

MET 350 Thermal Applications

Test 3

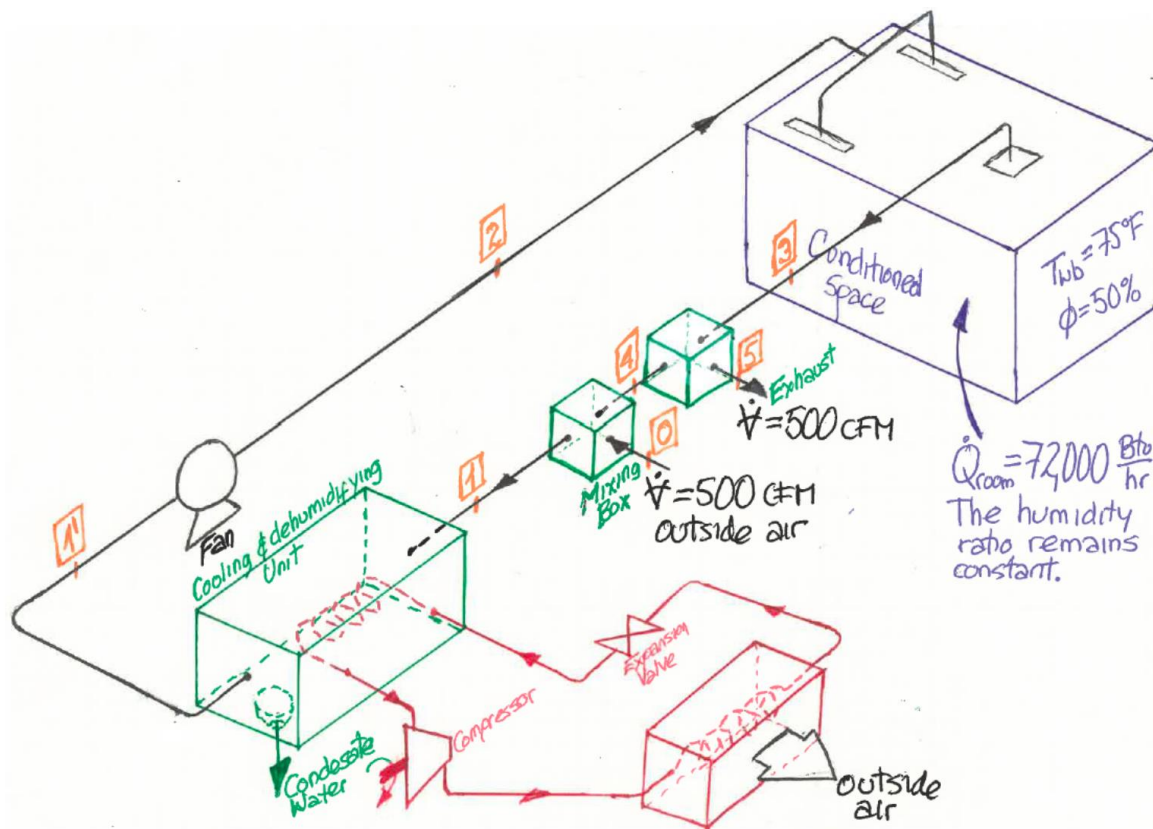
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Part 1:

1. Purpose: to find the following conditions of the air side of an air conditioning system.
  - a. The quantity of the air supplied to the space.
  - b. The state of the air at each of the points shown in the drawing (provide the dry bulb temperature and the humidity ratio of each state).
  - c. Draw all the processes in the attached psychrometric chart.
  - d. The required capacity of the cooling and dehumidifying unit.
  - e. The amount of liquid water drained in the cooling and dehumidifying unit.
2. Drawings & Diagrams

Air Conditioned Space Diagram



3. Source: Thermodynamics, an engineering approach, 9th edition, McGraw-Hill, 2019
4. Design Considerations: There is no infiltration of outside air into the space, nor is there any source of water inside the space; the humidity ratio of the air remains the same between states 2 and 3. The cooling and dehumidifying processes follow an ideal behavior. Also, assume the fan is ideal and does not change the air state. The air entering the conditioned space would be at 55°F, which is 20F below the desired room temperature.
5. Data and variables:
  - a.  $T_3 = 75 \text{ }^\circ\text{F}$
  - b.  $\phi_3 = 50\%$
  - c.  $T_0 = 90 \text{ }^\circ\text{F}$
  - d.  $\phi_0 = 60\%$
  - e.  $\dot{V}_0 = 500 \text{ CFM}$
  - f.  $\dot{V}_5 = 500 \text{ CFM}$
  - g.  $\dot{V}_3 = 72,000 \frac{\text{ft}^3}{\text{h}}$
6. Procedures:
  - a. Labels state 0-5
  - b. Using the psychrometric chart to find the various states.
  - c. Utilize first law and conservation of mass to find solutions.
7. Calculations:

$$T_0 = 75^\circ\text{F} \quad w_1 = 0.0091 \quad T_{\text{SAT}5} = 55.5^\circ\text{C}$$

$$\phi_1 = 50\% \quad h_1 = 28 \text{ BTU/lb} \quad v_1 = 13.68 \text{ ft}^3/\text{lb}$$

$$T_0 = 90^\circ\text{F} \quad w_0 = 0.0185 \quad T_{\text{SAT}0} = 74.2^\circ\text{C}$$

$$\phi_0 = 60\% \quad h_0 = 41.8 \text{ BTU/lb} \quad v_0 = 14.28 \text{ ft}^3/\text{lb}$$

$$\dot{m}_{\text{OA}} = \frac{\text{CFM}}{v_0} = \frac{500}{14.28} = 35 \text{ lb/min} \quad 2100 \text{ lb/hr}$$

$$\dot{Q}_0 = \dot{m}_{\text{OA}} (h_0 - h_1) = 2100 (41.8 - 28) = 28980 \text{ BTU/hr}$$

$$\dot{Q}_T = \dot{Q}_1 + \dot{Q}_0 = 28980 + 72,000 = 100980 \text{ BTU/hr}$$

$$\dot{Q}_{\text{in}} = \dot{m}_a (h_3 - h_2) \quad \dot{m}_a = \frac{\dot{Q}_{\text{in}}}{h_3 - h_2} = \frac{75,000}{28 - 18.5} = 7894.74 \text{ lb/hr}$$

b)	0	1	1'	2	3	4	5
$T_0 = 90^\circ\text{F}$	$T_1 = 81^\circ\text{F}$	$T_{1'} = 55^\circ\text{F}$	$T_2 = 55^\circ\text{F}$	$T_3 = 75^\circ\text{F}$	$T_4 = 75^\circ\text{F}$	$T_5 = 75^\circ\text{F}$	
$\phi_0 = 60\%$	$\phi_1 = 51\%$	$\phi_{1'} = 100\%$	$\phi_2 = 100\%$	$\phi_3 = 50\%$	Same as 3	Same as 3	
$w_0 = 0.0185$	$w_1 = 0.0118$	$h_{1'} = 18.5$	$h_2 = 18.5$	$h_3 = 28$			
$h_0 = 41.8$	$h_1 = 32$	$v_{1'} = 13.06$	$v_2 = 13.06$	$v_3 = 13.68$			
$v_0 = 14.28$	$v_1 = 13.48$	$w_{1'} = 0.0045$	$w_2 = 0.0045$	$w_3 = 0.0091$			

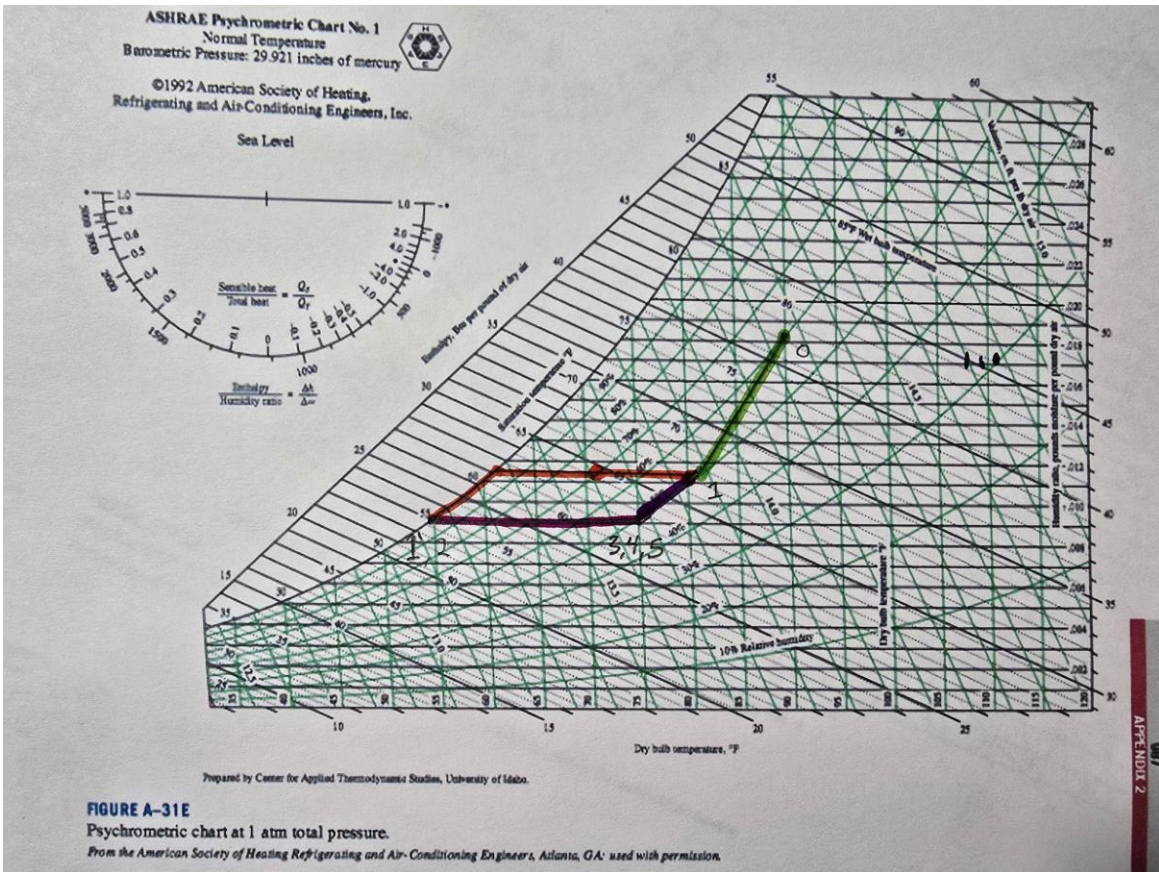
$$\dot{V} = \dot{m}_a \cdot v_2 = 7894.75 \cdot 13.06 = \frac{103,088.45}{60} \text{ ft}^3/\text{hr}$$

$$a) \quad \dot{V} = 1718.14 \text{ CFM}$$

$$y_0 = \frac{500}{1718.14} = 0.291 \quad y_4 = \frac{1218.14}{1718.14} = 0.709$$

$$h_1 = (0.291)(41.8) + (0.709)(28) = 32$$

C.



$$w_1 = y_o \cdot w_o + y_4 w_4 \quad (0.291/0.0185) + (0.709)(0.0091) = 0.0184 \text{ lb/lb}$$

$$Q_{\text{coil}} = \dot{m}_a (h_1 - h_1') = 7894.74 \text{ lb/hr} (32 - 18.5) = 106,579 \text{ Btu/hr}$$

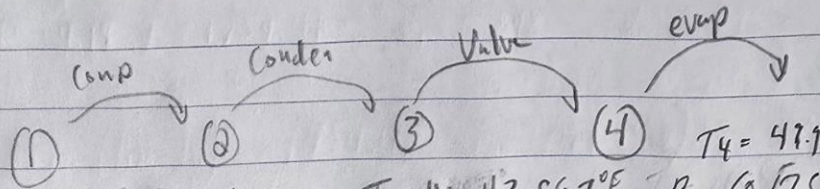
d) Capacity =  $\frac{106,579}{12,000} = 8.88 \text{ tons}$

$$\dot{m}_w = \dot{m}_a (w_1 - w_1') = 7894.74 (0.0184 - 0.0045) = 57.95 \text{ lb/hr}$$

e)  $V_{\text{water}} = \frac{57.95}{8.34} = 6.95 \text{ gal/hr}$

Part 2:

1. Purpose: Find the following information on the refrigeration side of the air conditioning plant.
  - a. The operating pressure of the evaporator and the condenser. Keep in mind that the temperatures of the refrigerant should be appropriate for the heat transfer to occur. Follow the rule of thumb provided in class.
  - b. The state of the refrigerant after each of the elements of the vapor-compression refrigeration cycle (provide pressure, temperature, enthalpy, and quality of each state).
  - c. The P-v and T-s diagrams.
  - d. The COP of your designed cycle.
  - e. The required refrigerant mass flow rate.
  - f. The power required by the compressor in HP.
  - g. The waste heat rate.
2. Drawings & Diagrams: Same as Part 1
3. Source: Thermodynamics, an engineering approach, 9th edition, McGraw-Hill, 2019
4. Design Considerations: The system uses R-134a refrigerant. The waste heat is rejected to the outside air, the refrigerant leaves the evaporator superheated by 2.7 °C and is subcooled by 6.3 °C at the exit of the condenser, and the isentropic efficiency of the compressor is 80%
5. Data and variables:
  - a.  $T_1=49.9$  °F
  - b.  $T_3=98.7$  °F
  - c.  $\eta_c = 80\%$
6. Procedures:
  - a. Utilize the R-134a saturation and superheat tables to find various states.
  - b. Find the heat rejection and the work, then find the COP.
  - c. Find Mass flow rate.
  - d. Find the work input and convert to HP.
  - e. Find the waste heat rate.
7. Calculations:



g)  $T_1 = 45 + 4.9 = 49.9$   $T_2 = 105.73$   $T_3 = 110 - 11.3 = 98.7^\circ\text{F}$   $T_4 = 60.175 \text{ Psi}$   
 $P_1 = 60.175 \text{ Psi}$   $P_2 = 136.2$   $P_3 = 136.2 \text{ Psi}$   $h_3 = h_4$   
 $h_1 = 110.15 \frac{\text{Btu}}{\text{lbm}}$   $h_2 = 117.69$   $h_3 = 45.13$   $h_4 = h_3 = 45.13$   
 $B_1 = 154.13 \text{ Psi}$   $X_2 = 1/15$   $X_3 = 0$   $P_{sat,4} = 60.175$   $X_4 = \frac{h_4 - h_{f,4}}{h_{fg,4}}$   
 $S_1 = 0.22131$

b)  $X_1 = 1$

$q_L = h_1 - h_4$   
 $110.15 - 45.13$

$q_L = 65.02 \frac{\text{Btu}}{\text{lbm}}$

$W_{in} = h_2 - h_1$   
 $117.69 - 110.15$

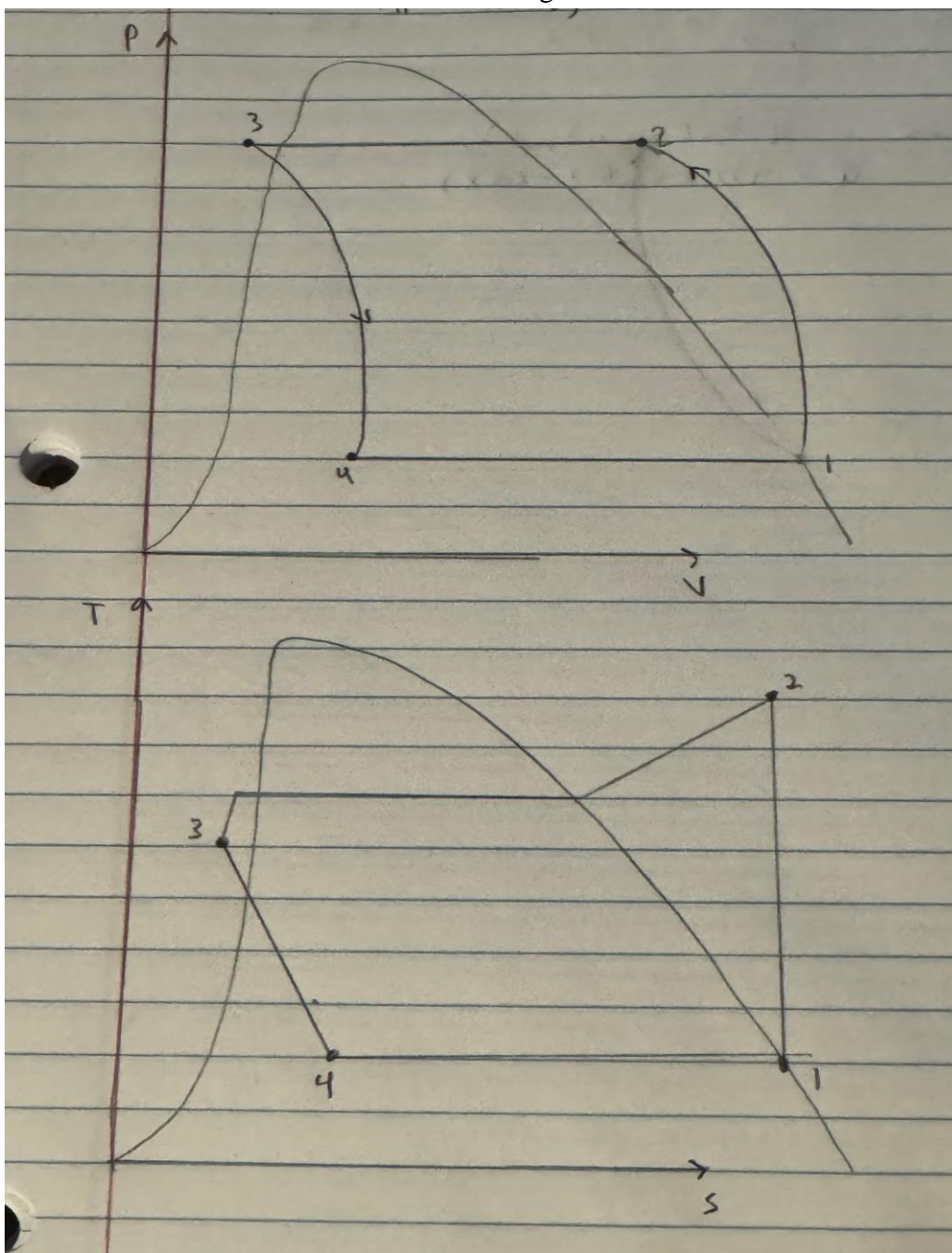
$W_{in} = 7.54 \frac{\text{Btu}}{\text{lbm}}$

$X_4 = \frac{45.13 - 28.124}{110.15}$

$= 0.154$

d)  $COP = \frac{q_L}{W_{in}} = \frac{65.02}{7.54} = 8.62$

# P-v and T-s Diagrams



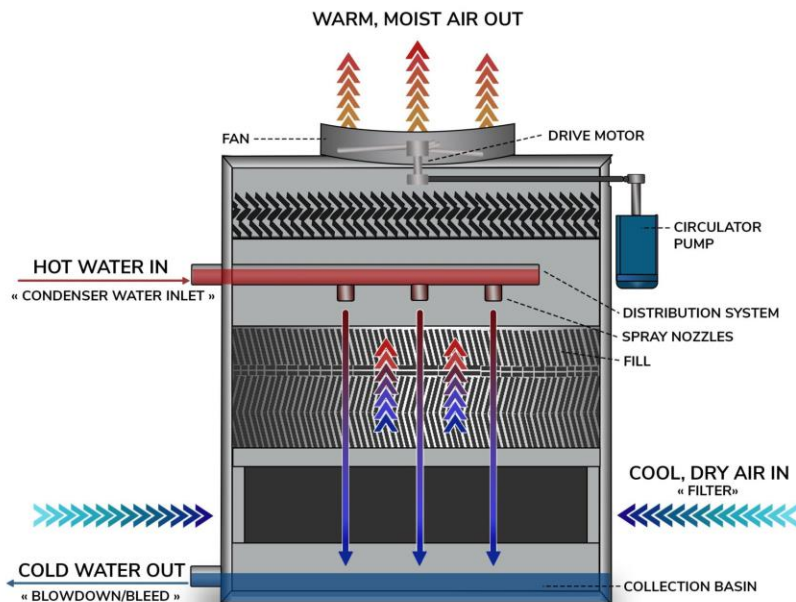
$$e. \quad \dot{m} = \frac{\dot{Q}}{q_c} = \frac{160,579 \text{ BTU/hr}}{65.02 \text{ BTU/lbm}} = 5748 \text{ lbm/hr}$$

$$f. \quad \dot{W}_{in} = \dot{m} \cdot W_{in} = 5748 \cdot 9.54 = 43,341 \text{ BTU/hr}$$

$$g. \quad \dot{Q}_H = \dot{m} (h_2 - h_3) = 5748 / (117.69 - 45.13) = 417075$$

Part 3:

1. Purpose: To use water to absorb the waste heat of the cycle instead of rejecting it to the outside air.
  - a. The volume flow rate of outside air into the cooling tower.
  - b. The mass flow rate of the required makeup water.
2. Drawing & Diagrams:



3. Source: Thermodynamics, an engineering approach, 9th edition, McGraw-Hill, 2019

4. Design Considerations: Assume the air leaves the cooling tower with a relative humidity of 90%. Also, assume that the temperature changes of the water and the air are about 3 °F
5. Data and variables:
  - a.  $T_1 = 90$  °F
  - b.  $\phi_1 = 60\%$
  - c.  $T_2 = 93$  °F
  - d.  $\phi_2 = 90\%$
6. Procedures:
  - a. Find the enthalpy and relative humidity of  $T_2$ .
  - b. Find the mass flow rate of outside air.
  - c. Compute the volumetric flow rate of outside air.
  - d. Find the mass flow rate of make-up water.
7. Calculations:

3

$$T_1 = 90^\circ\text{F} \quad T_2 = 93^\circ\text{F}$$

$$\phi_1 = 60\% \quad \phi_2 = 90\%$$

$$w_1 = 0.0185 \quad w_2 = 0.0325$$

$$h_1 = 41.8 \quad h_2 = 55$$

$$t_1 = 14.28$$

$$\dot{m}_a = \frac{Q}{h_2 - h_1} = \frac{106579}{55 - 41.8} = 8074 \text{ lb dry air/hr}$$

$$\dot{V} = \dot{m}_a t_1 = \frac{8074}{60} (14.28) = 115297 \text{ ft}^3/\text{hr}$$

$$\dot{V} = 1922 \text{ CFM}$$

$$\dot{m}_w = \dot{m}_a (w_2 - w_1) = 8074 (0.0325 - 0.0185)$$

$$\dot{m}_w = \frac{113}{8.34} \text{ lbm/hr} \quad \dot{m}_w = 13.6 \text{ gal/hr}$$

8. Summary: Overall, the design works as intended, cooling the conditioned space to 75 °F while the pipes are around 55 °F. The air temperature in the pipes must be lower than the air-conditioned space temperature. Air is sucked out of state 5, where it is then re-added to the system in state 4. The outside air flows at  $6.95 \frac{\text{ft}^3}{\text{h}}$  through the pipes where it enters a cooling and humidifying unit. In the cooling and humidifying unit, refrigerant R-134a is heated and subcooled to cool the air in the pipes. R-134a is superheated to 105.93 °F and then cooled to around 94.9 °F. R-134a repeats this cycle in the unit. Once the air is cooled and dehumidified, condensate water and outside air are exhausted from the unit. Afterward, a fan pushes the air into the air-conditioned space.
9. Materials: Air, Water, and R-134a
10. Analysis: Overall, the design works as intended. Outside air is cooled and dehumidified to cool a room to 75 °F and  $\phi = 60\%$ . A fan pushes air into the air-conditioned space. If someone wishes to cool the space to 65 °F, the air in the pipes must be cooled to that temperature as well. A reasonable temperature might be around 45-55 °F. The same applies if a person wishes to heat up a space. Instead of using a cooling and dehumidifying unit, a person would need a heating and humidifying unit. The process would work the same way as the cooling unit; the only difference would be that the air is heated rather than cooled. If a person were to cool down two rooms, the amount of air needed to flow through the pipes and the amount of cool air that needs to be cooled would increase. If the same amount of air is applied to two rooms, then the rooms will not reach the necessary temperature. Inside the cooling and dehumidifying unit, the refrigeration cycle is a vapor-compression cycle. In such a cycle, air is superheated and then cooled back down to the original temperature. The same applies to a heating system with humidification if the space needs to be heated rather than cooled. When outside air is added to preexisting air from the conditioned space, their temperatures would either increase or decrease, depending on the mass flow rates of the two air streams. For example, if the air from the space is 1 gallon per minute, while the air from outside is 2 gallons per minute, then the temperature would be closer to the air from outside. If the mass flow rates were equal, the temperature would be midway. For the cooling tower, it required the volumetric flow rate from the outside air and the mass flow rate of the required makeup water. The makeup water is used to continuously replace the water lost to evaporation. The outside air into the cooling tower acts as a heat sink. We need the flow rates of the two because they must balance each other out. If they are unbalanced, then there would either be too much water or too much air. When there is too much water, the cooling tower would overflow or overcool. When there is too much air, then there is too much evaporation and the water will quickly dry up. When there is no air within the cooling tower, the tower may break.

