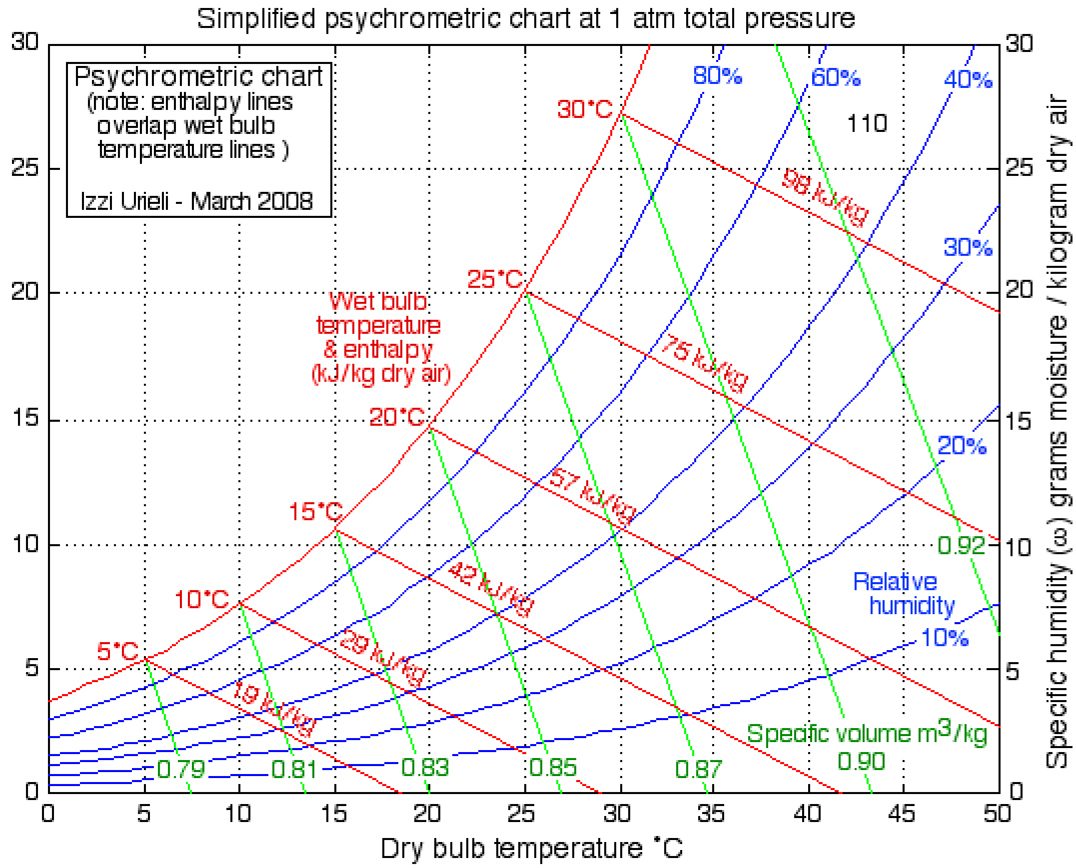
Air - Water Vapor Mixtures Part II

The Psychrometric Chart and Air-Conditioning Processes

We notice from the development in **Section a)** that the equations relating relative and specific humidity, temperature (wet and dry bulb), pressure (air, vapor) and enthalpy are quite tedious and inconvenient. For this reason a **Psychrometric Chart** relating all the relevant variables was developed which is extremely useful for designing and evaluating air-conditioning and cooling tower systems.

At first appearence the psychrometric chart is quite confusing, however with some practice it becomes an extremely useful tool for rapidly evaluating air-conditioning processes. The most popular chart in common usage is that developed by **ASHRAE** (American Society of Heating, Refrigeration and Air-Conditioning Engineers), however we feel that the construction of a simplified version of the chart based on approximations of the various equations can be a very useful tool for developing an understanding of it's usage. This approach was suggested by **Maged El-Shaarawi** in his article "On the Psychrometric Chart" published in the ASHRAE Transactions (Paper #3736, Vol 100, Part 1, 1994) and inspired us to produce the following simplified psychrometric chart:



The basic information used to construct the chart is the water vapor saturation data (Tsat, Pg) which is obtained from steam tables over the range from Tsat = 0.01°C through 50°C. The specific humidity ω is then evaluated using the relative humidity φ as a parameter to produce the various relative humidity curves (blue lines) as follows:

$$\omega\left[{}^{\text{kg vap}}\!\!/_{\text{kg dry air}}\right] = 0.622\left(\frac{\phi . P_g}{P - \phi . P_g}\right)$$

where P is the standard atmospheric pressure 101.325 [kPa].

The saturation curve (100% relative humidity) also known as the dew point curve is drawn as a red line. Notice that on the saturation curve the wet and dry bulb temperatures have the same values.

The major simplifying assumption in the construction of the chart is that the enthalpy of the mixture is assumed to be constant throughout the adiabatic saturation process (described in **Section a**). This implies that the evaporating liquid added does not significantly affect the enthalpy of the air-vapor mixture, leading to the constant slope wet bulb temperature / enthalpy (red) lines defined by:

$$h_{air+vap}\left[{kJ}/{kg\ dry\ air}\right] = T[^\circ C] + \omega(2500 + 2T[^\circ C])$$

which is further finally reduced to:

$$h_{air+vap}\left[{kJ}/{kg\ dry\ air}\right] \approx T[^\circ C] + 2500.\omega$$ enthalpy

Note that on the $\omega = 0$ axis (dry air) h = T [°C]

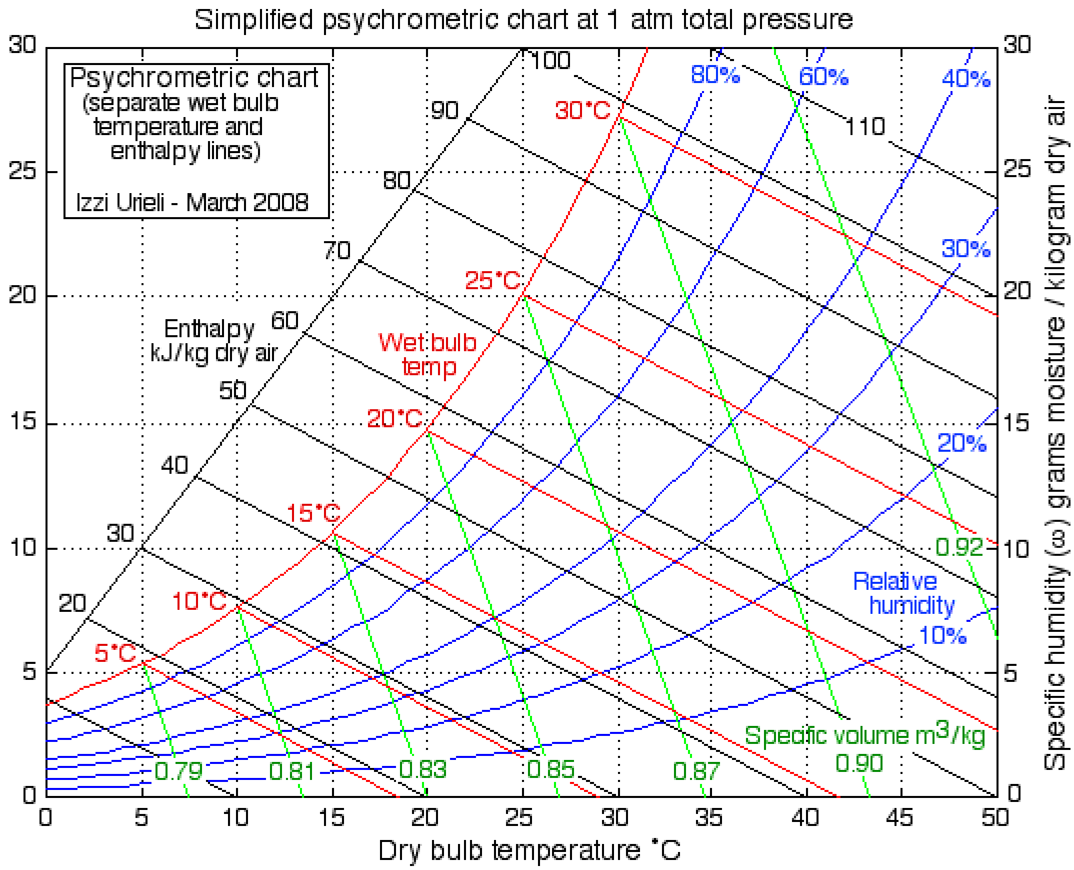
Finally, the specific volume of the air-vapor mixture (green lines) is determined from the ideal gas relation as

$$v\left[{m^3}/{kg\ dry\ air}\right] = \left(\frac{R_{air}\,(T_{sat} + 273)}{P - P_g}\right)$$ specific volume at saturation

and at $\omega = 0$, $$T[^\circ C] = \left(\frac{P.v}{R_{air}}\right) - 273$$

where the gas constant R_{air} = 0.287 [kJ/kg.K]

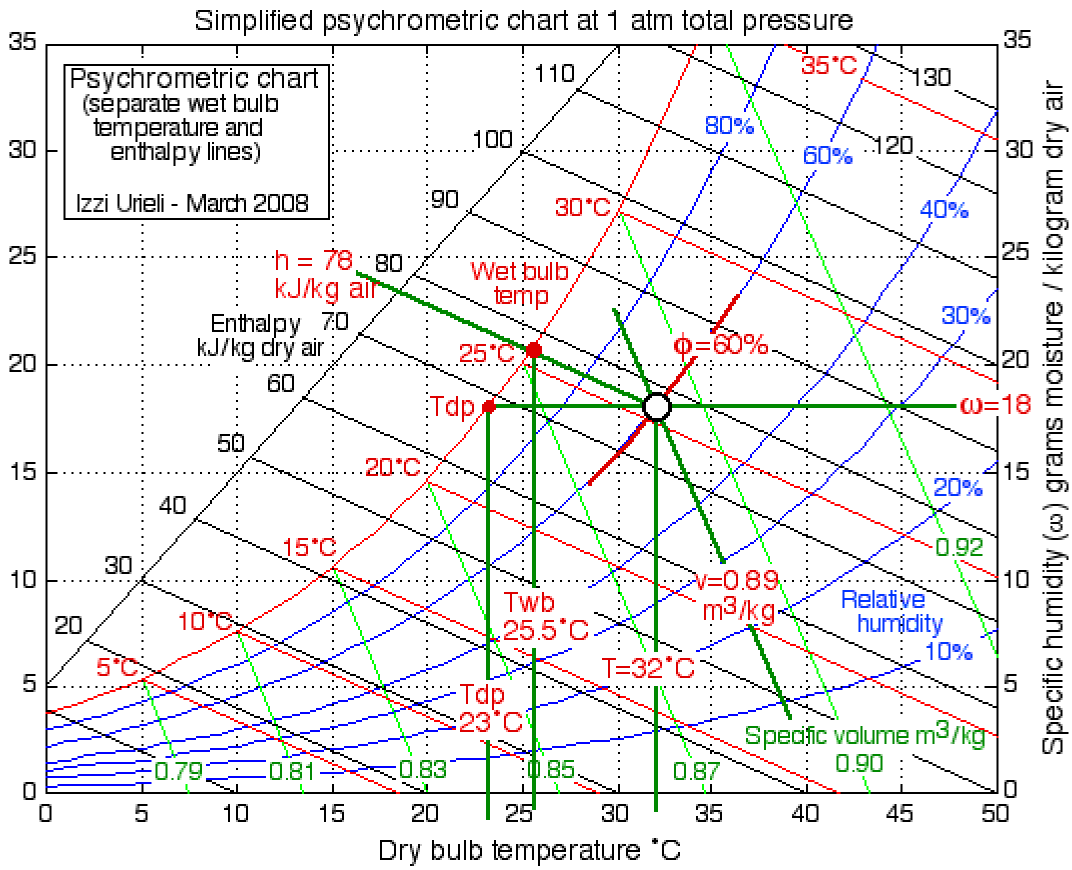
It is normal practice to separate out the overlapping enthalpy / wet bulb temperature lines allowing them to be separately evaluated. Thus we introduce an oblique enthalpy axis and enthalpy (black) lines as follows:



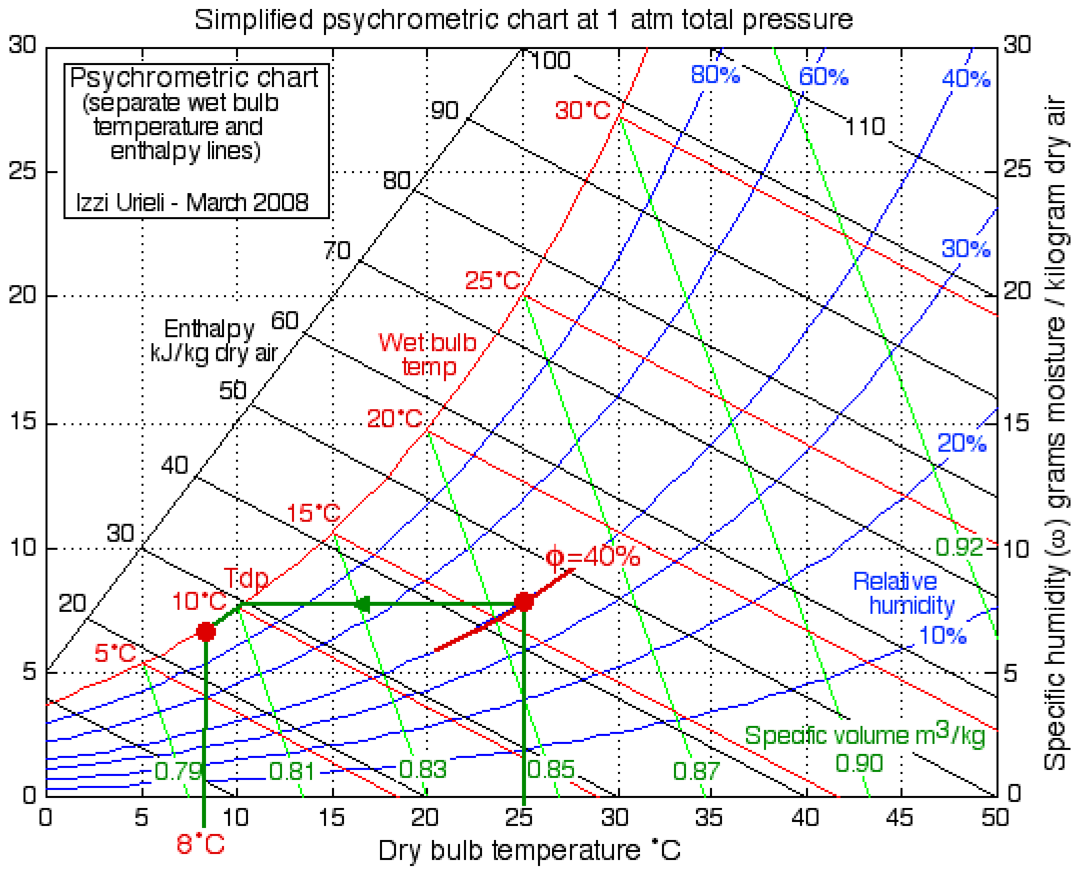
The four equations highlighted above were programmed in MATLAB and used to plot the simplified psychrometric charts shown above. Refer to the link:
MATLAB program for plotting a Simplified Psychrometric Chart

An excellent NebGuide (University of Nebraska-Lincoln Extension Publication) on **How to use a Simplified Psychrometric Chart** has been provided by David Shelton, and is also available as a **pdf file** (968k). This guide reduces the confusion by separately explaining 4 of the 6 sets of curves which make up a psychrometric chart. Definitely read this guide before continuing.

Solved Problem 10.1 - Assume that the outside air temperature is 32°C with a relative humidity φ = 60%. Use the psychrometric chart to determine the specific humidity ω [18 gm-moisture/kg-air], the enthalpy h [78 kJ/kg-air], the wet-bulb temperature T_{wb} [25.5°C], the dew-point temperature T_{dp} [23°C], and the specific volume of the dry air v [0.89m3/kg]. Indicate all the values determined on the chart.

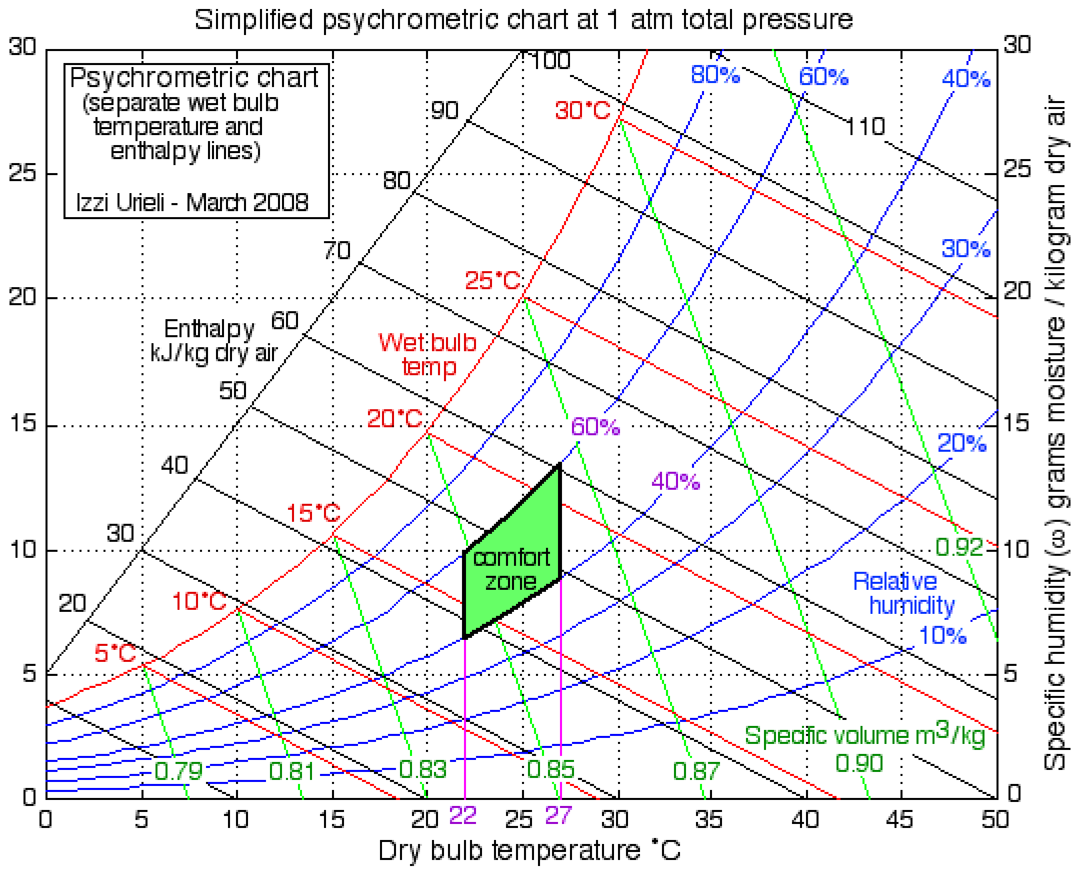


Solved Problem 10.2: Assume that the outside air temperature is 8°C. If the air in a room is at 25°C with a relative humidity φ = 40%, use the psychrometric chart to determine if the windows of that room which are in contact with the outside will become foggy.

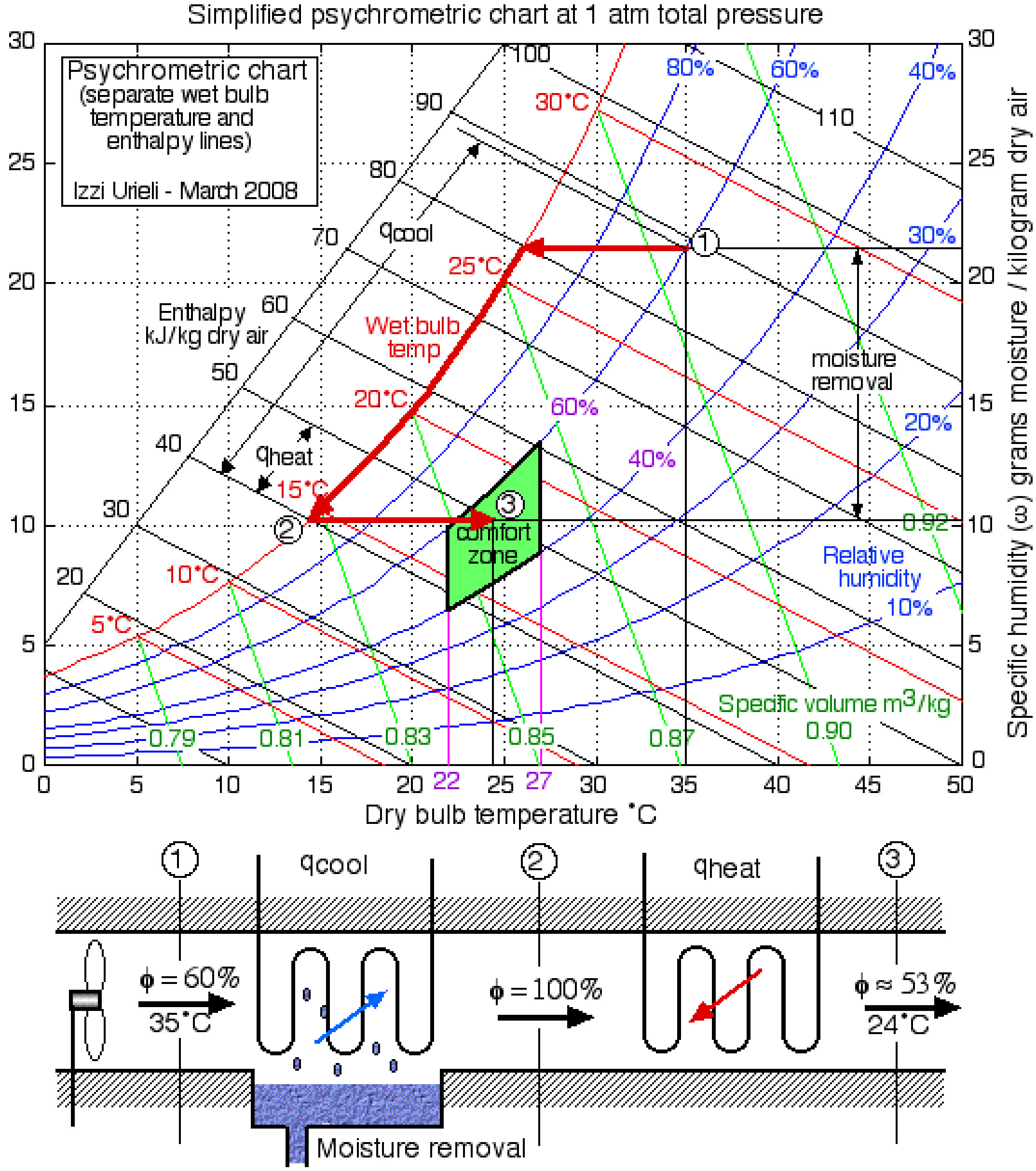


The air in contact with the windows will become colder until the dew point is reached. Notice that under the conditions of 25°C and 40% relative humidity the dew point temperature is slightly higher than 10°C, At that point the water vapor condenses as the temperature approaches 8°C along the saturation line, and the windows will become foggy.

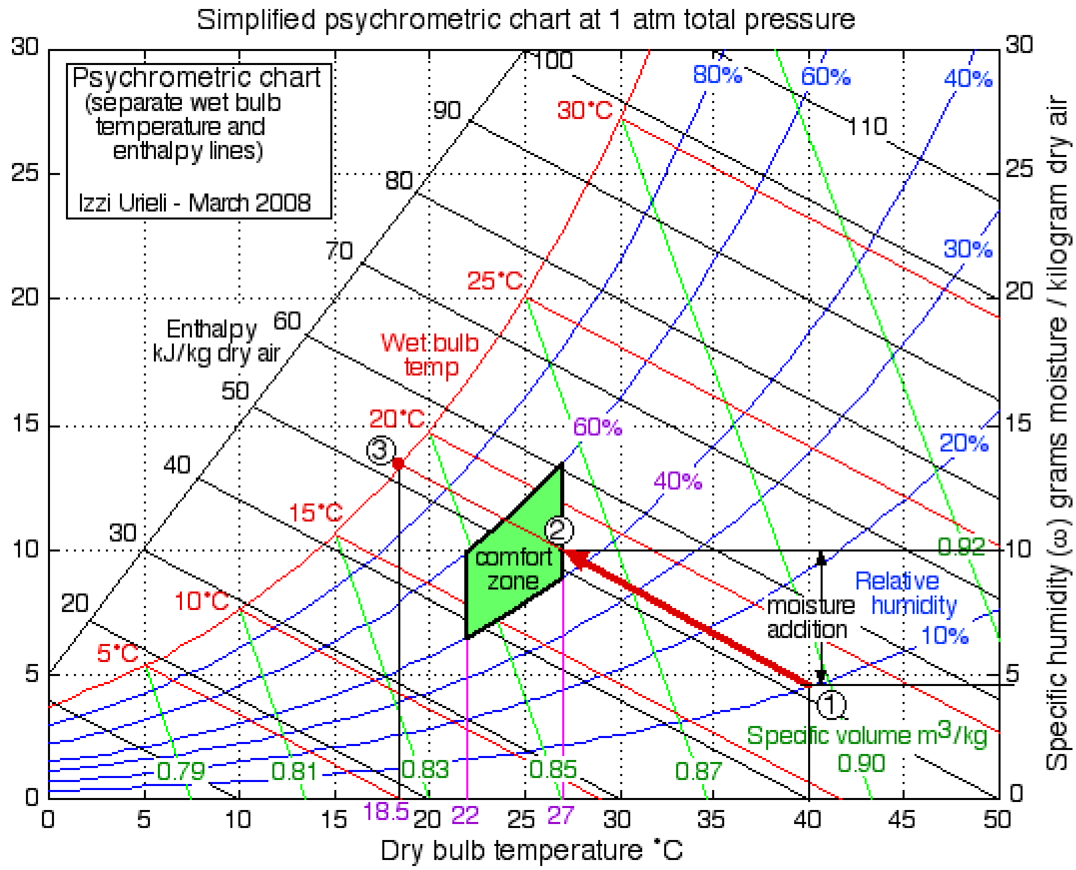
One of the major applications of the Psychrometric Chart is in air conditioning, and we find that most humans feel comfortable when the temperature is between 22°C and 27°C, and the relative humidity φ between 40% and 60%. This defines the "comfort zone" which is portrayed on the Psychrometric Chart as shown below. Thus with the aid of the chart we either heat or cool, add moisture or dehumidify as required in order to bring the air into the comfort zone.

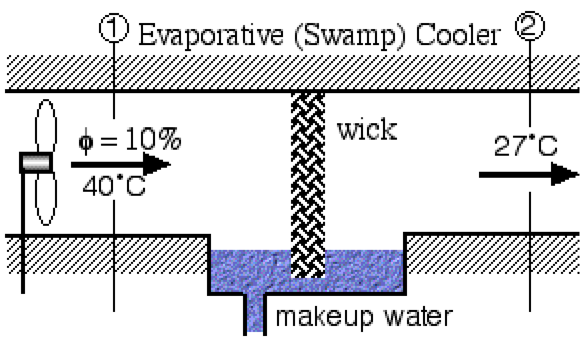


Solved Problem 10.3: Outside air at 35°C and 60% relative humidity is to be conditioned by cooling and heating so as to bring the air to within the "comfort zone". Using the Psychrometric Chart neatly plot the required air conditioning process and estimate (a) the amount of moisture removed [11.5g-H20/kg-dry-air], (b) the heat removed [(1)-(2), q_{cool} = 48kJ/kg-dry-air], and (c) the amount of heat added [(2)-(3), q_{heat} = 10kJ/kg-dry-air].



Solved Problem 10.4:: Hot dry air at 40°C and 10% relative humidity passes through an evaporative cooler. Water is added as the air passes through a series of wicks and the mixture exits at 27°C. Using the psychrometric chart determine (a) the outlet relative humidity [45%], (b) the amount of water added [5.4g-H20/kg-dry-air], and (c) the lowest temperature that could be realized [18.5°C].





This type of cooler is extremely popular in hot, dry climates, and is popularly known as a **Swamp Cooler**. An interesting application of using a swamp cooler to cool drinking water in extremely hot environments is described in the posting of Rich Oppel in the At War blog of the New York Times: **'Drinking From Socks'**.

An interesting and informative description on **Psychrometric Chart Use** for livestock and greenhouse applications has been presented in a University of Connecticut website by Michael Darre. Other websites that we found interesting is that of **Wikipedia** on Psychrometrics, and one by Sam Hui (Hong Kong University) on using the psychrometric chart in the **'Climatic Design of Buildings'**.

Source: http://www.ohio.edu/mechanical/thermo/Applied/Chapt.7_11/Chapter10b.html