HVAC: Evaporative Cooling

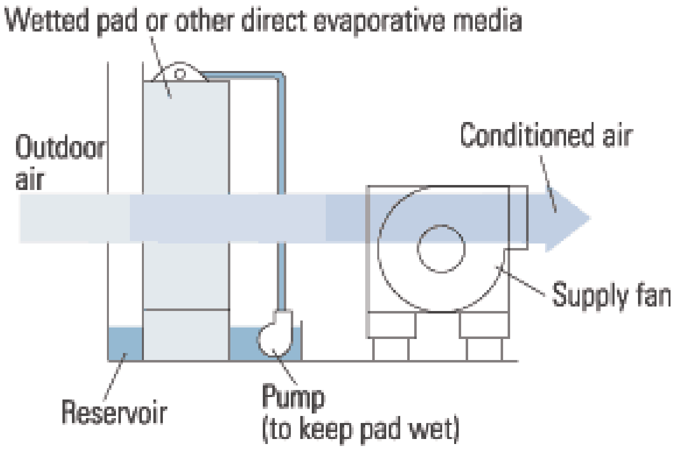
Evaporative cooling is a process by which moisture is added to air in order to reduce air temperature and increase relative humidity. It occurs when moisture is added to air that has a relative humidity of less than 100 percent. The lower the relative humidity, the greater the cooling effect that is possible when moisture is added. The technology is a versatile and energy-efficient alternative or adjunct to compressor-based cooling. In favorable climates (most of the western United States and other dry-climate areas worldwide), evaporative cooling can meet most or all building cooling loads using one-fourth the energy of conventional equipment. It can also be applied cost-effectively when integrated with conventional chiller systems. Using evaporative technology can also improve a facility's load profile.

What Are the Options?

Direct. Direct evaporative cooling is the term applied to comfort-cooling applications that simply add moisture directly to an airstream to cool the air while increasing its relative humidity (see **Figure 1**). In most applications, moisture is added to a moving stream of outdoor air that is delivered to the indoors while an equal quantity of indoor air is exhausted from the building. Because a direct evaporative cooling system does not recirculate any air, it is imperative that the building's exhaust system is able to match the rate at which conditioned air is introduced to the space. If this is not done, the building will become pressurized, which leads to insufficient airflow as well as difficulty in closing doors and air whistling through stairwells and elevator shafts.

Figure 1: Direct evaporative cooler

Wet-surface direct evaporative coolers typically use pumped recirculating water systems to keep the media wet. A fan blows air through the media, thereby cooling the air and increasing its humidity.



Source: E SOURCE

In operation, pumped recirculating water systems typically keep a pad of woven fibers or corrugated paper wet while air flows through the pad. The pad absorbs water by capillary action and maximizes contact between the airstream and the wet medium. To ensure that all surfaces are wet, more water is usually pumped than can be evaporated and excess water drains from the bottom of the media into a sump. An automatic refill system replaces evaporated water.

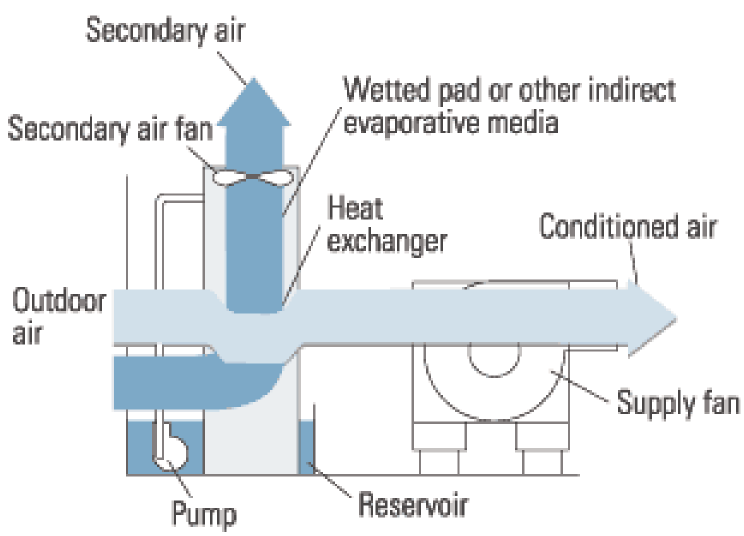
Indirect. Indirect systems cool air without adding moisture (see **Figure 2**). They are more expensive and use more energy than direct systems, but they can provide energy efficiency in applications where direct evaporative cooling may not be practical. In operation, an indirect evaporative process cools air or water on one side of an impermeable heat-exchange surface such as a thin plastic plate or tube. The wet side cools the dry side without adding moisture (because there is no direct contact between the water and the airstream to be cooled). Water sprayed on a hot roof, for example, evaporates at the roof surface and cools the roof deck, which cools indoor space below without increasing indoor humidity.

Heat exchangers for indirect evaporative coolers were usually made of aluminum or stainless steel until plastic models were introduced in the 1970s and 1980s to reduce costs. Plastic heat exchangers aren't as effective at heat transfer, but they weigh less, are easy to manufacture, and resist corrosion.

A cooling tower that provides heat rejection for a water-cooled air conditioning system can do double duty as an indirect evaporative cooler. This can be accomplished in several different ways. The most common way is called a “water-side economizer” and it employs a plate-and-frame heat exchanger (PFHX) between the condenser water loop and the chilled water loop. During cool, dry conditions, the cooling tower works to lower the temperature of the condenser water, and this cold water is pumped through the PFHX. Heat is transferred from the chilled water loop (which provides the actual cooling effect for building air) into the condenser water without the use of compressors. Pumping energy is higher when using a water-side economizer, so the savings in chiller energy must be weighed against this increase to determine when it makes sense to use the PFHX. The purpose of the PFHX is to prevent dirt and other contaminants from migrating from the condenser water system (which is open to the atmosphere) to the chilled water system (which is closed).

Figure 2: Air-to-air indirect evaporative cooler

In a typical inderect evaporative air cooler, the essential element is a heat exchanger in which dry air contacts heat-exchange surfaces whose other sides are cooled evaporatively.



Source: E SOURCE

A simpler version of the water-side economizer is colloquially referred to as a "strainer cycle." This option omits the PFHX, so that water passing through the cooling tower is pumped directly to the cooling coils. The most significant drawback to this approach is the introduction of dirt and debris to the chilled water piping and coils (which can reduce heat-transfer efficiency). This approach takes its name from the fact that the strainers located throughout the chilled water system to catch debris will need to be cleaned more often because of the "dirtier" condenser water flowing through the typically pristine chilled water system.

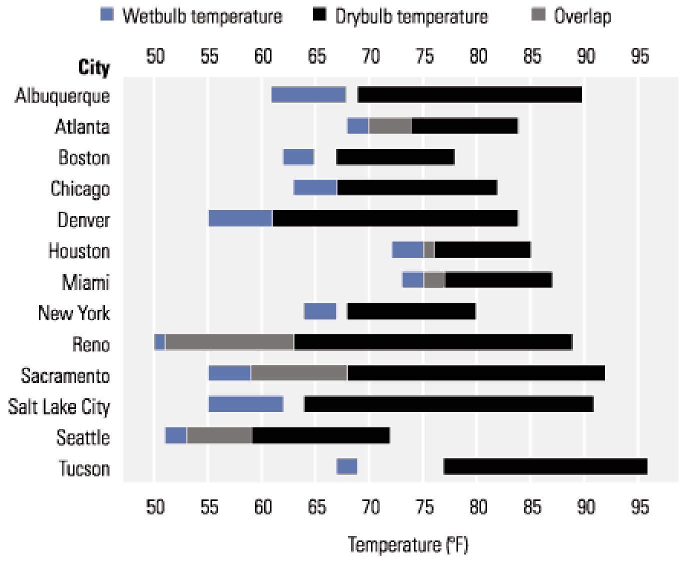
Two-stage. Two-stage evaporative cooling provides air that is cooler than either a direct or indirect single-stage system can provide individually. In many cases, these two-stage systems provide better comfort than a compressor-based system, because they maintain a more favorable indoor humidity range. Two-stage systems place an indirect cooling section on the upstream side of a direct cooling stage. The first stage cools without adding moisture. Primary air leaving the first stage can be directly evaporatively cooled to a lower temperature than is possible with direct cooling alone, with less moisture addition. The indirect stage can use either an evaporative heat exchange approach or a tower/coil approach, which connects a cooling tower to a finned cooling coil in the supply air ahead of the direct stage.

How to Make the Best Choice

Assess the potential for evaporative cooling in your climate. Figure 3 shows average July daily wetbulb and drybulb temperature ranges for 13 U.S. cities. (Drybulb temperature is what a standard thermometer indicates. Wetbulb temperature accounts for the moisture content of the air. The wetbulb temperature is always lower than or equal to the drybulb temperature. When the wetbulb temperature and the drybulb temperature are equal, it means that the air is "saturated"—it has reached the dew point—and cannot hold additional moisture.) In five of the cities shown (Albuquerque, Boston, New York, Salt Lake City, and Tucson), the average wetbulb range is fully below the drybulb range, and in all five the wetbulb range is below 70° Fahrenheit (F). The arid climates of Albuquerque, Salt Lake City, and Tucson make them excellent locations for evaporative cooling. In more humid locations like Boston and New York, evaporative cooling may be used in dry weather, but will need to be supplemented by compressor-based cooling in hot, humid weather.

Figure 3: Daily average wetbulb and drybulb temperatures in July for selected cities

Cities where the wetbulb range is fully below the drybulb range are excellent candidates for evaporative cooling of commercial buildings.



Source: Davis Energy Group

The five cities with wetbulb ranges extending to or below 55°F are all in the West in regions that are ideal for evaporative cooling. (However, Seattle's low drybulb temperature range means cooling loads can usually be satisfied with outdoor air.) Locations with average July wetbulb temperature ranges extending above 70°F (Atlanta, Houston, and Miami) are not good candidates for evaporative cooling in July.

Consider eliminating compressor-based cooling. Prospects for completely eliminating compressor-based cooling are best in high-altitude climates that have dry air and lower summer daytime temperatures, as represented by Denver in Figure 3. In very hot summer climates like Phoenix (not shown), where afternoon July wetbulb temperatures often exceed 75°F, there are times when even a good two-stage evaporative cooler cannot cool air to desired indoor temperatures without exceeding the ASHRAE relative humidity limits. However, in these climates, direct or indirect evaporative cooling (or a combination of the two) can usually satisfy full cooling loads for 10 months of the year and can be applied to ventilation air all year. Cost-effectiveness in these locales depends on local utility rates, the duration of the cooling season, cooling load patterns, and ventilation air quantities. In addition, even when a two-stage evaporative cooler cannot meet the entire cooling load, it can reduce the load that is met by the compressor by 50 to 80 percent. For this reason, combined direct/indirect/mechanical cooling systems usually have a much smaller compressorized refrigeration capacity than a system where there is no evaporative system.