Psychrometric Chart Fundamentals

ENGINEERING MANUAL OF AUTOMATIC CONTROL

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.

Density: The mass of air per unit volume. Density can be expressed in kilograms per cubic meter 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.

Joule (J): The unit of measure for energy, work, and heat. This section uses joule as a unit of heat where 4.2 joules will raise the temperature of 1 gram of water 1 kelvin.

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.

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.

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.

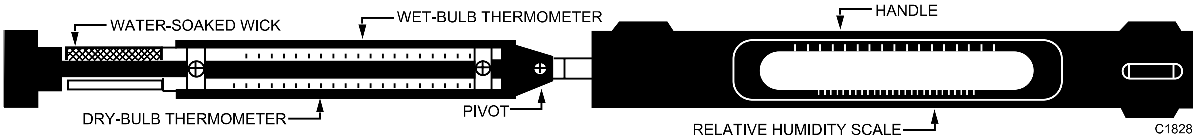

Fig. 1. Sling Psychrometer.

Specific volume: The volume of air per unit of mass. Specific volume can be expressed in cubic meters per kilogram of dry air. The reciprocal of density.

Total heat (also termed enthalpy): The sum of sensible and latent heat expressed in Kilojoule per unit of mass of the air. Total heat, or enthalpy, is usually measured from zero degrees Celsius 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 4.57 meters per second 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, 0 to 50°C
Chart No. 2 —	Low temperatures, –40 to 10°C
Chart No. 3 —	High temperatures, 10 to 120°C
Chart No. 4 —	Very High temperatures, 100 to 200°C
Chart No. 5 —	Normal temperature at 750 meters above sea level, 0 to 50°C
Chart No. 6 —	Normal temperature at 1500 meters above sea level, 0 to 50°C
Chart No. 7 —	Normal temperature at 2250 meters above sea level, 0 to 50°C

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 meters per kilogram 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

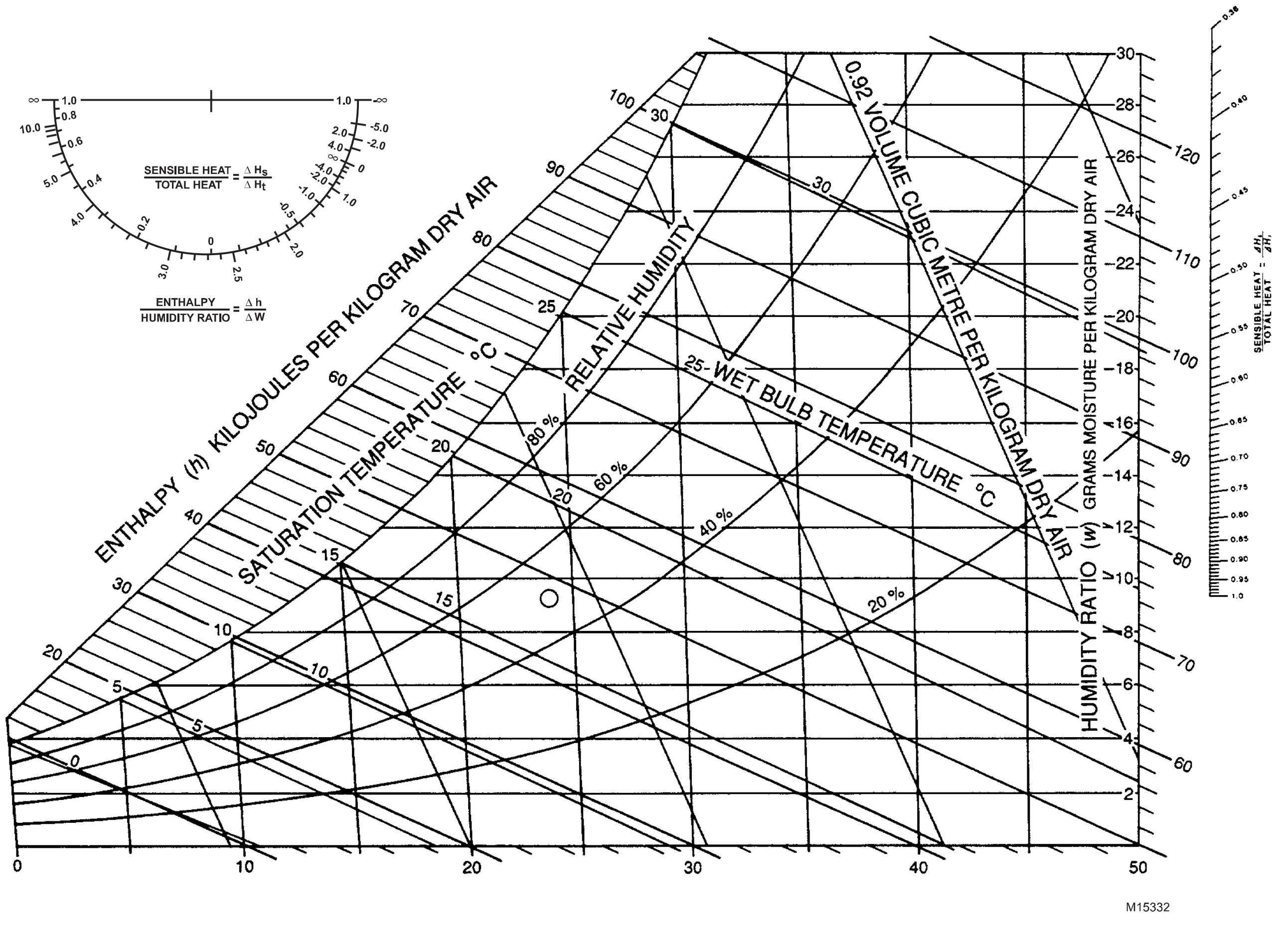

Fig. 2. Abridged Chart No. 1.

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 21°C dry-bulb and 15.5°C wet-bulb lines cross (Fig. 3, Point A), the following additional values can be determined:

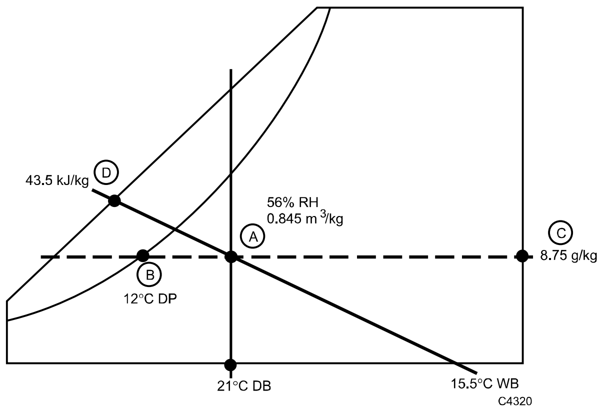

Fig. 3.

— Relative humidity is 56 percent (Point A)
— Volume is 0.845 cubic meters per kilogram of dry air (Point A)
— Dew point is 12°C (Point B)
— Moisture content is 8.75 grams of moisture per kilogram of dry air (Point C)
— Enthalpy (total heat) is 43.5 kilojoules per kilogram of dry air (Point D)
— Density is 1.163 kilograms per cubic meter (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 25°C (Fig. 4, Point A), the following values can be read:

— Wet-bulb temperature is 19.5°C (Point A)
— Volume is 0.86 cubic meters per kilogram of dry air (Point A)
— Dew point is 17°C (Point B)
— Moisture content is 12.0 grams of moisture per kilogram of dry air (Point C)
— Enthalpy is 56.0 kilojoules per kilogram of dry air (Point D)
— Density is 1.163 kilograms per cubic meter (reciprocal of volume)

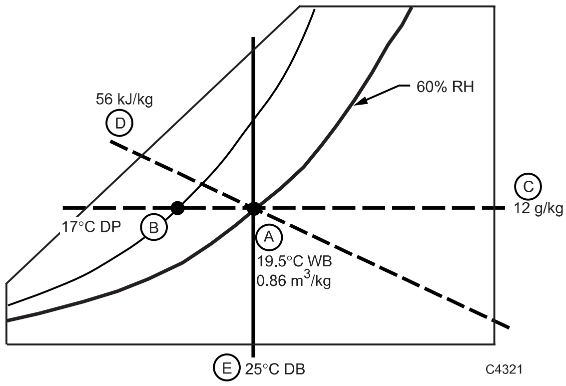

Fig. 4.

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 56.0 kilojoules per kilogram 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 25.5 kilojoules per kilogram of dry air. The difference between this enthalpy reading and the original enthalpy reading is latent heat. In this example 56.0 minus 25.5 equals 30.5 kilojoules per kilogram 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.

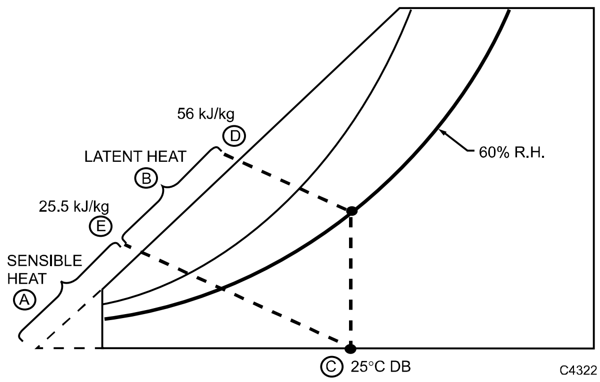

Fig. 5.

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.

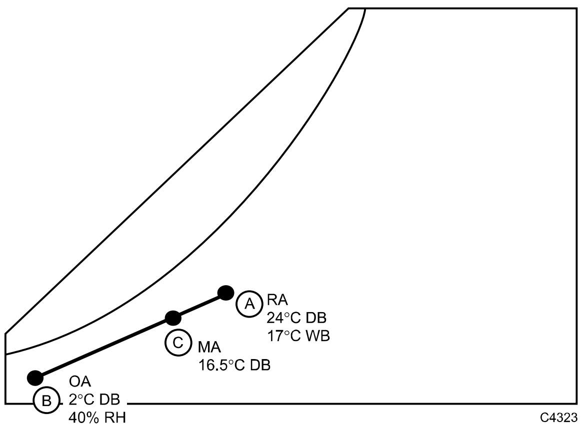

Fig. 6. Example A, Chart No. 1.

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 24°C dry bulb and 17°C wet bulb.
3. Outdoor air condition is 2°C 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: $(2/3 \times 75) + (1/3 \times 36) = 16.5$°C dry bulb
4. The mixed air conditions are read from the point at which the line, drawn in Step 2, intersects the 16.5°C 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°C to 10°C temperature range. This is the temperature range immediately below that of Chart No. 1. Note that there is an overlap of temperatures between 0°C and 10°C. The overlap is important when transferring values from one chart to another.

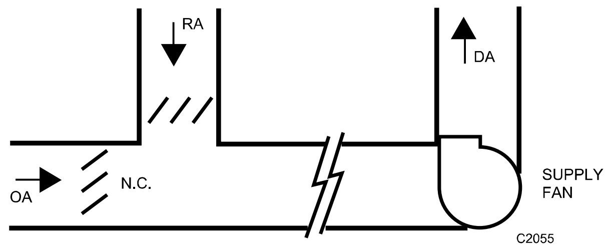

Fig. 7. Example B, Ventilating System.

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 24°C dry bulb and 17°C wet bulb.
3. Outdoor air condition is –12°C 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
2. Plot the return air (RA) condition on Chart No. 1, Fig. 9.

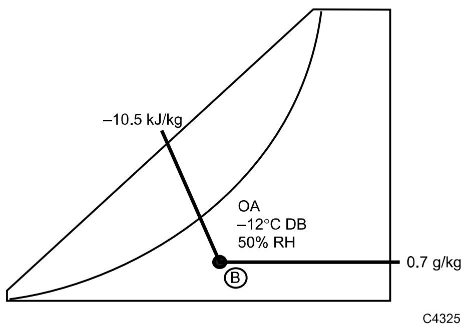

Fig. 8. Example B, Chart No. 2.

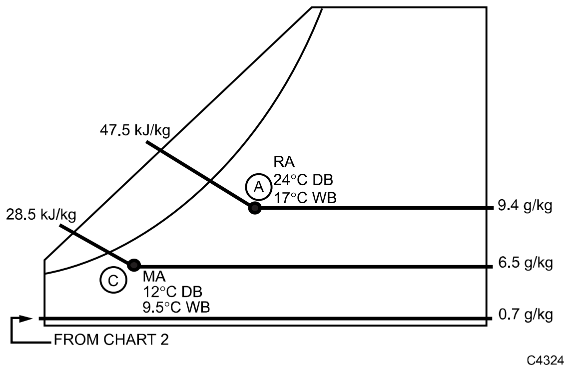

Fig. 9. Example B, Chart No. 1

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 47.5 kilojoules per kilogram 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 –10.5 kilojoules per kilogram of dry air.
   c. Using the determined values, calculate the mixed air enthalpy:

      (2/3 x 47.5) + (1/3 x –10.5) = 28.2 kilojoules per kilogram 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 9.4 grams of moisture per kilogram 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 0.7 grams of moisture per kilogram of dry air. Also, project this value on to Chart No. 1 as shown in Figurre 9.
   c. Using the determined values, calculate the mixed air moisture content:

      (2/3 x 9.4) + (1/3 x 0.7) = 6.5 grams of moisture per kilogram of dry air

5. Using the enthalpy value of 28.2 kJ/kg and the moisture content value of 6.5g, plot the mixed air conditions, Point C, on Chart No. 1, Figure 9, by drawing a horizontal line across the chart at the 6.5g moisture content level and a diagonal line parallel to the enthalpy lines starting at the 28.2 kilojoules per kilogram of dry air enthalpy point. Point C yields 12°C dry-bulb and 9.5°C 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 13°C dry bulb to 30°C 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 3.8 grams of moisture per kilogram of air. Determine the total heat added as follows:

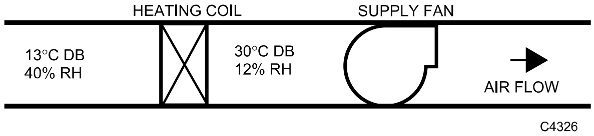

Fig. 10. Fan System with Heating Coil.

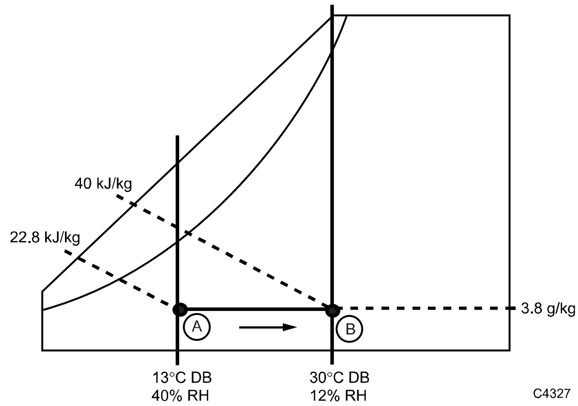

Fig. 11.

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.

40.0 – 22.8 = 17.2 kilojoules per kilogram 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 32°C to 21°C 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 21°C cannot hold as much moisture as air at 32°C. Consequently, the same amount of moisture results in a higher percentage relative humidity at 21°C than at 32°C. Calculate the total heat removed as follows:

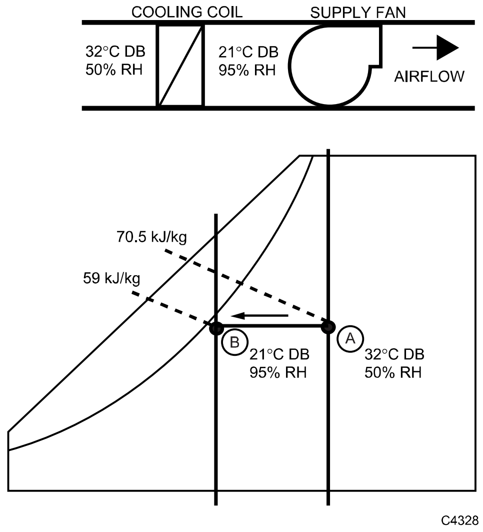

Fig. 12.

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

70.5 – 59.0 = 11.5 kilojoules per kilogram 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 –18°C dry bulb and 75 percent rh (Point A) contains about 0.55 grams of moisture per kilogram of dry air. The 0.55 grams of moisture per kilogram of dry air is carried over to Chart No. 1 (Fig. 14) and a horizontal line (constant moisture line) is drawn.

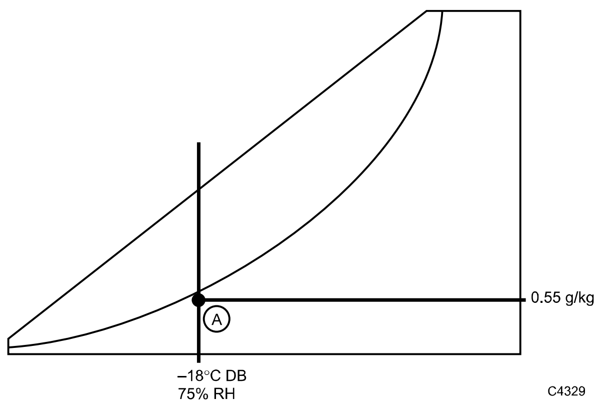

Fig. 13. Chart No. 2.

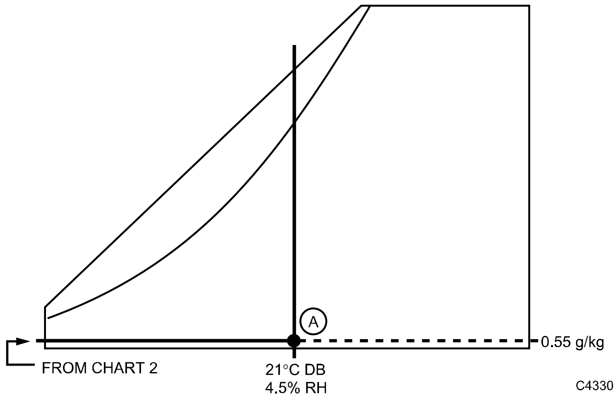

Fig. 14. Chart No. 1.

The outdoor air (–18°C at 75 percent rh) must be heated to a comfortable indoor air level. If the air is heated to 21°C, 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 0.55 grams of moisture per kilogram 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 –18°C to 21°C and then maintained at a constant 21°C.

Figure 15 provides an example of raising the relative humidity by adding moisture to the air. Assume this example represents a room that is 9 by 12 meters with an 2.5 meter 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 21°C, the moisture to be added can be determined as follows:

1. The moisture content required for 21°C air at 35 percent rh is 5.5 grams of moisture per kilogram of dry air.
2. The moisture content of the heated air at 21°C and 4.5 percent rh is 0.55 grams of moisture per kilogram of dry air.
3. The moisture required is:

5.5 g/kg – 0.55 g/kg = 4.95 grams of moisture per kilogram of dry air

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

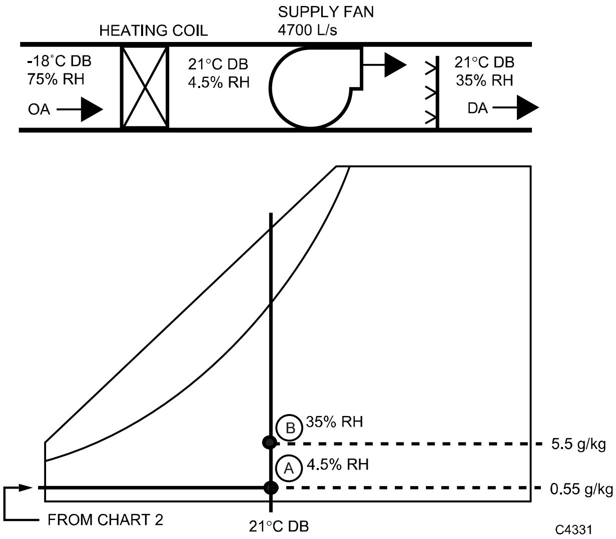

Fig. 15.

The space contains the following volume:

9m x 12m x 2.5m = 270 cubic meters

Two air changes per hour is as follows:

$2 \times 270m^3$ = 540 cubic meters per hour

or

540 ÷ (60 x 60) = 150 liters per second

This amount of air is brought into the room, heated to 21°C, and humidified. Chart No. 2 (Fig. 13) illustrates that outdoor air at –18°C has a volume of 0.712 cubic meters per kilogram. The reciprocal of this provides the density or 1.404 kilograms per cubic meter. Converting the cubic meters per hour of air to kilograms per hour provides:

$540\ m^3/hr \times 1.404\ kg/m^3$ = 758.2 kilograms of air per hour

For the space in the example, the moisture that must be added is:

758.2 kg/hr x 4.95 g/kg = 3753 grams
= 3.75 kilograms of water per hour

EXAMPLE 2:

Determine the moisture required to provide 24°C air at 50 percent rh using 10°C air at 52 percent rh.

In this example, assume that 4700 liters of air per second must be humidified. First, plot the supply air Point A, Figure 16, at 10°C and 52 percent rh. Then, establish the condition after the air is heated to 24°C 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 24°C dry-bulb temperature line (Point B).

The air at Points A and B has 4.0 grams of moisture per kilogram of air. While the moisture content remains the same after the air is heated to 24°C (Point B), the relative humidity drops from 52 percent to 21 percent. To raise the relative humidity to 50 percent at 24°C, find the new point on the chart (the intersection of the 24°C dry-bulb line and the 50 percent rh curve or Point C). The moisture content at this point is 9.3 grams of moisture per kilogram of dry air. Calculate the moisture to be added as follows:

9.3 g/kg – 4.0 g/kg = 5.3 grams of moisture per kilogram of dry air

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

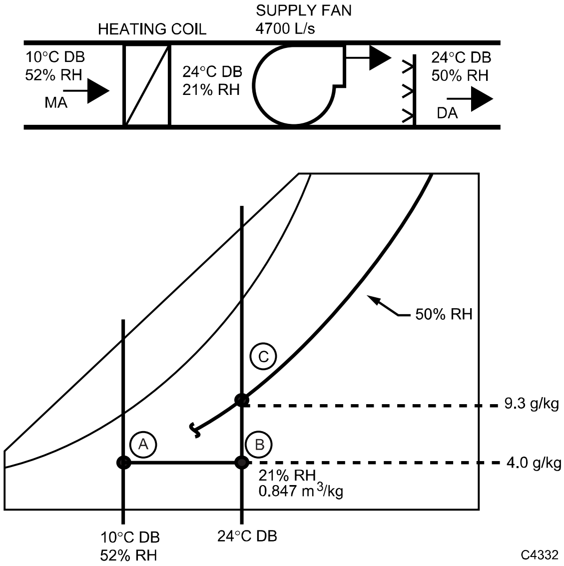

Fig. 16.

At 24°C and 21 percent relative humidity, the psychrometric chart shows that the volume of one kilogram of air is about 0.847 cubic meters. There are two ways to find the weight of the air. One way is to use the volume to find the weight. Assuming 4700 liters (4.7 m^3) per second of air:

$4.7 m^3/s \div 0.847 m^3/kg$ = 5.55 kilograms of air per second

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

$1 \div 0.847 m^3/kg$ = 1.18 kilograms per cubic meter

The weight is then:

$4.7 m^3/kg \times 1.18 kg/m^3$ = 5.55 kilograms of air per second

If each kilogram of dry air requires 5.3 grams of moisture, then the following moisture must be added:

5.55 kg/s x 5.3 g/kg = 29.4 grams of moisture per second

Thus, a humidifier must provide 105.8 kilograms of water per hour to raise the space humidity to 50 percent at 24°C.

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 100°C or higher. The enthalpy includes the heat needed to raise the water temperature from 0 to 100°C, or 419 kJ plus 2256 kJ to change the water into steam. This is a total of 2675 kJ per kilogram of water at 0 kPa (gage) 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 13 °C dry-bulb temperature (Point A) and is heated to 32 °C 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 Kilojoule per kilogram is located on the enthalpy/humidity ratio scale ($\Delta h / \Delta W$) of the nomograph. This value, 2675 kilojoules per kilogram, 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 32 to 33°C.

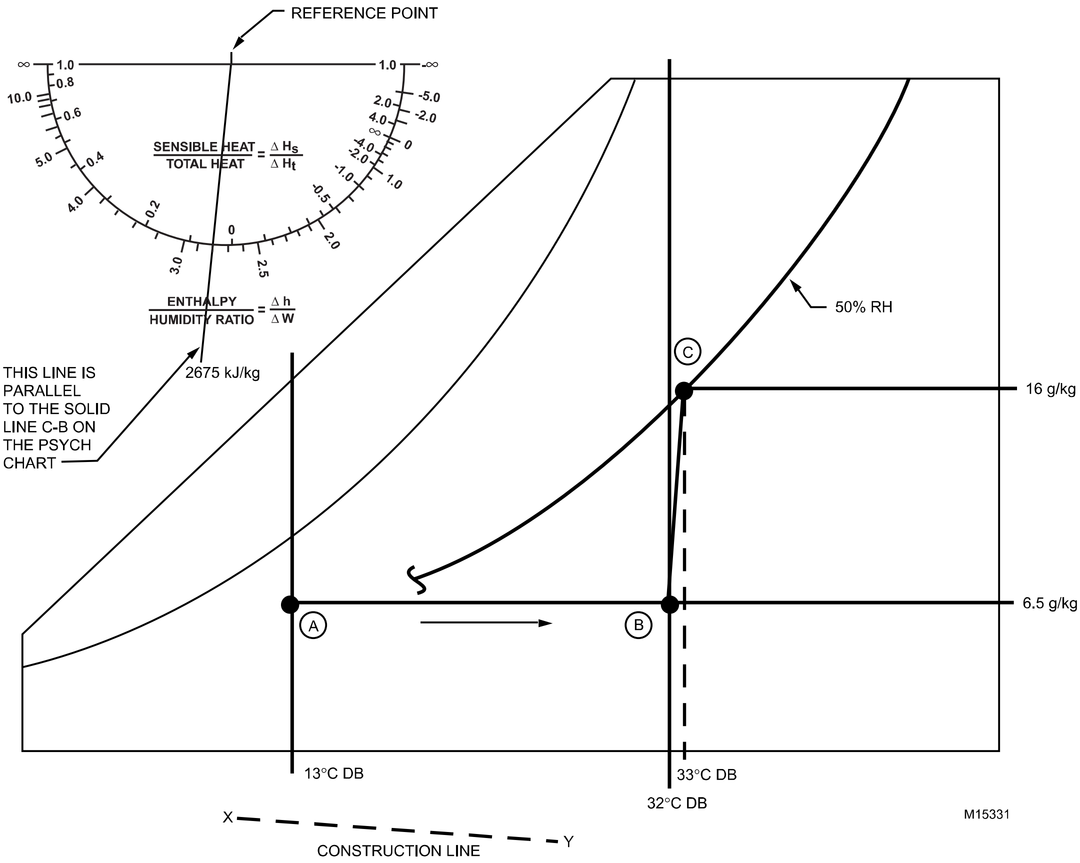
REFERENCE POINT
SENSIBLE HEAT / TOTAL HEAT = Δ Hs / Δ Ht
ENTHALPY / HUMIDITY RATIO = Δ h / Δ W
THIS LINE IS PARALLEL TO THE SOLID LINE C-B ON THE PSYCH CHART
2675 kJ/kg
50% RH
C
16 g/kg
6.5 g/kg
A
B
13°C DB
33°C DB
32°C DB
M15331
X
Y
CONSTRUCTION LINE

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:

74.5 kJ/kg – 49.0 kJ/kg = 25.5 kilojoules per kilogram of dry air

The steam raised the temperature of the air from 32°C dry bulb to 33°C 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:

74.5 kJ/kg – 49.8 kJ/kg = 24.7 kilojoules per kilogram of dry air

The remaining 0.8 kJ/kg is sensible heat. The actual moisture added per kilogram of dry air is 9.5 grams. The specific volume of the entering air at Point B is 0.874 cubic meters per kilogram.

For a 4.72 cubic meters per Second system, the weight of the air passing through is:

$4.72\ m^3/s \div 0.874\ m^3/kg$ = 5.4 kilograms per second

The weight of the moisture added is:

5.4 kg/s x 9.5 g/kg = 51.3 grams per second of moisture

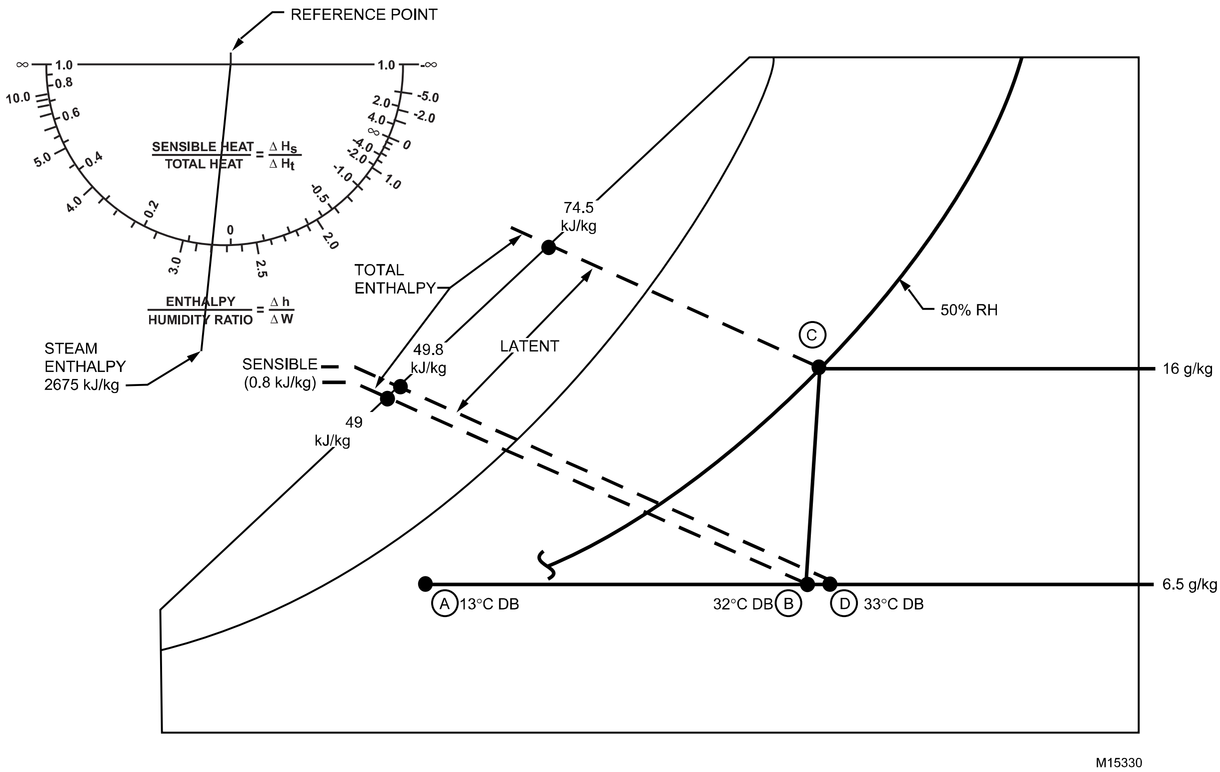

Fig. 18.

Recalling that the steam added 25.5 kilojoules per kilogram of dry air, the total heat added is:

5.4 kg/s x 25.5 kJ/kg = 137.7 kilojoules per second

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 32°C 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.

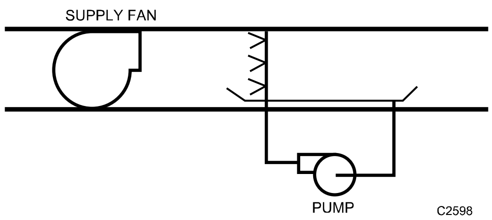

Fig. 19. Recirculating Air Washer.

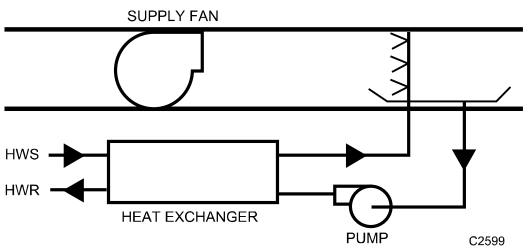

Fig. 20. Heated Air Washer.

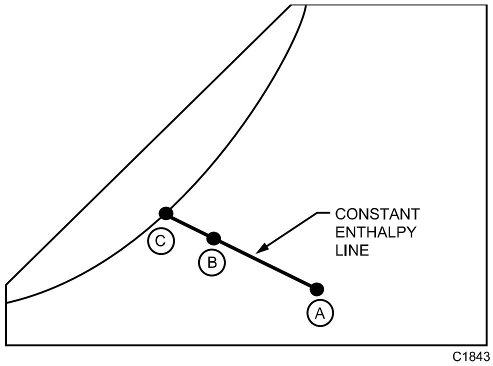

Fig. 21.

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.

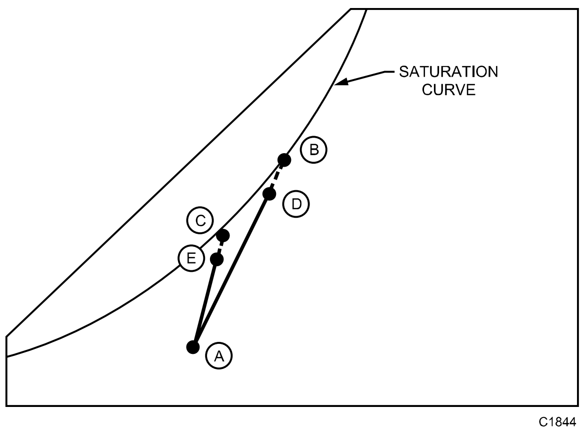

Fig. 22.

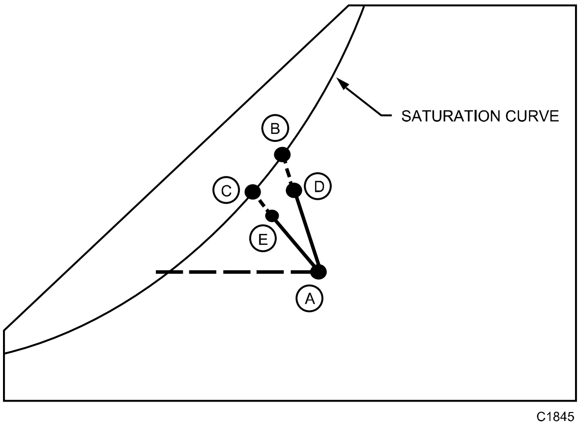

Fig. 23.

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 0 and 100°C are so close. The enthalpy of water at 0°C is zero and at 100°C it is 419 kilojoules per kilogram. If air at Point A (Fig. 24) is humidified by 100°C water, the process follows a line parallel to line C-D and the 26°C 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 0°C and 100°C 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.

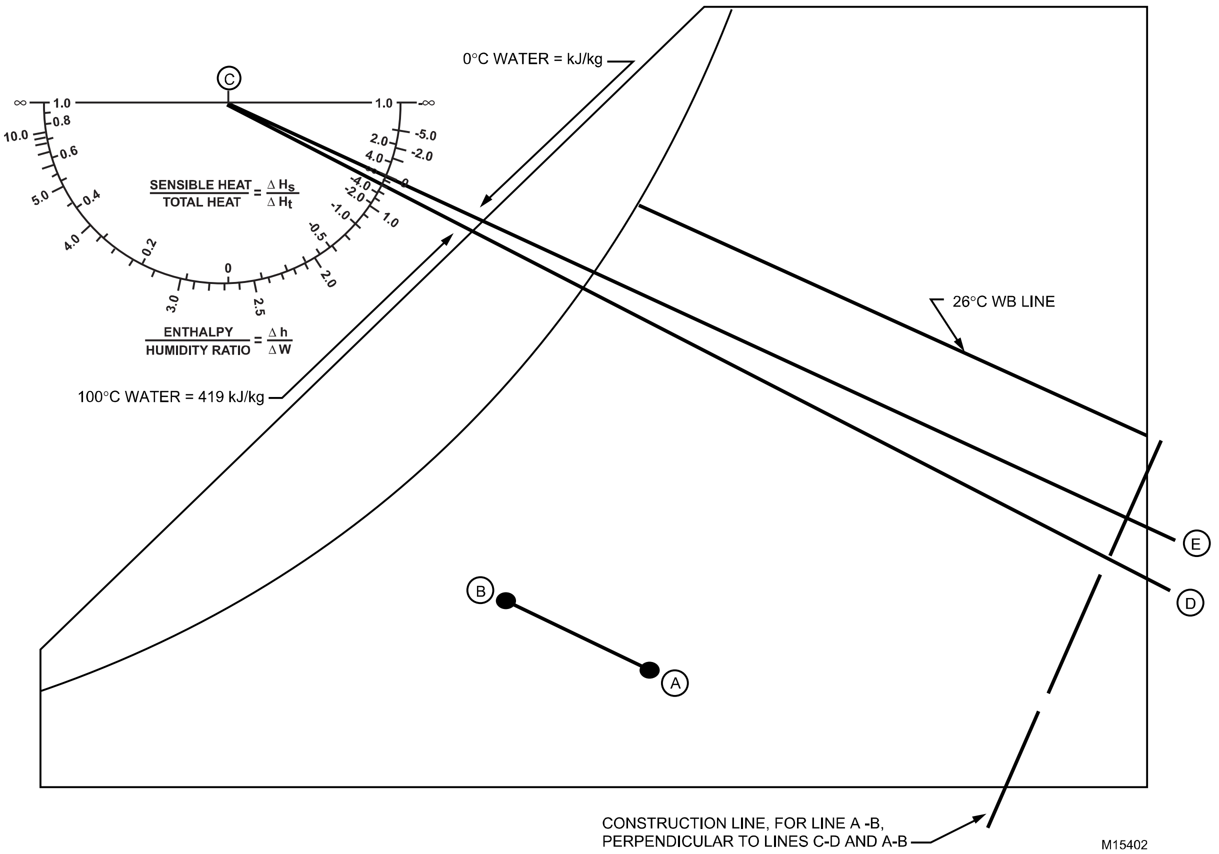

Fig. 24. Psychrometric Chart Showing Line A–B Parallel to Line C–D.

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.

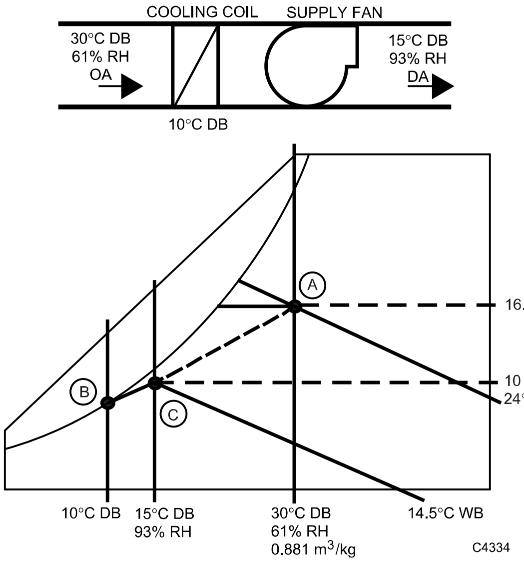

Fig. 25.

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 kilogram of dry air can be read on the humidity ratio scale and is determined as follows:

1. The entering air condition is 30°C dry bulb and 61 percent rh (Point A). The moisture content is 16.5 grams of moisture per kilogram of dry air.
2. The leaving air condition is 15°C dry bulb and 93 percent rh (Point C). The moisture content is 10 grams of moisture per kilogram of dry air.
3. The moisture removed is:

   16.5 g/kg – 10 g/kg = 6.5 grams of moisture per kilogram of dry air

The volume of air per kilogram at 30°C dry bulb and 24°C wet bulb (Point A) is 0.881 cubic meters per kilogram of dry air. If 2.5 cubic meters of air per second passes through the coil, the weight of the air is as follows:

$2.5\ m^3/s \div 0.881\ m3/kg$ = 2.84 kilograms per second

The kilograms of water removed is as follows:

2.84 kg/s x 16.5 g/kg = 46.9 grams per second

or

$$\frac{46.9\ g/s \times 60 \times 60}{1000 g/kg} = 176.0 \text{ kilograms per hou}$$

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 10°C. 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.

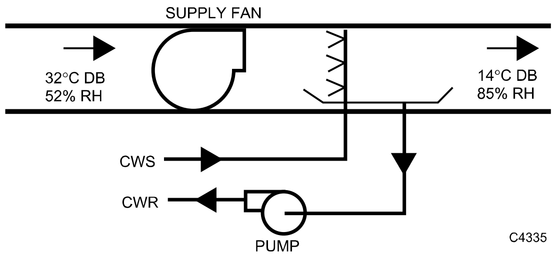

Fig. 26. Air Washer Used for Cooling and Dehumidification.

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:

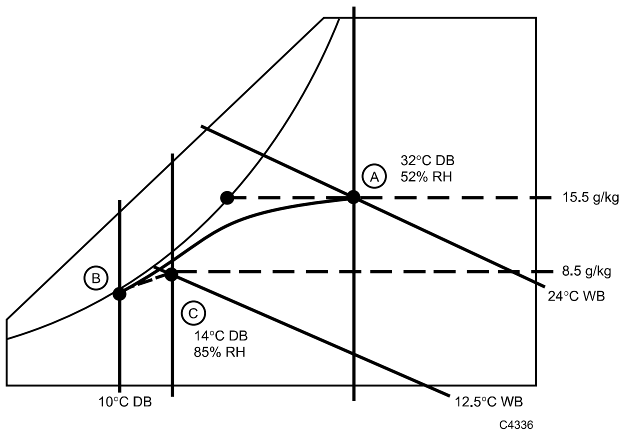

Fig. 27.

1. The entering condition air is 32°C dry bulb and 52 percent rh (Point A). The moisture content is 15.5 grams of moisture per kilogram of dry air.
2. Air that contacts the spray droplets follows the saturation curve to the spray temperature, 10°C 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 14°C dry bulb and 85 percent rh (Point C). The moisture content is 8.5 grams of moisture per kilogram of dry air.
4. The moisture removed is:

15.5 g/kg – 8.5 g/kg = 7 grams of moisture per kilogram 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.

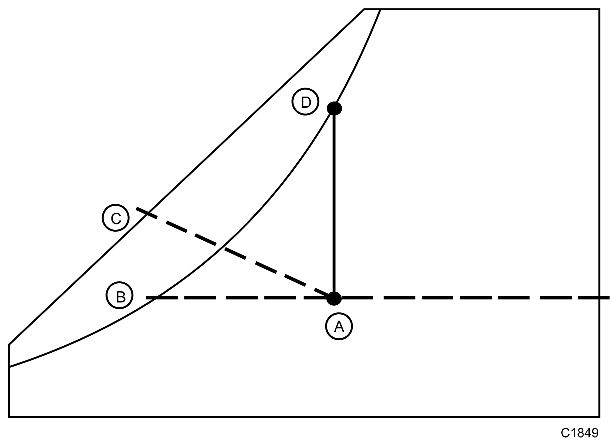

Fig. 28.

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.

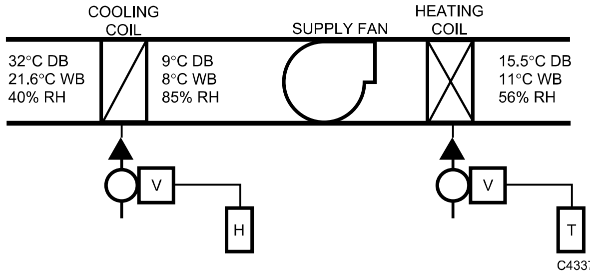

Fig. 29. Fan System with Dehumidification and Reheat.

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.

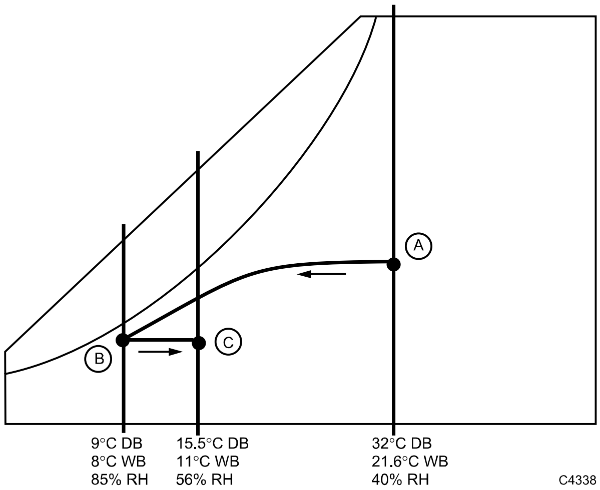

Fig. 30.

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 kilogram of dry air. Zero moisture is the bottom line of the chart.
— To find the sensible heat content of any air in kilojoules, 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 kilojoules per kilogram of dry air on the enthalpy scale.

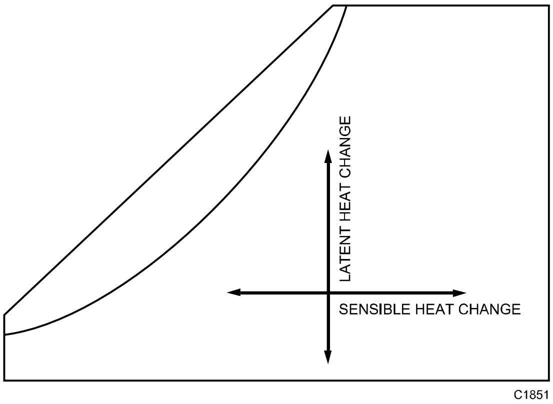

Fig. 31.

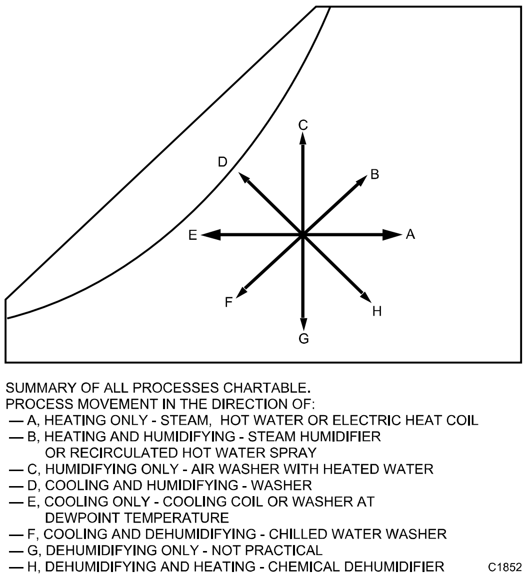

Fig. 32.

ASHRAE PSYCHROMETRIC CHARTS

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

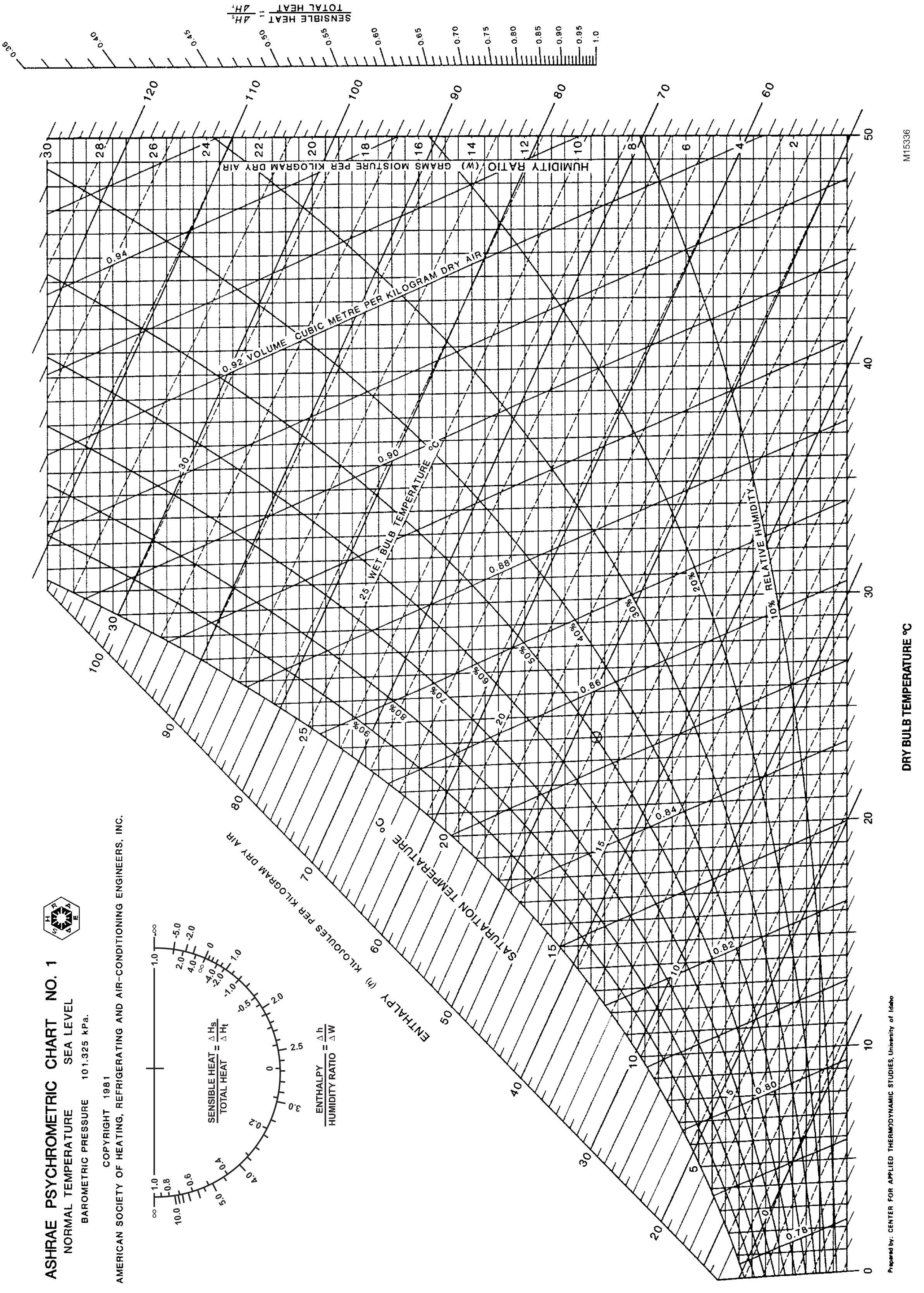

Fig. 33. ASHRAE Psychrometric Chart No. 1.

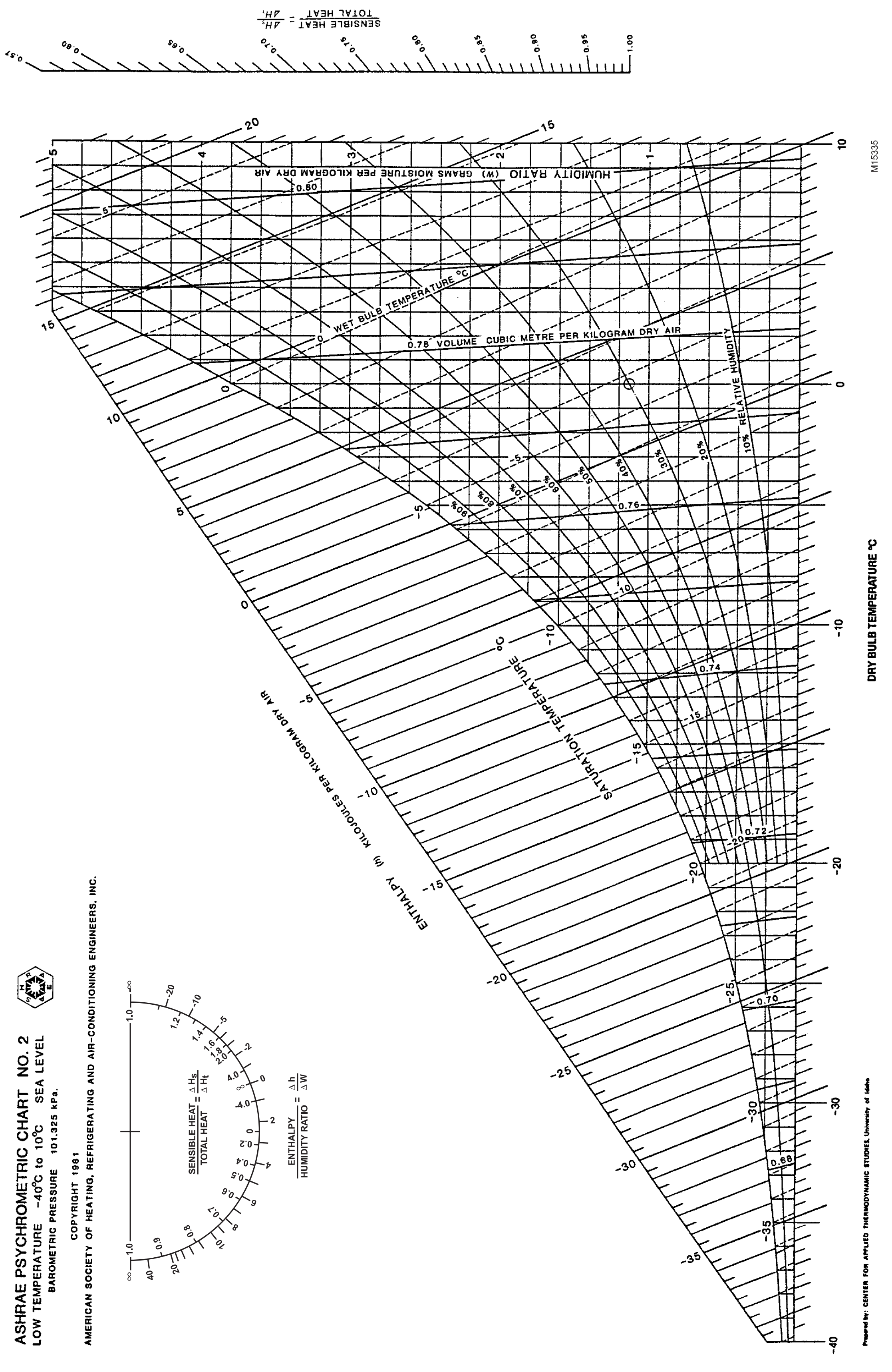

Fig. 34. ASHRAE Psychrometric Chart No. 2.