The HVACR Training Authority

THE PSYCHROMETRIC CALCULATOR

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INTRODUCTION

Problems involving changes in temperature, humidity, and other properties of air can be solved by any of three methods. The three methods are psychrometric tables, psychrometric charts, and the psychrometric calculator. As you know, tables are more accurate than charts, since the values listed often have up to three or four decimal places. Even using temperatures in 1°F increments, however, you may have to make estimates when working with tables. If you don't want to estimate, you must interpolate, which can involve a good deal of time-consuming effort. (To interpolate, in this sense, means to perform mathematical calculations to obtain values that fall between those listed.)

Psychrometric charts are relatively simple to use, but they are also less accurate. From any given point on the chart, all other properties of air can be found.

This involves following a number of lines. The lines might be horizontal,vertical, diagonal, or curved. Accuracy depends largely on a person's ability to trace these lines carefully, and on the method of interpolation used.

This chapter explains the use of a psychrometric calculator. If any two properties are given, you can use the psychrometric calculator to obtain all other properties with reasonable accuracy. Occasionally you will have to make some visual interpolations (estimates), but no calculations are required, because the calculator does the work for you automatically.

PROPERTIES OF THE RSES CALCULATOR

Look at the RSES psychrometric calculator included with your SAM. The various parts of the calculator are shown in Figure 1. The extended portion (A) has four scales printed on it. The first (innermost) scale shows the dry-bulb temperature, given in increments of 1°F. The second scale shows the specific volume of dry air, given in cubic feet per pound (ft^3/lb). This is completely dry air, with absolutely no moisture or water vapor present. The scale is marked in increments of 1/100 (0.01) ft^3/lb.

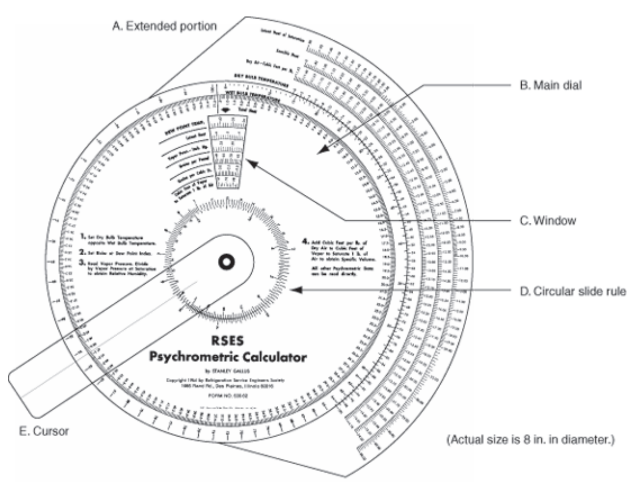


FIGURE 1. Psychrometric calculator

The third scale on the extended portion of the calculator shows sensible heat values, given in Btu per pound (Btu/lb) of air. The scale is marked in increments of 1/10 (0.10) Btu/lb. The last (outermost) scale show the latent heat of saturation, also given in Btu per pound. Note that the increments range from 1/50 to 1/2 Btu/lb. The scale changes are due to the fact that as the dry-bulb temperature of the air increases, its ability to hold moisture also increases. But this is not a proportionate relationship (it will not follow a straight line). The latent heat of saturation is the amount of heat that must be extracted from the air, when the air is completely saturated with moisture, in order to condense all water vapor present.

At the edge of the main dial (B) are two scales, one showing the wet-bulb temperature (in °F) and the other the corresponding total heat (in Btu/lb).

Through the “window” or cut-out (C) in the main dial, six different scales are visible. Beginning with the outer edge and working toward the center, the first scale shows the dew point temperature, given in 1°F increments. Next is latent heat, given in increments of 2/10 (0.2) Btu/lb. Below latent heat is vapor pressure, given in inches of mercury (in. Hg). This is pressure of water vapor that corresponds to a given dew point temperature. The scale is marked in increments of 1/100 (0.01) in. Hg.

The scales labeled *grains per pound and grains per cubic foot* show the actual amount of water present at a particular dew point temperature. There are 7,000 grains per pound, so you can find the pounds of water vapor simply by dividing 7,000 into the total grains of moisture, This represents the actual weight of water vapor, in pounds, per pound of air, or the density in pounds per cubic foot. The last (innermost) scale in the window is labeled cubic feet of vapor to saturate 1 lb of air. This shows the amount of space occupied by the water vapor alone.

The small inner circle (D) is a circular slide rule. It can be used for multiplication or division, and is equivalent to a 6-in. slide rule. Its operation is discussed later in this chapter.

Note the hairline running down the center of the transparent cursor (E). You can use the cursor to help you line up scales (read values directly below the hairline).

OPERATIONS

GIVEN DRY-BULB AND WET-BULB TEMPERATURES

Let’s look at an example to find out how to use the calculator. Design summer conditions for the Chicago area are 95°F db and 75°F wb. Turn the wheel until these two values are lined up with each other. Place the cursor directly over them, as shown in Figure 2. You should obtain the following readings:

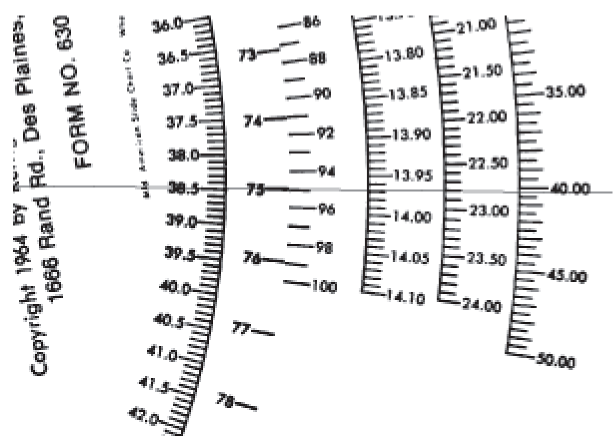


FIGURE 2. Lining up dry-bulb and wet-bulb temperatures

Total heat . . . . 38.5 Btu/lb

Wet-bulb temperature . . . . . . 75°F

Dry-bulb temperature. . . . . . . 95°F

Dry air . . . . 13.97 ft^3 /lb

Sensible heat . . . . 22.80 Btu/lb

Latent heat of saturation . . . . 40.25 Btu/lb

Without moving the main dial, place the cursor directly over the heavy black arrow that points to the window, as shown in Figure 3. The following values can be read in the window:

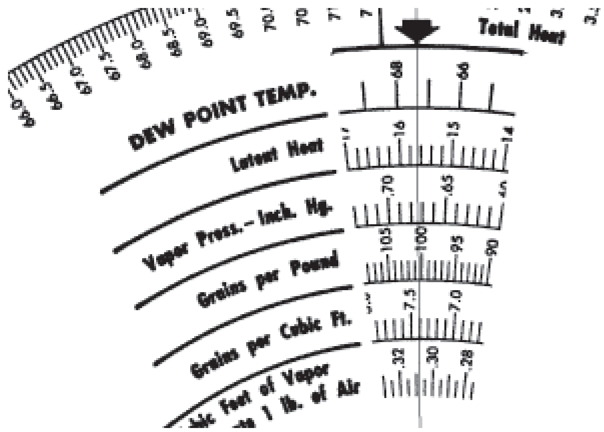


FIGURE 3. Cursor lined up with window arrow

Dew point temperature . . . . . 67.3°F

Latent heat . . . . 15.70 Btu/lb

Vapor pressure . . . . 0.675 in. Hg

Grains per pound. 100.5

Grains per cubic foot 7.4

Vapor to saturate 1 lb of air . . 0.308 ft^3

You must know one other property in order to determine relative humidity. That property is the vapor pressure at saturation. To find the vapor pressure at saturation, move the main dial until the dry-bulb temperature (95°F) appears in the window on the dew point scale. Use the cursor to line up the temperature with the heavy black arrow, as shown in Figure 4, and then read the vapor pressure. Vapor pressure at saturation equals 1.66 in. Hg.

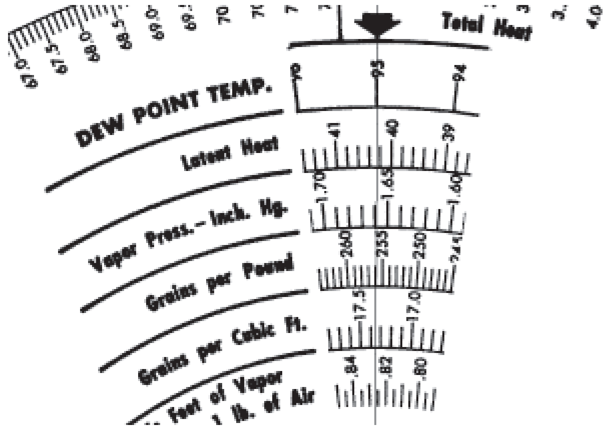


FIGURE 4. Reading vapor pressure

Putting the values that you have found for heat in the proper order, you have:

Wet-bulb 75°F		38.5 Btu/lb (total heat)
Dry-bulb 95°F	−	22.8 Btu/lb (sensible heat)
Dew Point 67.3°F	=	15.7 Btu/lb (latent heat)

(Recall that sensible heat plus latent heat equals total heat.) Continuing with the values for specific volume:

Dry air		13.97 ft^3/lb
Water vapor	−	0.308 ft^3/lb
Secific volume of the mixture	=	14.278 ft^3/lb

Depending on the source of reference, you can calculate relative humidity in three different ways, as follows:

$$\frac{\text{Vapor pressure} \quad 0.675 \text{ in. Hg}}{\text{Vapor pressure at saturation} \quad 1.660 \text{ in. Hg}} = 40\%\text{RH}$$

$$\frac{\text{Grains/lb} \quad 100.5}{\text{Grains/lb at saturation} \quad 256.0} = 39\%\text{RH}$$

$$\frac{\text{Latent heat} \quad 15.70 \text{ Btu/lb}}{\text{Latent heat at saturation} \quad 40.25 \text{ Btu/lb}} = 39\%\text{RH}$$

Note that in each of these methods, the saturated condition is always divided into the actual condition. The results are not too far from each other, but the first method (vapor pressure) is generally accepted. It will be used in this chapter for the sake of consistency.

GIVEN THE DRY-BULB AND DEW POINT TEMPERATURES

Generally, dry-bulb and wet-bulb temperatures will be known, since they are the easiest to obtain inexpensively. A simple sling psychrometer reads dry-bulb and wet-bulb temperatures directly. However, it is possible to use a dew point indicator to find dew point temperatures. Let's look at the procedure for reading values from given dry-bulb and dew point temperatures. Assume, for example, that you have a given dry-bulb temperature of 90°F, and a given dew point temperature of 70°F.

Use the cursor to line up 70°F on the dew point scale with the heavy black arrow above the window, as shown in Figure 5. When they are directly in line, read all the properties below. Now, without shifting the main dial, move the cursor over the dry-bulb temperature of 90°F, as shown in Figure 6. The wet-bulb temperature is approximately 75.4°F. All other properties can be read directly.

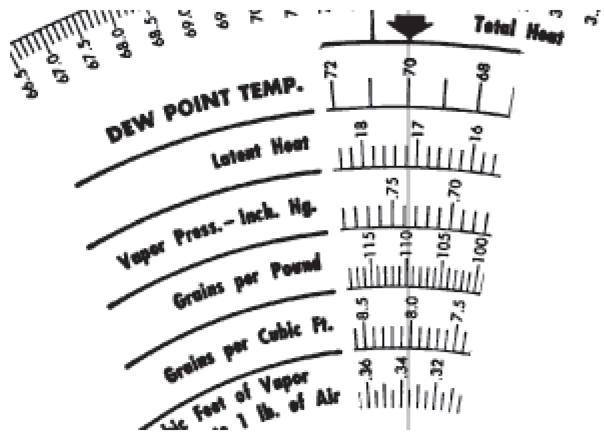


FIGURE 5. Lining up dew point temperature with window arrow

FIGURE 6. Cursor over dry-bulb temperature lines up with correct wet-bulb temperature

GIVEN DRY-BULB TEMPERATURE AND RELATIVE HUMIDITY

Assume that you have a given dry-bulb temperature of 80°F, and a given relative humidity of 50%. First, turn the main dial until the dry-bulb temperature (80°F) appears in the window on the dew point scale. Use the cursor to line up the temperature with the heavy black arrow, as shown in Figure 7A. You should obtain a vapor pressure reading of 1.03 in. Hg. Multiply the vapor pressure at saturation by the relative humidity to find the actual vapor pressure (1.03 in. Hg x 0.50 = 0.515 in. Hg). Next locate 0.515 in. Hg on the vapor pressure scale. Line it up with the arrow above the window, as shown in Figure 7B, and read the dew point temperature, which is 59.8°F. Now you can proceed as if the dry-bulb and dew point temperatures were given.

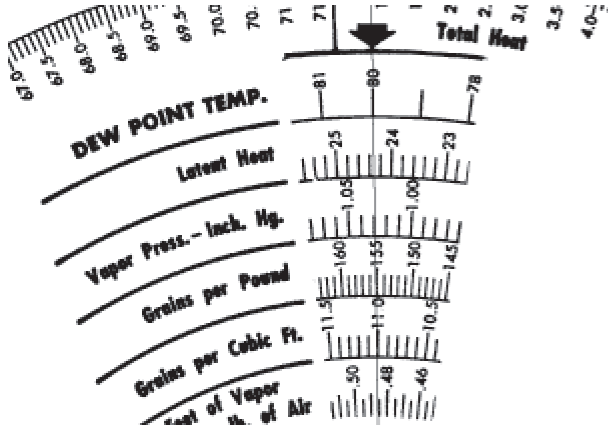


FIGURE 7A. Reading vapor pressure

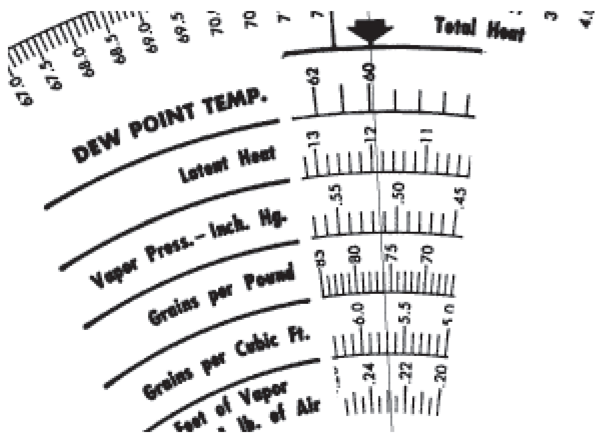


FIGURE 7B. Reading dew point temperature

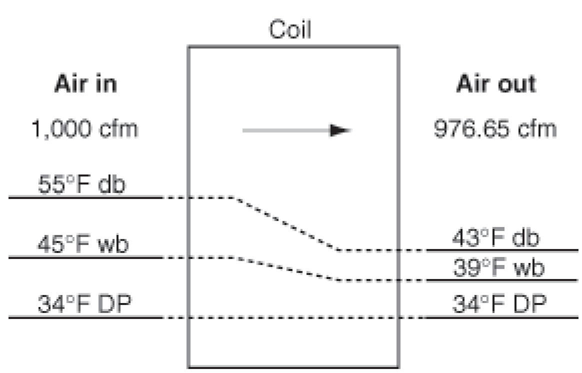
PSYCHROMETRIC CALCULATIONS

SENSIBLE COOLING ALONE

When humidity is not involved, but sensible cooling is required, the dry-bulb temperature changes while the dew point temperature remains constant. In any problem that deals only with sensible cooling, the total weight in pounds remains constant, but the cfm changes (since air contracts as it is cooled).

EXAMPLE.

The following example gives the results of sensible cooling only. (The abbreviation “DP” is used for dew point.)



Line up 55°F on the dry-bulb scale with 45°F on the wet-bulb scale, as shown in Figure 8, and read the following properties under the hairline indicator:

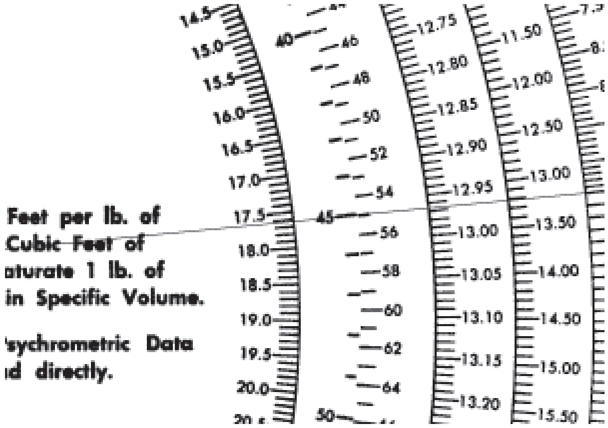


FIGURE 8. Lining up dry-bulb and wet-bulb temperatures

17.57 Btu/lb total heat

13.17 Btu/lb sensible heat

4.4 Btu/lb latent heat (17.57 – 13.17)

12.965 ft^3 /lb dry air

Without moving the main dial, swing the cursor over the arrow, as shown in Figure 9. You should obtain the following readings:

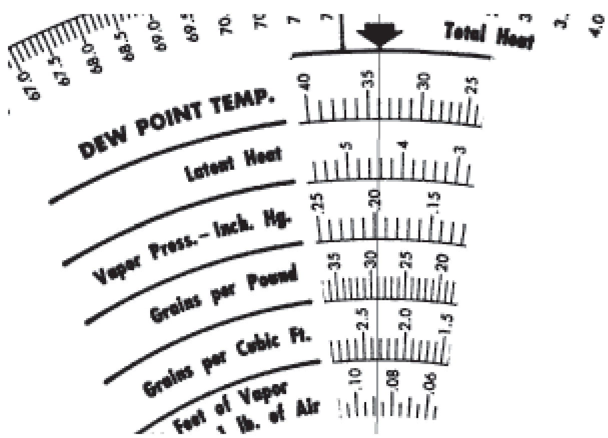


FIGURE 9. Cursor over arrow lines up with other values in window

34°F dew point

4.4 Btu/lb latent heat

0.085 ft^3 water vapor to saturate 1 lb of air

Adding, you get the specific volume of the mixture:

$$\begin{array}{ll} & 12.965\ ft^3/lb\ dry\ air \\ + & \underline{0.085\ ft^3/lb\ water\ vapor} \\ = & 13.050\ ft^3/lb\ specific\ volume\ of\ the\ mixture \end{array}$$

Divide this figure into 1,000 cfm to find out how much air is entering the coil:

$$\frac{1{,}000\ cfm}{13.05\ ft^3/lb} = 76.6 lb/min\ air\ entering\ the\ coil$$

Without moving the main dial, move the cursor to align 43°F db and 39°F wb, as shown in Figure 10. You should read the following:

FIGURE 10. Moving cursor only to find heat values

14.75 Btu/lb total heat

10.35 Btu/lb sensible heat

4.40 Btu/lb latent heat (14.75 – 10.35)

12.66 ft^3 /lb dry air

Since the cubic feet of water vapor (0.085) remains constant at the same dew point temperature, the specific volume of the outlet mixture is 12. 745 ft^3 /lb (12.66 dry air + 0.085 water vapor). Now multiplying, you get:

12.75 ft^3 /lb x 76.6 lb/min = 976.65 cfm

Note that the original 1,000 cfm has contracted to 976.65 cfm during the cooling process.

The amount of heat removed per minute can also be calculated. The total heat removed is:

$$\begin{array}{rl} & 17.57 \text{ Btu/lb air in} \\ - & \underline{14.75 \text{ Btu/lb air out}} \\ = & 2.82 \text{ Btu/lb heat removed} \end{array}$$

2.82 Btu/lb x 76.6 lb/min = 216 Btu/min total heat removed

The sensible heat removed is:

$$\begin{array}{rl} & 13.17 \text{ Btu/lb air in} \\ - & \underline{10.35 \text{ Btu/lb air out}} \\ = & 2.82 \text{ Btu/lb heat removed} \end{array}$$

2.82 Btu/lb x 76.6 lb/min = 216 Btu/min total heat removed

Note that in this case the total heat removed is the same as the sensible heat removed, since no latent heat was involved.

One change that did occur was in relative humidity. This can be shown as follows. Turn the wheel until the dry-bulb temperature of the incoming air (55°F) appears on the dew point scale. Use the cursor to line up the temperature with the heavy black arrow and read the vapor pressure in the window (approximately 0.433 in. Hg). Now do the same for the given dew point temperature of 34°F. The vapor pressure of the incoming air at saturation would be 0.195 in. Hg. You can solve for relative humidity by dividing:

$$\frac{0.195 \text{ in. Hg}}{0.433 \text{ in. Hg}} = 45\% \text{ RH(air in)}$$

Due to constant latent heat, the actual vapor pressure remains constant at 0.195 in. Hg. Use the psychrometric calculator to find the saturated vapor pressure of the leaving air at a dry-bulb temperature of 43°F (0.278 in. Hg). Thus you have:

$$\frac{0.195 \text{ in. Hg}}{0.278 \text{ in. Hg}} = 70\% \text{ RH(air out)}$$

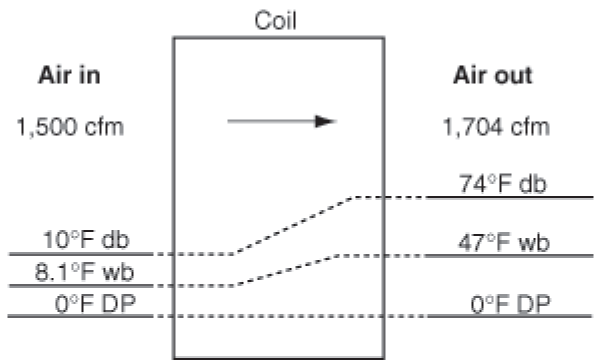
Sensible cooling alone always increases the relative humidity of the air leaving the coil, since it lowers the moisture-holding ability of the air.

SENSIBLE HEATING ALONE

As with sensible cooling, the latent heat content remains constant in situations that involve sensible heating only. Thus, the dew point temperature also remains unchanged. Solving a problem for sensible heating alone is essentially the same as solving a problem for sensible cooling alone, but in reverse. Sensible heating alone applies primarily to steam or hot water heating, or to any other system, domestic or commercial, in which no water vapor is added.

EXAMPLE.

An interesting problem is one in which 100% outdoor air is brought in and heated by a steam, hot water, or electrical heating coil. Look at the values shown below:



First, line up 0°F on the dew point scale with the arrow and the hairline cursor, as shown in Figure 11. At this point, you should read the following properties:

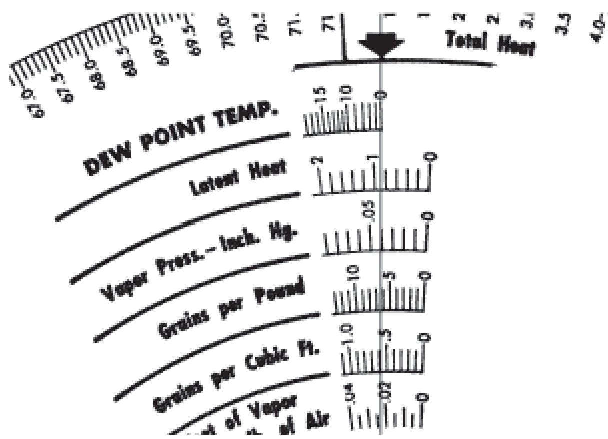


FIGURE 11. Lining up dew point temperature to read other values in window

0.85 Btu/lb latent heat

0.037 in. Hg vapor pressure

0.015 ft^3 to saturate 1 lb of air

Now, without moving the main dial, move the cursor over 10°F on the dry-bulb temperature scale, as shown in Figure 12. The wet-bulb temperature is 8.1°F.

FIGURE 12. Finding "air in" values

The other properties are:

$$\begin{array}{rl} & 3.23 \text{ Btu/lb total heat} \\ - & \underline{2.38 \text{ Btu/lb}} \text{ sensible heat} \\ = & 0.85 \text{ Btu/lb latent heat} \end{array}$$

$$\begin{array}{rl} & 11.83 \text{ ft}^3\text{/lb dry air} \\ + & \underline{0.015 \text{ ft}^3\text{/lb}} \text{ water vapor} \\ = & 11.845 \text{ ft}^3\text{/lb specific volume} \end{array}$$

$$\frac{1{,}500 \text{ cfm}}{11.845 \text{ ft}^3\text{/lb}} = 126.6 \text{ lb/min}$$

Keep the dew point in line with the arrow, and move the cursor over the dry-bulb temperature of the leaving air (74°F), as shown in Figure 13. At this point, the wet-bulb temperature is approximately 47°F.

FIGURE 13. Finding "air out" values

The other properties are:

$$\begin{array}{rl} & 18.63\ \text{Btu/lb total heat} \\ - & \underline{17.78\ \text{Btu/lb}}\ \text{sensible heat} \\ = & 0.85\ \text{Btu/lb latent heat} \end{array}$$

$$\begin{array}{rl} & 13.44\ \text{ft}^3\ \text{/lb dry air} \\ + & \underline{0.017\ \text{ft}^3\ \text{/lb}}\ \text{water vapor} \\ = & 13.457\ \text{ft}^3\ \text{/lb specific volume} \end{array}$$

13.46 ft^3 /lb x 126.6 lb/min = 1,704 cfm

Notice that the original 1,500 cfm of entering air has expanded to 1,704 cfm after being heated. The amount of heat added per pound is:

$$\begin{array}{rl} & 18.63\ \text{Btu/lb total heat out} \\ - & \underline{3.23\ \text{Btu/lb}}\ \text{total heat in} \\ = & 15.40\ \text{Btu/lb total heat added} \\ \\ & 17.78\ \text{Btu/lb sensible heat out} \\ - & \underline{2.38\ \text{Btu/lb}}\ \text{sensible heat in} \\ = & 15.40\ \text{Btu/lb sensible heat added} \end{array}$$

Again, the total heat per pound is equal to the sensible heat per pound. Multiplying lb/min by Btu/lb gives you the total heat input in Btu/min:

126.6 lb/min x 15.40 Btu/lb = 1,950 Btu/min, or 117,000 Btu/hr

To find the relative humidity, divide the vapor pressure at saturation into the actual vapor pressure at the dew point temperature.

$$\frac{\text{at } 0°\text{F (dew point)} \quad 0.037\ \text{in. Hg vapor pressure}}{\text{at } 10°\text{F (saturation)} \quad 0.060\ \text{in. Hg vapor pressure}} = 61.6\%\ \text{RH (air in)}$$

$$\frac{\text{at } 0°\text{F (dew point)} \quad 0.037\ \text{in. Hg vapor pressure}}{\text{at } 74°\text{F (saturation)} \quad 0.841\ \text{in. Hg vapor pressure}} = 4.4\%\ \text{RH (air out)}$$

What happened in the above process was this: The outside air, with little moisture content, had a high relative humidity (61.6%). Why? Because at a dry-bulb temperature of 10°F, the air could not hold a great deal of water vapor--thus the low vapor pressure. Bringing this air inside (with the same low moisture content) and heating it enabled it to hold much more water vapor at saturation. The result was a higher vapor pressure. This is a normal occurrence when air infiltrates indoors during winter conditions. The air inside will be very dry, as indicated by the very low relative humidity (4.4%).

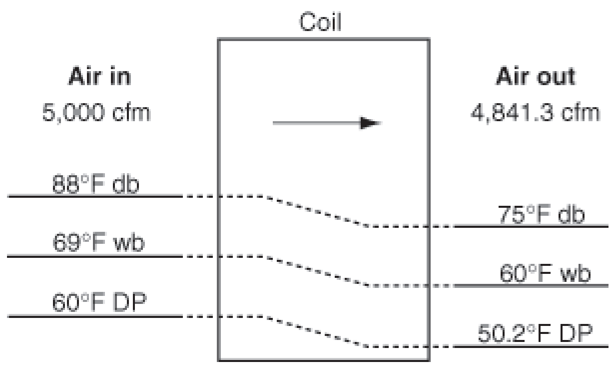
DEHUMIDIFICATION AND COOLING

The combination of dehumidification and cooling is found in practically all residential air conditioning systems, and in most commercial systems. Mechanical refrigeration cannot dehumidify without removing sensible heat as well. For dehumidification alone, chemical desiccants must be used. *Dehumidification* is the removal of water vapor present in the air. The amount of water vapor present within an occupied zone varies, depending on the number of people present, the type of activity in which they are engaged, the condition of the outside air, the structure of the building, and the amount of infiltration. The examples discussed in this Lesson refer specifically to summer air conditioning, but controlled humidity conditions are also required in other types of applications (the storage of meat, for example, in walk-in coolers).

Water vapor can be measured in grains per cubic foot of air, grains per pound of air, inches of mercury, and latent heat content. The dew point temperature is an indication of the amount of water vapor present. Problems of this kind are primarily concerned with changes in dew point and dry-bulb temperatures. But in changing either one, the wet-bulb temperature will also change.

EXAMPLE.

Using the conditions given below, determine how much sensible and latent heat (in Btu per hour) and how much moisture (in gallons per hour) must be removed.



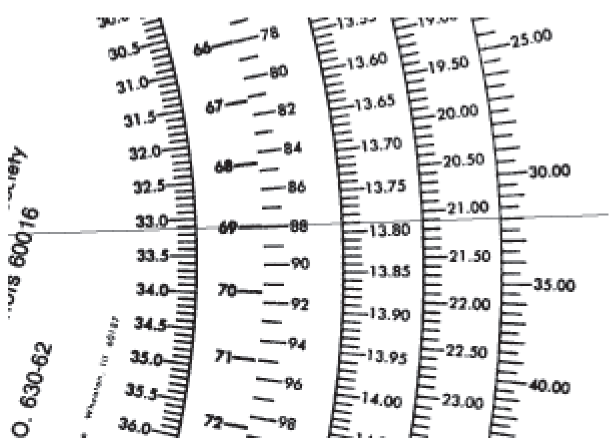


FIGURE 14a. Reading "air in" properties

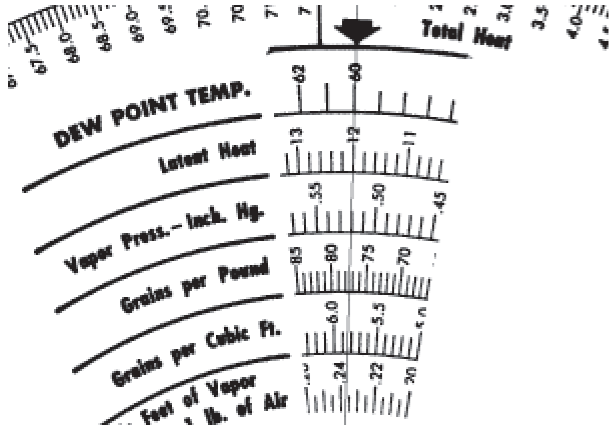


FIGURE 14b. Reading "air in" properties

In working this problem, note that the air contracts. The volume of air leaving the coil will be reduced. The total weight will also decrease, due to the removal of water vapor. First, find all the properties of the air entering and leaving the coil. As shown in Figures 14 and 15, you should obtain the following readings:

Air in	Air out
5,000 cfm	--
88°F db	75°F db
13.79 ft^3 /lb dry air	13.47 ft^3 /lb dry air
21.12 Btu/lb sensible heat	18.0 Btu/lb sensible heat
69°F wb	60°F wb
33.12 Btu/lb total heat	26.40 Btu/lb total heat
60°F DP	50.2°F DP
12.0 Btu/lb latent heat	8.28 Btu/lb latent heat
0.52 in. Hg vapor pressure	0.362 in. Hg vapor pressure
77 grains/lb	53.7 grains/lb.
5.8 grains/ft^3	4.12 grains/ft^3
0.235 ft^3 to saturate 1 lb of air	0.16 ft^3 to saturate 1 lb of air
1.33 in. Hg vapor pressure,	0.870 in. Hg vapor pressure,
saturation	saturation

FIGURE 15a. Reading "air out" properties

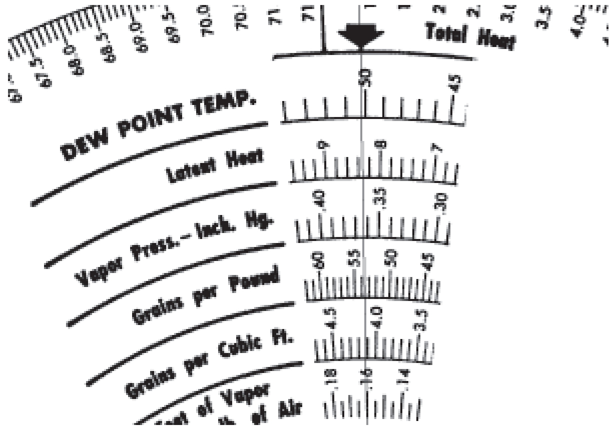


FIGURE 15b. Reading "air out" properties

To find relative humidity:

$$\text{Air in } \frac{0.52 \text{ in. Hg vapor pressure at } 60°F \text{ DP}}{1.33 \text{ in. Hg vapor pressure at saturation}} = 39\% \text{ RH}$$

$$\text{Air out } \frac{0.362 \text{ in. Hg vapor pressure at } 50.2°F \text{ DP}}{0.870 \text{ in. Hg vapor pressure at saturation}} = 41.5\% \text{ RH}$$

Note that even though moisture was removed, relative humidity increased.

$$\begin{array}{rl} & 13.79 \text{ ft}^3/\text{lb dry air} \\ + & \underline{0.235 \text{ ft}^3/\text{lb water vapor}} \\ = & 14.025 \text{ ft}^3/\text{lb specific volume} \end{array}$$

Find the pounds of air entering the coil per minute by dividing the cfm by the specific volume:

$$\frac{5{,}000 \text{ cfm}}{14.025 \text{ ft}^3/\text{lb}} = 356.5 \text{ lb/min}$$

The amount of moisture removed equals:

$$\begin{array}{lrl} \text{Air in} & & 77 \text{ grains/lb} \\ \text{Air out} & - & \underline{53.7 \text{ grains/lb}} \\ & = & 23.3 \text{ grains/lb removed} \end{array}$$

23.3 grains/lb x 356.5 lb/min = 8,306 grains/min

$$\frac{8{,}306 \text{ grains/min}}{7{,}000 \text{ grains/lb}} = 1.19 \text{ lb/min}$$

To find the amount of water removed in gallons per hour:

$$\frac{1.19 \text{ lb/min} \times 60 \text{ min/hr}}{8.33 \text{ lb/gal}} = 8.6 \text{ gal/hr}$$

The amount of sensible heat removed is:

$$\begin{array}{lrl} \text{Air in} & & 21.12 \text{ Btu/lb} \\ \text{Air out} & - & \underline{18.00 \text{ Btu/lb}} \\ & = & 3.12 \text{ Btu/lb sensible heat removed} \end{array}$$

3.12 Btu/lb x 356.5 lb/min = 1,112 Btu/min sensible heat

The cfm of air leaving the coil has changed. Part of the air has contracted due to the drop in temperature, and some of the water vapor has condensed. The water vapor amounts to only 1.2 lb/min condensed, so for all practical purposes the total weight of the air remains unchanged.

To determine the cfm of the air leaving the coil, multiply the specific volume by pounds of air per minute minus the 1.2 lb/min of condensed water:

$$13.63 \text{ ft}^3\text{/lb} \times (356.5 \text{ lb/min} - 1.2 \text{ lb/min condensed water}) = 4{,}842.7 \text{ cfm air out}$$

$$\begin{array}{lrl} \text{Air in} & & 5{,}000 \text{ cfm} \\ \text{Air out} & - & \underline{4{,}843 \text{ cfm}} \\ & = & 157 \text{ cfm (air contracted and water vapor condensed)} \end{array}$$

The amount of latent heat removed is:

$$\begin{array}{lrl} \text{Air in} & & 12.00 \text{ Btu/lb} \\ \text{Air out} & - & \underline{8.28 \text{ Btu/lb}} \\ & = & 3.72 \text{ Btu/lb latent heat removed} \end{array}$$

$$3.72 \text{ Btu/lb} \times 356.5 \text{ lb/min} = 1{,}326.2 \text{ Btu/min latent heat removed}$$

Adding, you get:

$$\begin{array}{l} \ \ \ 1{,}112 \text{ Btu / min sensible heat removed} \\ -\ \underline{1{,}326 \text{ Btu / min}} \text{ latent heat removed} \\ =\ 2{,}438 \text{ Btu/min total heat removed} \end{array}$$

$$\frac{2{,}438 \text{ Btu / min}}{200 \text{ Btu / min / ton}} = 12.19 \text{ tons}$$

HUMIDIFICATION AND HEATING

Most applications that involve simultaneous humidification and heating occur during the heating season. The control of humidity requires that moisture be added or taken away at a given rate. A vapor barrier is of the utmost importance in controlling humidity.

Be aware that as moisture is added to a room, the amount of moisture that leaves depends directly on the vapor pressure differential, and on the quality of the vapor barrier. According to Dalton's Law of partial pressures, water vapor acts as an individual gas. That is, it exerts its own force depending on the difference in vapor pressure--between one side of a dividing wall and the other, for example. The difference in water vapor pressure between two sides of a wall tends to equalize. Vapor barriers are used in wall construction to retard this process.

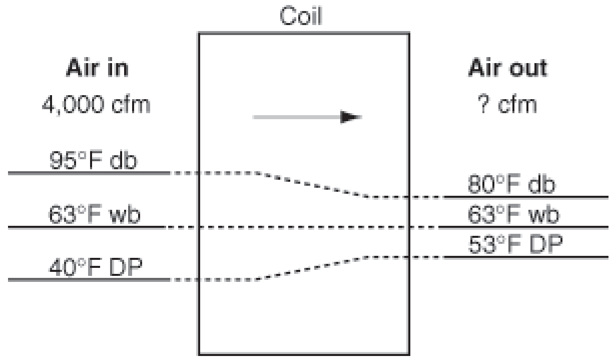
If the rate of the water vapor diffusing into a structure is greater than that of the water vapor leaving the structure, then the overall humidity of the conditioned space will increase. Conversely, if more moisture is being lost to the outside than is being gained from the outside, then the overall humidity of the conditioned space will decrease.

Problems involving humidification and heating are solved in exactly the same way as those involving dehumidification and cooling, but in reverse. For this reason, no examples of problems involving humidification and heating are shown here. If you want further practice, look at the last problem involving dehumidification and cooling. To apply it to humidification and heating, simply take the properties of air leaving the coil and use them as the properties of air entering the coil. The same rules apply, even though you are working the problem "in reverse." It is the change in conditions in which you are interested.

ADIABATIC COOLING (EVAPORATIVE COOLING)

In evaporative cooling, a pump circulates water from a pan to a spray header. The spray distributes water evenly over a matted or finned surface. The surface is wetted and air is passed through. Generally, this type of system is used where the air is warm and dry. As air is forced past the wetted surface, a small amount of water is vaporized. This increases the latent heat content of the air. The heat used to vaporize water from the wetted surface comes from the sensible heat content of the air itself. It is used to effect a change of state. As a direct result of a loss in the sensible heat content, the dry-bulb temperature of the air drops.

A typical problem involving "adiabatic" cooling is given below.



Notice that the dry-bulb temperature drops 15°F and the dew point temperature increases 13°F, but the wet-bulb temperature remains constant. Sensible heat loss, which causes the drop in dry-bulb temperature, is used to vaporize some of the water, thus increasing the latent heat in exactly the same proportion. As a result, there is no loss or gain of total heat. There is only a heat exchange. The term *adiabatic* is used to describe a process in which there is neither a loss nor a gain in the total heat content.

In order to find the relative humidity of the air (in and out), the amount of water vaporized, and the cfm and lb/min of the air leaving the coil, the first step is to use the calculator to determine all known conditions. As shown in Figure 16 below and Figure 17, you should obtain the following readings:

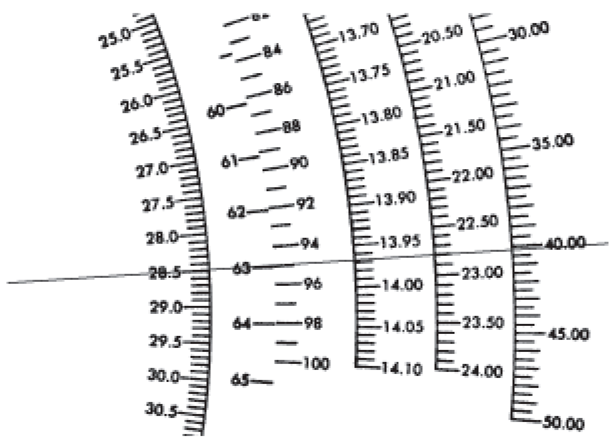


FIGURE 16a. Reading "air in" properties

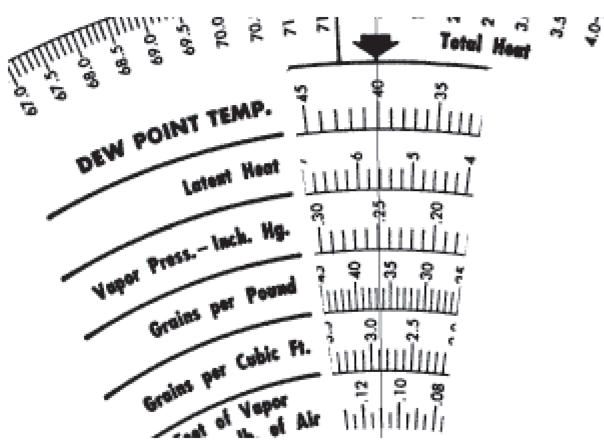


FIGURE 16b. Reading "air in" properties

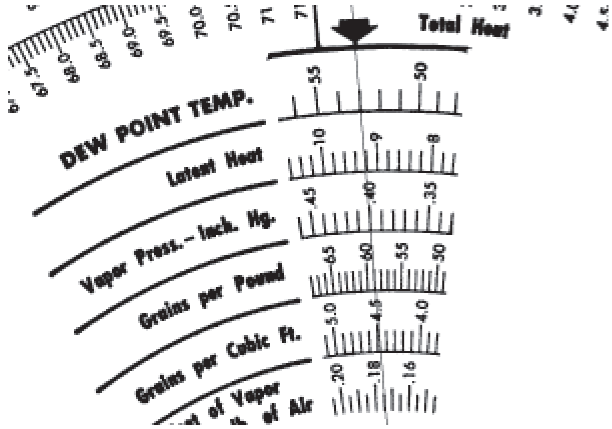


FIGURE 17a. Reading "air out" properties

FIGURE 17b. Reading "air out" properties

Air in	Air out
4,000 cfm	--
95°F db	80°F db
13.97 ft^3 /lb dry air	13.59 ft^3 /lb dry air
22.8 Btu/lb sensible heat	19.2 Btu/lb sensible heat
63°F wb	63°F wb
28.5 Btu/lb total heat	28.5 Btu/lb total heat
40°F DP	53°F DP
5.6 Btu/lb latent heat	9.21 Btu/lb latent heat
0.25 in. Hg vapor pressure	0.40 in. Hg vapor pressure
36 grains/lb	60 grains/lb
2.85 grains/ft^3	4.6 grains/ft^3
0.11 ft^3 to saturate 1 lb of air	0.18 ft^3 to saturate 1 lb of air
1.66 in. Hg vapor pressure, saturation	1.03 in Hg vapor pressure, saturation

To find the relative humidity:

$$\text{Air in} \quad \frac{0.25 \text{ in. Hg vapor pressure}}{1.66 \text{ in. Hg vapor pressure at saturation}} = 15\% \text{ RH}$$

$$\text{Air out} \quad \frac{0.40 \text{ in. Hg vapor pressure}}{1.03 \text{ in. Hg vapor pressure at saturation}} = 39\% \text{ RH}$$

To find the amount of water vaporized, first determine the pounds of air handled:

$$
\begin{aligned}
& \quad 13.97\ \text{ft}^3/\text{lb dry air} \\
& +\underline{0.11\ \text{ft}^3/\text{lb}}\ \text{water vapor} \\
& = 14.08\ \text{ft}^3/\text{lb specific volume}
\end{aligned}
$$

$$\frac{4{,}000\ \text{cfm}}{14.08\ \text{ft}^3/\text{lb}} = 284\ \text{lb}/\text{min}$$

The amount of water vapor added is determined as follows:

$$
\begin{array}{lll}
\text{Air out, 53°F DP} & & 60\ \text{grains}/\text{lb} \\
\text{Air in, 40°F DP} & - & \underline{36\ \text{grains}/\text{lb}} \\
\text{Water added} & = & 24\ \text{grains}/\text{lb}
\end{array}
$$

$$24\ \text{grains}/\text{lb} \times 284\ \text{lb}/\text{min} = 6{,}816\ \text{grains}/\text{min}$$

$$\frac{6{,}816\ \text{grains}/\text{min}}{7{,}000\ \text{grains}/\text{lb}} = 0.97\ \text{lb}/\text{min}$$

$$\frac{0.97\ \text{lb}/\text{min} \times 60\ \text{min}/\text{hr}}{8.33\ \text{lb}/\text{gal}} = 6.99\ \text{gal}/\text{hr added}$$

The cfm of the air leaving the coil equals:

$$
\begin{aligned}
& \quad 13.59\ \text{ft}^3/\text{lb dry air} \\
& +\underline{0.18\ \text{ft}^3/\text{lb}}\ \text{water vapor} \\
& = 13.77\ \text{ft}^3/\text{lb specific volume}
\end{aligned}
$$

$$13.77\ \text{ft}^3/\text{lb} \times 284\ \text{lb}/\text{min} = 3{,}911\ \text{cfm}$$

Next, determine the sensible heat per pound extracted and the quantity of latent heat per pound added:

$$
\begin{array}{lll}
\text{Air in, 95°F db} & & 22.80\ \text{Btu}/\text{lb sensible heat} \\
\text{Air out, 80°F db} & - & \underline{19.20\ \text{Btu}/\text{lb}}\ \text{sensible heat} \\
 & = & 3.60\ \text{Btu}/\text{lb sensible heat removed} \\
 & & \\
\text{Air out, 53°F DP} & & 9.21\ \text{Btu}/\text{lb latent heat} \\
\text{Air in, 40°F DP} & - & \underline{5.60\ \text{Btu}/\text{lb}}\ \text{latent heat} \\
 & = & 3.61\ \text{Btu}/\text{lb latent heat added}
\end{array}
$$

For all practical purposes, the amount of sensible heat removed equals the latent heat added.

AIR MIXTURE CALCULATIONS

In any air conditioning system, a certain quantity of the air that enters the conditioned space is recirculated. In many areas, this is governed by city health codes. They state that a certain percentage of outside air must be provided for proper ventilation. For example, if 50% of the total cfm must be outside air, then 50% can be recirculated air. A simple problem involving these types of air mixtures is given below.

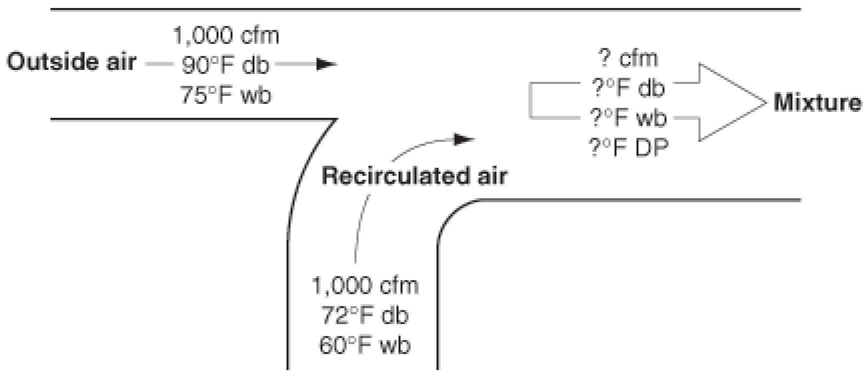


FIGURE 18a. Reading “outside air” properties

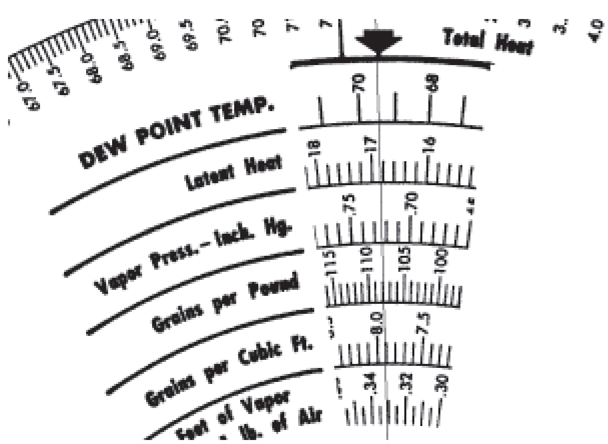


FIGURE 18b. Reading “outside air” properties

FIGURE 19a. Reading "recirculated air" properties

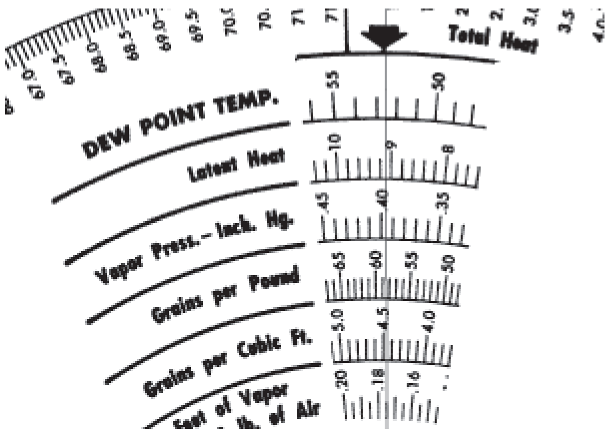


FIGURE 19b. Reading "recirculated air" properties

Use the psychrometric calculator, as shown in Figures 18 and 19, to find the following properties:

Outside air	Recirculated air
1,000 cfm	1,000 cfm
90°F db	72°F db
13.84 ft^3 /lb	13.39 ft^3 /lb
21.60 Btu/lb sensible heat	17.28 Btu/lb sensible heat
75°F wb	60°F wb
69.5°F DP	52.5°F DP
16.90 Btu/lb latent heat	9.10 Btu/lb latent heat
108 grains/lb	58.5 grains/lb
0.334 ft^3 vapor	0.176 ft^3 vapor

Now find the quantity of air in pounds per minute, first for the outside air:

$$
\begin{aligned}
& 13.84 \text{ ft}^3/\text{lb} \\
+ & \underline{0.334 \text{ ft}^3/\text{lb}} \text{ water vapor} \\
= & 14.174 \text{ ft}^3/\text{lb specific volume} \\
& \frac{1{,}000 \text{ cfm}}{14.17 \text{ ft}^3/\text{lb}} = 70.6 \text{ lb/min}
\end{aligned}
$$

Next, find the quantity of air for the recirculated air, again calculated in pounds per minute:

$$\begin{array}{l} \quad 13.39\ \text{ft}^3/\text{lb} \\ +\underline{0.176\ \text{ft}^3/\text{lb}}\ \text{water vapor} \\ =13.566\ \text{ft}^3/\text{lb specific volume} \\ \quad \dfrac{1{,}000\ \text{cfm}}{13.57\ \text{ft}^3/\text{lb}} = 73.7\ \text{lb}/\text{min} \end{array}$$

Now multiply the pounds of air per minute by the Btu per pound of sensible heat for both outside air and recirculated air. This product is the sensible heat for both quantities. Add the sensible heats together and divide by the total number of pounds per minute. This value is the average sensible heat content per pound of air for the mixture.

Refer to the sensible heat content in Btu/lb on the calculator, and read the dry-bulb temperature shown opposite. For the outside air:

70.6 lb/min x 21.60 Btu/lb = 1,525 Btu/min sensible heat

For the recirculated air:

73.7 lb/min x 17.27 Btu/lb = 1,272.8 Btu/min sensible heat

Adding the sensible heats:

$$\begin{array}{l} \quad 1{,}525.0\ \text{Btu}/\text{min} \\ +\underline{1{,}272.8\ \text{Btu}/\text{min}} \\ =2{,}797.8\ \text{Btu}/\text{min} \end{array}$$

Dividing the total sensible heat by the total number of pounds per minute:

$$\frac{2{,}797.8\ \text{Btu}/\text{min}}{73.7\ \text{lb}/\text{min} + 70.7\ \text{lb}/\text{min}} = 19.4\ \text{Btu}/\text{lb sensible heat}$$

19.4 Btu/lb sensible heat = 80.8°F db (mixed air)

You do not have to find all of the properties of the air to be mixed in order to obtain end temperatures. However, you do have to work from the sensible heat content to find the mixed dry-bulb temperature. The second property is a matter of choice. You can use the moisture content in grains per pound, for example, or the latent heat content in Btu per pound (both obtained from the dew point temperature). Or you can use the total heat content (obtained from a given wet-bulb temperature).

You can find the average dew point temperature and then determine the wet-bulb temperature, or you can find the average wet-bulb temperature and then determine the dew point. The second of these methods is usually easier, and is generally used to determine the average total heat.

You can solve this same problem working from the total heat content, as follows:

Outside air:

75°F wb = 38.5 Btu/lb total heat

70.6 lb/min x 38.5 Btu/lb = 2,718 Btu/min total heat

Recirculated air:

60°F wb = 26.4 Btu/lb total heat

73.7 lb/min x 26.4 Btu/lb = 1,946 Btu/min total heat

Total:

$$\begin{array}{l} 2{,}718 \text{ Btu/min} \\ \underline{+1{,}946 \text{ Btu/min}} \\ =4{,}664 \text{ Btu/min} \end{array}$$

$$\frac{4{,}664 \text{ Btu/min}}{73.7 \text{ lb/min} + 70.7 \text{ lb/min}} = 32.3 \text{ Btu/lb total heat}$$

32.3 Btu/lb total heat = 67.8°F wb (mixed air)

Once the various properties of the mixture are found, the mixture is treated as the "air in" value in the previous examples, and calculations are carried out in exactly the same way.

SHORT METHOD

A slightly less accurate but more convenient method of calculation is explained below. Values from the previous example are used for direct comparison.

To determine dry-bulb temperature:

$$\begin{array}{lcr} \text{Outside air } 90°\text{F db} \times 1{,}000 \text{ cfm} & & 90{,}000 \\ \text{Recirculated air } 72°\text{F db} \times 1{,}000 \text{ cfm} & + & \underline{72{,}000} \\ & = & 162{,}000 \end{array}$$

$$\frac{162{,}000}{2{,}000 \text{ cfm total}} = 81°\text{F db}$$

As you can see, using this simple procedure gives you an answer of 81°F db, compared to 80.8°F db using the more accurate method.

To determine wet-bulb temperature:

$$\begin{array}{lr} \text{Outside air } 75°\text{F db} \times 1{,}000 \text{ cfm} & 75{,}000 \\ \text{Recirculated air } 60°\text{F db} \times 1{,}000 \text{ cfm} & +\ \underline{60{,}000} \\ & =135{,}000 \end{array}$$

$$\frac{135{,}000}{2{,}000 \text{ cfm total}} = 67.5°\text{F db}$$

In this case, the "short method" gives you an answer of 67.5°F wb, versus 67.8°F wb using the longer method. Try solving for dew point temperature.

You should find the accuracy of the results to be similar.

Now determine the new specific volume of the mixture:

$$\begin{array}{l} \ \ 13.61 \text{ ft}^3/\text{lb dry air} \\ +\underline{0.25 \text{ ft}^3/\text{lb}} \text{ water vapor} \\ =13.86 \text{ ft}^3/\text{lb specific volume} \end{array}$$

$$13.86 \text{ ft}^3/\text{lb} \times 144 \text{ lb/min} = 1{,}995.8 \text{ cfm}$$

13.86 ft^3 /lb x 144 lb/min = 1,995.8 cfm

The air contracts slightly in the process of mixing, resulting in a reduction of about 5 cfm.

OPERATION OF THE CIRCULAR SLIDE RULE

The circular slide rule portion of the calculator is equivalent to a straight rule approximately 6.5 in. long. This represents only a part of a complete slide rule. It deals specifically with multiplication and division. It consists of two identical scales, called the "C" and "D" scales. As shown in Figure 20, the small, innermost scale on the movable dial is the "C" scale. The outer, stationary scale is the "D" scale. The large number 1 on each scale is known as the "index."

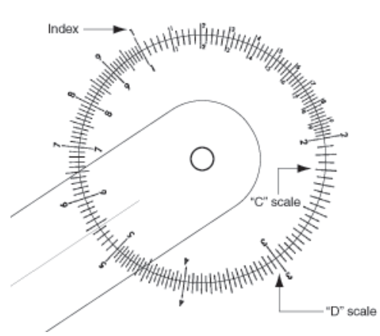


FIGURE 20. Parts of the circular slide rule

MULTIPLYING

Assume, for example, that you wish to multiply

15 x 20. First line up the index on the “D” scale with 15 (the small number 5) on the “C” scale. Now move the cursor so that the hairline is directly over the number 2 on the “D” scale, as shown in Figure 21. Read the results on the “C” scale. The cursor is directly over the large digit 3. Obviously, you should realize that if 2 x 15 is 30, then 20 x 15 must be 300.

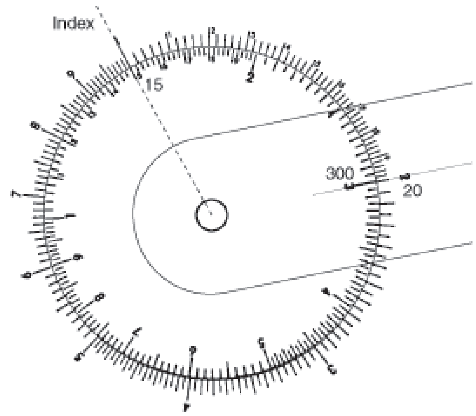


FIGURE 21. Multiplying 15 times 20

DIVIDING

When dividing two numbers, you simply reverse the multiplication procedure. For example, to divide 78 by 13, first place the cursor hairline over 78 on the “D” scale (8/10 of the way between 7 and 8). Next, move the “C” scale until the number 13 (the small number 3) is directly under the same hairline, as shown in Figure 22. The answer, which is read on the “D” scale, is directly above the index on the “C” scale. As you can see, the answer in this case is 6.

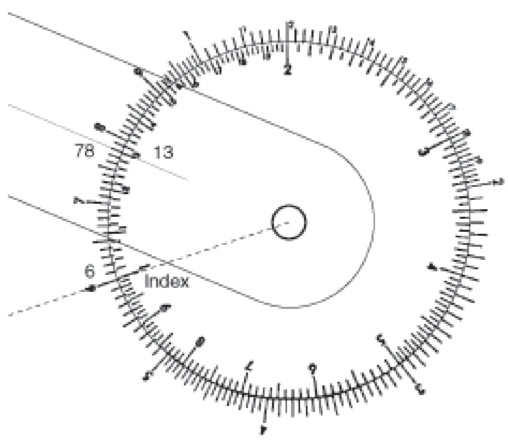


FIGURE 22. Dividing 78 by 13

