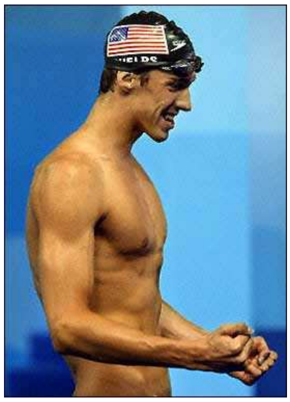
Factsheet

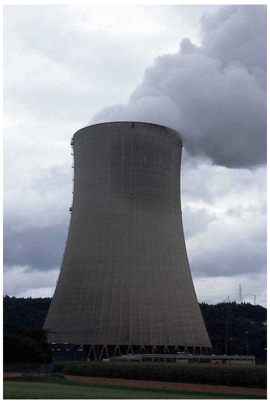
9 mar. 2009

Evaporative Cooling – direct

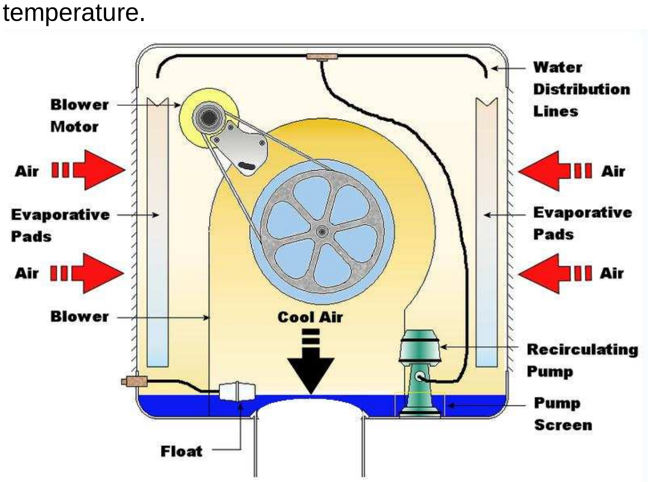
Direct evaporative cooling is what makes you feel “cold” when you get out of the water after a swim. The liquid (water) on your skin evaporates into the dry air. Heat is needed to evaporate the liquid. This heat is taken from the liquid itself and from the gas (the air) and surfaces (the skin) in contact with the evaporating liquid.



An evaporative cooler uses a fan to direct outdoor air through or along moist surfaces. In industrial cooling towers, falling water droplets are used to moisturize the air. A water pump is needed to circulate the water, this circulation of water is necessary to prevent any water soluble substances from depositing on the evaporative surfaces. Water must be drained from the reservoir to prevent building up of too high concentrations of soluble materials. Chemicals are added to the water to prevent microbiological growth (e.g. legionella pneumophila bacteria).



Evaporative coolers, such as depicted below, have been used extensively to cool homes in hot and dry climates. Industrial cooling towers (such as depicted in the picture above on the left) are somewhat different, as they are used to cool down hot water – where the end temperature is not necessarily below the ambient temperature.



Capacity

The amount of water that can be evaporated into ambient air (Δx in kg water / kg air) depends on the initial and final conditions of the air, especially the relative humidity (φ in %) and saturated water vapour pressure (P_{sat} in Pascal).

$$\Delta x = 0{,}622 \cdot P_{sat} \cdot \{ \varphi_{final} / (P_{ambient} - P_{sat} \cdot \varphi_{final}) - \varphi_{initial} / (P_{ambient} - P_{sat} \cdot \varphi_{initial}) \} \quad [kg/kg]$$

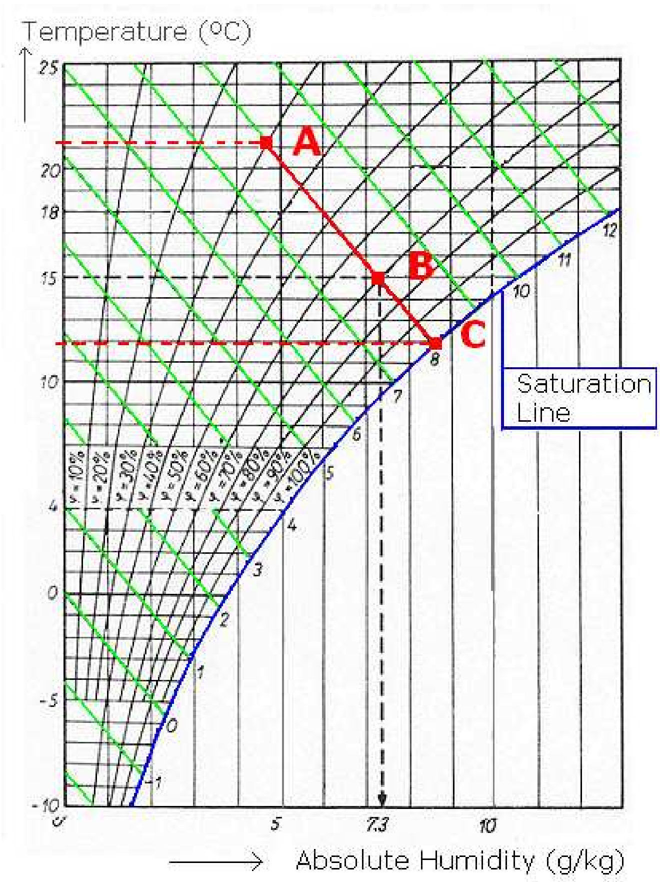
In this formula $P_{ambient}$ is the ambient pressure, which is normally 101325 Pascal (1 atm). The saturated vapour pressure (P_{sat} in Pascal) is highly dependent on temperature. The amount of “cold” generated – or better, amount of heat absorbed – Q is equal to the amount of evaporated water per time interval (*time* in seconds), multiplied with the heat of evaporation (2500,6 kJ/kg):

$$Q = 2500{,}6 \cdot \Delta x / time \quad [kW]$$

The final relative humidity of the outgoing air depends on the size and efficiency of the evaporating surface, values from 95 % to almost 100 % are possible. The final temperature of the outgoing air is in between the initial temperature and the wet bulb temperature. When the outgoing air is fully saturated (φ_{final} = 100 %) the temperature is equal to the wet bulb temperature T_{wb}. For values of final relative humidity φ_{final}, the final temperature can be approximated by:

$$T_{final} = T_{initial} - \{(\varphi_{final} - \varphi_{initial}) / (100 - \varphi_{initial})\} \cdot (T_{initial} - T_{wb})$$

The Mollier Diagram (below) presents conditions of moist air. An example situation is depicted with points A, B and C.
In the example, the initial condition of air at temperature of 21,3 ºC and relative humidity of 30% is marked “A”. The water content (absolute humidity) in this case is 4,7 g/kg.



When water evaporates into this air, the condition of the air moves along a line of constant enthalpy (green lines). For perfect evaporative cooling the final condition is the dew point, which is the intersection of the enthalpy line and the saturation line (point "C"). The dew point in this case has a temperature of 11,7 ºC and a water content of 8,6 g/kg. Thus, into each kg of air 0,0039 kg of water can be evaporated (8,6 minus 4,7 gram).

At an air flow rate of 1000 kg/hr. this equals 3,9 kg of water being evaporated per hour, providing a cooling capacity of (3,9 · 2500,6) / 3600 = 2,71 kW

When the evaporation is not continued until saturation (e.g. when the wetting surface is too small), the air will be moisturized only partly. This is depicted in the figure as point "B" (air moisturized until 70% relative humidity. The end temperature then is 14,8 ºC and the absolute humidity 7,3 g/kg. At an air flow rate of 1000 kg/hour the cooling capacity then is (2,6 · 2500,6) / 3600 = 1,81 kW

In very humid climates the direct evaporative cooler has a limited applicability. Because the ambient air is nearly saturated direct evaporative coolers will not provide significant cooling.

The cold air supplied by the direct evaporative cooler has a high humidity. In cases where this is not desired, it is better to apply an indirect evaporative cooler (*Factsheet Indirect evaporative cooling*).

Costs

Costs for a direct evaporative unit of 400 m3/hr are estimated at 750 Euro (2008) excluding installation. Running costs include costs for electricity (fan & pump), water (and possibly water treatment chemicals) and maintenance.

Table: Specifications for a small direct evaporative cooling unit. Unit size 400 m3/hr.
Coefficient of performance (COP) equals Cooling Capacity (kW) divided by electrical power input (kW).
Unit contains one fan (full power 0,11 kW) and one water pump (0,02 kW).
Where the desired temperature is higher than or equal to the outdoor condition, cooling is "free"
Where the desired temperature is lower than the wet bulb temperature, direct evaporative cooling is not possible (NA).

Desired Temperature	**Outdoor conditions**					
	25ºC / 50%		**15ºC / 50%**		**5ºC / 50%**	
	Capacity (kW)	COP	Capacity (kW)	COP	Capacity (kW)	COP
18 ºC	0,92	7,1	(free)	-	(free)	-
5 ºC	NA (under T_{wb})	-	NA (under T_{wb})	-	(free)	-
0 ºC	NA (under T_{wb})	-	NA (under T_{wb})	-	NA (under T_{wb})	-
-18 ºC	NA (under T_{wb})	-	NA (under T_{wb})	-	NA (under T_{wb})	-

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This renewable cooling research is executed with practical input by NVKL and financial support by the Dutch Ministry of Economic Affairs; program *Energie Onderzoek Subsidie: lange termijn (EOS-LT)*.