 F for many hours or where the load is variable.

Another area to be concerned with is making sure that the chillers are able to be automatically started and operated during the times when the tower water is cooled to free cooling temperatures or, when free cooling is no longer available, until the temperature rises to normal chiller operating temperatures. In general, centrifugal, reciprocating, and screw chillers require the tower water to be between 55 and 65 F for smooth startup and operation with full tower water flow. Absorption chillers usually require 60 to 65 F tower water. However, the free cooling system needs tower water temperatures below these limits to provide even partial free cooling (precooling).

There are two ways to insure proper chiller startup and operation with colder-than-design tower water temperatures. The preferred method is to arrange the piping so that the HX is the first piece of equipment to receive tower water. Then, the chillers can be piped with their own bypass. This is shown in Fig. 4. Since the cold water circulates only between the HX and the towers, the remaining tower water in the piping around the chillers is about equal to the temperature of the mechanical room, or about 60 F. This allows the chillers to start up and operate with the three-way control valve open to the winter bypass (initially fully bypassing the tower). As the temperature at sensor T-winter warms up to about 65 F, the valve modulates to allow some of the colder water to mix with the winter bypass water to maintain 65 F to the chillers (or as cool as the chillers can handle). This method works with any type of chiller, including absorption machines.

The other method is head pressure control. This uses a signal from the chiller's refrigerant system to modulate a valve to bypass tower water from the chiller at low head pressures. The flow diagram for this is shown in Fig. 5. By bypassing flow from the chiller, the remaining flow has a higher temperature rise, allowing the chiller to operate. This does not work with absorption chillers as they operate with a different cycle. A three-way valve is shown in Fig. 5 for each chiller. A two-way could be considered if the minimum flow is enough to prevent the pump from cavitating. This minimum flow information must be coordinated with both the chiller and pump manufacturers.

The temperature sensor that controls the tower fan speed should be close to the towers so that the response time is minimized. The farther away from the towers, the longer it takes for the temperature change resulting from a change in fan speed to be sensed. This is due to the fact that at reduced winter flow, the velocity in the piping could be reduced to under 4 fps. At this speed, it takes about 25 sec for each 100 ft of pipe through which the water travels. During this time, the water may be overcooled before the control system can respond. As Figs. 4 and 5 show, if a sensor is used near the towers, one must use a second temperature sensor for control of the main tower bypass valve. If the towers are close to the chiller room, one temperature sensor can control both the fans and main bypass valve.

An additional consideration is the type of cooling tower used. This can be important for trouble-free operation. In general, induced draft towers operate better in subfreezing weather than forced draft towers due to better equalization of air flow across the fill, which results in more uniform temperature gradients. Also, it is important to specify that the towers provide uniform flow across the fill at the lowest expected flow rate. For example, if three towers are used and the free cooling flow is one-third of the design flow, select the towers to provide uniform flow across the fill at one-third flow. The manufacturer can accomplish this in gravity towers by raising the perimeter orifices so that only at higher flow rates will the water level in the hot water basin be high enough to flow through them. For towers with spray nozzles, the nozzles can be at two levels, with each level giving good coverage of the fill. One level is set above the main header and one below so that at low flow, only the lower nozzles operate.

Conclusions

Optimization and trouble-free operation of free cooling can be accomplished by taking the time to design each component for this mode of operation. The items that should be considered include:

- The design of the building's cooling system and cooling coils.
- The design and placement of the heat exchanger in the chilled water piping loop, allowing the warmest entering chilled water temperature to enter the HX and also allow for precooling of the chilled water when full free cooling is not available.
- The best type of cooling tower for the application and insuring proper water distribution at reduced flow.
- Precautions to prevent freezing of the outdoor piping and tower basins.
- Adequate temperature control during subfreezing weather and varying load conditions.
- The design of the tower water piping system to allow for automatic startup and operation of chillers with cold tower water. HPAC