# Psychrometric Chart Fundamentals

## Contents

# INTRODUCTION

This section provides information on use of the psychrometric chart as applied to air conditioning processes. The chart provides a graphic representation of the properties of moist air including wet- and dry-bulb temperature, relative humidity, dew point, moisture content, enthalpy, and air density. The chart is used to plot the changes that occur in the air as it passes through an air handling system and is particularly useful in understanding these changes in relation to the performance of automatic HVAC control systems. The chart is also useful in troubleshooting a system.

For additional information about control of the basic processes in air handling systems, refer to the Air Handling System Control Applications section.

# DEFINITIONS

To use these charts effectively, terms describing the thermodynamic properties of moist air must be understood. Definition of these terms follow as they relate to the psychrometric chart. Additional terms are included for devices commonly used to measure the properties of air.

**Adiabatic process:** A process in which there is neither loss nor gain of total heat. The heat merely changes from sensible to latent or latent to sensible.

**British thermal unit (Btu):** The amount of heat required to raise one pound of water one degree Fahrenheit.

**Density:** The mass of air per unit volume. Density can be expressed in pounds per cubic foot of dry air. This is the reciprocal of specific volume.

**Dew point temperature:** The temperature at which water vapor from the air begins to form droplets and settles or condenses on surfaces that are colder than the dew point of the air. The more moisture the air contains, the higher its dew point temperature. When dry-bulb and wet-bulb temperatures of the air are known, the dew point temperature can be plotted on the psychrometric chart (Fig. 4).

**Dry-bulb temperature:** The temperature read directly on an ordinary thermometer.

**Isothermal process:** A process in which there is no change of dry-bulb temperature.

**Latent heat:** Heat that changes liquid to vapor or vapor to liquid without a change in temperature or pressure of the moisture. Latent heat is also called the heat of vaporization or condensation. When water is vaporized, it absorbs heat which becomes latent heat. When the vapor condenses, latent heat is released, usually becoming sensible heat.

**Moisture content (humidity ratio):** The amount of water contained in a unit mass of dry air. Most humidifiers are rated in grains of moisture per pound of dry air rather than pounds of moisture. To convert pounds to grains, multiply pounds by 7000 (7000 grains equals one pound).

**Relative humidity:** The ratio of the measured amount of moisture in the air to the maximum amount of moisture the air can hold at the same temperature and pressure. Relative humidity is expressed in percent of saturation. Air with a relative humidity of 35, for example, is holding 35 percent of the moisture that it is capable of holding at that temperature and pressure.

**Saturation:** A condition at which the air is unable to hold any more moisture at a given temperature.

**Sensible heat:** Heat that changes the temperature of the air without changing its moisture content. Heat added to air by a heating coil is an example of sensible heat.

**Sling psychrometer:** A device (Fig. 1) commonly used to measure the wet-bulb temperature. It consists of two identical thermometers mounted on a common base. The base is pivoted on a handle so it can be whirled through the air. One thermometer measures dry-bulb temperature. The bulb of the other thermometer is encased in a water-soaked wick. This thermometer measures wet-bulb temperature. Some models provide slide rule construction which allows converting the dry-bulb and wet-bulb readings to relative humidity.

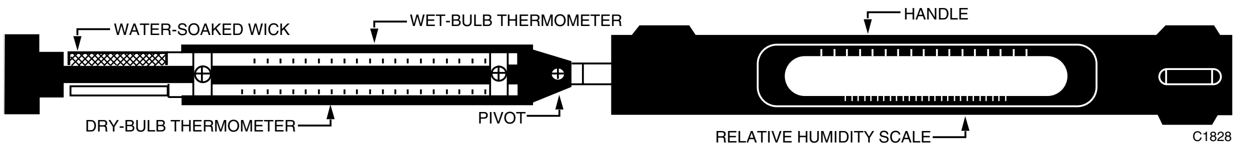



**Fig. 1. Sling Psychrometer.**

Although commonly used, sling psychrometers can cause inaccurate readings, especially at low relative humidities, because of factors such as inadequate air flow past the wet-bulb wick, too much wick wetting from a continuous water feed, thermometer calibration error, and human error. To take more accurate readings, especially in low relative humidity conditions, motorized psychrometers or hand held electronic humidity sensors are recommended.

**Specific volume:** The volume of air per unit of mass. Specific volume can be expressed in cubic feet per pound of dry air. The reciprocal of density.

**Total heat (also termed enthalpy):** The sum of sensible and latent heat expressed in Btu or calories per unit of mass of the air. Total heat, or enthalpy, is usually measured from zero degrees Fahrenheit for air. These values are shown on the ASHRAE Psychrometric Charts in Figures 33 and 34.

**Wet-bulb temperature:** The temperature read on a thermometer with the sensing element encased in a wet wick (stocking or sock) and with an air flow of 900 feet per minute across the wick. Water evaporation causes the temperature reading to be lower than the ambient dry-bulb temperature by an amount proportional to the moisture content of the air. The temperature reduction is sometimes called the evaporative effect. When the reading stops falling, the value read is the wet-bulb temperature.

The wet-bulb and dry-bulb temperatures are the easiest air properties to measure. When they are known, they can be used to determine other air properties on a psychrometric chart.

# DESCRIPTION OF THE PSYCHROMETRIC CHART

The ASHRAE Psychrometric Chart is a graphical representation of the thermodynamic properties of air. There are five different psychrometric charts available and in use today:

- Chart No. 1 — Normal temperatures, 32 to 100F
- Chart No. 2 — Low temperatures, –40 to 50F
- Chart No. 3 — High temperatures, 50 to 250F
- Chart No. 4 — Normal temperature at 5,000 feet above sea level, 32 to 120F
- Chart No. 5 — Normal temperature at 7,500 feet above sea level, 32 to 120F

Chart No. 1 can be used alone when no freezing temperatures are encountered. Chart No. 2 is very useful, especially in locations with colder temperatures. To apply the lower range chart to an HVAC system, part of the values are plotted on Chart No. 2 and the resulting information transferred to Chart No. 1. This is discussed in the EXAMPLES OF AIR MIXING PROCESS section. These two charts allow working within the comfort range of most systems. Copies are provided in the ASHRAE PSYCHROMETRIC CHARTS section.

# THE ABRIDGED PSYCHROMETRIC CHART

Figure 2 is an abridged form of Chart No. 1. Some of the scale lines have been removed to simplify illustrations of the psychrometric processes. Smaller charts are used in most of the subsequent examples. Data in the examples is taken from full-scale charts

The major lines and scales on the abridged psychrometric chart identified in bold letters are:

— Dry-bulb temperature lines
— Wet-bulb temperature lines
— Enthalpy or total heat lines
— Relative humidity lines
— Humidity ratio or moisture content lines
— Saturation temperature or dew point scale
— Volume lines in cubic feet per pound of dry air

The chart also contains a protractor nomograph with the following scales:

— Enthalpy/humidity ratio scale
— Sensible heat/total heat ratio scale

When lines are drawn on the chart indicating changes in psychrometric conditions, they are called process lines.

With the exception of relative humidity, all lines are straight. Wet-bulb lines and enthalpy (total heat) lines are not exactly the same so care must be taken to follow the correct line. The dry-bulb lines are not necessarily parallel to each other and incline slightly from the vertical position. The purpose of the two enthalpy scales (one on the protractor and one on the chart) is to provide reference points when drawing an enthalpy (total

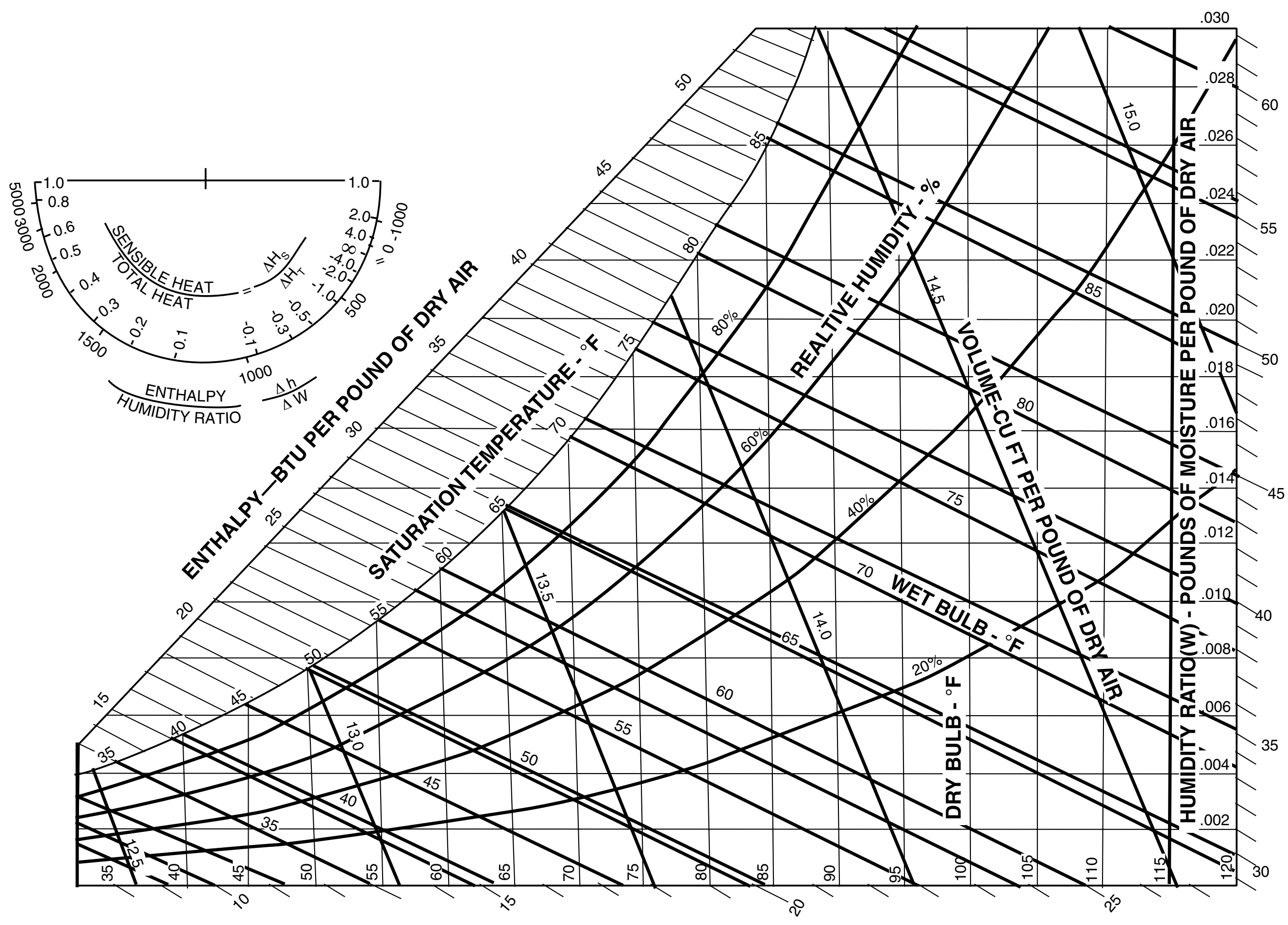



Fig. 2. Abridged Chart No. 1.

heat) line. The protractor nomograph, in the upper left corner, is used to establish the slope of a process line. The mechanics of constructing this line are discussed in more detail in the STEAM JET HUMIDIFIERS section.

The various properties of air can be determined from the chart whenever the lines of any two values cross even though all properties may not be of interest. For example, from the point where the 70F dry-bulb and 60F wet-bulb lines cross (Fig. 3, Point A), the following additional values can be determined:

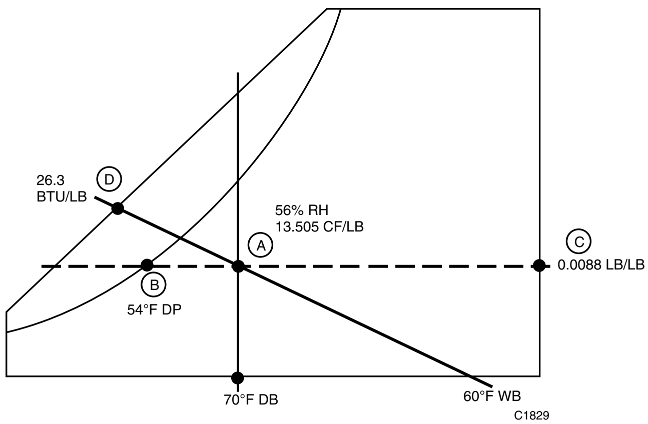



**Fig. 3.**

— Relative humidity is 56 percent (Point A)
— Volume is 13.505 cubic feet per pound of dry air (Point A)
— Dew point is 54F (Point B)
— Moisture content is 0.0088 pounds of moisture per pound of dry air (Point C)
— Enthalpy (total heat) is 26.3 Btu per pound of dry air (Point D)
— Density is 0.074 pounds per cubic foot (reciprocal of volume)

Figure 4 is another plotting example. This time the dry-bulb temperature line and relative humidity line are used to establish the point. With the relative humidity equal to 60 percent and the dry-bulb temperature at 77F (Fig. 4, Point A), the following values can be read:
— Wet-bulb temperature is 67.5F (Point A)
— Volume is 13.8 cubic feet per pound of dry air (Point A)
— Dew point is 62.5F (Point B)
— Moisture content is 0.012 pounds of moisture per pound of dry air (Point C)
— Enthalpy is 31.6 Btu per pound of dry air (Point D)
— Density is 0.0725 pounds per cubic foot (reciprocal of volume)

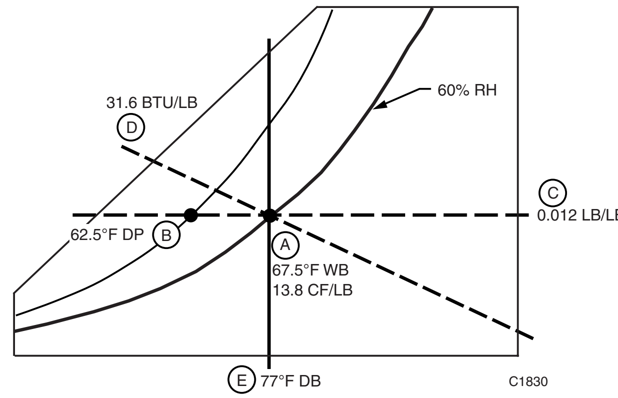



**Fig. 4.**

Figure 5 is the same as Figure 4 but is used to obtain latent heat and sensible heat values. Figures 4 and 5 indicate that the enthalpy (total heat) of the air is 31.6 Btu per pound of dry air (Point D). Enthalpy is the sum of sensible and latent heat (Line A to E + Line E to D, Fig. 5). The following process determines how much is sensible heat and how much is latent heat. The bottom horizontal line of the chart represents zero moisture content. Project a constant enthalpy line to the enthalpy scale (from Point C to Point E). Point E enthalpy represents sensible heat of 18.7 Btu per pound of dry air. The difference between this enthalpy reading and the original enthalpy reading is latent heat. In this example 31.6 minus 18.7 equals 12.9 Btu per pound of dry air of latent heat. When the moisture content of the air changes but the dry-bulb temperature remains constant, latent heat is added or subtracted.

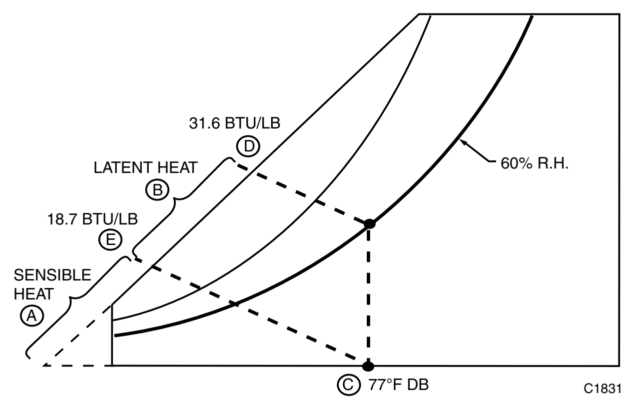



**Fig. 5.**

# EXAMPLES OF AIR MIXING PROCESS

The following examples illustrate use of the psychrometric chart to plot values and determine conditions in a ventilating system. The examples also show how to obtain the same results by calculation. Example A requires only Chart No. 1. Example B requires both Charts No. 1 and 2 since the outdoor air temperature is in the range of Chart No. 2.

EXAMPLE A:

Plotting values where only Chart No. 1 (Fig. 6) is required.

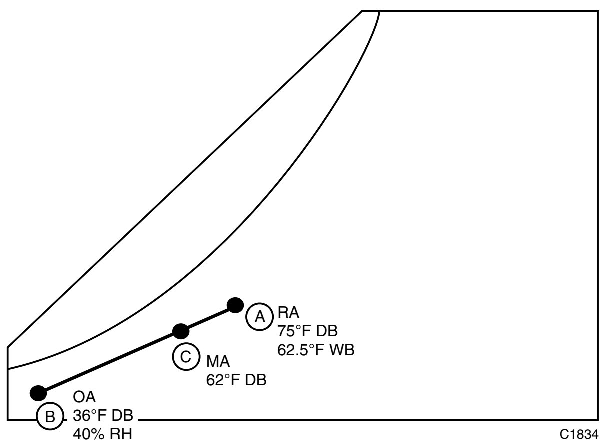



**Fig. 6. Example A, Chart No. 1.**

In this example:
1. A fixed quantity of two-thirds return air and one-third outdoor air is used.
2. The return air condition is 75F dry bulb and 62.5F wet bulb.
3. Outdoor air condition is 36F dry bulb and 40 percent rh.

To find the mixed air conditions at design:
1. Plot the return air (RA) condition (Point A) and outdoor air (OA) condition (Point B).
2. Connect the two points with a straight line.
3. Calculate the mixed air dry-bulb temperature:

   $(2/3 \times 75) + (1/3 \times 36) = 62F$ dry bulb
4. The mixed air conditions are read from the point at which the line, drawn in Step 2, intersects the 62F dry-bulb line (Point C).

EXAMPLE B:

Plotting values when both Chart No. 1 and Chart No. 2 are required.

In this example, a ventilating system (Fig. 7) is used to illustrate how to plot data on Chart No. 2 and transfer values to Chart No. 1. Chart No. 2 is similar to Chart No. 1 except that it covers the –40 to 50F temperature range. This is the temperature range immediately below that of Chart No. 1. Note that there is an overlap of temperatures between 35F and 50F. The overlap is important when transferring values from one chart to another.

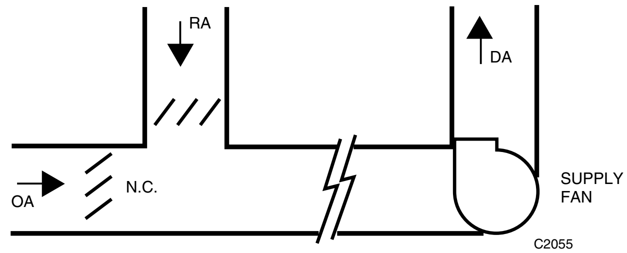



**Fig. 7. Example B, Ventilating System.**

This example illustrates mixing two different air conditions with no change in total heat (enthalpy). Any changes in the total heat required to satisfy space conditions are made by heating, cooling, humidification, or dehumidification after the air is mixed.

In this example:
1. A fixed quantity of two-thirds return air and one-third outdoor air is used.
2. The return air condition is 75F dry bulb and 62.5F wet bulb.
3. Outdoor air condition is 10F dry bulb and 50 percent rh.

To find the mixed air condition:
1. Plot the outdoor air (OA) condition on Chart No. 2, Fig. 8

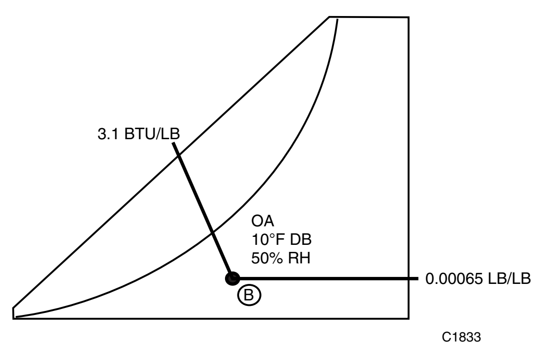



**Fig. 8. Example B, Chart No. 2.**

2. Plot the return air (RA) condition on Chart No. 1, Fig. 9.

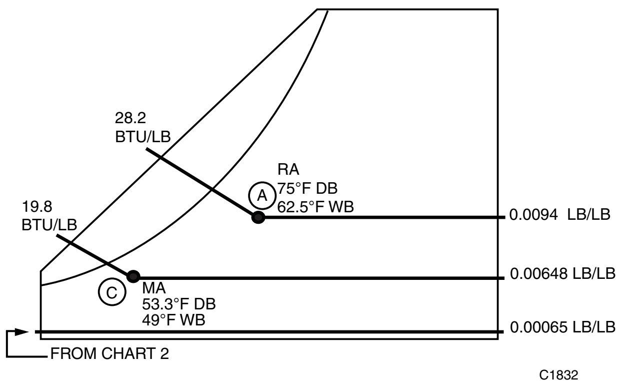



**Fig. 9. Example B, Chart No. 1**

3. Calculate the mixed air enthalpy as follows:
   a. For the return air, project a line parallel to the enthalpy line from Point A to the enthalpy scale on Figure 9. The value is 28.2 Btu per pound of dry air.
   b. For the outdoor air, project a line parallel to the enthalpy line from Point B to the enthalpy scale on Figure 8. The value is 3.1 Btu per pound of dry air.
   c. Using the determined values, calculate the mixed air enthalpy:

      (2/3 x 28.2) + (1/3 x 3.1) = 19.8 Btu per pound of dry air

4. Calculate the mixed air moisture content as follows:
   a. For the return air, project a line from Point A horizontally to the moisture content scale on Figure 9. The value is 0.0094 pounds of moisture per pound of dry air.
   b. For the outdoor air, project a line from Point B horizontally to the moisture content scale on Figure 8. The value is 0.00065 pounds of moisture per pound of dry air. Also, project this value on to Chart No. 1 as shown in Figure 9.
   c. Using the determined values, calculate the mixed air moisture content:

      (2/3 x 0.0094) + (1/3 x 0.00065) = 0.00648 pounds of moisture per pound of dry air

5. Using the enthalpy value of 19.8 and the moisture content value of 0.00648, plot the mixed air conditions, Point C, on Chart No. 1, Figure 9, by drawing a horizontal line across the chart at the 0.00648 moisture content level and a diagonal line parallel to the enthalpy lines starting at the 19.8 Btu per pound of dry air enthalpy point. Point C yields 53.3F dry-bulb and 49F wet-bulb temperature.
6. Read other conditions for the mixed air (MA) from Chart No. 1 as needed.

# AIR CONDITIONING PROCESSES

## HEATING PROCESS

The heating process adds sensible heat to the system and follows a constant, horizontal moisture line. When air is heated by a steam or hot water coil, electric heat, or furnace, no moisture is added. Figure 10 illustrates a fan system with a heating coil. Figure 11 illustrates a psychrometric chart for this system. Air is heated from 55F dry bulb to 85F dry bulb represented by Line A-B. This is the process line for heating. The relative humidity drops from 40 percent to 12 percent and the moisture content remains 0.0035 pounds of moisture per pound of air. Determine the total heat added as follows:

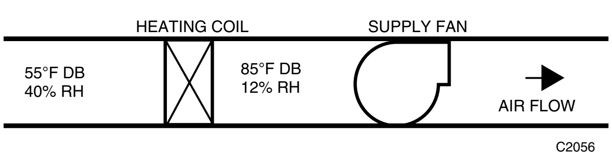



**Fig. 10. Fan System with Heating Coil.**

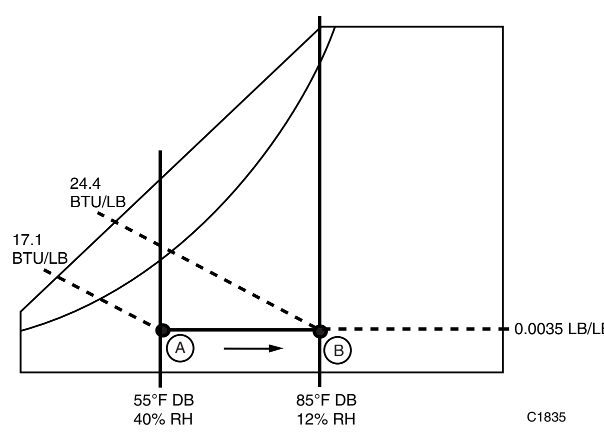



**Fig. 11.**

1. Draw diagonal lines parallel to the constant enthalpy lines from Points A and B to the enthalpy scale.
2. Read the enthalpy on the enthalpy scale.
3. Calculate the enthalpy added as follows:

   Total heat at Point B – total heat at Point A = total heat added.

   24.4 – 17.1 = 7.3 Btu per pound of dry air

Since there is no change in moisture content, the total heat added is all sensible. Whenever the process moves along a constant moisture line, only sensible heat is changed.

## COOLING PROCESS

The cooling process removes sensible heat and, often, latent heat from the air. Consider a condition where only sensible heat is removed. Figure 12 illustrates a cooling process where air is cooled from 90F to 70F but no moisture is removed. Line A-B represents the process line for cooling. The relative humidity in this example increases from 50 percent (Point A) to 95 percent (Point B) because air at 70F cannot hold as much moisture as air at 90F. Consequently, the same amount of moisture results in a higher percentage relative humidity at 70F than at 90F. Calculate the total heat removed as follows:

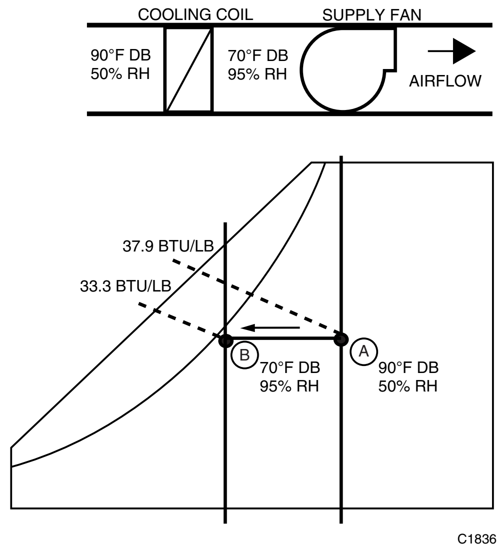



**Fig. 12.**

Total heat at Point A - total heat at Point B = total heat removed.

37.9 – 33.3 = 4.6 Btu per pound of dry air

This is all sensible heat since there is no change in moisture content.

# HUMIDIFYING PROCESS

## BASIC PROCESS

The humidifying process adds moisture to the air and crosses constant moisture lines. If the dry bulb remains constant, the process involves the addition of latent heat only.

Relative humidity is the ratio of the amount of moisture in the air to the maximum amount of moisture the air can hold at the same temperature and pressure. If the dry-bulb temperature increases without adding moisture, the relative humidity decreases. The psychrometric charts in Figures 13 and 14 illustrate what happens. Referring to Chart No. 2 (Fig. 13), outdoor air at 0F dry bulb and 75 percent rh (Point A) contains about 0.0006 pounds of moisture per pound of dry air. The 0.0006 pounds of moisture per pound of dry air is carried over to Chart No. 1 (Fig. 14) and a horizontal line (constant moisture line) is drawn.

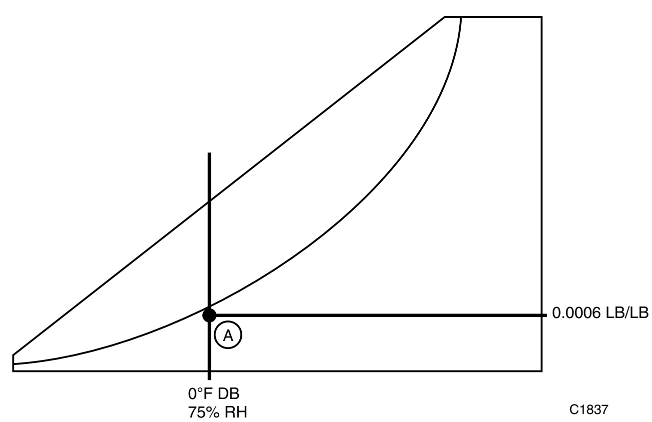



**Fig. 13. Chart No. 2.**

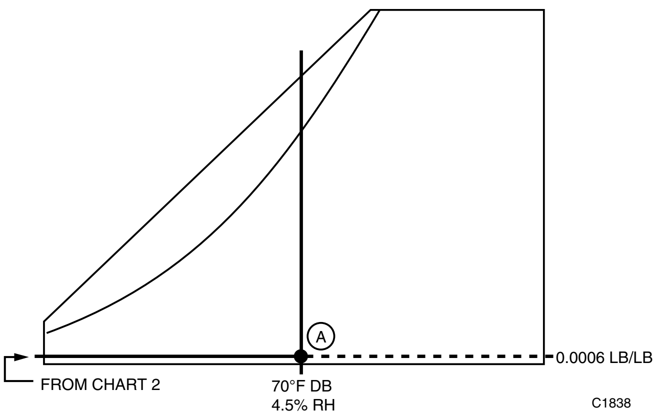



**Fig. 14. Chart No. 1.**

The outdoor air (0F at 75 percent rh) must be heated to a comfortable indoor air level. If the air is heated to 70F, for example, draw a vertical line at that dry-bulb temperature. The intersection of the dry-bulb line and the moisture line determines the new condition. The moisture content is still 0.0006 pounds of moisture per pound of dry air, but the relative humidity drops to about 4.5 percent (Point A, Fig. 14). This indicates a need to add moisture to the air. Two examples of the humidifying process follow.

EXAMPLE 1:

Determine the amount of moisture required to raise the relative humidity from 4.5 percent to 35 percent when the air temperature is raised from 0 to 70F and then maintained at a constant 70F.

Figure 15 provides an example of raising the relative humidity by adding moisture to the air. Assume this example represents a room that is 30 by 40 feet with an 8-foot ceiling and two air changes per hour. Determine how much moisture must be added to raise the relative humidity to 35 percent (Point B).

To raise the relative humidity from 4.5 percent (Point A) to 35 percent (Point B) at 70F, the moisture to be added can be determined as follows:

1. The moisture content required for 70F air at 35 percent rh is 0.0056 pounds of moisture per pound of dry air.
2. The moisture content of the heated air at 70F and 4.5 percent rh is 0.0006 pounds of moisture per pound of dry air.
3. The moisture required is:

   0.0056 – 0.0006 = 0.005 pounds of moisture per pound of dry air

Line A-B, Figure 15, represents this humidifying process on the psychrometric chart.

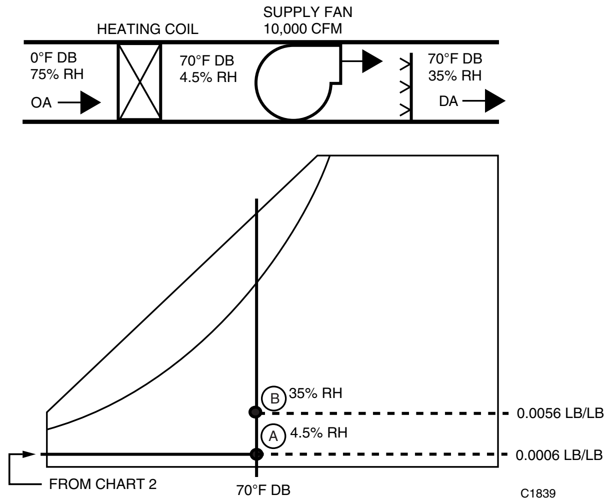



**Fig. 15.**

The space contains the following volume:

30 x 40 x 8 = 9600 cubic feet

Two air changes per hour is as follows:

2 x 9600 = 19,200 cubic feet per hour

This amount of air is brought into the room, heated to 70F, and humidified. Chart No. 2 (Fig. 13) illustrates that outdoor air at 0F has a volume of 11.5 cubic feet per pound. The reciprocal of this provides the density or 0.087 pounds per cubic foot. Converting the cubic feet per hour of air to pounds per hour provides:

19,200 x 0.087 = 1670 pounds of air per hour

For the space in the example, the following moisture must be added:

1670 x 0.005 = 8.5 pounds of water per hour

Since a gallon of water weighs 8.34 pounds, it takes about one gallon of water per hour to raise the space humidity to 35 percent at 70F.

EXAMPLE 2:

Determine the moisture required to provide 75F air at 50 percent rh using 50F air at 52 percent rh.

In this example, assume that 10,000 cubic feet of air per minute must be humidified. First, plot the supply air Point A, Figure 16, at 50F and 52 percent rh. Then, establish the condition after the air is heated to 75F dry bulb. Since the moisture content has not changed, this is found at the intersection of the horizontal, constant moisture line (from Point A) and the vertical 75F dry-bulb temperature line (Point B).

The air at Points A and B has 0.004 pounds of moisture per pound of air. While the moisture content remains the same after the air is heated to 75F (Point B), the relative humidity drops from 52 percent to 21 percent. To raise the relative humidity to 50 percent at 75F, find the new point on the chart (the intersection of the 75F dry-bulb line and the 50 percent rh curve or Point C). The moisture content at this point is 0.009 pounds of moisture per pound of dry air. Calculate the moisture to be added as follows:

0.009 – 0.004 = 0.005 pounds of moisture per pound of dry air

Line B-C in Figure 16 represents this humidifying process on the psychrometric chart.

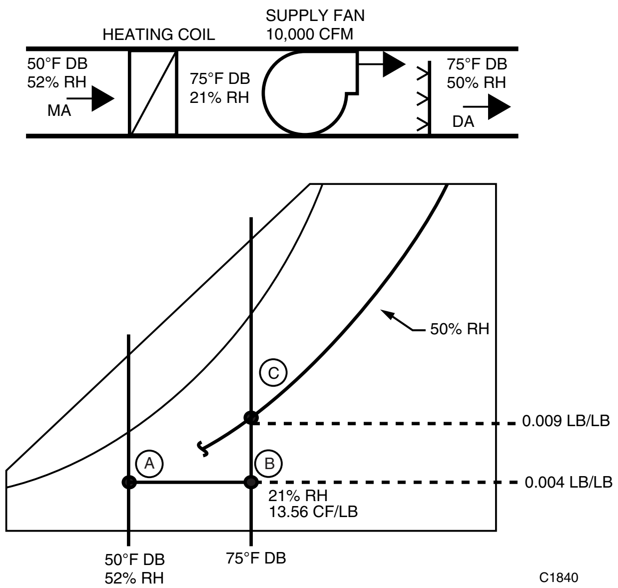



**Fig. 16.**

At 75F and 21 percent relative humidity, the psychrometric chart shows that the volume of one pound of air is about 13.58 cubic feet. There are two ways to find the weight of the air. One way is to use the volume to find the weight. Assuming 10,000 cubic feet of air:

10,000 ÷ 13.58 = 736 pounds of air

The other way is to use the density to find the weight. The reciprocal of the volume provides the density as follows:

1 ÷ 13.58 = 0.0736 pounds per cubic foot

The weight is then:

10,000 x 0.0736 = 736 pounds of air per minute

If each pound of dry air requires 0.005 pounds of moisture, then the following moisture must be added:

736 x 0.005 = 3.68 pounds of moisture per minute

This converts to:

3.68 x 60 minutes = 220.8 pounds per hour

Since one gallon of water weighs 8.34 pounds, the moisture to be added is as follows:

220.8 ÷ 8.34 = 26.5 gallons per hour

Thus, a humidifier must provide 26.5 gallons of water per hour to raise the space humidity to 50 percent at 75F.

## STEAM JET HUMIDIFIER

The most popular humidifier is the steam-jet type. It consists of a pipe with nozzles partially surrounded by a steam jacket. The jacket is filled with steam; then the steam is fed through nozzles and sprayed into the air stream. The jacket minimizes condensation when the steam enters the pipe with the nozzles and ensures dry steam for humidification. The steam is sprayed into the air at a temperature of 212F or higher. The enthalpy includes the heat needed to raise the water temperature from 32 to 212F, or 180 Btu plus 970 Btu to change the water into steam. This is a total of 1150 Btu per hour per pound of water at 0 psig as it enters the air stream. (See Properties of Saturated Steam table in General Engineering Data section). The additional heat added to the air can be plotted on Chart No. 1 (Figure 17) to show the complete process. In this example, air enters the heating coil at 55F dry-bulb temperature (Point A) and is heated to 90F dry-bulb temperature (Point B) along a constant moisture line. It then enters the humidifier where the steam adds moisture and heats the air to Point C.

Figure 17 also shows use of the protractor nomograph. Assume the relative humidity of the air entering the humidifier at Point B is to be raised to 50 percent. A process line can be constructed using the protractor nomograph. The total heat of the entering steam in Btu per pound is located on the enthalpy/humidity ratio scale ($\Delta h$ / $\Delta W$) of the nomograph. This value, 1150 Btu per pound, is connected to the reference point of the nomograph to establish the slope of the process line on the psychrometric chart. A parallel line is drawn on the chart from Point B up to the 50 percent relative humidity line (Point C). The Line B-C is the process line. The Line X-Y (bottom of the chart) is simply a perpendicular construction line for drawing the Line B-C parallel to the line determined on the nomograph. Note that the dry-bulb temperature increased from 90 to 92F.

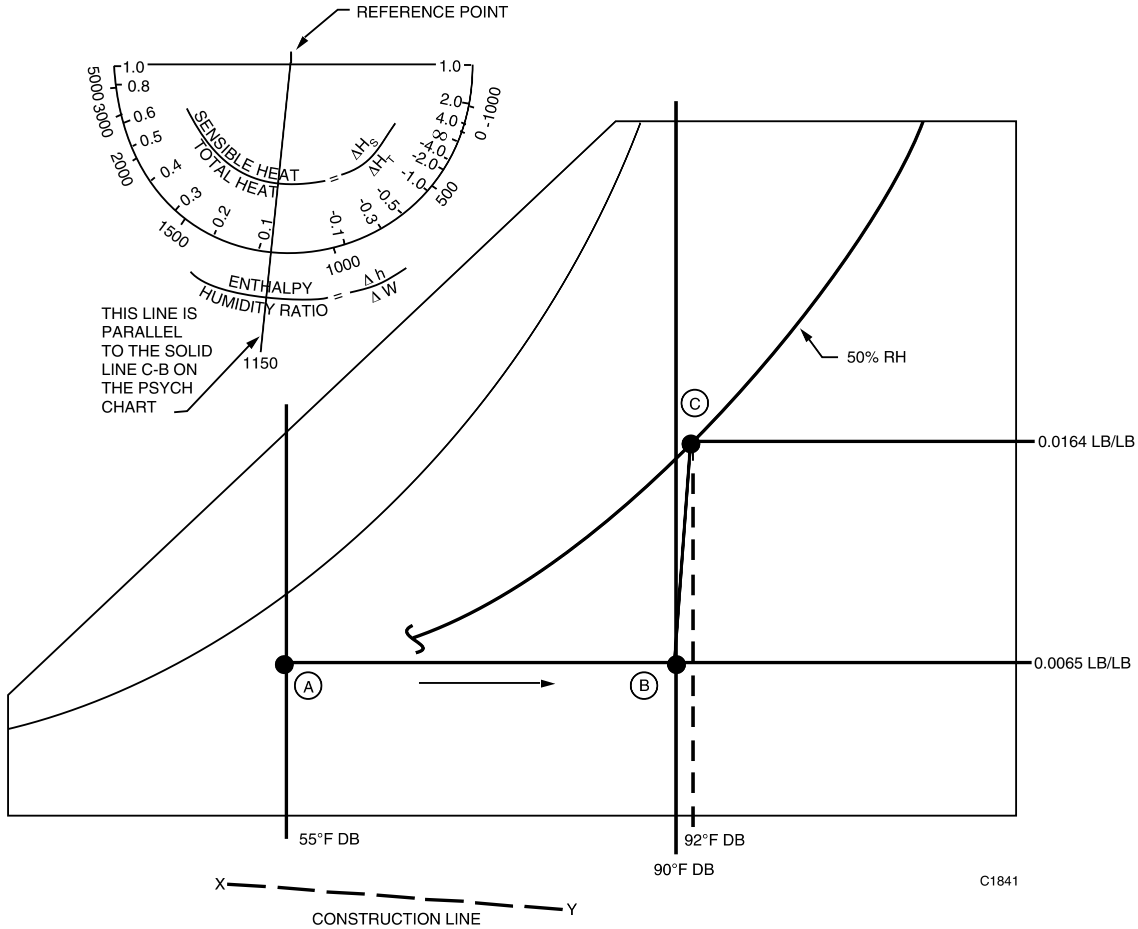

REFERENCE POINT
SENSIBLE HEAT
TOTAL HEAT
ENTHALPY
HUMIDITY RATIO
THIS LINE IS PARALLEL TO THE SOLID LINE C-B ON THE PSYCH CHART
1150
50% RH
C
0.0164 LB/LB
0.0065 LB/LB
A
B
55°F DB
92°F DB
90°F DB
C1841
X
Y
CONSTRUCTION LINE

**Fig. 17.**

Figure 18 is the same as the chart shown in Figure 17 except that it graphically displays the amount of heat added by the process. Enthalpy (total heat) added is determined by subtracting the enthalpy of the dry, heated air at Point B from the enthalpy of the humidified air at Point C as follows:

40.3 – 28.7 = 11.6 Btu per pound of dry air

The steam raised the temperature of the air from 90F dry bulb to 92F dry bulb. To find the latent heat added by the steam humidifier to the air, determine the enthalpy at Point D (the enthalpy of the heated air without added moisture) and subtract it from the enthalpy of the humidified air at Point C. This is as follows:

40.3 – 29.6 = 10.7 Btu per pound of dry air

The remaining 0.9 Btu is sensible heat. The actual moisture added per pound of dry air is 0.0099 pounds. The specific volume of the entering air at Point B is 14 cubic feet per pound.

For a 10,000 cubic feet per minute system, the weight of the air passing through is:

10,000 ÷ 14 = 714.3 pounds per minute

The weight of the moisture added is:

714.3 x 0.0099 = 7.07 pounds per minute of moisture

Since one gallon of water weighs 8.34 pounds, the moisture to be added is as follows:

7.07 ÷ 8.34 = 0.848 gallons per minute

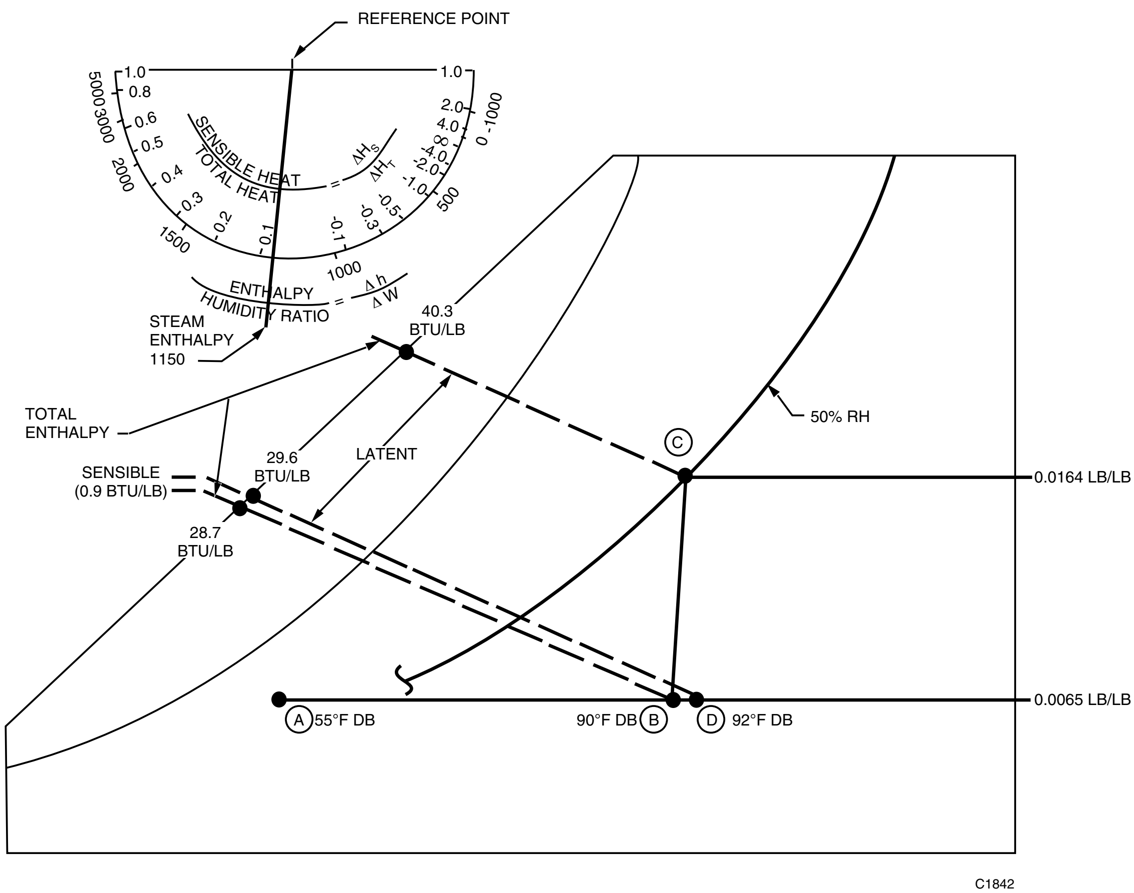



**Fig. 18.**

This converts to:

0.848 x 60 minutes = 50.9 gallons per hour

Recalling that the steam added 11.6 Btu per pound of dry air, the total heat added is:

714.3 x 11.6 = 8286 Btu per minute

This converts to:

8286 x 60 minutes = 497,160 Btu per hour

Summarized, a steam humidifier always adds a little sensible heat to the air, and the Process Line B–C angles to the right of the 90F starting dry-bulb line because of the added sensible heat. When the process line crosses the moisture content lines along a constant dry-bulb line, only latent heat is added. When it parallels a constant, horizontal moisture line, only sensible heat is added.

## AIR WASHERS

Air washers are also used as humidifiers particularly for applications requiring added moisture and not much heat as in warm southwestern climates. A washer can be recirculating as shown in Figure 19 or heated as shown in Figure 20. In recirculating washers, the heat necessary to vaporize the water is sensible heat changed to latent heat which causes the dry-bulb temperature to drop. The process line tracks the constant enthalpy line because no total heat is added or subtracted. This process is called “adiabatic” and is illustrated by Figure 21. Point A is the entering condition of the air, Point B is the final condition, and Point C is the temperature of the water. Since the water is recirculating, the water temperature becomes the same as the wet-bulb temperature of the air.

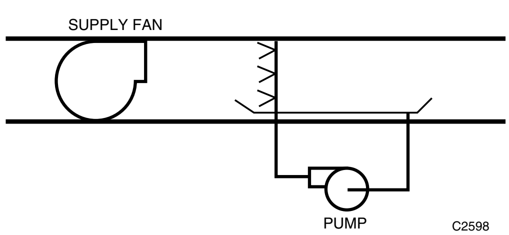



**Fig. 19. Recirculating Air Washer.**

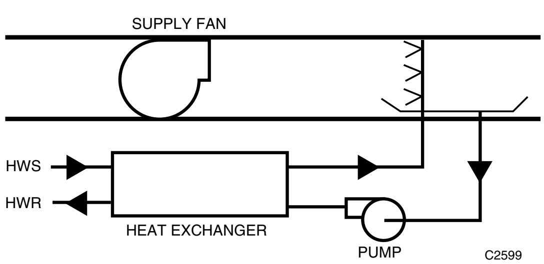



**Fig. 20. Heated Air Washer.**

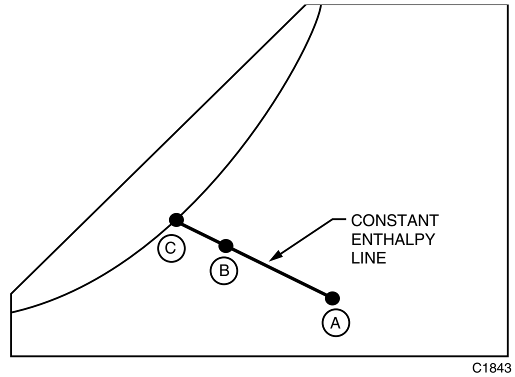



**Fig. 21.**

The next two psychrometric charts (Fig. 22 and 23) illustrate the humidifying process using a heated air washer. The temperature to which the water is heated is determined by the amount of moisture required for the process. Figure 22 shows what happens when the washer water is heated above the air dry-bulb temperature shown at Point A. The temperature of the water located at Point B on the saturation curve causes the system air temperature to settle out at Point D. The actual location of Point D depends upon the construction and characteristics of the washer.

As the humidity demand reduces, the water temperature moves down the saturation curve as it surrenders heat to the air. This causes the water temperature to settle out at a point such as Point C. The final air temperature is at Point E. Note that the final air temperature is above the initial dry-bulb temperature so both sensible and latent heat have been added to the air.

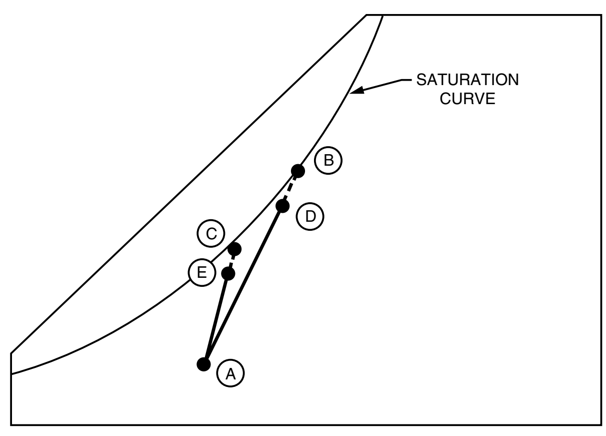



**Fig. 22.**

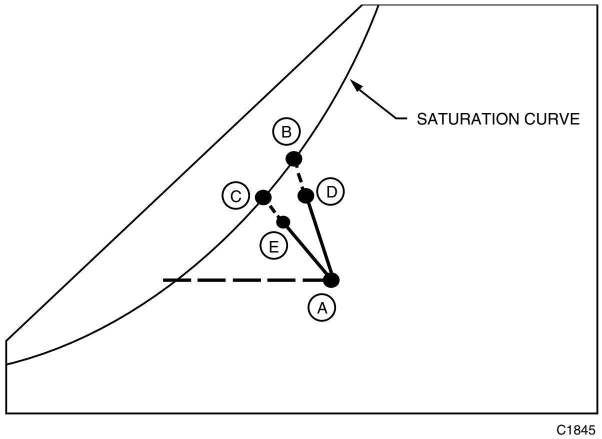



**Fig. 23.**

Figure 23 illustrates a heated washer where the water temperature is between the dry-bulb and wet-bulb temperatures of the air. The air is humidified but also cooled a little. Point B represents the initial and Point C the final temperature of the water with reduced humidity demand. Point A represents the initial and Point E the final temperature of the air. The location of Points D and E depends on the construction and characteristics of the washer. The temperature of the water in a washer is always located on the saturation curve. Note that the dry-bulb temperature of the air is reduced as it passes through the washer. This happens because some of its heat is used to evaporate the water; however, the humidity of the air rises considerably. In this case, some of the sensible heat of the air becomes latent heat in the water vapor, but the enthalpy of the air is increased because of the heat in the water.

## VAPORIZING HUMIDIFIER

Vaporizing and water spray humidifiers operate on the principal of breaking water up into small particulates so they are evaporated directly into the air. This process is essentially adiabatic since the enthalpy lines of the water vapor for 32 and 212F are so close. The enthalpy of water at 32F is zero and at 212F it is 180 Btu per pound. If air at Point A (Fig. 24) is humidified by 212F water, the process follows a line parallel to line C-D and the 80F WB line and ends at a point such as Point B. The actual water temperature of a vaporizing or water spray humidifier will be between 32 and 212F and will usually be around room temperature so using the zero enthalpy line (C-E) as reference will not introduce a significant error into the process.

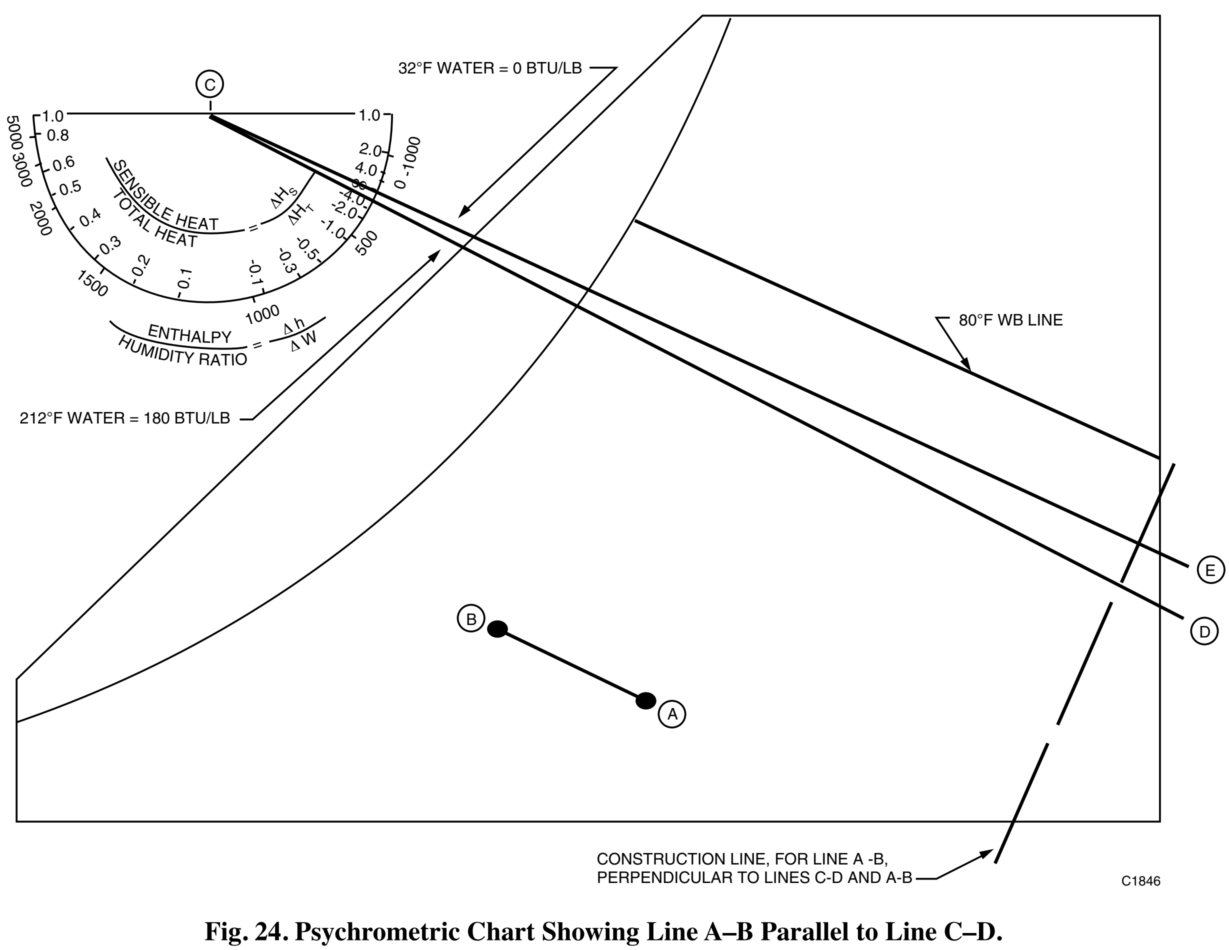



**Fig. 24. Psychrometric Chart Showing Line A–B Parallel to Line C–D.**

## COOLING AND DEHUMIDIFICATION

### BASIC PROCESS

Cooling and dehumidification can be accomplished in a single process. The process line moves in a decreasing direction across both the dry-bulb temperature lines and the constant moisture lines. This involves both sensible and latent cooling.

Figure 12 illustrates cooling air by removing sensible heat only. In that illustration, the resulting cooled air was 95 percent relative humidity, a condition which often calls for reheat (see DEHUMIDIFICATION AND REHEAT). Figure 25 illustrates a combination of sensible and latent cooling. Whenever the surface temperature of the cooling device (Point B), such as a chilled water coil, is colder than the dew point temperature of the entering air (Point A), moisture is removed from the air contacting the cold surface. If the coil is 100 percent efficient, all entering air contacts the coil and leaving air is the same temperature as the surface of the coil.

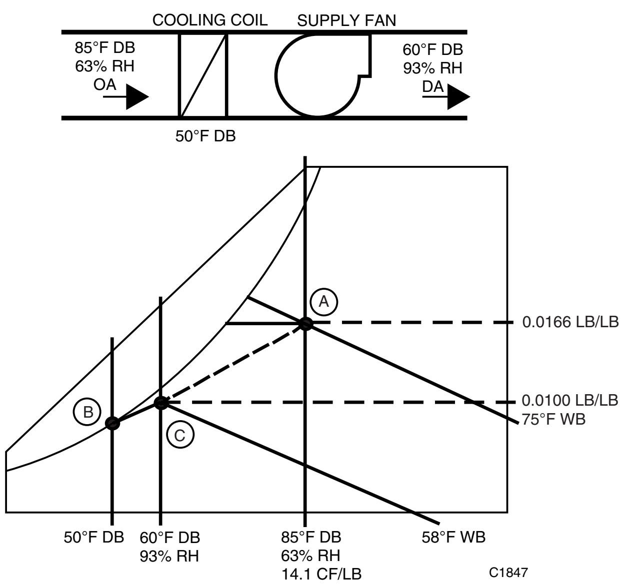



**Fig. 25.**

All coils, however, are not 100 percent efficient and all air does not come in contact with the coil surface or fins. As a result, the temperature of the air leaving the coil (Point C) is somewhere between the coolest fin temperature (Point B) and the entering outdoor air temperature (Point A). To determine this exact point requires measuring the dry-bulb and wet-bulb temperatures of the leaving air.

To remove moisture, some air must be cooled below its dew point. By determining the wet-bulb and the dry-bulb temperatures of the leaving air, the total moisture removed per pound of dry air can be read on the humidity ratio scale and is determined as follows:

1. The entering air condition is 85F dry bulb and 63 percent rh (Point A). The moisture content is 0.0166 pounds of moisture per pound of dry air.
2. The leaving air condition is 60F dry bulb and 93 percent rh (Point C). The moisture content is 0.0100 pounds of moisture per pound of dry air.
3. The moisture removed is:

   0.0166 – 0.0100 = 0.0066 pounds of moisture per pound of dry air

The volume of air per pound at 85F dry bulb and 75F wet bulb (Point A) is 14.1 cubic feet per pound of dry air. If 5000 cubic feet of air per minute passes through the coil, the weight of the air is as follows:

$5000 \div 14.1 = 355$ pounds per minute

The pounds of water removed is as follows:

$355 \times 0.0066 = 2.34$ pounds per minute

or

$2.34 \times 60$ minutes $= 140.4$ pounds per hour

Since one gallon of water weighs 8.34 pounds, the moisture to be removed is as follows:

$140.4 \div 8.34 = 16.8$ gallons per hour

### AIR WASHERS

Air washers are devices that spray water into the air within a duct. They are used for cooling and dehumidification or for humidification only as discussed in the HUMIDIFYING PROCESS—AIR WASHERS section. Figure 26 illustrates an air washer system used for cooling and dehumidification. The chiller maintains the washer water to be sprayed at a constant 50F. This allows the chilled water from the washer to condense water vapor from the warmer entering air as it falls into the pan. As a result, more water returns from the washer than has been delivered because the temperature of the chilled water is lower than the dew point (saturation temperature) of the air. The efficiency of the washer is determined by the number and effectiveness of the spray nozzles used and the speed at which the air flows through the system. The longer the air is in contact with the water spray, the more moisture the spray condenses from the air.

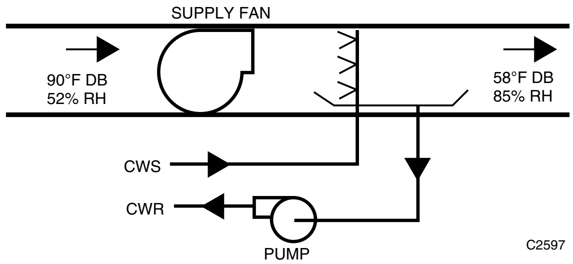



**Fig. 26. Air Washer Used for Cooling and Dehumidification.**

Figure 27 is a chart of the air washer process. If a washer is 100 percent efficient, the air leaving the washer is at Point B. The result as determined by the wet-bulb and dry-bulb temperatures is Point C and is determined as follows:

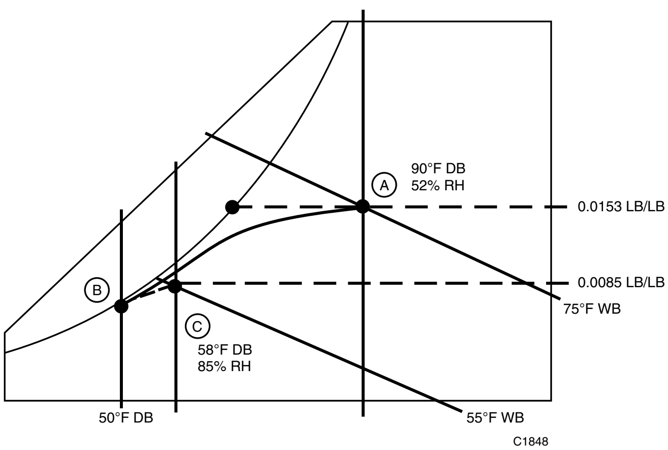



**Fig. 27.**

1. The entering condition air is 90F dry bulb and 52 percent rh (Point A). The moisture content is 0.0153 pounds of moisture per pound of dry air.
2. Air that contacts the spray droplets follows the saturation curve to the spray temperature, 50F dry bulb (Point B), and then mixes with air that did not come in contact with the spray droplets resulting in the average condition at Point C.
3. The leaving air is at 58F dry bulb and 85 percent rh (Point C). The moisture content is 0.0085 pounds of moisture per pound of dry air.
4. The moisture removed is:

$$0.0153 - 0.0085 = 0.068 \text{ pounds of moisture per pound of dry air}$$

Figure 28 summarizes the process lines for applications using washers for humidification or dehumidification. When the water recirculates, the process is adiabatic and the process line follows the Constant Enthalpy Line A-C. The water assumes the wet-bulb temperature of the air as the process line extends. Note that whenever the washer water temperature is between the dew point (Point B) and the dry-bulb (Point D) temperature of the air, moisture is added and the dry-bulb temperature of the air falls. If the water temperature is above the dry-bulb temperature of the air (to the right of Point D), both the air moisture and the dry-bulb temperature increase. Whenever the water temperature is below the dew point temperature (Point B), dehumidification occurs as well as dry-bulb cooling. This process always falls on a curved line between the initial temperature of the air and the point on the saturation curve representing the water temperature. The exact leaving air temperature depends upon the construction and characteristics of the washer.

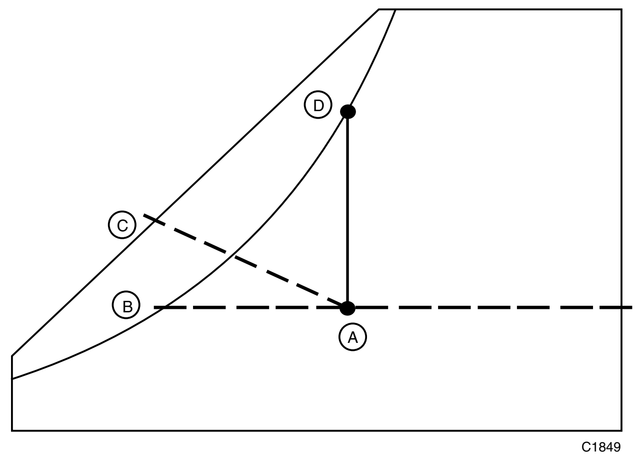



**Fig. 28.**

## DEHUMIDIFICATION AND REHEAT

Dehumidification lowers the dry-bulb temperature, which often requires the use of reheat to provide comfortable conditions. Dehumidification and reheat are actually two processes on the psychrometric chart. Applications, such as computer rooms, textile mills, and furniture manufacturing plants require that a constant relative humidity be maintained at close tolerances. To accomplish this, the air is cooled below a comfortable level to remove moisture, and is then reheated (sensible heat only) to provide comfort. Figure 29 is an air conditioning system with both a cooling coil and reheat coil.

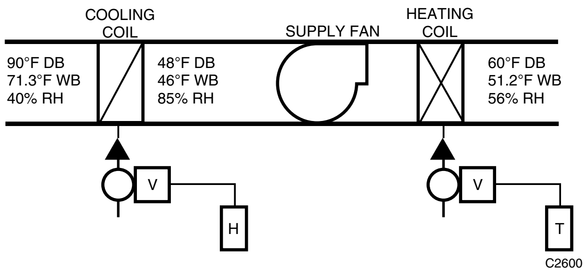



**Fig. 29. Fan System with Dehumidification and Reheat.**

Figure 30 illustrates cooling and dehumidification with reheat for maintaining constant relative humidity. Air enters the coils at Point A, is cooled and dehumidified to Point B, is reheated to Point C, and is then delivered to the controlled space. A space humidistat controls the cooling coil valve to maintain the space relative humidity. A space thermostat controls the reheat coil to maintain the proper dry-bulb temperature.

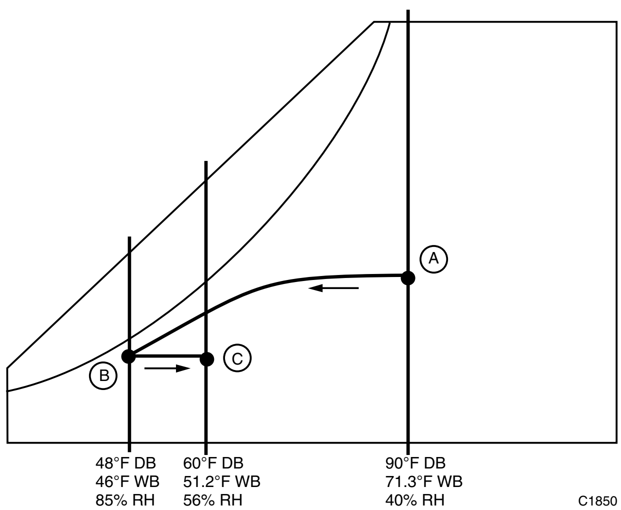



**Fig. 30.**

## PROCESS SUMMARY

Figures 31 and 32 summarize some principles of the air conditioning process as illustrated by psychrometric charts.

— Sensible heating or cooling is always along a constant moisture line.

— When latent heat is added or removed, a process line always crosses the constant moisture lines.

— Enthalpy and humidity ratio, or moisture content, are based on a pound of dry air. Zero moisture is the bottom line of the chart.

— To find the sensible heat content of any air in Btu, follow the dry-bulb line to the bottom of the chart and read the enthalpy there, or project along the enthalpy line, and read the Btu per pound of dry air on the enthalpy scale.

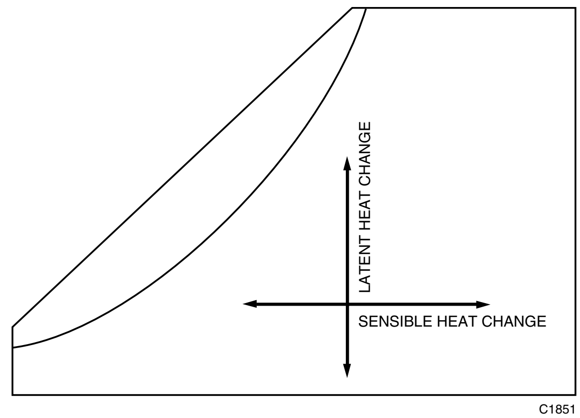
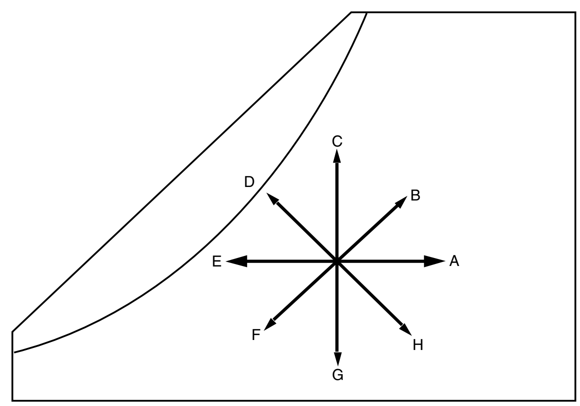



**Fig. 31.**




SUMMARY OF ALL PROCESSES CHARTABLE.
PROCESS MOVEMENT IN THE DIRECTION OF:
— A, HEATING ONLY - STEAM, HOT WATER OR ELECTRIC HEAT COIL
— B, HEATING AND HUMIDIFYING - STEAM HUMIDIFIER OR RECIRCULATED HOT WATER SPRAY
— C, HUMIDIFYING ONLY - AIR WASHER WITH HEATED WATER
— D, COOLING AND HUMIDIFYING - WASHER
— E, COOLING ONLY - COOLING COIL OR WASHER AT DEWPOINT TEMPERATURE
— F, COOLING AND DEHUMIDIFYING - CHILLED WATER WASHER
— G, DEHUMIDIFYING ONLY - NOT PRACTICAL
— H, DEHUMIDIFYING AND HEATING - CHEMICAL DEHUMIDIFIER
C1852

**Fig. 32.**

# ASHRAE PSYCHROMETRIC CHARTS

The following two pages illustrate ASHRAE Psychrometric Charts No. 1 and No. 2.

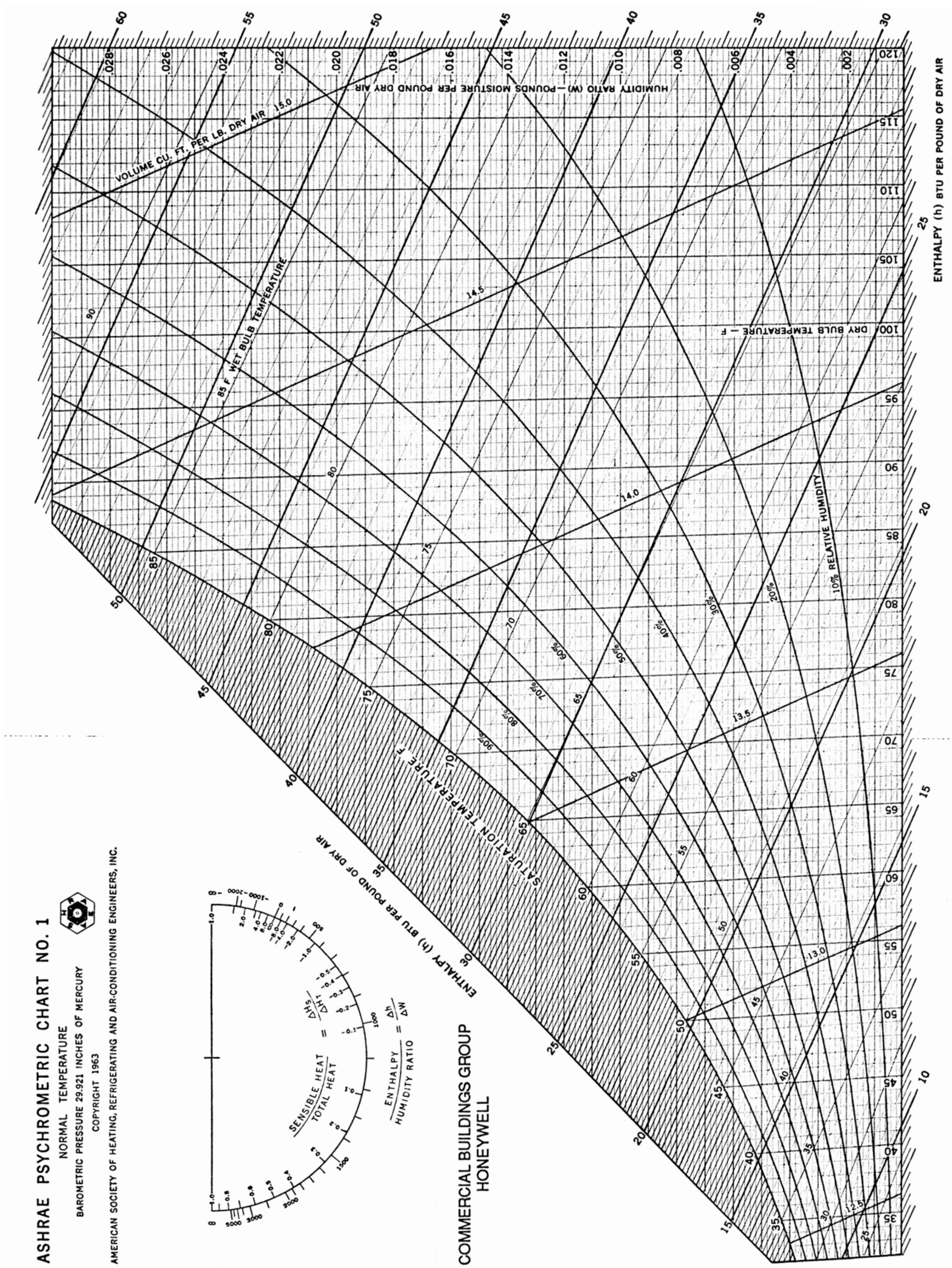



**Fig. 33. ASHRAE Psychrometric Chart No. 1.**

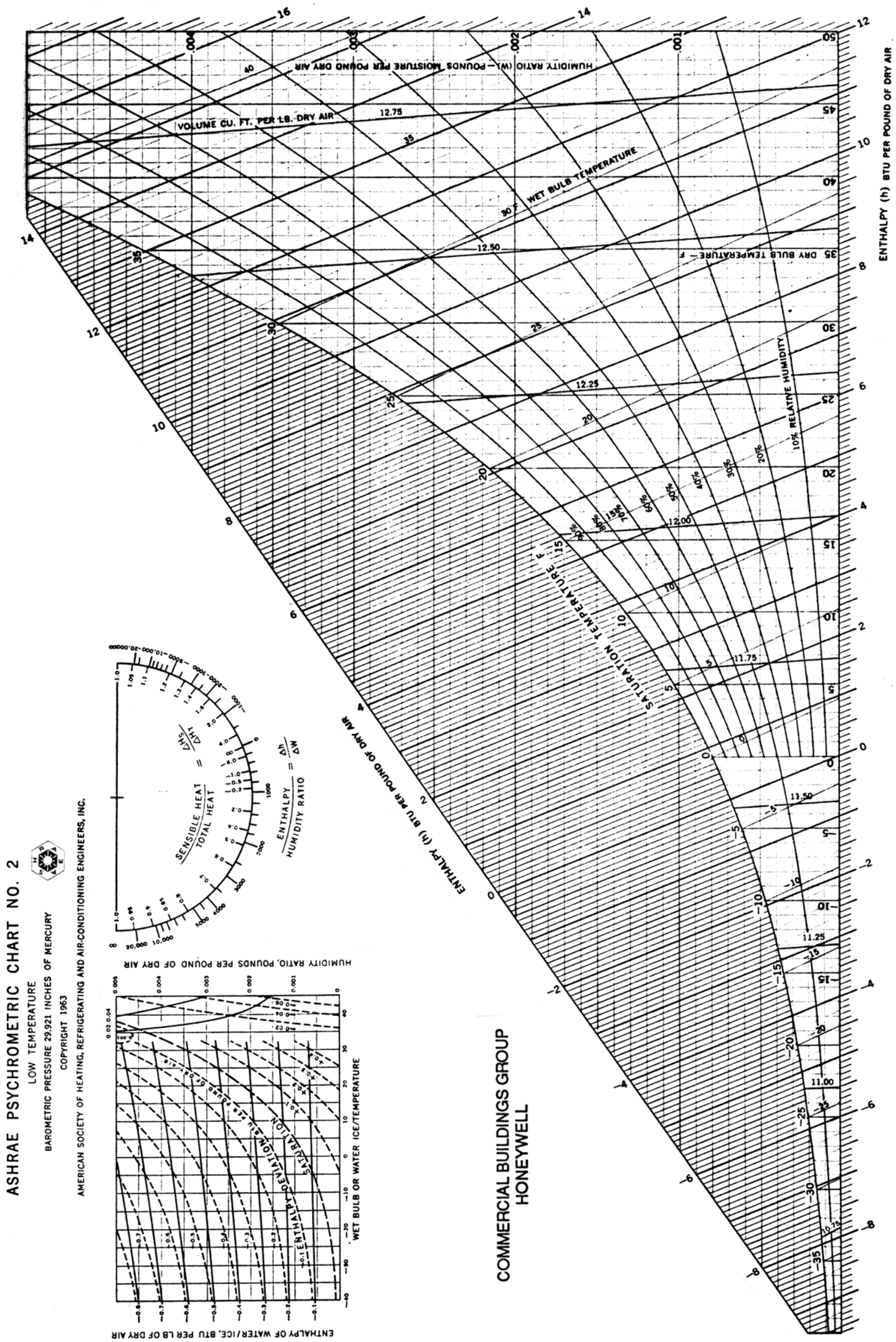



**Fig. 34. ASHRAE Psychrometric Chart No. 2.**