

***Pyschrometric Sample Problem
Pharmaceutical Engineering Graduate Program
New Jersey Institute of Technology***

Background

A pharmaceutical company wishes to construct a manufacturing space which will require an HVAC system that functions within the following parameters:

Space drybulb temperature = 70 °F
Space relative humidity = 50%

Internal sensible load (Q_s) = 88,000 BTU/hour
Internal latent load (Q_L) = 12,000 BTU/hour

Minimum outside air flow = 400 CFM
Design outdoor air drybulb temperature = 94 °F
Design outdoor air wetbulb temperature = 74 °F

Problem

1. Calculate the required supply airflow and temperature
2. Calculate the cooling coil load to provide this supply air using mixed air
3. Calculate the cooling coil load to provide this supply air using 100% outside air

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Solution to Problem # 1

Calculating the required airflow and temperature requires the simultaneous solution of the following three equations:

1. $Q_s = 1.08 \times \text{CFM} \times \Delta T$
2. $Q_L = 0.69 \times \text{CFM} \times \Delta \text{Grains}$
3. The equation that relates dewpoint to absolute humidity ratio (beyond the scope of this discussion)

Don't worry – there is an easier way!!!! The problem can be solved graphically using the psychrometric chart.

1. Plot a point on the psychrometric chart, indicating the target space conditions – in this case 70 °F/50 %RH
2. Calculate the internal sensible heat ratio (SHR) which equals the internal sensible load (Q_s) divided by the internal total load (Q_t). Since $Q_t = Q_s + Q_L$:

$$\text{SHR} = Q_s / (Q_s + Q_L) = 88,000 / (88,000 + 12,000) = 0.88$$

3. Draw a line on the psychrometric chart from the 0.88 SHR mark through the standard space condition “dot”.
4. Draw a line parallel to this line, through the desired space condition point .
5. Read the temperature where this new line crosses the saturation line. This will be the best supply air temperature to simultaneously satisfy the sensible and latent loads. In this case, the line crosses at 48.5 °F, which is both the drybulb and dewpoint temperature.
6. Using equation # 1 above, solve for CFM.

$$\begin{aligned} Q_s &= 1.08 \times \text{CFM} \times \Delta T \text{ or} \\ \text{CFM} &= Q_s / (1.08 \times \Delta T) = 88,000 / (1.08 \times (70 - 48.5)) = 3,790 \text{ CFM} \cong 3,800 \text{ CFM.} \end{aligned}$$

Answer

3800 CFM at 48.5 °F (saturated) will simultaneously satisfy the indicated sensible and latent loads.

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Solution to problem # 2

To calculate the cooling coil load, calculate the enthalpy of the mixed air (which is the air entering the coil) and supply air (which is the air leaving the coil), and apply the following equation:

$$Q_t = 4.5 \times \text{CFM} \times \Delta H$$

1. Plot the outside air conditions and space conditions on the psychrometric chart. Draw a line between them. This is called the mixed air line.
2. Algebraically calculate the mixed air drybulb temperature, which is the weighted average of the return air drybulb temperature* and the outside air drybulb temperature. In this case, 3,800 CFM of supply air is required, and 400 CFM of this needs to be outside air, so there is 3,400 CFM of return air (3,800-400 = 3,400). The weighted average drybulb temperature calculation is as follows:

$$3,800 \times T_{\text{mixed air}} = 400 \times T_{\text{outside air}} + 3,400 \times T_{\text{return air}}$$

$$T_{\text{mixed air}} = (400 \times T_{\text{outside air}} + 3,400 \times T_{\text{return air}}) / 3,800 = (400 \times 94 + 3,400 \times 70) / 3,800 = 72.5 \text{ } ^\circ\text{F}$$

3. Plot the point on the mixed air line where the drybulb temperature = 72.5 °F. This is the mixed air point.
4. Graphically read the enthalpy of the mixed air. In this case, it is 26.5 BTU/#dry air.
5. Plot the supply air point. Graphically read its enthalpy. In this case, it is 19.5 BTU/#dry air.
6. Apply the equation $Q_t = 4.5 \times \text{CFM} \times \Delta H =$

$$4.5 \times 3800 \times (26.5 - 19.5) = 119,700 \text{ BTU/hour} \cong 120,000 \text{ BTU/hour or } \mathbf{10 \text{ tons}}$$

(one ton = 12,000 BTU/hour)

* Please note that this problem assumes that the return air drybulb temperature = the space drybulb temperature. Normally, this is not the case, due to return duct and fan heat gain.

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Solution to problem # 3

Similar to the last problem, the following equation:

$$Q_t = 4.5 \times \text{CFM} \times \Delta H$$

In this case, however, there is no need to calculate mixed air since we are using 100% outside air. Graphically read the enthalpy of the outside air and supply air (previously completed) and apply these values to the above equation.

1. Graphically read the enthalpy of the outside air. In this case, it is 37.5 BTU/#dry air.
2. Graphically read the enthalpy of the supply air. This was previously read at 19.5 BTU/# dry air.
3. Apply the equation $Q_t = 4.5 \times \text{CFM} \times \Delta H =$

$$4.5 \times 3,800 \times (37.5-19.5) = 307,800 \text{ BTU/hour or } \mathbf{25.7 \text{ tons}} \text{ (one ton = 12,000 BTU/hour)}$$

