Psychrometric Chart

This Carrier Psychrometric Chart embodies one of the greatest advancements in the presentation of psychrometric data since the publication of the original chart by Dr. Willis H. Carrier in 1911. (1)

The inclusion of Enthalpy deviation lines (2) makes possible accurate readings of the enthalpy of air for both saturated and non-saturated conditions.

The chart is universal in application. These data are presented for standard barometric pressure of 29.92 inches of mercury, and include a table for extending values to various barometric pressures.

For information regarding further use of chart see Carrier SYSTEM DESIGN MANUAL, Part 1, Chapter 8—"Applied Psychrometrics."
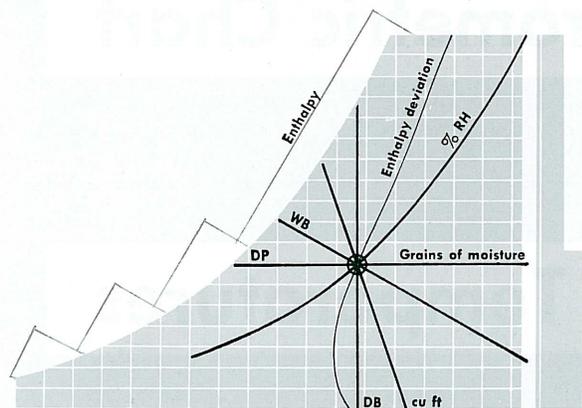
Definitions • Abbreviations • Symbols

Fig. 1. Properties of Moist Air

PSYCHROMETRICS—The thermodynamics of moist air.

DRY-BULB TEMPERATURE, DB (t_{db})—Temperature of air as registered by an ordinary thermometer.

WET-BULB TEMPERATURE, WB (t_{wb})—Temperature registered by a thermometer whose bulb is covered by a wetted wick and exposed to a current of rapidly moving air.

DEWPOINT TEMPERATURE, DP (t_{dp})—Temperature at which condensation of moisture begins when the air is cooled.

RELATIVE HUMIDITY, % RH, (ϕ)—Ratio of actual water vapor pressure in air to the pressure of saturated water vapor in air at the same temperature.

SPECIFIC HUMIDITY Moisture content **(W)**—Weight of water vapor in grains or pounds per pound of dry air.

ENTHALPY Total heat **(h)**—A thermal property indicating the quantity of heat in the air above an arbitrary datum, in Btu per pound of dry air. The datum for dry air is 0 F and, for the moisture content, 32 F water.

VAPOR PRESSURE (e)—The pressure exerted by the water vapor contained in the air in inches of mercury.

VOLUME (as used in psychrometrics) **(V)**—Cubic feet of the mixture per pound of dry air.

SENSIBLE HEAT FACTOR (SHF)—The ratio of sensible heat to total heat load.

POUNDS OF DRY AIR is the basis for calculations so remain constant during all psychrometric processes.

h_d = Enthalpy deviation, Btu per pound of dry air.

h_{wb} = Enthalpy of air saturated at the wet-bulb temperature, Btu per pound of dry air.

q = Heat added in process, Btu per pound of dry air. (Heat removed = −q).

w = Weight of moisture added to air, grains or pounds per pound of dry air. (Moisture rejected = −w).

h_w = Enthalpy of liquid water or ice added in the process, Btu per pound of dry air (Enthalpy of moisture rejected = −h_w).

Subscripts e and l indicate entering and leaving air conditions in the process; These are: $h_{ewb} \cdot h_{lwb}$, $h_{ed} \cdot h_{ld}$, $W_{ea} \cdot W_{la}$, $h_{ea} \cdot h_{la}$ and $t_{ewb} \cdot t_{lwb}$.

1—"*Rational Psychrometric Formulae*" by Willis H. Carrier, Transactions A.S.M.E. 1911 Vol. 33 p 1005

2—"*A New Psychrometric Chart*" by E. P. Palmatier and D. D. Wile, Carrier Corporation, *REFRIGERATING ENGINEERING*, July 1946

How to Use

DRY-BULB, WET-BULB, DEWPOINT TEMPERATURES, and RELATIVE HUMIDITY are so related that, if two properties are known, all other properties shown in Fig. 1 may be read from the chart. When air is saturated, dry-bulb, wet-bulb, and dewpoint temperatures are identical. *See Examples 1 and 2.*

ENTHALPY of air for any given condition is the enthalpy at saturation corrected by the enthalpy deviation due to the air not being in a saturated state. The enthalpy (h) in Btu per pound of dry air is the enthalpy at saturation (h_{wb}) plus the enthalpy deviation (h_d). (h = h_{wb} + h_d) *See Example 2.*

If there is any increase or decrease in moisture content of air in a psychrometric process, the heat added (q) or removed (−q) is the difference between the enthalpy of final and of initial air minus the enthalpy of the moisture (liquid water or ice) added (h_w) or rejected (−h_w). q = h_{la} − h_{ea} − h_w. *See Examples 4 and 5.*

The enthalpy of added or rejected moisture is shown in the small graphs at the top of the chart.

Enthalpy of added or rejected moisture and enthalpy deviation are usually omitted in applications not requiring precise results—as in comfort air conditioning. Error due to omissions for wet-bulb temperatures below 32 F is much larger than for that above 32 F.

SENSIBLE HEAT FACTOR is involved in certain methods of calculations for the application of air conditioning equipment. A scale along the right-hand margin of the chart, together with an origin at 80 DB and 50% RH, affords a convenient means of reading the sensible heat factor. *See Example 4(a).*

BAROMETRIC PRESSURES differing from standard (29.92 in. of mercury) by one inch of mercury or less may be assumed as standard in problems not requiring precise results, as in comfort air conditioning.

When dry-bulb and dewpoint temperatures are known for air at non-standard barometric pressures, values of percent relative humidity and grains of moisture per cubic foot are correct as obtained from the standard chart. However, for any given dry-bulb and wet-bulb temperatures at non-standard barometric pressures, all properties of air must be corrected.

Correction tables and examples are shown on the chart for correcting specific humidity, enthalpy, and volume for non-standard barometric pressures.

To correct for values of dewpoint temperatures and relative humidity at non-standard barometric pressures:

1—Calculate the true vapor pressure (e) by formula

$$e = \frac{W \times p}{4360 + W}$$

where W is specific humidity corrected for non-standard barometric pressure in inches of mercury.

2—Locate calculated e in second column of correction table and read corresponding saturation temperature in first column as dewpoint temperature (same as Wet-Bulb temperature at saturation).

3—Determine relative humidity by dividing calculated vapor pressure (e) by the saturated vapor pressure in second column corresponding to the dry-bulb temperature at saturation (same as Wet-Bulb first column).

PSYCHROMETRIC MEASUREMENTS—Correct procedure must be followed in taking dry-bulb and wet-bulb temperature readings to obtain accurate values of properties of air. Instructions for taking readings are given in the American Society of Heating, Refrigerating and Air Conditioning Engineer's Guide.
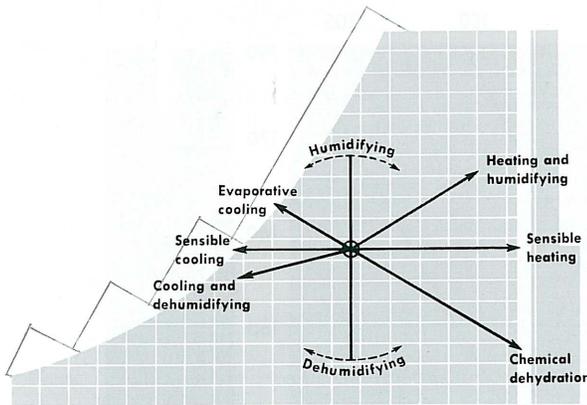
Fig. 2. Air Conditioning Processes

AIR CONDITIONING PROCESSES such as heating, cooling, humidifying, and dehumidifying may be shown graphically on the chart. *See Figure 2.*

Humidifying and dehumidifying processes may be represented by a variety of lines. Humidifying is represented by a line directed upward from the initial condition, dehumidifying by a line directed downward.

Heating or *cooling* air without change in moisture content involves a change in sensible heat only and takes place along a horizontal line to right or left respectively. Changes occur in dry-bulb and wet-bulb temperatures, relative humidity, and enthalpy. Specific humidity and dewpoint temperature remain constant.

In *heating* and *humidifying*, both sensible heat and specific humidity increase and the process takes place along a line sloping upward and to the right. Changes occur in dry-bulb, wet-bulb, and dewpoint temperatures, and in enthalpy. Relative humidity may not change depending upon the slope of the line.

In *cooling* and *dehumidifying*, both sensible heat and specific humidity decrease, and the process takes place along a line sloping downward and to the left. Changes occur in dry-bulb, wet-bulb, and dewpoint temperatures, and in enthalpy. Relative humidity may or may not change depending upon the slope of the line.

In *evaporative cooling*, air is brought in contact with spray water at a temperature equal to the wet-bulb temperature of the air. The process takes place upward along the wet-bulb line. As sensible heat of the initial air vaporizes the water, the dry-bulb temperature of the air is lowered. The sensible heat used to vaporize the water enters the air as latent heat in added vapor, therefore no heat is added or removed in the process. Wet-bulb temperature remains constant. Dewpoint temperature, relative humidity, specific humidity, and enthalpy increase. (In most evaporative cooling installations, heat may be added or removed during the process by outside sources, but usually the amount is negligible.)

In *chemical dehydration*, the air is brought in contact with a chemical which either adsorbs or absorbs moisture from the air. The heat thus liberated is added to the air and is approximately equal to the latent heat of vaporization of the moisture removed. The process is indicated by a line sloping downward, approximately along the wet-bulb line. The slope may be either greater or less than the wet-bulb line depending upon whether heat is stored, liberated, or absorbed in the process.

Examples

Example 1. Reading Properties of Air

Given $\begin{cases} DB = 70\ F \\ WB = 60\ F \end{cases}$ Find $\begin{cases} \%\ RH \\ DP \\ Volume \\ Gr\ of\ moisture\ per\ lb\ dry\ air \\ Gr\ of\ moisture\ per\ cu\ ft \end{cases}$

Locate point of intersection on the chart of vertical line representing 70 DB and oblique line representing 60 WB. All values are read from this point of intersection.

Interpolate between relative humidity lines on 70 DB line, read RH = 56%

Follow horizontal line left to saturation curve, read DP = 53.6 F

Interpolate between lines representing cubic feet per pound of dry air, read v = 13.53 cu ft

Follow horizontal line to right, read grains of moisture per pound of dry air, W = 61.4 gr

Grains of moisture per pound of dry air (61.4) divided by cubic feet per pound of dry air (13.53) = 4.54 gr per cu ft

Example 2. Reading Properties of Air

Given $\begin{cases} RH = 50\% \\ WB = 60\ F \end{cases}$ Find $\begin{cases} DB \\ DP \\ Gr\ of\ moisture\ per\ lb\ dry\ air \\ Enthalpy \end{cases}$

Locate point of intersection on the chart of 50% RH line and oblique line representing 60 WB. All values are read from this point.

Follow vertical line downward to dry-bulb temperature scale, read DB = 71.9 F

Follow horizontal line left to saturation curve, read DP = 52.3 F

Follow horizontal line to right, read grains of moisture per pound of dry air, W = 58.4 gr

Follow wet-bulb line to "Enthalpy at saturation" scale and read h_{wb} = 26.46 Btu. Read enthalpy deviation for point of intersection h_d = −.08 Btu. Enthalpy of air at given condition $h = h_{wb} + h_d = 26.46 + (−.08) = 26.38$ Btu per lb of dry air.
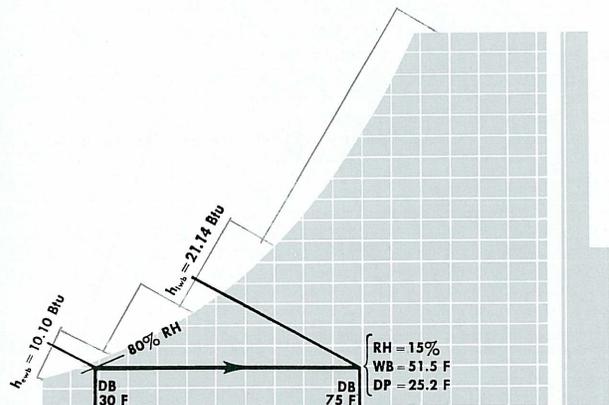
Example 3. Heating Process

Fig. 3. Heating Process

(No change in moisture content)

Given $\begin{cases} Initial\ Air \begin{cases} DB = 30\ F \\ RH = 80\% \end{cases} \\ \\ Air\ heated\ to\ 75\ DB \end{cases}$ Find $\begin{cases} Final\ Air \begin{cases} \%\ RH \\ WB \\ DP \end{cases} \\ \\ Heat\ added \end{cases}$

Locate the condition of initial air on the chart. Follow horizontal line to 75 DB. Read: RH = 15% : WB = 51.5 F : DP = 25.2 F

Exact Solution—Heat added:
Read enthalpy at saturation initial air h_{ewb} = 10.10 Btu
Read enthalpy deviation initial air h_{ed} = .06 Btu
Enthalpy of initial air $h_{ea} = h_{ewb} + h_{ed} = 10.10 + .06 = 10.16$ Btu
Read enthalpy at saturation of final air h_{lwb} = 21.14 Btu
Read enthalpy deviation of final air h_{ld} = −0.10 Btu
Enthalpy of final air $h_{la} = h_{lwb} + h_{ld} = 21.14 + (−0.10) = 21.04$ Btu
Heat added $q = h_{la} − h_{ea} = 21.04 − 10.16 = 10.88$ Btu per lb of dry air.

Approximate Solution—Heat added:
$q = h_{lwb} − h_{ewb} = 21.14 − 10.10 = 11.04$ Btu per lb of dry air.
The approximate solution is 1.5% higher than exact solution.
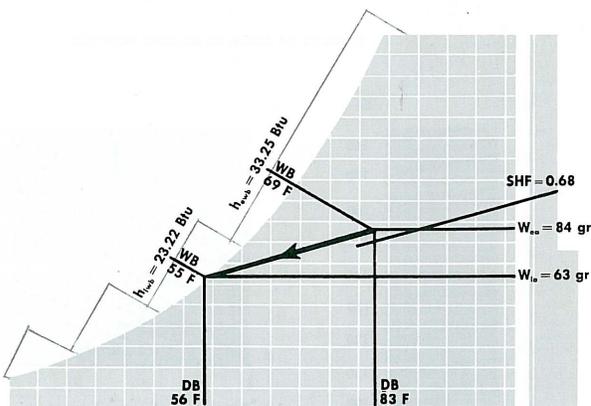
Example 4. Cooling and Dehumidifying Process

Fig. 4. Cooling and Dehumidifying

(a) Moisture rejected as water condensate

Given
- Initial Air $\begin{cases} DB = 83\ F \\ WB = 69\ F \end{cases}$
- Final Air $\begin{cases} DB = 56\ F \\ WB = 55\ F \end{cases}$
- Condensate rejected at 55 F

Find
- Heat removed
- Sensible Heat Factor

Locate initial and final conditions of air on chart.

Read: $h_{ewb} = 33.25$ Btu $h_{lwb} = 23.22$ Btu
$h_{cd} = -0.12$ Btu $h_{ld} = -0.01$ Btu
$h_{ca} = 33.25 + (-0.12) = 33.13$ Btu $h_{la} = 23.22 + (-0.01) = 23.21$ Btu

Read grains of moisture in initial air $W_{ca} = 84$
Read grains of moisture in final air $W_{la} = 63$
$w = W_{la} - W_{ca} = 63 - 84 = -21$ gr (moisture rejected)

Read enthalpy of rejected moisture (h_w) from diagrams at top of chart for 21 grains and 55 F = -0.08 Btu

Exact Solution—Heat removed:

$q = h_{la} - h_{ca} - h_w = 23.21 - 33.13 - (-0.08) = -9.84$ Btu per lb dry air.

Approximate Solution—Heat removed:

$q = h_{lwb} - h_{ewb} = 23.22 - 33.25 = -10.03$ Btu per lb dry air.
Approximate solution is 1.9% higher than exact solution.
To determine Sensible Heat Factor, draw a line between initial and final conditions. Draw a line parallel to this line from reference point (80 DB, 50 RH) to Sensible Heat Factor scale, read SHF = 0.68.

(b) Moisture rejected as ice

Given
- Cold Room held at $\begin{cases} DB = 30\ F \\ WB = 28\ F \end{cases}$
- Infiltration Air $\begin{cases} DB = 80\ F \\ WB = 67\ F \end{cases}$
- Moisture freezes on cooling coil at 20 F

Find
- Cooling Load

From procedure followed in preceding examples, read:

Infiltration Air: Cold Room Air:
$h_{ewb} = 31.62$ Btu $h_{lwb} = 10.10$ Btu
$h_{cd} = -0.10$ Btu $h_{ld} = .06$ Btu
$h_{ca} = 31.62 + (-0.10) = 31.52$ Btu $h_{la} = 10.10 + .06 = 10.16$ Btu
$W_{ca} = 78$ gr $W_{la} = 19$ gr
$w = W_{la} - W_{ca} = 19 - 78 = -59$ gr moisture rejected
h_w (for ice 59 gr and 20 F) = -1.26 Btu

Exact Solution—Cooling load:

$q = h_{la} - h_{ca} - h_w = 10.16 - 31.52 - 1.26 = -22.62$ Btu per lb of dry air.

Approximate Solution—Cooling load:

$q = h_{lwb} - h_{ewb} = 10.10 - 31.62 = -21.52$ Btu per lb of dry air.
Approximate solution is 5% lower than exact solution.

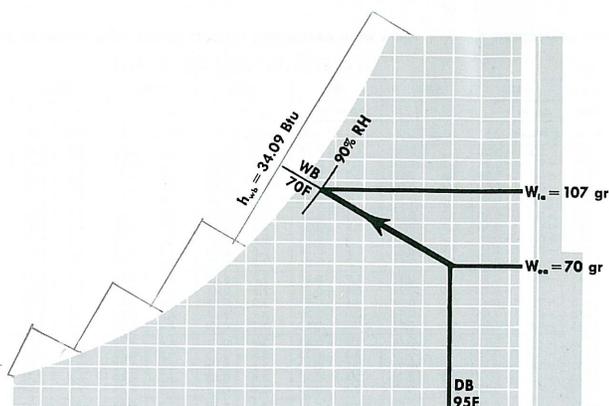## Example 5. Spray or Evaporative Cooling

Fig. 5. Spray or Evaporative Cooling

Given
- Initial Air $\begin{cases} DB = 95\ F \\ WB = 70\ F \end{cases}$
- Spray water humidifies air to 90% RH

Find
- WB
- Moisture added
- Heat added

Locate the condition of initial air on chart. Spray make-up water is at wet-bulb temperature of initial air so that the air absorbs moisture without a change in total heat (adiabatic absorption). The wet-bulb temperature of the air remains constant:
Therefore $t_{ewb} = t_{lwb} = 70$ WB
Locate condition of final air: WB = 70 F, RH = 90%
From chart read:
$W_{ca} = 70$ gr $W_{la} = 107$ gr
$h_{ewb} = 34.09$ Btu $h_{lwb} = 34.09$ Btu
$h_{cd} = -0.22$ Btu $h_{ld} = -0.02$ Btu
Moisture added (w) = $107 - 70 = 37$ gr per lb of dry air
h_w (diagram at top of chart for 37 gr and 70 F) = 0.2 Btu
$h_{ca} = 34.09 + (-0.22) = 33.87$ Btu
$h_{la} = 34.09 + (-0.02) = 34.07$ Btu
Heat added q = $34.07 - 33.87 - 0.2 = 0$ Btu per lb of dry air
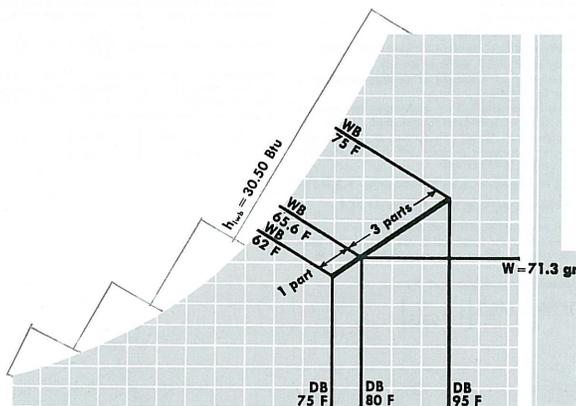
Example 6. Mixture of Air

Fig. 6. Mixture of Air

Given
- Inside Air 3 parts by weight $\begin{cases} DB = 75\ F \\ WB = 62\ F \end{cases}$
- Entering Air 1 part by weight $\begin{cases} DB = 95\ F \\ WB = 75\ F \end{cases}$

Find
- Properties of Mixture

Locate on chart conditions of inside and entering air. Draw line connecting two points. Measure off distance equal to ¼ of line, starting from inside air condition. Point thus established represents condition of mixture of inside and entering air.

Read properties of mixture:
DB = 80 F, WB = 65.6 F, h = $30.50 + (-0.11) = 30.39$ Btu.
Moisture content (W) = 71.3 gr per lb of dry air.

When air quantities being mixed are at widely different temperatures, the above method is slightly in error. For exact solution calculate properties of mixture on basis of specific humidity and enthalpy.