Two Stage Evaporative Cooling

Two stage cooler installed on the terrace of Secunderabad Club. Photo courtesy United Engineering Corp.

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Evaporative cooling is responsible for the chill you feel when a breeze strikes your skin-the air evaporates the water on your skin, with your body heat providing the energy. Traditionally, since ancient times, people used to hang wet mats in their doors and windows, and wind blowing through the mats cooled the air - one of the early attempts at air cooling. This basic idea was refined through the centuries: mechanical fans to provide air movement in the 16th century, cooling towers with fans that blew water-cooled air inside factories in the early 19th century, desert or swamp coolers in the 20th century.

Direct Evaporative Cooling

The simple examples given above illustrate *direct evaporative cooling*. Here, outside air is drawn (by means of a fan) through a water-saturated medium or pad and cooled by evaporation (*Figure 1*). A recirculating water pump is used to keep the pad wet.

Direct evaporative cooling adds moisture to the air stream until the air stream is close to saturation. The dry bulb temperature is reduced, while the wet bulb temperature stays the same. The total heat content, or enthalpy, of the air remains unchanged since the latent heat required to vaporize some of the water is drawn from the air which gets cooled in the process. This is illustrated in the psychrometric chart (*Figure 2*) as process A - B, in which the air is shown cooled from 103°F dry bulb / 72°F wet bulb to 77°F db / 72°F wb temperature.

In heat exchanger theory, evaporative cooler pads are considered constant temperature heat exchangers, whose surface is at the wet-bulb temperature of the air passing through them. How close the evaporatively cooled air gets to the prevailing wet bulb temperature is called the saturation effectiveness or adiabatic efficiency. Direct evaporative cooling has an adiabatic efficiency of 60 to 80%, depending on the type of wetted pad media and the face velocity of air across the pad.

A quick check for evaporative pad performance is to measure the temperature of the water in the cooler sump (which nearly equals the

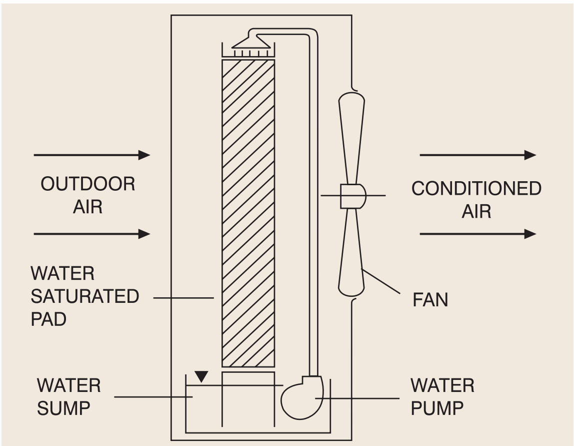

Figure 1 : Direct evaporative cooling

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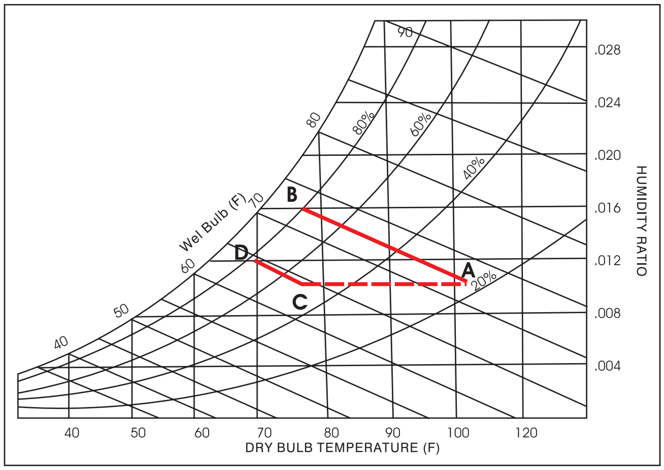

Figure 2 : A-B – Direct evaporative cooling
A-C-D – Two stage cooling

wet-bulb temperature of outside air) and apply it in the following formula for saturation effectiveness :

Saturation effectiveness =

(temperature difference between outside air and air leaving cooler/temperature difference between outside air and sump water) × 100 %.

The most common wetted pads used in evaporative cooling are made of shredded wood fibres, which have a naturally wettable surface, packed in a plastic net. These pads are 25 to 50 mm thick. The thicker pads are more effective since they can hold a larger quantity of water. Fiber pads must operate at low air velocities (less than 1 metre / second) to prevent water from being pulled off the pad by the airstream. They are therefore used on coolers that have air inlets on many sides. The pads are simply discarded every year or two and replaced with new ones. Wood fibre pad coolers usually cost the least and require the most maintenance.

More advanced evaporative coolers use a rigid-sheet pad, comprising a stack of bonded corrugated cellulose sheets. The pads have a corrugation or fluted pattern that forces water to flood the pad's air inlet side where most of the evaporation of water occurs. The pads may also be chemically impregnated to stiffen the material, improve wettability and prevent decay and decomposition. These pads are usually 100 to 300 mm thick.

Rigid pads allow air to move through at higher velocities (of upto 3 metres / second) than is possible with wood fibre pads. Coolers using rigid-sheet pads usually have a single air inlet (and are often referred to as "single-inlet coolers"). These pads are substantially more expensive than wood-fibre pads, but they can last for many years if water quality is properly maintained with a bleed-off or sump dump system. Therefore the life cycle cost for these pads can equal the cost of fibre pads.

Indirect Evaporative Cooling

With indirect evaporative cooling, a secondary (scavenger) air stream is evaporatively precooled by water by direct contact. The cooled secondary air stream goes through a heat exchanger, where it indirectly cools the primary air stream (without coming into contact with it).

In *Figure3*, the direct evaporative precooler and the heat exchanger together constitute an indirect evaporative cooler.

Indirect evaporative cooling provides only sensible cooling and does not add moisture to the primary air stream, as illustrated by the horizontal dotted line A - C in the psychrometric chart (*Figure2*). Both the dry bulb and wet bulb temperatures are reduced.

Indirect evaporative cooling units are used as pre-coolers with some very distinct advantages:

- To provide sensible cooling at a high energy efficiency ratio. Compared to conventional refrigerated units the cooling output, per watt of input, can be increased ten or more times, significantly decreasing operation costs.
- To pre-cool the (fresh) air entering cooling coils in a conventional airconditioning system. This will reduce the sensible cooling load resulting in a reduction in the size of the coil, refrigeration unit, and heat

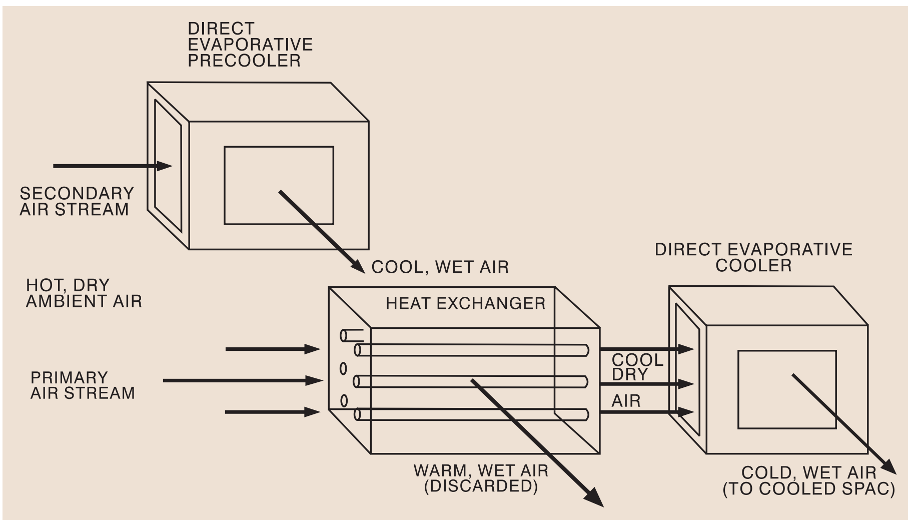

Figure 3 : Schematic diagram of two stage evaporative cooling

continued on page 98

continued from page 94

rejection unit. The connected electrical load, as well as operating costs, are reduced.

- To sensibly pre-cool the air to direct evaporative units to increase their effectiveness. This is the two-stage system concept.

Two Stage Cooling

In two stage cooling (also referred to as indirect / direct evaporative cooling), the primary air stream is first pre-cooled sensibly by indirect evaporative cooling. Since this precooling adds no humidity to the air, it can still be subsequently direct-evaporatively cooled, which is carried out in a direct evaporative section with a rigid pad (*Figure 3*). However, since the pre-cooled air can hold less moisture, the final relative humidity is lower (about 60 to 65%) than that reached with direct evaporative cooling.

A rather startling feature of two-stage evaporative coolers is that they can produce air colder than the outside wet bulb temperature. In other words, the adiabatic efficiency is higher than 100%. In practice, an adiabatic efficiency of 115% can be achieved. This process is illustrated by the line A - C - D in *Figure 2*.

Figure 4 depicts an illustration of a two stage cooling machine, many units of which have been installed at several locations in India.

Description of Operation

Outside air drawn into the unit is divided into 3 air streams: primary, intermediate and secondary.

The water in the sump B is cooled by direct evaporative cooling as it cascades over the direct evaporative cooling pad D. This evaporatively chilled water is pumped upwards through the indirect cooling coil, where it sensibly cools the primary and intermediate airstreams, while picking up heat from the two airstreams. This energy is rejected by the the exhaust fan E as it draws secondary air through the upper portion of the direct cooling pad D and intermediate air through both the indirect and direct cooling media.

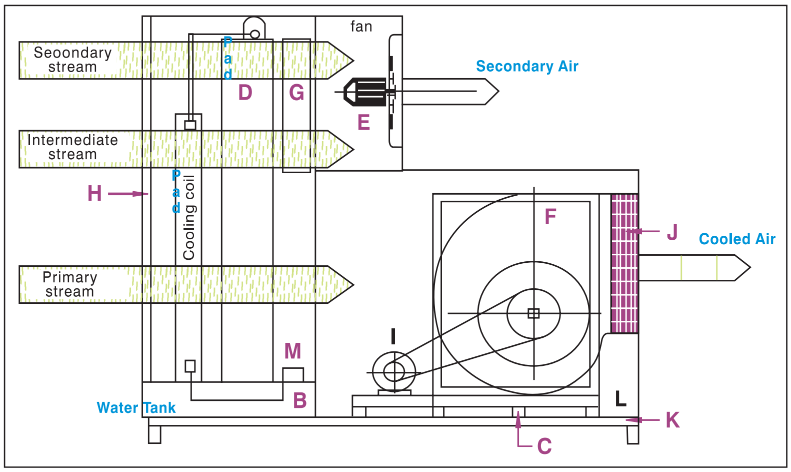

Figure 4 : Two stage cooling machine

The secondary air stream flowing through the upper portion of the direct cooling coil cools the water causing it to approach the outside wet bulb temperature. As the water passes over the intermediate air stream, it is further cooled near the new, low wet bulb temperature of the Intermediate air stream.

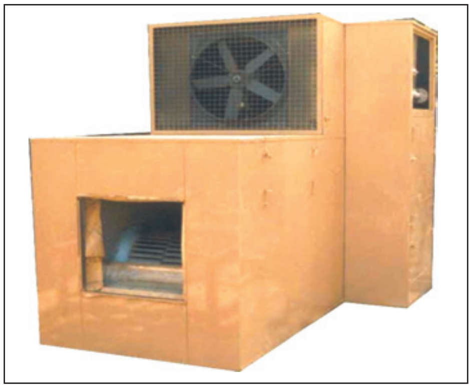

Figure 5 : Two stage cooling machine

The primary air, drawn by the supply fan F, is first sensibly cooled in the indirect cooling coil to a lower dry bulb and wet bulb temperature. It is then evaporatively cooled in the direct cooling pad, causing the leaving air temperature to approach a new, lower wet bulb temperature.

Advantages of Two Stage Evaporative Cooling

- Two-stage cooling allows the use of energy-saving evaporative cooling technology for design conditions where direct evaporative cooling is inadequate.
- The energy consumption is around half that of air conditioning, while the capital cost is also significantly lower.
- In many cases, two-stage systems can provide better comfort than a compressor-based system because they maintain a more favorable indoor humidity range. Hence, they can replace mechanical refrigeration in many applications.
- The conditioned space is cooled by 100% fresh air, hence there are no IAQ related problems. Typically, two-stage cooling systems are designed for 25 to 40 air changes per hour, similar to ventilation.
- Since no refrigerant is used, the system is environmentally friendly.

Disadvantages

- It is less effective in coastal areas which have high relative humidity.
- There is a significant temperature variation in the cooled space round the year, depending on the prevailing ambient dry and wet bulb temperatures.

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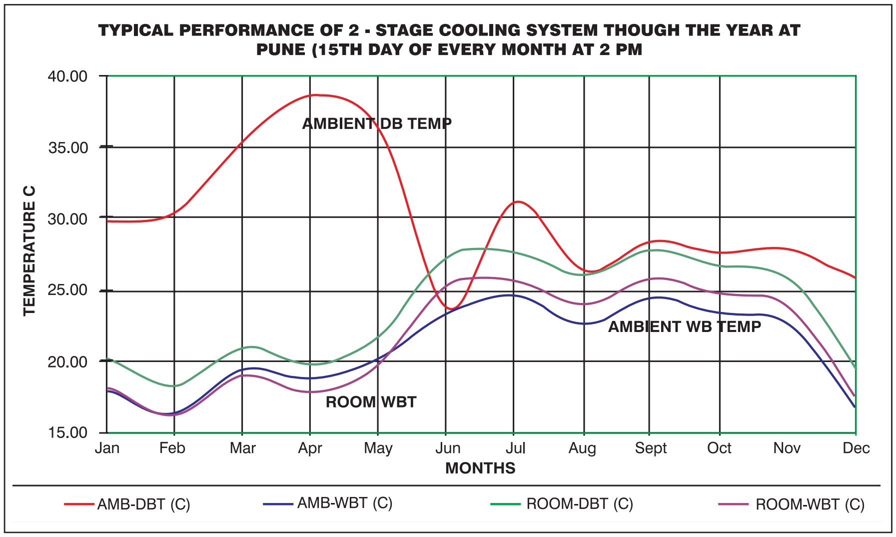

Figure 6 : Typical performance of 2-stage cooling system at Pune

Figure 6 illustrates the typical performance of a two stage cooling system round the year at an installation in Pune.

Table 1 indicates the average leaving air temperatures which may be expected in summer in some important Indian cities with two-stage cooling.

Applications

A basic requirement for the effective application of two-stage cooling is that the wet bulb depression of the ambient air at the site should be more than 10°C. This is true in most parts of India (with the exception of Kashmir and the coastal belt), viz. the wet bulb depression varies between 10 and 25°C for the greater part of the year.

Location	Dry Bulb °C	Wet Bulb °C	Air Temp. Leaving 2-Stage Cooler °C
Ahmedabad	41.2	23.5	20
Allahabad	42.2	23.5	19.8
Bangalore	34	19.6	16.7
Bhopal	40.5	21.7	17.9
Bhubhaneswar	37.6	26.6	24.4
Bikaner	43.4	22.4	18.2
Chennai	37.3	26.7	24.6
Gwalior	42.5	22.9	19
Hissar	43.3	25.8	22.3
Hyderabad	39.2	22.5	19.2
Jabalpur	41.2	23.2	19.6
Jaipur	41.4	22.6	18.8
Kolkata	36.2	26.1	24.1
Kota	42.4	22.6	18.6
Lucknow	40.8	24.8	21.6
Mumbai	34.3	23.3	21.1
Nagpur	42.6	23.9	20.2
New Delhi	40.6	23.8	20.4
Patna	39.5	23.7	20.5
Pune	37.4	20.4	17

Table 1 : Expected average temperatures in some important Indian cities in summer with 2-stage cooling

Two stage cooling systems have been successfully installed in several cities in India for diverse applications such as offices, residences, commercial complexes, restaurants, bars, hospitals, industry (such as pharma, garments, food processing, automobile), cinemas, libraries and clubs.

In conclusion, it may be said that two-stage cooling is an attractive energy saving alternative to conventional airconditioning for comfort cooling applications wherever the temperature of the cooled space need not be maintained within close limits round the year and a variation of a few degrees can be tolerated.

References

1. Literature from United Engineering Corporation, 147, R. P. Road, Secunderabad 500003. *(www.smartcool.co.in)*
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