MET 350 Thermal Applications Final Project:

Air Conditioning System Design

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5/2/2019

Abstract

For this project, we were asked to design an air-conditioning system, refrigeration cycle system, and an alternative water-cooling system for a space at a local shipyard. We were to design these systems knowing certain parameters for each of the different systems. Our final design consisted of the alternative water-cooling system with a cooling tower that can be seen later in the document. Our design is based off pre-existing air-conditioning systems.

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1. List of Tables

a. Tables used were found in the appendices of the book and are shown in the calculations

2. List of Figures

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Figure 1.2 - Calculations for 1a, 1b, 1d, 1e

Figure 1.3 Calculations for 2a-2g

Figure 1.4 Calculations for 3a & 3b

Figure 1.5 Schematic of proposed cooling tower

Figure 1.6 Layout of project area and system

3. Project Information

3a. Job Site Location

The location of this project is a space at a local shipyard with unspecified dimensions.

3b. Specifications & Design Philosophy

This project involves designing the air-conditioning system, the refrigeration cycle system, and an alternative water-cooling system for the refrigeration system. For the air-conditioning system, the space is to be maintained at 75 F with a relative humidity of 50%. The heat gained to the space from the walls is 72,000 Btu/hr. In this space, there is no air coming in from the outside and no source water. The outside air around the space has a temperature of 90 F and a relative humidity of 60%.

For the refrigeration cycle system, cooling and dehumidifying unit operate on a vapor-compression refrigeration cycle and use refrigerant R-134a. Also, waste heat will be rejected to the outside air. The refrigerant will leave the evaporator superheated by 2.7 C and subcooled by 6.3 C at the exit of the condenser and the compressor's isentropic efficiency is 80%

The alternative water-cooling system is a redesign of the vapor-compression refrigeration cycle design. For this, water will be used to absorb the waste heat instead of rejecting it to the outside. Air will leave the proposed cooling tower with a relative humidity of 90% and temperature changes in the water and air are approximately 3 F.

3c. Sources

Cengel & Boles. "Thermodynamics-An Engineering Approach." 8th edition, McGraw Hill. 2015

3d. Materials & Specifications

i. Materials

ia) Air-Conditioning System Design

-Air (The fluid that is being cooled in the area)

-Compressor (Required for cycle)

-Expansion Valve (Required for cycle)

-Cooling Unit (Required for cycle)

-Dehumidifying Unit (Required for cycle)

ib) Refrigeration Cycle System Design

-Air (The fluid that is being cooled in the area)

-Refrigerant R-134a

-Compressor (Required for cycle)

-Expansion Valve (Required for cycle)

-Cooling Unit (Required for cycle)

-Dehumidifying Unit (Required for cycle)

ic) Alternative Water-Cooling System Design

-Air (The fluid that is being cooled in the area)

--Compressor (Required for cycle)

-Expansion Valve (Required for cycle)

-Cooling Unit (Required for cycle)

-Dehumidifying Unit (Required for cycle)

-Cooling tower (Required by client)

ii. Fluids Characteristics

iia) Air-Conditioning System Design

- Pressure from the outside and inside air were found to help determine the temperature and flowrate of the system in the beginning.

iib) Refrigeration Cycle System Design

- Considered internal pressure and temperature of how it would affect the humidity ratio and the flow rate of the system.

iic) Alternative Water-Cooling System Design

- While creating the alternative water-cooling system, the viscosity and flowrate of the make-up water had to be calculated due to the entry it was coming from. Also, the internal temperature couldn't be hotter than the outside temperature of air.

3e. Preliminary Drawings & Sketches

Found in Design Calculations

3f. Methodology

AIR-CONDITIONING SYSTEM DESIGN: In order to be able to find the states of the air with in the space to the outside air, we had to use the psychrometric chart to determine the temperature we believe it would've been based off the humidity given to us. With that, we were able to find the Q of the outside air using $ma(h_1 - h_2)$, the flow rate of the beginning with $ma = \frac{q}{(h_3 - h_2)}$, and the humidity ratio of state one was found as well.

REFRIGERATION CYCLE SYSTEM: With the states being found from the chart, my partner and I moved on to trying to find the saturated temperature through the tables found in the book (A-13E, A-12E) we tried to focus on block P=40psia on the superheated table. We then found *m* using the *Q* equation with *Q=outside air.* $(h_2 - h_1)$ was used to find the internal humidity ratio and found the *COP* and Q_{out} after.

ALTERNATIVE WATER-COOLING SYSTEM: After going through the numbers and concepts of the previous information, we decided to go with a design like an AC unit someone would find next to a house for an apartment complex. We determined the temps, enthalpy, and humidity from the psychrometric chart and from the knowledge that internal cannot be hotter than outer air. Using the information given, we interpolated the h_w from the saturated table (A-12E) and then found $C\ p_{h20}$. Flow rate of the outside air and the make-up water was found after (ma, mw).

3g. Design Calculations

i. Air-Conditioning System Design

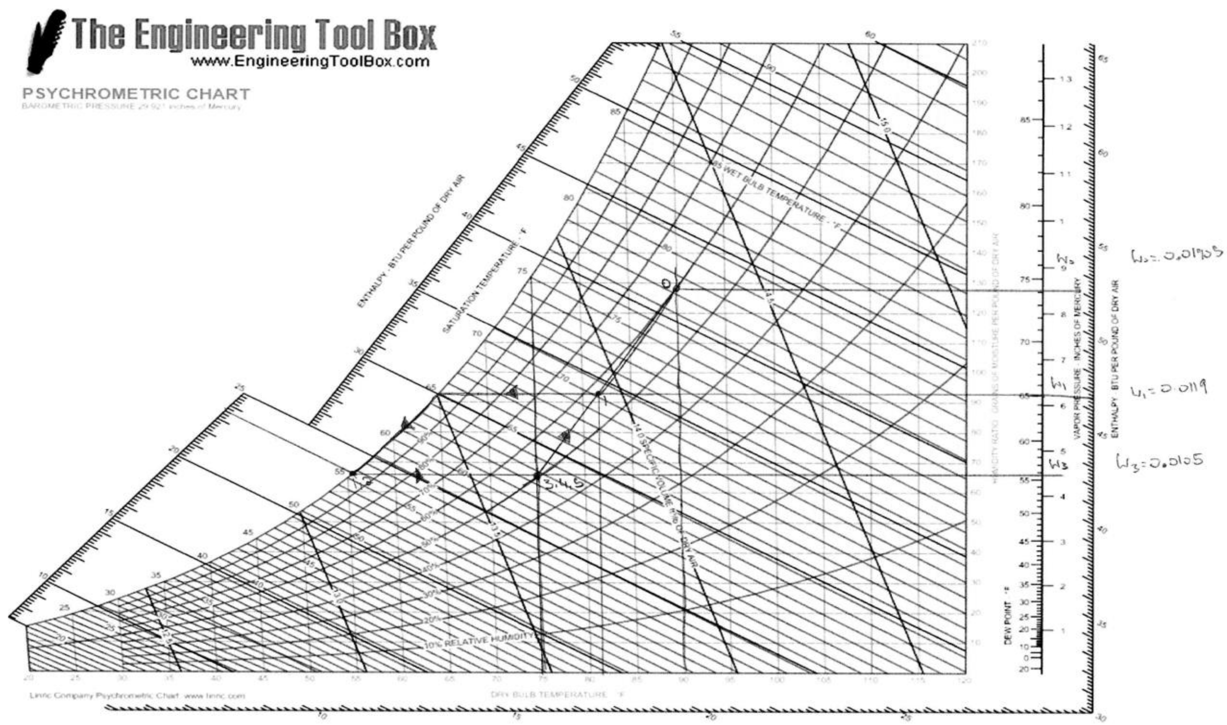
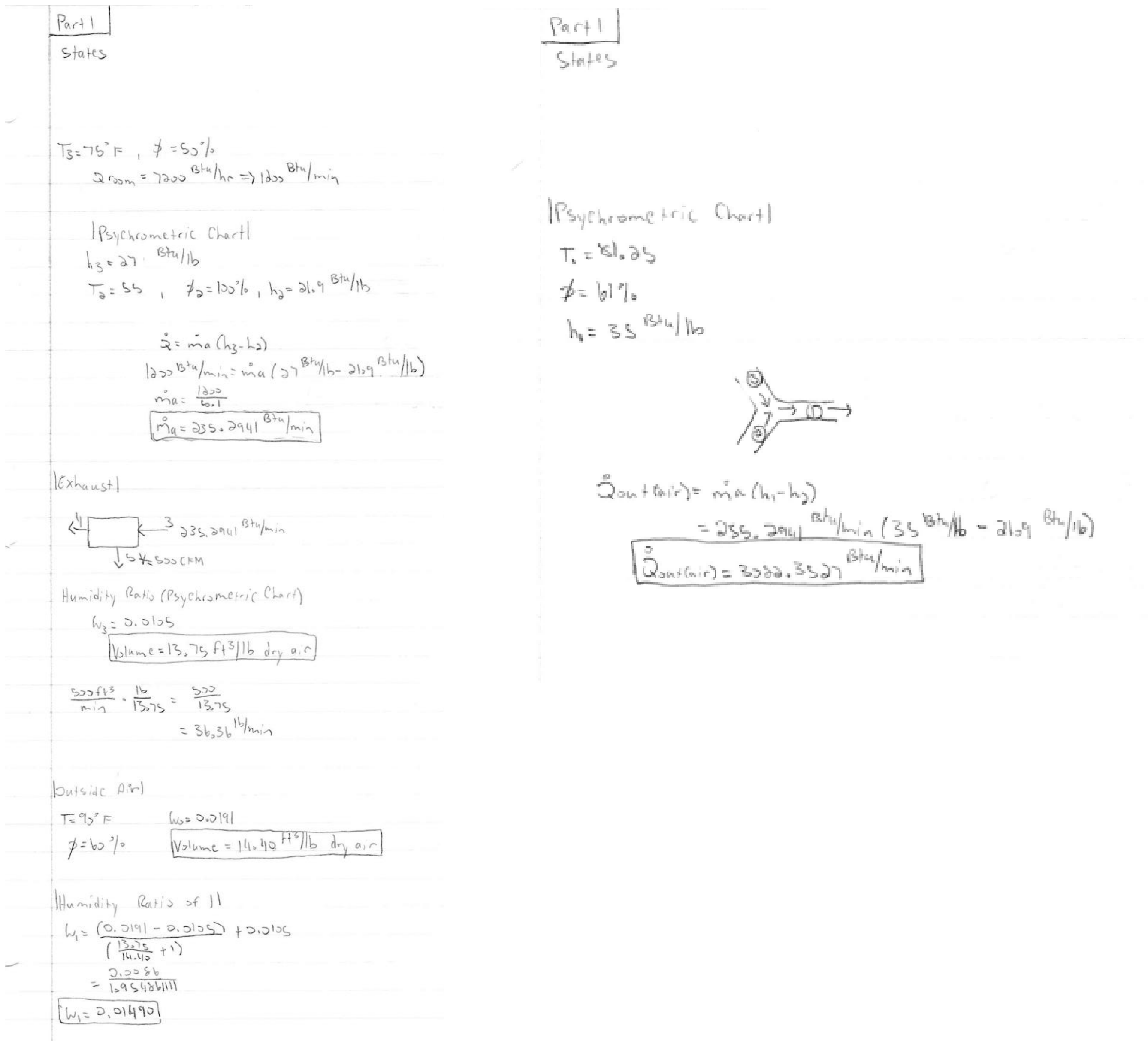


Figure 1.1 Psychrometric Chart & Processes of the Cycle



Part 1

States

$T_3 = 75^\circ F$, $\phi = 50\%$

$\dot{Q}_{room} = 7200\ Btu/hr \Rightarrow 1200\ Btu/min$

|Psychrometric Chart|

$h_3 = 27\ Btu/lb$

$T_2 = 55$, $\phi_2 = 100\%$, $h_2 = 21.9\ Btu/lb$

$\dot{Q} = \dot{m}_a (h_3 - h_2)$

$1200\ Btu/min = \dot{m}_a (27\ Btu/lb - 21.9\ Btu/lb)$

$\dot{m}_a = \frac{1200}{5.1}$

$\boxed{\dot{m}_a = 235.2941\ Btu/min}$

|Exhaust|

4 ← ☐ ← 3 235.2941 Btu/min

↓5 500 CFM

Humidity Ratio (Psychrometric Chart)

$\omega_3 = 0.0105$

$\boxed{Volume = 13.75\ ft^3/lb\ dry\ air}$

$\frac{500\ ft^3}{min} \cdot \frac{lb}{13.75} = \frac{500}{13.75}$

$= 36.36\ lb/min$

|Outside Air|

$T = 90^\circ F$, $\omega_0 = 0.0191$

$\phi = 60\%$, $\boxed{Volume = 14.40\ ft^3/lb\ dry\ air}$

|Humidity Ratio of 1|

$\omega_1 = \frac{(0.0191 - 0.0105)}{\left(\frac{13.75}{14.40} + 1\right)} + 0.0105$

$= \frac{0.0086}{1.95486111}$

$\boxed{\omega_1 = 0.01490}$

Part 1

States

|Psychrometric Chart|

$T_1 = 81.25$

$\phi = 61\%$

$h_1 = 35\ Btu/lb$

$\dot{Q}_{out(air)} = \dot{m}_a (h_1 - h_2)$

$= 235.2941\ Btu/min\ (35\ Btu/lb - 21.9\ Btu/lb)$

$\boxed{\dot{Q}_{out(air)} = 3082.3527\ Btu/min}$

Fig 1.2 Calculations for 1a, 1b, 1d, 1e

ii. Refrigeration Cycle System

Part 2

$\rightarrow$ ① $\xrightarrow{\text{Isen (Comp)}}$ ② $\xrightarrow[h_3 = h_4]{\text{P const.}}$ ③ $\xrightarrow[h_4 = h_3]{\text{Isenthalpic}}$ ④ $\xrightarrow{\text{P const (evap)}}$

$T_1 = 55°F$ $T_2 =$ $T_3 = 36.111°C$ $T_4 = -6.039°C$

|From A-13E Table (superheated)|

- Block P = 40 psia

$55°F - 29.01°F = 25.99°F$

$T_1 = -3.339°C$

$P_1 = 40\,psia = 275.79\,kPa$

|Interpolation|

$h_1 = 108.25\,Btu/lbm \Rightarrow 251.79\,kJ/kg$

$s_1 = 0.22522\,Btu/lbm \cdot R \Rightarrow 0.94286736\,kJ/kg$

$-3.339°C = T_{sat_1} + 2.7°C$ (superheated)

$T_{sat_1} = -6.039$ (T_4)

$T_3 = 90°F + 7°F = 97°F$

$\Rightarrow 36.111°C$

$36.111°C = T_{sat_3} - 6.3°C$ (subcooled, sat. table A-11E)

$T_{sat_3} = 42.411°C$

$\Rightarrow 108.340°F$

$P_3 = 159.75\,psia \Rightarrow 1101.437\,kPa$

|Saturated Table|

$h_3 = 47.500\,Btu/lbm \Rightarrow 110.485\,kJ/kg$

$s_3 = 0.08106\,Btu/lbm \cdot R \Rightarrow 0.3394\,kJ/kg$

|Interpolation|

$h_4 = h_{f_4} + x_4 h_{fg_4}$ $h_{f_4} = 19.015\,Btu/lbm \Rightarrow 44.229\,kJ/kg$

$h_{fg_4} = 87.245\,Btu/lbm \Rightarrow 202.932\,kJ/kg$

$110.485\,kJ/kg = 44.229\,kJ/kg + x_4(202.932\,kJ/kg)$

$x_4 = 0.3265$

Part 2

|Superheated|

$s_2 = 0.9429\,kJ/kg$

$h_{s_2} = 285.85\,kJ/kg$

$\eta_{comp} = \dfrac{h_{s_2} - h_1}{h_2 - h_1}$

$0.8 = \dfrac{285.85 - 251.79}{h_2 - 251.79}$

$h_2 = 294.365\,kJ/kg$

|Superheated|

$T_2 = 60°F = 15.556°C$

$Q_{in} = 3028.3527\,Btu/min = 53.251\,kJ/s$

$\dot{Q} = \dot{m}(h_1 - h_4) \Rightarrow 53.251\,kJ/s = \dot{m}(251.79 - 110.485)$

$\dot{m} = 0.376851491 5\,kJ/s$

$\dot{W}_{in} = \dot{m}(h_2 - h_1) = 0.3769(294.365 - 251.79)$

$\dot{W}_{in} = 16.0444 5225\,kJ/s \Rightarrow$ **21.515 hp**

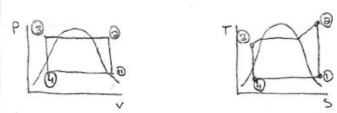
$COP = \dfrac{\dot{Q}}{\dot{W}_{in}} = \dfrac{53.251}{16.0444}$

$= 3.318977338$

$Q_{out} = \dot{m}(h_2 - h_3)$

$= 0.3768514915\,kJ/s\,(294.365 - 110.485)$

$Q_{out} = 69.295\,kJ/s$



State 1	State 2	State 3	State 4
$T_1 = -3.339°C$	$T_2 = 15.556°C$	$T_3 = 36.111°C$	$T_4 = -6.039°C$
$P_1 = 275.79\,kPa$	$P_2 = 1101.437\,kPa$	$P_3 = 1101.437\,kPa$	$P_4 = 275.79\,kPa$
x - superheated	x - superheated	x - subcooled	x - 0.3265
$h_1 = 251.79\,kJ/kg$	$h_2 = 294.365\,kJ/kg$	$h_3 = 110.485\,kJ/kg$	$h_4 = 110.486\,kJ/kg$
$s_1 = 0.94286736\,kJ/kg \cdot K$	$s_2 = 0.94286736\,kJ/kg \cdot K$	$s_3 = 0.3394\,kJ/kg \cdot K$	$s_4 =$ ——

$\dot{m} = 0.3768514915\,kg/s$ $Q_{out} = 69.295\,kJ/s$

$\dot{W}_{in} = 16.04445225\,kJ/s \Rightarrow 21.515\,hp$

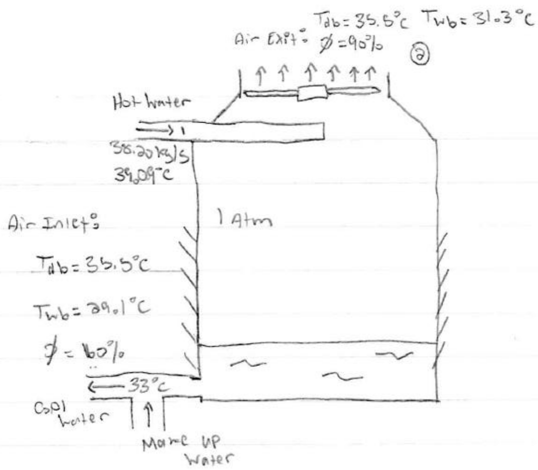
$COP = 3.318977338$

Fig 1.3 Calculations for 2a-2g

iii. Alternative Water-Cooling System

Part 3

Part 3



$\dot{m}_{H_2O} = 38.20$ kg/s

$T_{H_2O_1} = 39.09°C$

$T_{H_2O_2} = 33°C$

State 1	State 2
Air Inlet	Air Exit
$T_{db} = 35.5°C$	$T_{db} = 35.5°C$
$T_{wb} = 29.1°C$	$T_{wb} = 31.3°C$
$\phi = 60\%$	$\phi = 90\%$
$w_1 = 0.0119$	$w_2 = 0.0300$
$h_1 = 80$ kJ/kg Dry Air	$h_2 = 108$ kJ/kg Dry Air

$$\dot{m}_a = \frac{\dot{m}_{H_2O}\, C_{pH_2O}\,(T_{H_2O_1} - T_{H_2O_2})}{(h_2 - h_1) - (w_2 - w_1)\, h_w}$$

Interpolated

$h_w \Rightarrow h_x @ 35.5°C$

$h_w = 140.105$ kJ/kg

$C_p H_2O = 4.34$ kJ/kg·K

$$\dot{m}_a = \frac{(38.20\text{ kg/s})(4.34\text{ kJ/kg·K})(39.09°C - 33°C)}{(108-80)\text{ kJ/kg} - (0.0300-0.0119)\cdot 140.105\text{ kJ/kg}} \Rightarrow \frac{1009.64892}{25.4640995}$$

$\dot{m}_a = 39.650 \frac{kJ}{s}$ Dry air - Flow of outside air

$\dot{m}_w = (0.0300 - 0.0119)\, 39.650$

$\dot{m}_w = 0.718$ kJ/s Water - Make up water

Fig 1.4 Calculations for 3a & 3b

4. Plot Plans

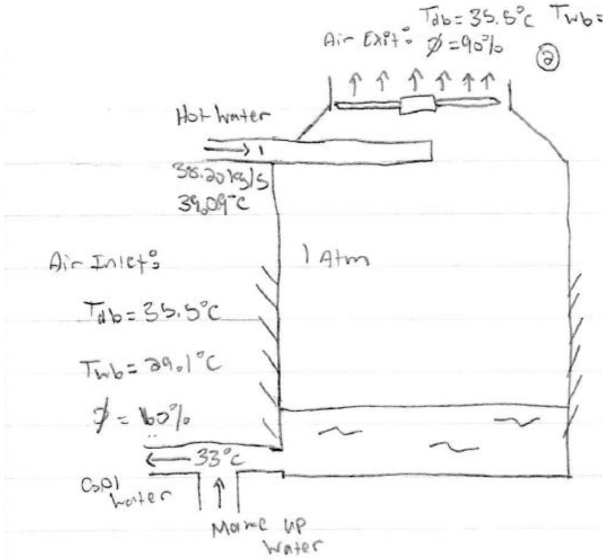


Fig 1.5 Schematic of proposed cooling tower

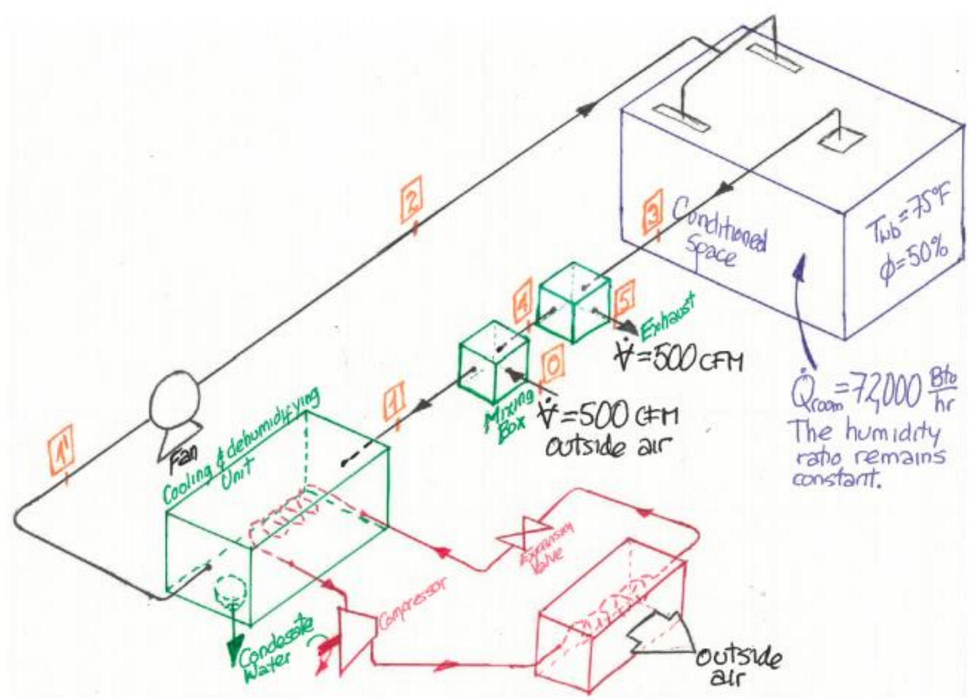


Fig 1.6 Layout of project area and system

5. Discussion

Originally, we wanted our design to be as small and thin as possible, but we realized that not enough air would be able to flow through the system, so we decided to go with a more traditional air-conditioning style unit.

6. Final Remarks

From the findings throughout the process of part a and part b, the results showed that we needed to be able to push the air and water successfully throughout the system by making sure flowrate was strong enough to keep a consistent motion. By using the psychrometric chart and the superheated and saturated tables in the book, we were able to accomplish that after determining the information from each state. The importance of this information helped us design the alternate water-cooling system that was also determined from the psychrometric.

7. Appendix

a. Foster Grubbs' Reflection

-When entering the job field, it is important to know the fundamentals of what we learned in school and to be able to apply them in a real-world setting. From what I've heard, a lot of companies will expect you to only know the basics of what you will be doing at your job, so it is good to have an understanding before you go in.

-Not from this class specifically, but also with thermodynamics, I will most likely be using them everyday when designing things, or at least have to think about them when developing.

-When explaining the project at an interview, I would explain what we were given and what we needed to calculate/design and the processes in which we achieved this. As for my contributions, I would include that technical writing and the process that were involved in this project.

-I would explain my strengths as having a good grasp on the fundamentals and practical applications of the class. As for my weaknesses, I would explain them as needed a better understanding of how to do the calculations.

-For our project, I feel that we have a good understanding on the calculations, but we could have added more information about the design of our systems.

-If I had to retake the class, I would tell myself to work on other problems outside of the assigned problems and attend office hours to have a better understanding of the material.

b. Jordan Whitaker's Reflection

Working on this project helped me realize the difficulties of trying to complete a given task with a short time frame and being somewhat disorganized and unknowledgeable about some of the problems presented. I think it would've been best if I was able to do more research about the information of what I needed and be more organized to complete a project in only a week. This valuable information will be crucial for application in an actual job involving systems that need to be created for the convenience of the client. If I were to be interviewed about this project I would present it as a task giving to my partner and I to develop an alternate water-cooling system that's calculations were determined from the environment and what the client wanted from the unit. I contributed to the majority of the calculations with my partner giving some of his insight throughout the process. I am very determined and hard working when given a task that needs to be completed. I don't shy from a challenge and willing to put in the work to be able to please my client. My weaknesses did affect the project for it wasn't worked on until we only had 3 days to complete it. This was because I was disorganized and worried about other things during the week. There was also issue of my trying to re-learn some of the knowledge shown to me earlier in the year. I addressed it by finally re-collecting myself and focusing on the project. With what I re-learned freshly in my head I was able to proceed through the problems that needed to be solved. The technical strengths of the project would be the mathematical side of it, showing that our information is close to what the client would want from the unit that we've created. The weakness aspect would be the report since it could be neater and have more guidance for engineers that may run into the same issues. I would tell my past self to make sure to stay organized throughout the school year and make sure to put in the effort in trying to imprint the information given to myself from the professor in order to improve my success rate with the final project.