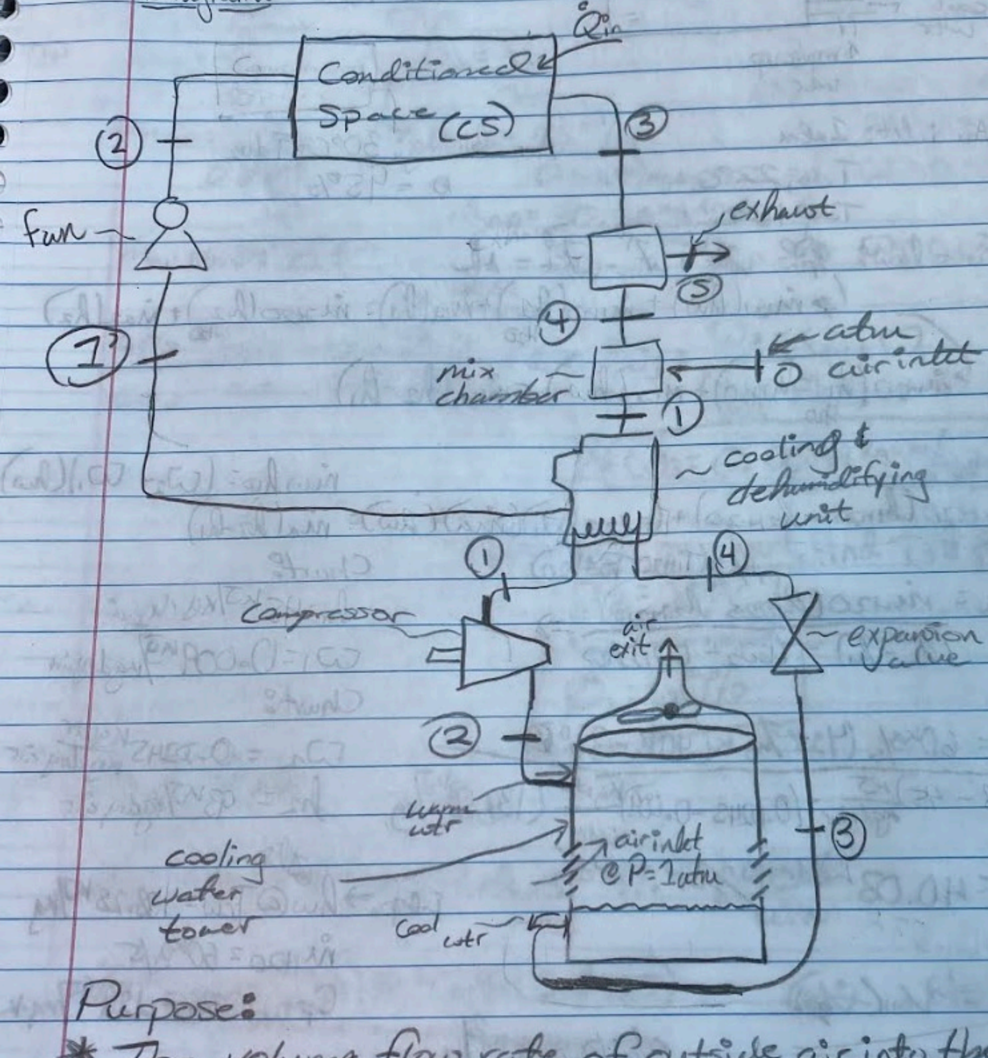
Test 3

Problem 3 extra credit:

Diagram:



Purpose:

* The volume flow rate of outside air into the cooling tower.
* The mass flow rate of the required makeup water.

Sources:
- Ayala
- Thermodynamics engineering approach textbook
- Notes and slides

Design Considerations:
- The mass flow rates of dry air of the cooling and dehumidifying unit will be the same as air-conditioned cycle.
- The $h_w = T_{H2O2}$ or cold water.
- The cooling tower will be a wet cooling tower.
- The air inlet pressure going into the wet cooling tower is 1 atm.
- The outside air conditions for inlet of air conditioned space and wet cooling tower will be the same.

Data given:
- The relative humidity at the air exit is 90%.
- The air inlet temperature, relative humidity, and pressure is the same as air inlet for air-conditioned.
- The temperature changes of water to air are about 3°F.

Procedure:
1.) Determine the temperatures and relative humidities.
Note made air inlet and air outlet to be 1 and 2 for simplicity
2.) Wrote the Psychrometric chart.
3.) Calculations: First law of wet cooling tower → determine rest of the known states
4.) Solved for the questions.

1 cbm
$T_{db}=90°F$
$\phi=60\%$

Calculations:

First Law of cooling tower:

$$\cancel{q_{in}}^{0}-\cancel{q_{out}}^{0}+\cancel{w_{in}}^{0}-\cancel{w_{out}}^{0}=\Delta h$$

$$\Delta h=\dot{m}_{H2O}(h_{H2O_2})+\dot{m}_w(h_w)+\dot{m}_a(h_1)=\dot{m}_a(h_2)+\dot{m}_{H2O}(h_{H2O_2})$$

$$\dot{m}_w(h_w)+\dot{m}_{H2O}(h_{H2O1}-h_{H2O2})=\dot{m}_a(h_2-h_1)$$

$$* \quad \dot{m}_a=\frac{(\omega_2-\omega_1)(h_w)+\dot{m}_{H2O}(C_{pH2O}(T_{H2O_2}-T_{H2O_1}))}{h_2-h_1}$$

$\dot{m}_w(h_w)=\omega_2-\omega_1(h_w)$

$\dot{m}_{H2O}(h_{H2O_2}-h_{H2O1})=\dot{m}_{H2O}(T_{H2O_2}-T_{H2O1})$

$3°F=T_{H2O1}-T_{db} \Rightarrow T_{H2O1}=93°F \Rightarrow 552.67R$

Tables: $h_1=41.8\ Btu/lbm\ dry\ air$

$v_1=14.25\ ft^3/lbm\ dry\ air$

$\omega_1=.0183\ lbm/lbm\ dry\ air$

interp. $h_{H2O1}\overset{=h_f}{@}T_{H2O1}=\underline{61.044\ Btu/lbm}$

$T_{H2O2}=75°F \Rightarrow 534.67R$

$h_w\overset{=h_f}{@}T_{H2O2} \Rightarrow 43.07\ Btu/lbm$

$C_{pH2O}=1.008\ Btu/lbm\cdot R$

Assume air exit $\cong T_{db2}=93°F$ b/c of tables

Tables:

$\omega_2=0.03\ lbm/lbm\ dry\ air$

$v_2=14.55\ ft^3/lbm\ dry\ air$

$h_2=55\ Btu/lbm\ dry\ air$

from question 1: $\frac{\dot{Q}_{out}}{\dot{m}_a}=\dot{m}_a(h_2-h_1)-\dot{m}_w(h_w)$

$\hookrightarrow \dot{Q}_{out}=4.42\frac{lbm}{s}(29.5-23)\ Btu/lbm\ dry\ air+(0.00515\frac{lbm}{s})(23.07\frac{Btu}{lbm})\Rightarrow \dot{Q}_{out}=28.73\frac{Btu}{s}$

$\dot{Q}_{in}=\Delta h_{1-2}\Rightarrow 13.2\ Btu/lbm\ dry\ air$

$\dot{m}_{H2O}=\frac{\dot{Q}_{out}}{\dot{Q}_{in}}=\frac{28.73\frac{Btu}{s}}{13.2\frac{Btu}{lbm}}\Rightarrow 2.1765\frac{lbm}{s}=\dot{m}_{H2O}$

$$* \ \dot{m}_{H2O} = \frac{(\omega_2 - \omega_1)(h_w) + \dot{m}_a(h_2 - h_1)}{c_{p,H2O}(T_{H2O2} - T_{H2O1})}$$

$$\hookrightarrow \dot{m}_{H2O} = \frac{(0.03 - 0.0188)\,\frac{lb_v}{lbm_{dry\,air}}\left(43.07\,\frac{Btu}{lbm}\right) + 4.44\,\frac{lb}{s}\,(55 - 41.8)\,\frac{Btu}{lbm_{dry\,air}}}{1.008\,\frac{Btu}{lbm \cdot R}\,(552.67 - 534.67)\,R}$$

$$\hookrightarrow \boxed{\dot{m}_{H2O} = 3.25\ lbm/s}$$

$$\dot{m}_a = \frac{1}{v_1}(\dot{V}_1) \Rightarrow 4.44\,\frac{lb}{s} \times 14.25\,\frac{m^3}{lbm} \Rightarrow \boxed{63.27\,\frac{m^3}{s} = \dot{V}_1}$$

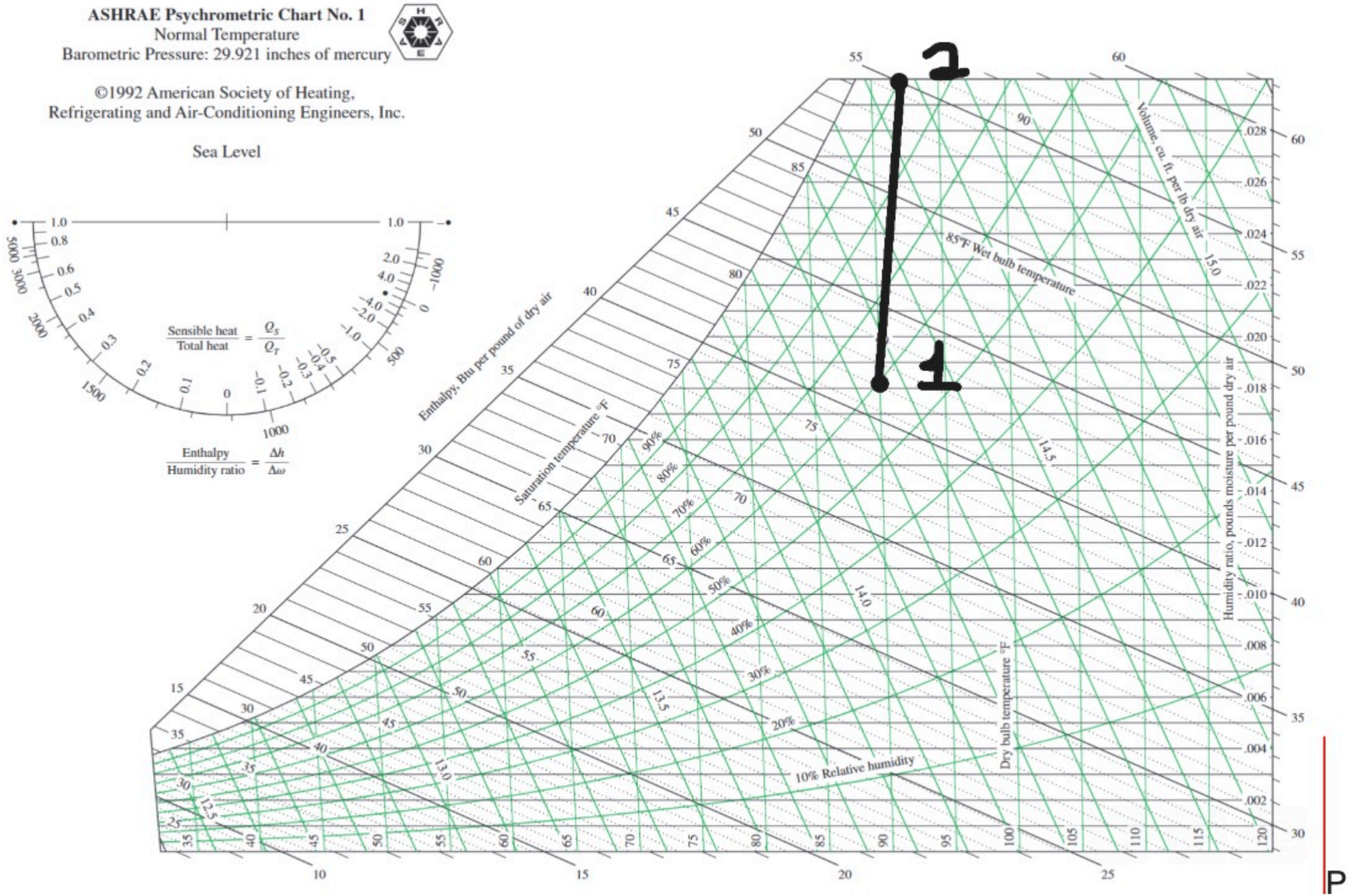
Summary:

For question 3 we focused on the wet cooling tower in the cooling and dehumidifying system. This system provides adequate cooling of the hot water after going through the evaporator. Air flows into the tower as the hot water is sprayed. This cools down the water, which falls into a water pool where the now cool water flows back through the evaporator. The hot air, after mixing with the sprayed warm water exits through the top of the system.

Materials:

- Water: Water is used from the evaporator to cool the condensed space.
- Air: The atmospheric air is used to cool down the warm water.

Analysis:
The design of a wet cooling tower provide adequate cooling of ambient air to cool the hot water. The ambient air is heated and exits through the top by a fan pushing the air back out into the atmosphere. The warm water is then cooled down by ambient air and fills up a pool. The cool water then goes back through the cool and dehumidifying unit, to then go back through the evaporator. If the ambient air rose above the warm water temperature then the ambient air cannot cool down the warm water. Therefore, the cooling and dehumidifying system cannot cool down the condensed space.



ASHRAE Psychrometric Chart No. 1
Normal Temperature
Barometric Pressure: 29.921 inches of mercury
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Sea Level
Sensible heat / Total heat = Q_S / Q_T
Enthalpy / Humidity ratio = Δh / $\Delta \omega$
Enthalpy, Btu per pound of dry air
Saturation temperature °F
85°F Wet bulb temperature
Volume, cu. ft. per lb dry air
Humidity ratio, pounds moisture per pound dry air
Dry bulb temperature °F
10% Relative humidity
2
1
P