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A New Era of Free Cooling

A previous *Engineers Newsletter* (Vol. 20, No. 1) promised more information on the application of "free cooling" to chilled water systems. In this issue, we will attempt to fulfill this promise. However … a word of caution. Free cooling will often legitimately masquerade as something else. We must be alert to the discovery of free cooling concepts that may seem to appear as something totally different.

No Free Lunch

Not surprising, truly free cooling is a myth. Just as there is no free lunch, free cooling is a **concept**, not a reality. Virtually all forms of free cooling carry an embedded cost. The cost may be economic, loss of comfort, or loss of control. It is the system designer's responsibility to assure his client that the end user's interests are maximized throughout the application process.

Back to the Basics

The starting point of this newsletter is the classic primary/secondary (decoupled) chilled water system. Familiarity with this common system is essential to understanding the free cooling concepts discussed here. Therefore a brief review. (For those readers unfamiliar with this form of hydraulic decoupling, please refer to **Trane Applications Manual CON-AM-21** and ***Engineers Newsletters*** Vol. 8, No. 4 and Vol. 12, No. 5.)

The decoupled primary/secondary system shown in Figure 1 has wide application. The number of chillers used is unlimited. Such a system can use a single chiller or as many as can be housed in a chiller plant. Chiller size and type are also not constrained. Long time readers of the newsletter will recognize salient technical aspects of this hydraulic arrangement:

- Divided into separately pumped "production" and "distribution" circuits.
- Hydraulically decoupled by a section of piping common to both circuits.
- Based on a supply/demand relationship between the two circuits.
- Individual chillers responsible for chilled water temperature control.
- All chillers operate on a common supply/return water temperature regimen.
- Advantageously applied to variable flow distribution.
- Advantageously applied to multiple chillers and the need for growing, flexible parts.
- Advantageously applied to systems utilizing high "delta-T's."

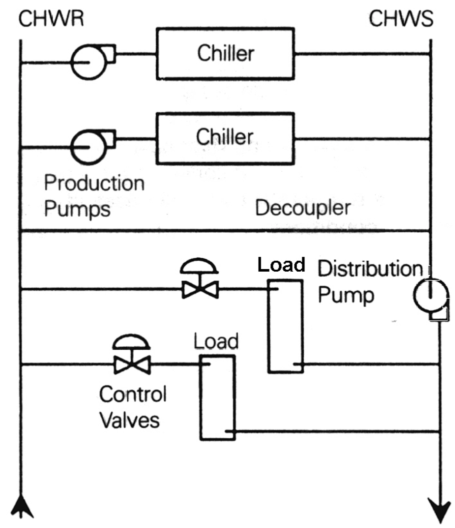

Figure 1. Decoupled Chilled Water System

It is important to fully grasp these simple characteristics in order to expand applications into "The New Era of Free Cooling."

Load Behavior

A critical operating characteristic of a variable flow distribution system is its elevated return water temperature behavior. A review of “building loads” at off-design conditions is imperative. Consider the normal chilled water cooling coil, Figure 2. Typically, cooling coils are selected at design conditions to supply conditioned air at a temperature between 52°F and 55°F. In order to minimize chilled water flow, relatively large chilled water temperature increases occur. In this example, water is supplied at 42°F and returned at 58°F, a 16-degree delta-T at design conditions. Clearly, coil fluid flows and heat transfer are “counterflow,” as the entering (cold) water contacts the leaving (coolest) air. In this example, a design value of 606.7 MBh (50.56 tons) of cooling capacity is transferred. Values shown in Figure 2 result from computer runs made using the ARI-certified Trane Cooling Coil Performance Program. The selected coil is a 33" × 144", six-row, Prima-Flo® coil with 135 fins-per-foot fin spacing.

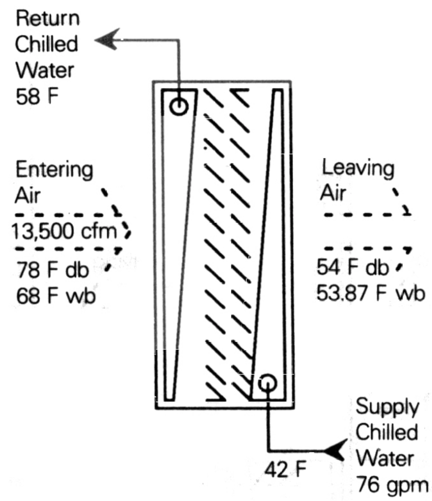

Figure 2. Cooling Coil at Design Conditions

At off-design conditions, a wide variety of system response scenarios are possible. Ordinarily, a modulating two-way valve regulates water flow to effect HVAC system control. Figures 3 and 4 depict typical off-design conditions for variable air volume (VAV) and constant air volume systems, respectively. While the impact on the chilled water systems are similar, they are not exactly the same, even though the gross space loads are identical. The small differences are a result of heat transfer and space humidity differences.

Figure 3 depicts the condition of approximately 50 percent design load (301.9 MBh) as applied to a VAV system. Such a system varies air volume, but maintains a supply air temperature of 54°F dry bulb. Using the same coil configuration and controlling coil performance by modulating water flow only, we note that the leaving air wet bulb temperature is maintained at 53.90°F. Latent heat removal remains high (total heat – sensible heat) at 122.7 MBh. Pay particular attention to the resulting leaving water temperature. By modulating the water flow to control 54°F leaving air stream, the leaving water temperature **actually rises to 61.34°F**. This behavior is vitally important to the chilled water distribution system.

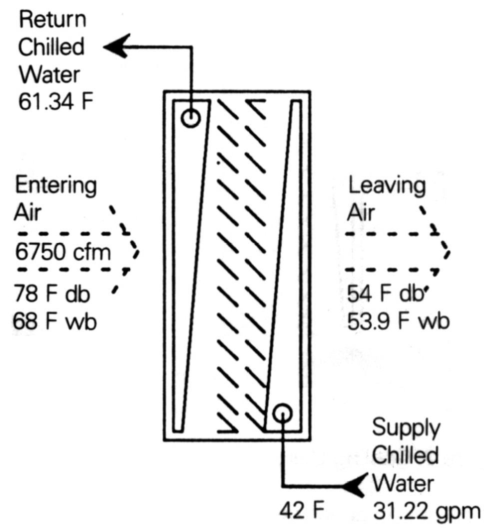

Figure 3. Cooling Coil in VAV System at 50-Percent Load

Figure 4 shows the same type of control applied to a constant air volume system. In this case, the supply air temperature must rise to accommodate decreased air system loading. In order to arrive at a 50-percent condition (300.1 MBh total heat), we permitted the leaving air dry bulb to rise to 61.7°F. In so doing, the coil performance dictates a leaving air wet bulb of 61.48°F and a latent heat removal of only 56.6 MBh. Quite clearly, this air system results in poorer space humidity control. However, we also need to note the resulting leaving chilled water condition. **It has risen to 68.43°F!**

Chart 1 summarizes coil performance parameters at the above three conditions.

Therefore, we can confidently predict that, regardless of the airside system used, control via modulation of a two-way chilled water valve results in **no decrease** in the temperature of returning chilled water. And, in fact, the **temperature actually rises at part-load conditions**.

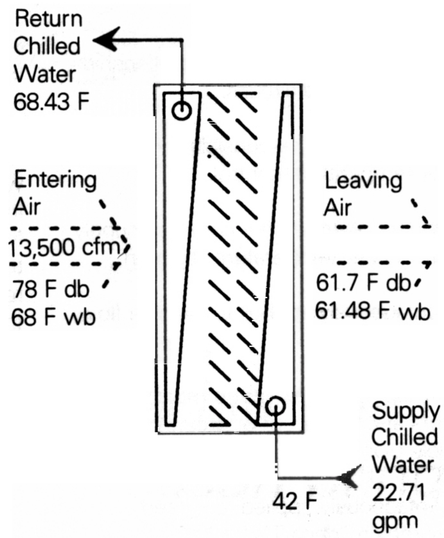

Figure 4. Cooling Coil in Constant Airflow System at 50-Percent Load

Chart 1

Variable	Full Load (Design)	Half Load (Var Air Vol)	Half Load (Const Air Vol)
Airflow – cfm	13500	6750	13500
Entering air dry bulb – °F	78.00	78.00	78.00
Entering air wet bulb – °F	68.00	68.00	68.00
Entering air relative humidity – %	60	60	60
Entering water temperature – °F	42.00	42.00	42.00
Water flow – gpm	76.01	31.22	22.71
Water delta-temperature – °F	16.00	19.34	26.43
Leaving water temperature – °F	**58.00**	**61.34**	**68.43**
Leaving air dry bulb – °F	54.00	54.00	61.70
Leaving air wet bulb – °F	**53.87**	**53.90**	**62.48**
Total heat transfer – MBh	606.7	301.9	300.1
Sensible heat transfer – MBh	358.5	179.2	243.5
Latent heat transfer – MBh	248.2	122.7	56.6
Airside pressure loss – in. wg	0.6655	0.2238	0.6083
Waterside pressure loss – ft/water	9.677	1.980	1.110

Back at the Plant

The significance of this load behavior cannot be underestimated, because it impacts the way loads are imposed on individual chillers. In order to “load” a chiller, two things must occur:

1 A design **water flow** condition must be established, and

2 A **return water temperature** equal to or greater than the design value must be provided.

Without **both** of these, a chiller is prevented from delivering its rated capacity. Therefore, it is vital that the system return water temperature be kept as high as possible.

Enter: Free Cooling

A second, and equally important benefit from high return water temperatures is the opportunity to "free cool." Obviously, the potential for free cooling is increased by the temperature difference between the supply of free cooling and the temperature of water to be cooled. Both sides of the equation are equally important.

Typically, one form of free cooling takes the form of something similar to Figure 5. A plate-and-frame heat exchanger provides for efficient transfer of heat from a warm fluid to a cool fluid. In this case, heat is transferred away from the chilled water stream and into a cooling tower water stream. This, like the cooling coil example, is a counterflow process. If the source of cooling tower water can deliver a temperature of 47°F, the chilled water stream can be cooled to within 3°F to 5°F of this value (50°F to 52°F).

In practice, the heat exchanger takes the place of a "compressor-less" chiller. Once energized by its dedicated pump, cooling is "free." But in this location, we would like to obtain design water temperature from the exchanger. A maximum cooling tower supply temperature of 39°F would be required to reach 42°F chilled water supply.

Obtaining such cold water from a cooling tower is fraught with operating problems. Consequently, we must choose between resetting the entire plant supply water temperature or mixing unequal supply temperatures. Neither choice is attractive, as increased primary flow is required and humidity control is sacrificed. As weather warms the cooling tower water, free cooling becomes more and more marginal. Finally, the effort becomes unproductive, even though the potential to free cool remains.

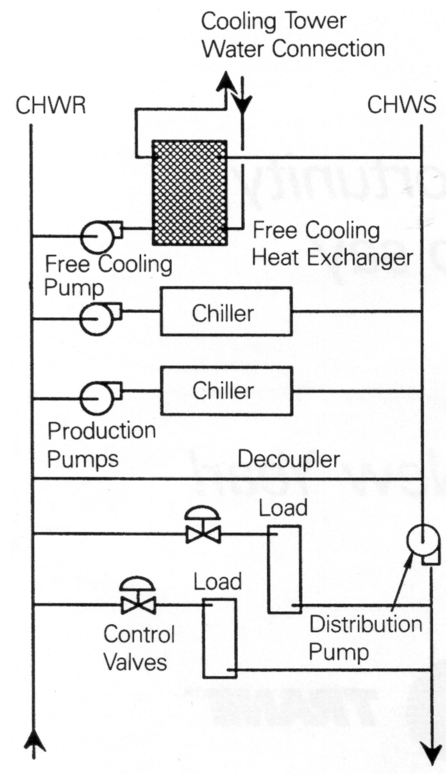

Figure 5. Free Cooling

Another Way to Skin the Cat

Earlier, we noted that a large temperature difference between the cooling tower water and the chilled water stream provides free cooling potential. Yet we have ignored the warmest chilled water and have been concentrating on the supply chilled water temperature. We have viewed the heat exchanger as "just another chiller." Let's rethink the exchanger location.

Figure 6 shows an alternative scheme, using exactly the same components. In this case, the warmest water in the system contacts the cooling tower water in the exchanger. Any time there is a temperature difference between these two streams, heat will transfer. Free cooling will occur. The temperature of the chilled water leaving the heat exchanger is unimportant. This permits a greatly expanded utilization of free cooling hours, since the return water temperature is significantly higher than supply.

At off-design conditions, the advantage is further assisted. As we saw earlier, the return water temperature from off-loaded coils actually rises. Since free cooling is usually associated with off-design conditions, we see an even greater number of hours of free cooling potential.

A simulation model that matches coincident weather (dry/wet bulb ambients), cooling tower performance, and chilled water loads can do a good job of predicting the increased benefit of this arrangement. Economically, it is a guaranteed winner because there are no added costs, compared to the arrangement shown in Figure 5.

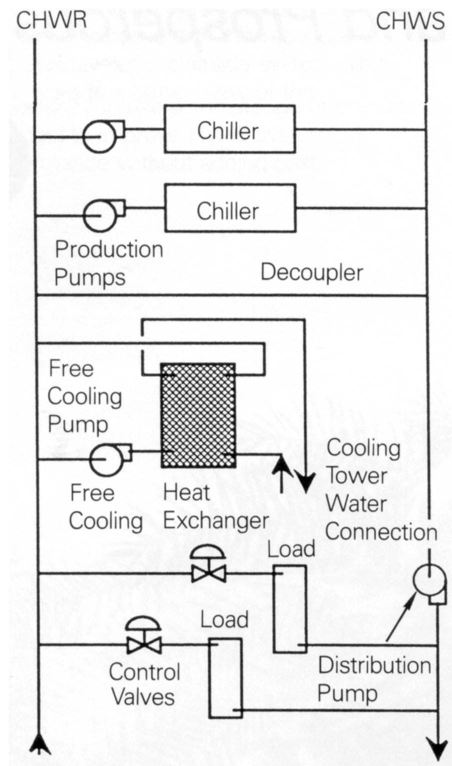

Figure 6. "Sidecar" Free Cooling

Hydraulics and Operation

The "sidecar free cooling" arrangement shown in Figure 6 is itself hydraulically decoupled from the primary system. The element of common piping is a section of return main located between the two tees. The primary system is unaffected by exchanger pump operation. Likewise, the exchanger pump need only address the pumping loss through the "clean" side of the exchanger. To engage free cooling, the pump is turned on. To disengage it, turn the pump off.

Control is also quite simple. Earlier we stated that free cooling can be obtained any time the source of cooling tower water is cooler than the return chilled water stream. Measurement and comparison of these two temperature values is all that is needed to make a binary "cool" or "no cool" decision. It is not difficult to imagine how such a control strategy can be incorporated into a chiller plant management scheme.

Separately, chiller plant management should also make a determination of the economics of obtaining the coolest possible cooling tower water temperature. This is by no means a "no brainer," as the "juice may not be worth the squeeze" as the ambient wet-bulb temperature approaches the return chilled water temperature. Software to perform these calculations in the chiller plant management environment are available, but not widely used … yet. We envision the day when it will.

Note that the heat exchanger pump does nothing to supply primary or secondary water to the system. Being hydraulically decoupled, its operation is an unconnected event. Therefore, one of the chiller pumps shown in Figure 6 must operate if a chiller is to augment free cooling. "Load" will be shed from this chiller by virtue of its decreased return water temperature. As free cooling assumes a greater portion of the total load, return water temperature "downstream" from the heat exchanger tee drops until it finally reaches the supply chilled water temperature. At this point, free cooling is handling **all** plant loads. The chiller and its pump are not needed, because the decoupler line handles the return water flow assignment.

Putting on New Masks

Figure 7 replaces the heat exchanger with a chiller operating as a heat pump. Free cooling masquerades as heat recovery. A more elaborate description of this application appears in the *Engineers Newsletter* (Vol. 20, No. 1) "Two Good Old Ideas Combine to Form One New Great Idea".

Figure 8 replaces the heat exchanger with a direct-fired absorption chiller. Imagine using gas as an effective way to shed electrical demand, controlled in a binary fashion **by the electric utility**. Since temperature control is not part of the strategy, the use of this form of "free cooling" is an on/off decision easily made by the utility itself, conceivably by remote signal.

Figure 9 replaces the heat exchanger with a partial storage ice storage system. This arrangement uses a similar heat exchanger to confine antifreeze fluids to the "sidecar" system. This system has the capability to operate in the classic ice storage modes while the chiller plant is in normal operation:

1 Make ice only.
2 Make ice and furnish instantaneous cooling.
3 Burn ice only.
4 Burn ice and furnish instantaneous cooling.
5 Store ice only.
6 Furnish instantaneous cooling only.

Each of these variations, and more, are possible by using the return chilled water stream as an important source of warm water. Development of this resource is a key objective of the airside system. This may provide a better view of the relationships between chilled water and airside systems. They are not separate. To design them separately is to miss an opportunity to use a knowledge of physics as a tool to improve HVAC system performance without adding cost.

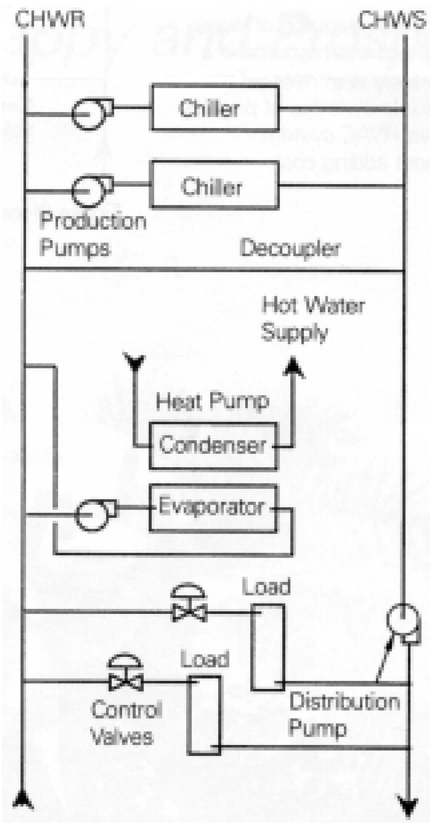

Figure 7. Heat-Recovery Free Cooling

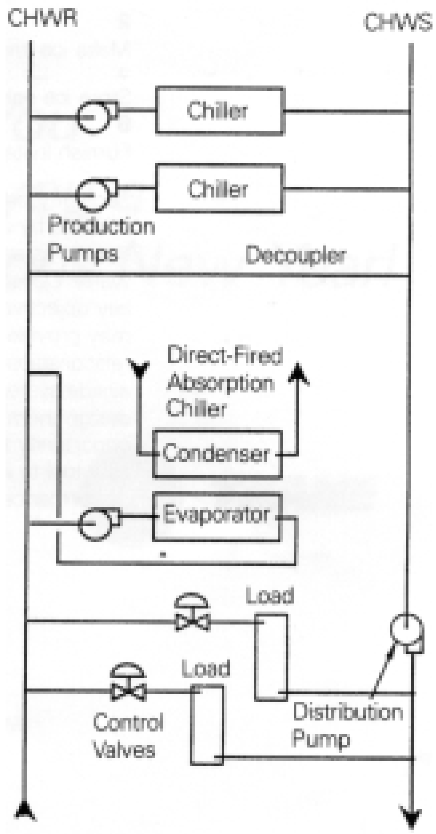

Figure 8. Electric-Demand-Control Free Cooling

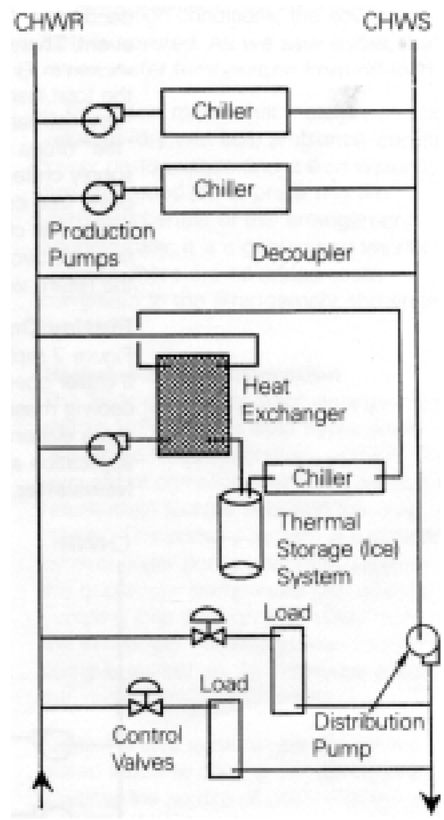

Figure 9. Ice-Storage Free Cooling