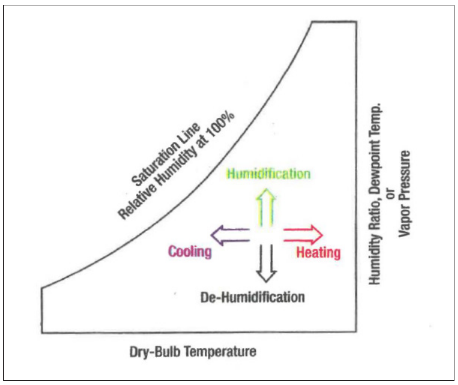
ENGINEERING WHITE PAPER

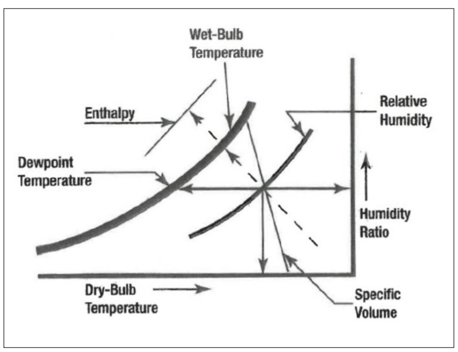
Internal use only

November 30, 2020

Psychrometrics

The purpose of HVAC equipment is to maintain indoor temperature, humidity and air quality. This is a complex task, and we often need tables and formulas to describe the processes involved. However, tables and numbers are a poor way to communicate with our customers and sell equipment. The psychrometric chart is a tool for graphing the temperature and humidity of air as it goes through HVAC processes, and this paper is an introduction to using it as a communication and sales tool.





A simplified Psychrometric Chart, showing processes (top) and properties of air (bottom)

The Psychrometric Chart

A Psychrometric Chart allows us to look up properties of air and visualize processes. While it appears complex at first glance, we only need to know two properties of air to plot it on the psychrometric chart. Once we plot a point on the Psychrometric Chart, we can look up most of the properties of air at that point. While the amount of information on the psychrometric chart can make it hard to read, it also makes it an invaluable resource.

Definitions

Absolute humidity: In psychrometrics we think of air as a mix of dry air and water vapor. Absolute humidity or humidity ratio is the ratio of mass of water vapor to mass of dry air. It is expressed as pounds of water per pound of dry air, or as grains per pound of dry air. One grain is 1/7000 of a pound. Absolute Humidity is shown by horizontal lines on the psych chart.

Saturation: Saturation is a state where one substance can exist as a stable mix of liquid and gas. For water vapor saturation is defined by the temperature and absolute humidity. The saturation curve is the top curve on the psychrometric chart and defines 100% relative humidity.

When we cool air, the amount of water it can hold gets lower and relative humidity gets higher, until it reaches 100% humidity. If we cool air beyond 100% humidity or saturation, water will condense out onto the cooling coil. To find the **saturation temperature** or **dew point** of air, follow the absolute humidity line to the left until you reach the 100% humidity curve, then go straight down and read the temperature shown.

Relative Humidity: Relative humidity is the percent of water vapor in the air compared to saturation, or the absolute humidity of the air divided by the absolute humidity at saturation. Relative humidity is a useful measure because it tells us how easily water will evaporate or condense. For human comfort and health, the ideal humidity range is 40-60%. Relative humidity is plotted on curved lines on the psychrometric chart.

Sensible Heat: Sensible heat is the energy needed to change the temperature of air. We call it sensible heat to distinguish it from latent heat. It takes approximately 0.24 BTU to heat one pound of air by one degree Fahrenheit. (One BTU is defined as the energy needed to heat one pound of water by one degree Farenheit). Sensible heat can be calculated from air flow (in standard cfm) as follows:

$$Q_{\text{sensible}}(\text{BTUH}) = 1.08 \times (\text{cfm}) \times \Delta T(°\text{F})$$

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Latent Heat: Latent heat is the energy needed to add humidity to air. Since energy is never created or destroyed, this heat is released when water condenses out of air. It takes approximately 1000 BTU to evaporate one pound of water. Latent heat can be calculated from air flow (in standard cfm) as follows:

Q_{latent}(BTUH) = 0.68 × (cfm) × ΔW(grains/lb)

Enthalpy

Enthalpy is the total amount of heat contained in air. Since air contains both latent heat and sensible heat, Enthalpy is the sum of these amounts. We define zero enthalpy as 0% humidity and 32°F, so the enthalpy of a volume of air is the energy required to heat it from 32°F to its current temperature and humidify it from 0% humidity to its current humidity. Enthalpy can also be negative, negative enthalpy is the energy required to heat air from its current temperature to 32°F minus the energy needed to humidfy from 0% humidity to its current humidity.

The psychrometric chart shows **specific enthalpy,** which is the energy contained per pound of dry air. The specific enthalpy is shown by solid lines running from the top left to bottom right of the psychrometric chart. To convert from specific enthalpy to BTU per hour (BTUH), use the following equation, where Δh is the change in specific enthalpy:

Q_{total}(BTUH) = 4.5 × (cfm) × Δh(BTU/lb)

Wet Bulb Temperature

The Wet Bulb Temperature is the temperature measured by a wet thermometer with air blowing over it. The wet bulb temperature is the lowest temperature we can produce by evaporative cooling. Wet bulb temperature is shown by dotted, sloped lines on the psychrometric chart. The wet bulb lines are almost parallel to the enthalpy lines but are slightly steeper.

Dry Bulb Temperature

The Dry Bulb Temperature is simply the temperature. The name Dry Bulb temperature is used to distinguish it from the Wet Bulb temperature. Dry Bulb temperature is plotted on vertical lines on the psychrometric chart.

Specific Volume

Specific volume is the volume occupied by one pound of dry air. It is measured in cubic feet per pound and is plotted on the steeply slanted lines on the psychrometric chart. Since we measure rooms in cubic feet and equipment by CFM, we use the specific volume to convert from pounds of dry air to cubic feet.

(cfm) = v (cu ft/lb) × (lbs/minute)

A standard CFM is defined at 13.3 cubic feet per lb. To convert from actual CFM to standard CFM, use:

(standard cfm) = (actual cfm) × v (cu ft/lb) / (13.3)

Plotting processes on the Psychrometric Chart

The real value of the Psychrometric Chart lies in illustrating the changes we make to air. Complex processes such as evaporative cooling and dehumidification are poorly understood by many engineers. This presents an opportunity for us to become trusted resources if we can communicate the information clearly.

Sensible cooling and heating are represented by horizontal movements on the psychrometric chart. Steam humidification is represented by movement up on the psychrometric chart. Since the amount of steam added to air is very small the temperature stays nearly the same, while humidity increases. Adiabatic processes do not add or remove energy from the air, so they move diagonally along the constant enthalpy lines.

Processes on the psychrometric chart can never cross the saturation line or 100% humidity line. As we cool towards saturation water will start to condense out of the air, and we will move along the saturation line. If we attempt to add humidity to saturated air it will not be absorbed.

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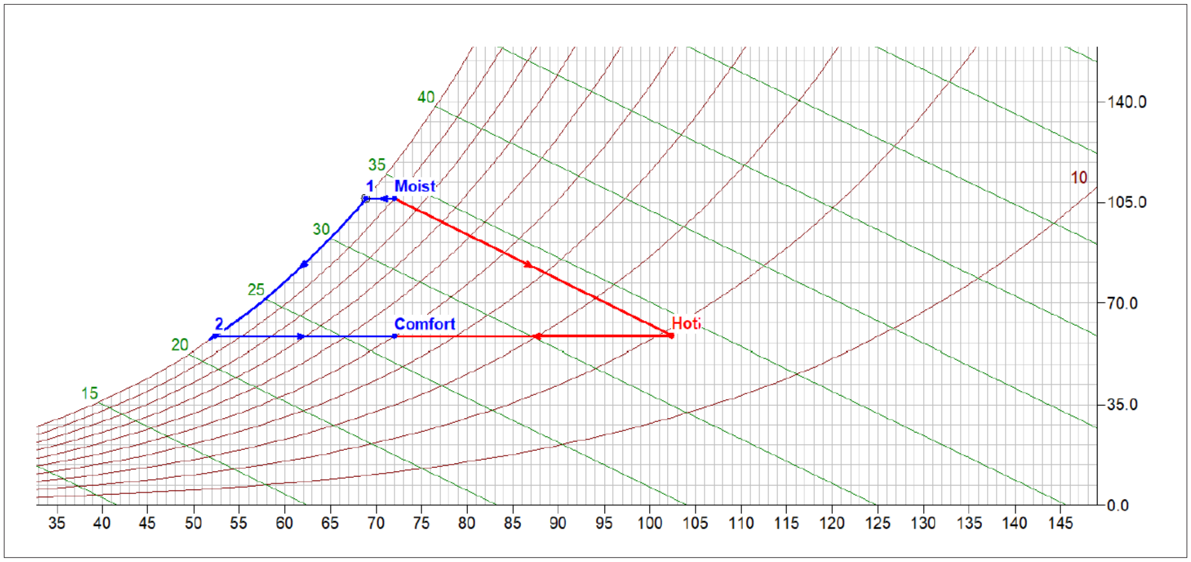

Example: Dehumidifying Outdoor Air

In the above chart, the point marked "Moist" represents outdoor air at 70°F and 90% relative humidity. For human comfort we would like to dehumidify to 50% relative humidity. We have two options for dehumidification, desiccant dehumidification or cooling to the desired dew point.

The desiccant humidification process is shown in red. Because desiccant dehumidification does not add or remove energy the process moves parallel to the constant enthalpy lines. Dehumidifying to the desired absolute humidity raises the air temperature to 102°F. We then need to cool the air back to the desired temperature.

We can also cool the air to the desired dew point with chilled water or DX cooling. This process is shown in blue and consists of first sensibly cooling the air to saturation, then continuing to cool the air along the saturation curve as water condenses out. We end with air at 100% humidity and 52°F, which must be reheated to a comfortable temperature.

Software

All the plots in this white paper were produced using the Daikin Psychrometrics Program. The program allows you to input points using two variables (such as temperature and relative humidity) and find all properties of air under those conditions. It also allows you to plot processes, input the CFM of conditioned air, and will output the heat requirements and other data. It is a powerful tool both for analyzing processes and communicating information to customers.

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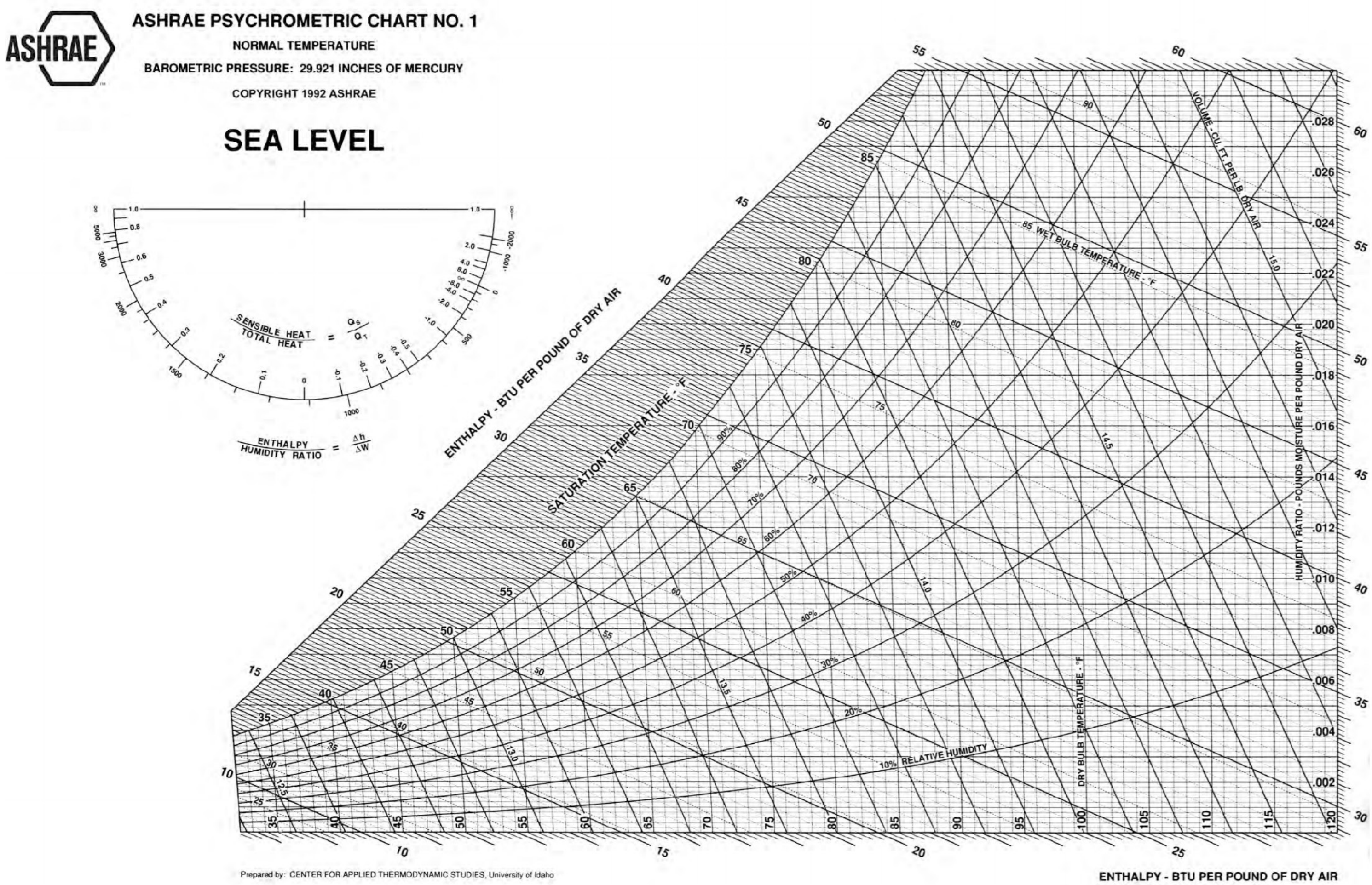
ASHRAE
ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 29.921 INCHES OF MERCURY
COPYRIGHT 1992 ASHRAE
SEA LEVEL
SENSIBLE HEAT / TOTAL HEAT = Qs / QT
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
VOLUME - CU. FT. PER LB. DRY AIR
WET BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
DRY BULB TEMPERATURE - °F
10% RELATIVE HUMIDITY
Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho
ENTHALPY - BTU PER POUND OF DRY AIR