Lecture 1 Notes

WI Capstone Design Process

phase 1 – planning
phase 2 – concept development
phase 3 – system level design
phase 4 – Detail design
phase 5 – Testing / refinement
phase 6 – Production ramp-up

Project learning → Roadmap → Conceptual design / prototyping → Detailed design → Fabrication validation → Product

↳ · Broadly define project
· Idea generation
· Problem definition
· High level analysis

Three areas of Project learning

People: · user groups · Focus groups · Ride-alongs
Tech: · Experimentation · Prototyping · Math models
Product: · competitive analysis · Observations · Dissection

→ Who are your stakeholders?
→ Ask questions to get to root cause
→ Have 20 questions for client interview

Areas of Need

· Functional performance
· Physical requirements
· Life cycle use
· Human factors / interface
· Reliability
· Manufacturing requirements

Conduct Observations & Activities

· Watch how product is used
· Personally use product
· Speak to those that use the product
· Identify & understand where and why changes can be made

Comparable Products

· Teardown competitors' products
· Learn what you can about pieces & parts

Marketplace Acceptance

· Understand what is important to customer
→ Technology → Research → Experiment → understand codes

14 June 17 | Team Formation

Important Product Specs

- Free/enterprise cooling
- Chill entire system, not individual heat sources
- Additives possible
- 75–100 tonnes cooling
- Fairly open size requirements
- South Campus chiller plant → location of final product
- Research & compile ideas
- 2-3 initial ideas → choose 1
- No set budget → minimize costs of course
- Water only
- 4 million gallons → total system storage
- Chilled water acts as regular temp water
- Water needs to be under 50 °F but above freezing
- High flow – erosion, low flow – fouling potential
- Velocity ≈ 4–9 ft/s

Warm water in → Chiller/Free cooling → Cold water outs → Device to be cooled → Warm water outs

Scott Smith — scsmith@uidaho.edu — Client contact info

Friday 1:30 in front of steam plant

- Bypass necessary → off for summer, on in winter

Tasks Completed

- All team members exchanged e-mail addresses & phone numbers
- Set weekly meeting for Tuesdays @ Noon in GJ design suite
- Met with Scott and discussed some of the basics of the project
- Began working on team contract

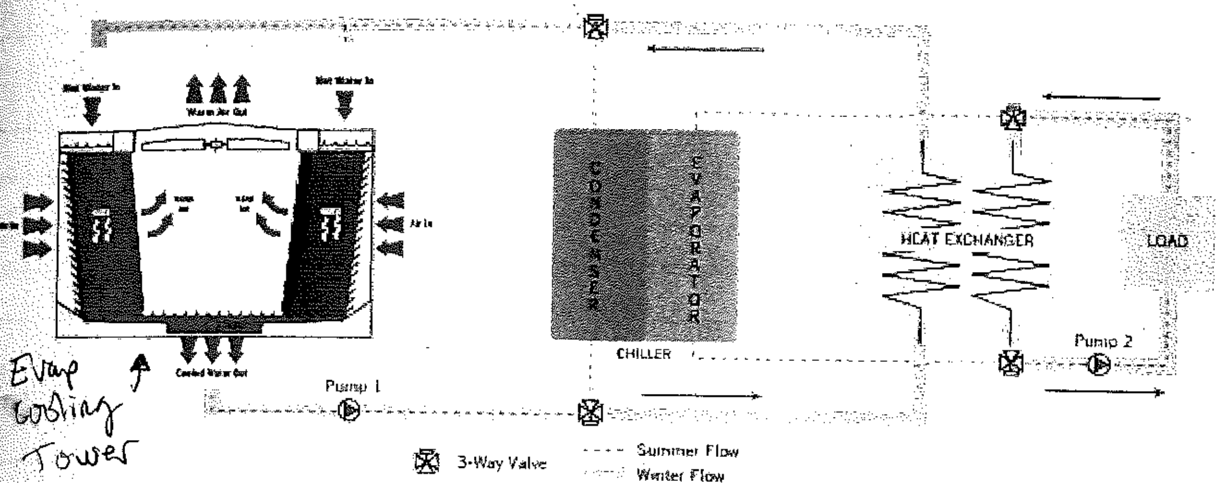
Reflection/Tasks Assigned

- We are each responsible for researching free cooling systems
- Frank is in charge of creating the team meeting agendas
- Kevin is in charge of documentation & will be typing up the team contracts
- Justin is in charge of the budget for the project

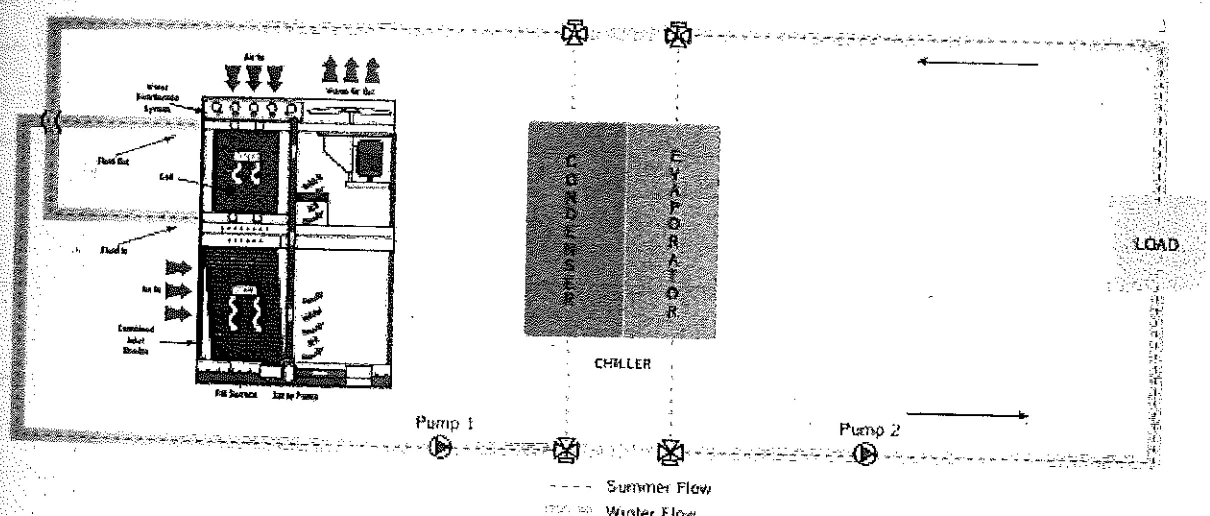
17 Initial Independent Project Research

Three Main Types of Free Cooling Systems

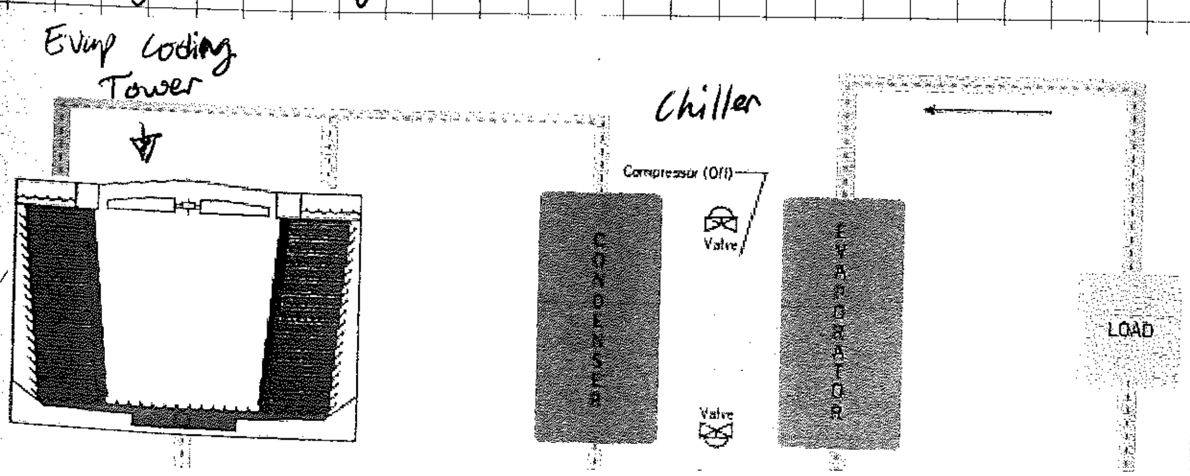
1) Cooling Tower & Heat Exchanger



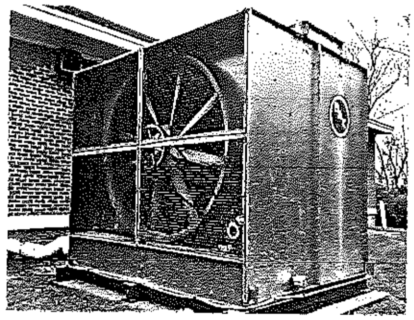
2) Closed Circuit Cooling Tower

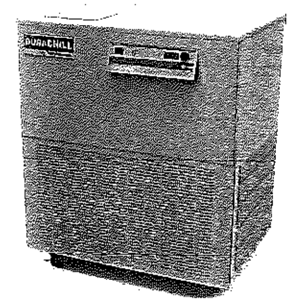


3) Refrigerant Migration



Common Components in all Free Cooling Systems





Cooling Tower — Conventional Chiller

Pros & Cons of each type of Free Cooling System

1) Cooling Tower & Heat Exchanger

- **Pros:**
  - Scott already owns a plate and frame heat exchanger ⇒ $ savings
  - Chiller completely bypassed in winter ⇒ lengthens chiller life
- **Cons:**
  - Heat exchanger must have $\Delta T > 5°$ to be economically realistic

2) Closed Circuit Cooling Tower

- **Pros:**
  - Tower water & cooling water don't mix, reduces contaminants in system
  - Very simple design ⇒ cooling tower & chiller
- **Cons:**
  - Requires special type of cooling tower ⇒ likely expensive

3) Refrigerant Migration

- **Pros:**
  - Simple design
  - Easy to switch from free cooling to conventional chiller cooling
- **Cons:**
  - Limited by phase change and requires very cold water to efficiently drive the cooling cycle
  - Doesn't completely bypass chiller in winter

Useful Links

http://baltimoreaircoil.com/english/resource-library/file/1473?dl=1
http://www.alabamapower.com/business/ways-to-save/chillers-space-cooling-options/free-cooling.html
https://en.wikipedia.org/wiki/Free_cooling
https://www.trane.com/Commercial/Uploads/PDF/11598/News%20Free%20Cooling%20using%20Water%20Econo
pdf

June 17

Lecture 2 Notes

Team Meetings

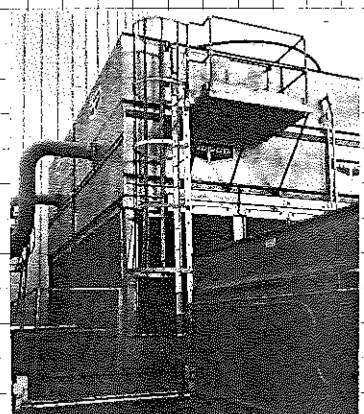
- Bring logbooks to all meetings
- Designate meeting leader, who brings the agenda
- Designate a recorder for the meetings
- Create a team binder
- Send Beyerlein agenda & meeting minutes for each meeting
- Review previous tasks and share progress with other members through logbook sharing
- Devote ample time to issues & future tasks
- Keep team contract handy
- Summarize key items in meeting minutes
- Circulate minutes

Email Guidelines

- Use meaningful subject line
- Don't reply to an old email with a new topic
- Keep to one topic per email
- Identify yourself & project in each email
- Identify required actions and who is in charge of completing those actions
- Don't send large files without receiver's permission
- Give files meaningful names
- Be very clear in email content
- Acknowledge that you received the email & its desired message by replying promptly
- Close the loop to better communication & understanding
- Be aware of email frequency
- Be polite
- Be careful with the "reply to all"
- Unreliable communication = uncertainty = death by 1,000 cuts

16 June 17 — South Campus Facility Tour

- Today we will tour the facility where our free cooling system will be installed

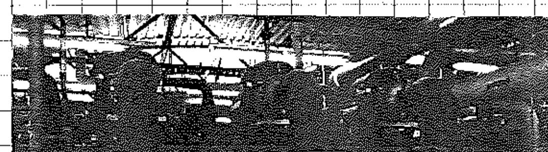


Cooling Tower

- Facility currently has two cooling towers
  - Must be drained in winter

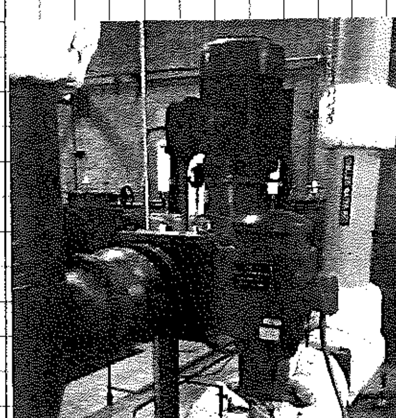
Current Problems

- Very prone to freezing
- Large amounts of water lost through evaporation
- water exposed to atmosphere so it must be chemically treated to prevent bacteria growth in system



Chiller

- Facility has two chillers
- Each chiller has four compressors that power R134a refrigeration cycle
- Variable output ≈ 10-125 tons

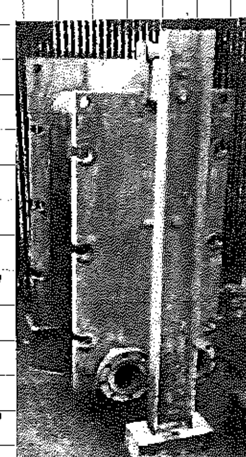


Specs

- 10 hp
- 1200 rpm
- 852 gpm

Plates

L = 32.5"
b = 16"
t = .04"
≈ 60 plates



Pumps

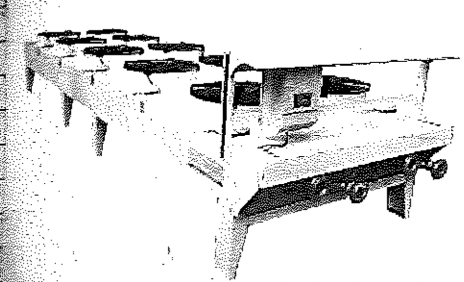
- Facility has two vertical inline pumps
- Used to pump water in cooling tower/condenser loop of system

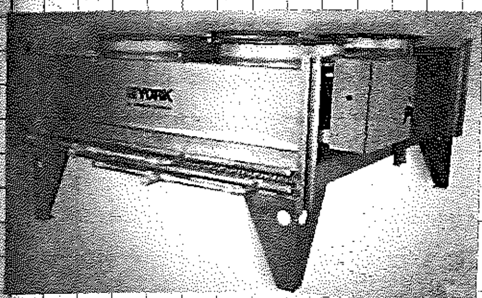
Plate & Frame HX

- potential use in our system
- Needs refurbished: new gaskets, paint, leak check

17 Potential Cooling Tower Alternative

Dry Coolers / Fluid Coolers

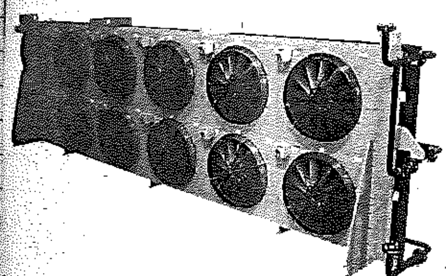




Horizontal/standard orientation

- Air flow from bottom to top
- Take up a fair amount of space
- less likely to impact neighboring units

Vertical Orientation

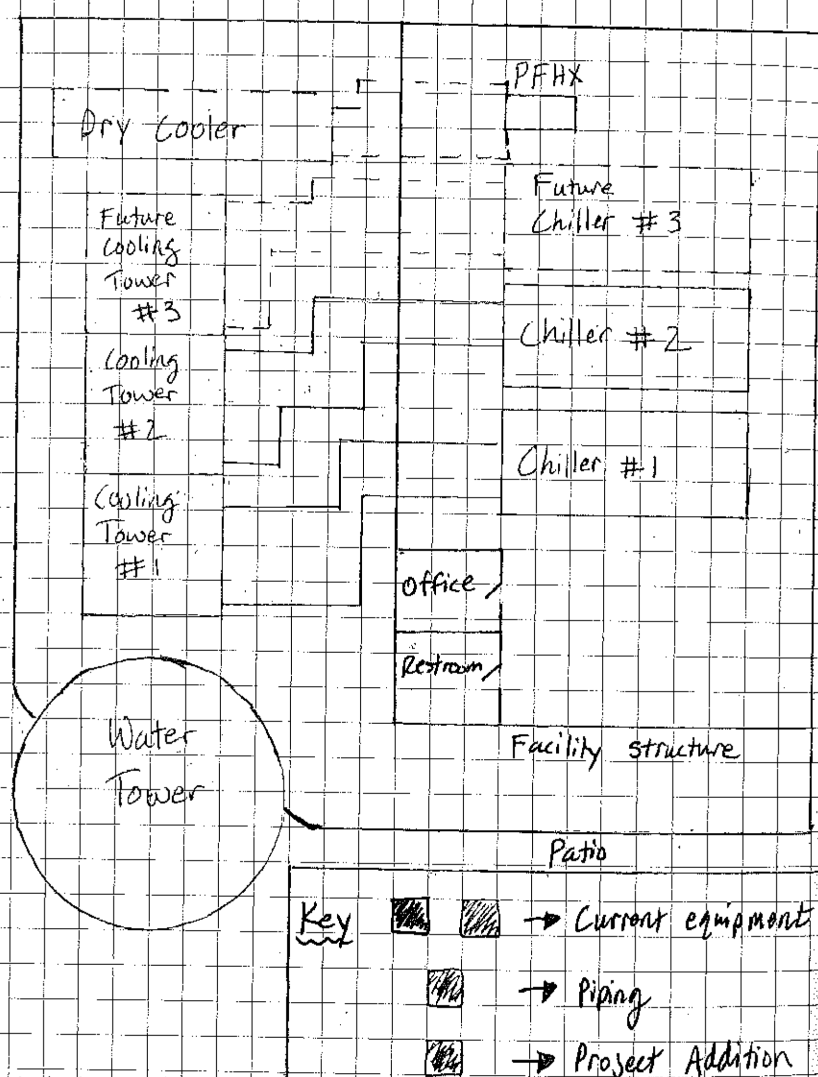


- Air flow from side-to-side
- Space saving
- Downside is the fact that efficiency is lower if multiple units are used in close proximity (exhaust from one unit enters inlet of adjacent unit)

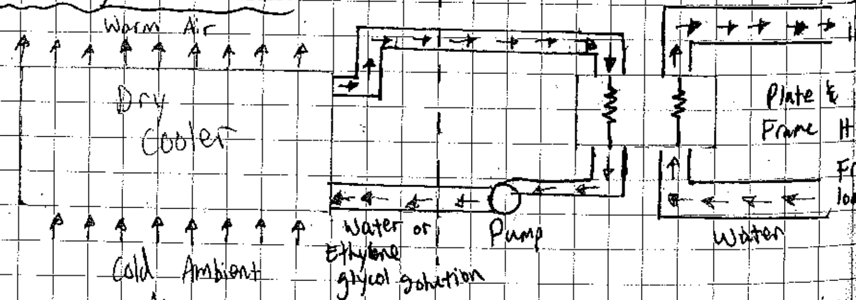
Benefits of Dry Coolers

- No evaporation = zero water loss
- Water is Not exposed to the environment
- Chemical treatment is not needed continuosly, only at time of system charging, if desired
- Dry coolers can cool liquids with 5-10 °F of ambient air temp
- Ethylene/propylene glycol can be added as antifreeze
- Low maintenance & long operating life

18 June 17 Initial Independent System Design



Project System Schematic



For increased cooling, could add another dry cooler & PFHX in series/parallel ne 7

Lecture 3 Notes

Rationale for Specs

- Need to know when you're done
- Need to know what is 'good'
- Agree on target specs before design development
- Refine & validate final specs before detail design
- Use specs to prevent scope creep

Developing Specs

Client Interview → list of needs → Target specs → Design/Development → Final specifications

Specs vs Needs

- use customer language to describe what customer wants
- subjective

Specs

→ [redacted] Consists of metric and a value

+ Measurable performance standards

Customer Needs

- Take notes
- Send list of needs back to customer for approval

Target Specs Process

1) Create list of customer needs
2) Prioritize customer needs
3) Prepare needs-metrics matrix
4) Establish ideal & marginal values
5) Compile benchmark info
6) Set appropriate target values

Target Value Selection

5 ways

At least, at most, between, exactly, set of values

Final Specs

- Develop technical models
- Develop cost model
- Refine target specs
- Make compromises
- Set appropriate values for final specs

Project Management

- Tasks must be assigned
- Time limits made
- Issues confronted & solved

Initiation → Planning & Design ⇄ Executing ⇄ Monitoring & Controlling → Closure

Measuring, evaluating, correction – Three good questions

Tools

- Team contract
- Mission statement
- Action register
- Meetings
- Project status report
- Schedule

20 June 17 | Instructor / Team Meeting #1

- Attendance: All members

Team Contract

- Dr Maughan looked over the contract and said it looked good
  - ↳ Made the suggestion to keep project learning in binder as well as in our logbooks

Logbooks

- Dr Maughan looked at our logbooks and also approved of what he saw
  - ↳ Suggested that we make frequent entries in our logbooks
  - → Also said to make entries meaningful and not just a list of tasks completed
    - i.e. calculations, reasonings, justification
- Ground source cooling?
- Need to justify all decisions made during project
- Understand what resources we have available for our use during the project

Schedule

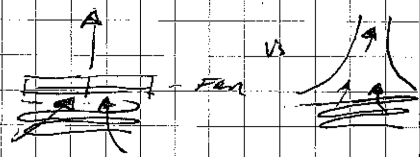
- Showed Dr Maughan rough schedules
  - ↳ said they could show more detail
- Prototype if possible
  - ↳ I don't think this is a viable option for our system
- Need to create list of customer needs

Reflection

Overall, this meeting was helpful in the fact that our work so far was checked over and deemed satisfactory. However, I think Dr. Maughan misunderstood the scale and scope of our project, since he did not seem to believe that our system was actually going to be built full scale.

17 Team Meeting #1

- Attendance: All members → Frank 10 mins late
- Need to do cost benefit analysis between forced vs natural convection
- Inlet temp 60-65 °F
- outlet temp 50-52 °F



- Many different dry cooler shapes
- Lifetime minimum → 10 years
- Reuse old heat exchanger
- Ground cooling not a great option
- Justify all our decisions with facts & calculations

1 tons = 12,000 $\frac{Btu}{hr}$

- Need to size heat exchanger, pump, & dry cooler
- Pump will be VFD
- Need to plan for snow storms, other inclimate weather

Future meetings:
↳ Top of Mcclure
→ Steam Plant

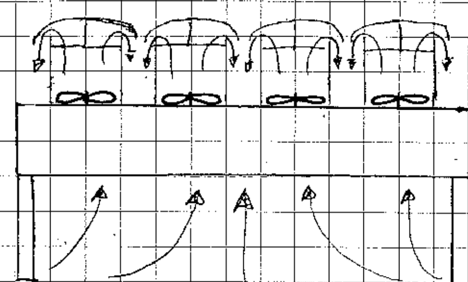
Also wants to show us the program that controls the current cold water system.

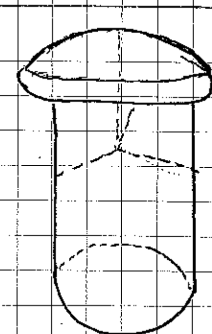
- Our system will be directly connected to the water tower
- This means that our system won't be directly connected into the cool water piping system.
  → However, this does not change any aspect of our design

Reflection:

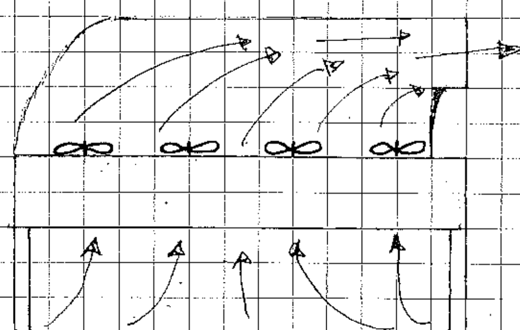
Todays meeting with the team and Scott was very beneficial. We got all of our questions answered and showed Scott where we are in our design. He seemed very pleased with what we have come up with and we decided to pursue our dry cooler / PFHX design.

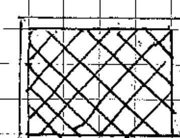
22 June 17 Dry Cooler Fan Protection Ideas





1) Individual pipe & cap

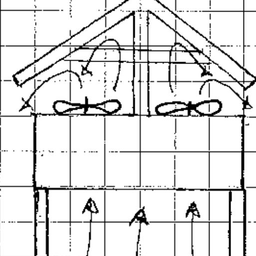




Possible screen on outlet to prevent debris from entering

2) Hood / Air Diverter

Pros & Cons



1) Simple design by may impact flow
2) Has less impact on flow but may be hard to manufacture
3) least restrictive but may not provide full protection to the fans

3) "Roof" / A-Frame cover

- Fan protection is necessary due to the likelyhood of snow & ice buildup on the dry cooling unit, especially if the unit is not running.
- Ideal fan protection will sufficiently shield the fans from inclimate weather without largely impacting the air flow

17 Lecture 4 Notes

Wikipage

- Descriptive name / title
- Naming convention for files/pictures

Needs

- Couple sentence description
- background
- specifications
- development & prototypes
- Need to cite sources
  - ↳ Try to use own images
- Make sure name is good, can't change
- Will get validation email when creating wiki
- Need to use Metadata box
- File naming: 2017_teamname_file description
- Use shared drive
- Wiki page name: Seasonal Free Cooling of University Data Center

Creation steps

1) Register a user
2) Create a new wikipage with a new title
3) Populate page with project information
   - ↳ Few sentences to describe project
   - ↳ Table of contents
   - ↳ Problem definition
   - ↳ Background, deliverables, specifications
   - ↳ Project Learning
   - ↳ Last two sections: Team Info & Document Archive

- Store copy of all wiki info on shared drive
- Possibly use code from other teams as a source code to edit for our project
- Use cheat sheet to help with page coding

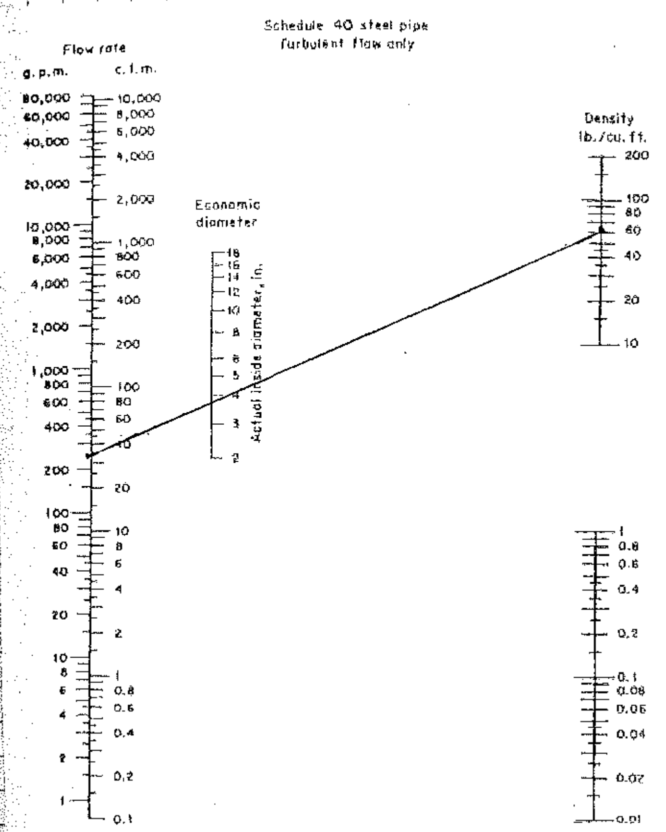
27 June 17 — Instructor/Team Meeting #2

- Thurday @ Noon, Front of steam plant → Meet Scott
- Next weeks instructor/team meeting → [redacted] Thursday @ noon
- pump flow range ≈ 250 gpm
- Two pumps, two heat exchangers (Dry cooler & PFHX)
- Approach temp ≈ 10° (Δ)
- Want to look @ all equipment to see if we can reuse
- For chilled water, losses are from piping & the pump & valves
- For fans, look @ manufacturers specs
- Fan placement matters for frost/ice buildup
- Run different temperatures for system
- Glycol flow may be ≈ 20% greater than water flow
- wind from west ≈ 90% of time
- Pipe class = 300 sch 40 steel pipe
- All design & calculations complete by end of summer
- shell & tube cleaning is hard
- HX too big → increase capacity of system, not bad if you already have it
- Try to use industry tools rather than textbook tools
  - ↳ more streamlined and easier to use

Reflection

Today's meeting went quite well. Both Scott and Dr Beyerlein seemed very pleased with where we are at in the project. At this point, we have the major components for the system selected, we just need to size everything out and determine if we own equipment that we can reuse and price out items that we are going to have to buy.

7 Estimation of Economic Diameter & Velocity



Coolant Loop

- Density of 20% Ethylene Glycol at 45 °F: $62.54 \frac{lbm}{ft^3}$
- Estimated Volumetric flow rate in coolant loop: 250 gpm
- To use this chart, connect Flow rate and density with line. where it crosses diameter scale is recommended inner diameter.

Based on this chart for sch 40 Steel pipe, the economic inside diameter is approximately 4"

TABLE 6.4
Economic velocity for schedule 40, carbon-steel pipe

Fluid density, lbm/ft^3	Economic velocity, ft/s
100	5.1
50	6.2
10	10.1
1	19.5
0.1	39.0
0.01	78.0

- To estimate economic velocity, the table to the left only requires the fluid density
- Again we will use $62.54 \frac{lbm}{ft^3}$
- Interpolating, this produces a value of approximately

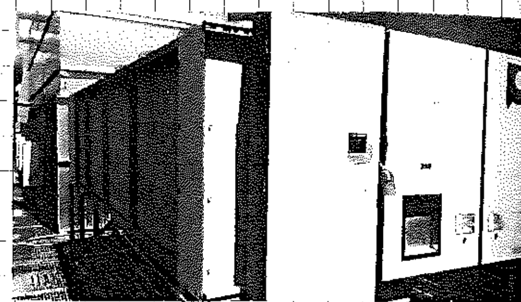
5.92 ft/s for economic velocity

While these values are estimates, they are quite reasonable and it is likely that our finalized system will use a pipe size similar to 4 Nom sch 40 and run with a velocity in the pipe, on average, at 6 ft/s

29 June 17 — North Campus & McClure Facility Tour

North

→ Chiller that will be moved to the south facility next year.

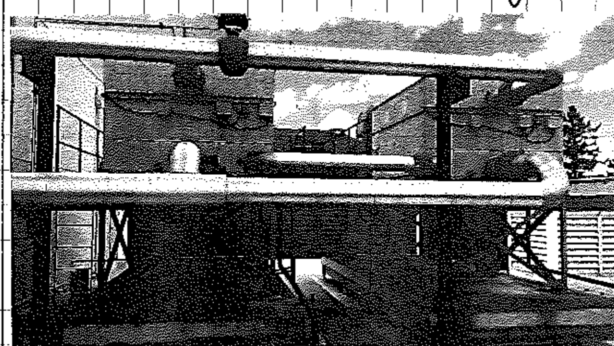


↑ Potential Dry Cooler alternative

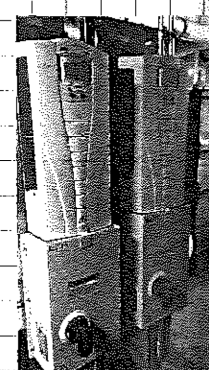
Pros: • Already have it
• Enclosed system

Cons: • Currently R12 or similar systems • Very loud → inefficient
• Would have to heavily modify to fit our needs → EG and VFD Fans
• Capacity of only ≈ 90 tons ref • Sitting for 10+ years unused

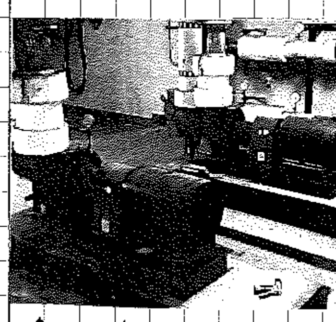
McClure: Home of Failed Free Cooling System



↑ Cooling Towers with detached, indoor basins
↳ still have problem with freezing



↑ VFD unit for primary pumps



↑ Secondary pumps

↑ personal favorite for system currently

Potential PFHX for use in our system ←
≈ 250 ton ref
• oversized but not a bad thing because it is equipment we already own.

17 Instructor/Team Meeting #3

↑ page #
error: Pg 17-24 omitted by notebook manufacturer AL

- Need diagram with stream flow / important values of system
- Need bill of materials
  - → could show specs for each piece of equipment
- Will be valves, wyes, other minor losses in the system
  - → need to take into account for pump selection
- Old Dry Cooler
  - → most of the noise from the compressor
  - → fans not so bad hopefully → may swap for VFD
- Try to estimate labor cost estimate
- Get a quote for PFHX to see savings by repurposing
- old dry cooler could produce more than 90 tons
- Calculations run for PFHX in McClure
  - → exceeds our needs, but not drastically, so it is a good fit for our system
- I got a good start on the wiki page over the weekend
  - → will still need to add more text along with pics & diagrams to be ready for Monday's presentation
- Meeting with team tomorrow to work on wiki and prepare for monday presentation
- Beyerlein will collect logbooks & portfolio on Tuesday after our meeting
- By Next Meeting
  - Labor cost estimate
  - Wiki updated and ready for presentation
  - Drawing of our system on existing floor plan

Reflection

Today's meeting went fairly well and we made some more progress on the design of our system. We will most likely be able to use repurposed parts for most of the system (Dry cooler & PFHX) which is good.

7 July 17 Initial WikiPage

For the past week, I have been working on creating the WikiPage for our team. So far, I have completed problem definition, background, deliverables, and specifications sections. Below is a copy of the code for the WikiPage.

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}}
{{InfoboxEntry
|title = Sponsor
|content =
<ul>
<li>[http://www.uidaho.edu/infrastructure/facilities University of Idaho Facilities]</li>
</ul>
}}
{{InfoboxEntry
|title = Team Name
|content = Free Breeze Brothers
}}
{{InfoboxEntry
|title = Duration
|content = Summer - Fall 2017
}}
{{InfoboxEntry
|title = Faculty Adviser
|content = Dr. Steve Beyerlein
}}
{{InfoboxEntry
|title = Client
|content = Scott Smith
}}
{{InfoboxEntry
|title = Team Members
|content =
<ul>
<li>Kevin Marwan</li>
<li>Justin Hinrichs</li>
<li>Alex Leppek</li>
<li>Frank Guo</li>
</ul>
}}
|}
```

The design and implementation of a free cooling system to chill water for the UI campus, during the winter months, is the main goal of this project. By considering system economics, environmental impact, and overall optimization, among other factors, the designed system will provide an efficient, cost-saving method of cooling water through the use of cold ambient air.

==Problem Definition==

Currently, to chill water for campus, the University uses vapor-compression chillers throughout the entire year. While this process is able to handle the load, this type of system experiences problems during the winter time. The main issue is with the evaporative cooling towers, which are prone to ice build-up. The reason for this is that the cooling water is directly exposed to the freezing conditions. When this build-up happens, damage may occur to the system, so ice must be manually removed from the cooling towers. There are a few methods for ice removal, but none of them are very efficient and all require human intervention into an otherwise automated system. Other than freezing, which interrupts system operation and is hard on equipment, other issues include working fluids freezing within pipes and flash freezing of humid exhaust air.

==Background==

Free cooling, also known as enterprise cooling, involves utilizing relatively low temperature ambient air to cool a working fluid within a system. Conversely, a conventional method for completing the same task would be to use refrigeration cycle chiller. However, free cooling is enticing for a few reasons. First, air is a working fluid within the system that does not have an associated monetary cost, hence the name "free" cooling. Secondly, operational costs for a free cooling system are generally lower, due to the fact that pumps and fans are the only main components that must be powered. In a conventional system, compressors and cooling towers, along with pumps, produce a much higher power demand while operating. Finally, a free cooling system can be a completely enclosed system, protecting it from the environment and eliminating the need for make-up water and continuous chemical treatment of the system.

==Deliverables==

For this project, the final product will be a complete design and analysis, with supporting calculations, of a free cooling system to chill water for the UI campus during the winter season. Once our design has been approved, the University will purchase and install the components outlined in our design to create a full scale, operational free cooling system.

==Specifications==

[[File:2017_FreeBreezeBrothers_Specs.JPG|frameless|center|650px|]]

==Project Design==

[[File:2017_FreeBreezeBrothers_HXs.JPG|center|600px|thumb|left|Potential Heat Exchangers for System]]

July 17 Initial Wikipage Presentations

Cerebrospinal Fluid Pump
Cardiac frequency pump · MRI compatable if possible
syringe type design · Belt & Flywheel design

ME 430 Experiments
Solar panel - single axis or double axis · photoresistors
Heat pipe - reverse engineering heat pipe for experimentation
· use labview · purchase off shelf ≈ 24" but most ≈ 6"

Bandbeasten
· Showmanship · Sousaphone stand - mostly all same size
- 30-40 lbs
- Have to fix to bleachers

Robotic Arm Cell
· Arms will perform drilling process · Add camera to robotic arm
· May have arm sort shapes · Arms are very complex
· Need to make safety mechanism · Pendant - joint angles

Logbooks
· Print out review form & put in logbook

Design Review
1) Validate problems definition
2) Dialouge with client
3) Agree on path forward
Powerpoint
Will be judged by peers / instructor / client
Use specs as checklist
Highlights trade-offs
Look at feedback objectively

Reflection
It seems that all teams have a very solid start on teir projects and have a good path laid out. I think our presentation went very well and that we were able to answer all of the audience's questions with ease.

10 July 17

LOGBOOK REVIEW FORM #1

Engineer	Reviewer	Date
Alex Leppek		10 July 2017

STEP 1: Inventory your six best logbook entries and rate each one using the rubric given to the right.

1 – Missing
2 – Incomplete, minimal long-term value to author
3 – Complete, clear long-term value to author
4 – Exemplary, considerable long-term value to others

Entry	Date	Rating (circle one)
Initial Independent Project Research	14 June 17	1 2 (3) 4
South Campus Facility Tour	16 June 17	1 2 (3) 4
Potential Cooling Tower Alternative	16 June 17	1 2 3 (4)
Initial Independent System Design	18 June 17	1 2 3 (4)
Dry Cooler Fan Protection Ideas	22 June 17	1 2 3 (4)
Estimation of Economic Diam. & Velocity	28 June 17	1 2 (3) 4

STEP 2: Self-assess your logbook in the areas below using the scales provided (*circle one*).

Project Management (in the context of ME 410, consider your client to be mentors, staff, and instructors) — (3)

Goals	1 – missing	2 – vague	(3) – multiple/divergent	4 – focused & strategic
Action Items	1 – missing	2 – minimal	(3) – clear & sequenced	4 – tasks remove bottlenecks
Team/Client Notes	1 – missing	2 – minimal	3 – moderate	(4) – extensive
OVERALL RATING	1 – insufficient	2 – sub-standard	(3) – good	4 – excellent

Design Development — (4)

Notes & Analysis	1 – missing	2 – sparse	3 – relevant	(4) – detailed, extensive
Decisions	1 – missing	2 – random, sparse	3 – highlights	(4) – comprehensive, justified
Illustrations	1 – missing	2 – unclear, messy	3 – basic w/o discussion	(4) – detailed w/ discussion
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

Assessment (of self & team) — (3)

Reflection	1 – missing	2 – little awareness	(3) – occasional	4 – regular & effective
Strengths	1 – missing	2 – little awareness	(3) – moderate	4 – detailed knowledge
Improvement	1 – missing	2 – little awareness	(3) – some areas cited	4 – detailed action plan
OVERALL RATING	1 – insufficient	2 – sub-standard	(3) – good	4 – excellent

Organization — (4)

Entries	1 – insufficient	2 – on demand, sparse	3 – regular	(4) – regular & spontaneous
Labels	1 – missing	2 – sparse & generic	3 – consistent	(4) – informative
Layout	1 – unclear	2 – haphazard	3 – readable	(4) – clear, structured, logical
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

My two greatest strengths in my logbook are organization and frequent entries. Organization adds value because it allows both myself and others to quickly find the desired information in my logbook. Frequent entries add value because it provides a better explanation of the path I took from start to finish on each of my tasks and the overall project. The two areas where I need the greatest improvement are assesment and project management. I can implement both of these by taking the time to explicitly document my goals for the week and do more reflections on my logbook entries.

Plan out time to do these on R[illegible] Review

July 17 Instructor/Team Meeting #4

- Floor Plan
  - ↳ Visio
- Fans → 73,365 CFM for dry cooler
  - → 11 hp each → 2-pass
  - → 14 ft - coil length → possible program change for fans
  - → VFD likely
- Need to do a pump comparison
  - ↳ should include minor losses
- Glycol concentration vs performance loss
- Cooling towers shut off before freezing = 12 hrs [redacted] of 32 °F
  - once towers are drained, no refill
- Look at october temperatures, find worst case conditions
- Warmest periods October & April/May
- McClure chiller only winter solution currently
- Could use old fans & motors with VFD
  - → Could run only some fans on VFD, other direct drive

Design

- Design from scratch
- Design with repurposing

} summary of specs, Performance models, Bill of materials for both, Floor plan

- Two distinct topics, associated costs
- Compare the two designs
- Installation → rough estimate
- Potential Design Review 1:00 pm July 31st

EXCELLENT JOB! FOLLOW THROUGH W/ IDEAS FOR LOGBOOK IMPROVEMENT VIA A WIKI TRACKED ASSIGNMENTS AND PROJECT MANAGEMENT ON A REGULAR SCHEDULE. SHARE YOUR LOGBOOK PRACTICES WITH OTHERS IN ME 429.

13 July 17 — Ethylene Glycol Research

Freezing Point Tables

Ethylene Glycol Solution (% by volume)		0	10	20	30	40	50	60
Temperature	(°F)	32	25.9	17.8	7.3	-10.3	-34.2	-63
	(°C)	0	-3.4	-7.9	-13.7	-23.5	-36.8	-52.8

↑ Table from Engineer's Toolbox

Temperature °F (°C)	Percent (vol.) DOWTHERM Fluid Concentration Required: For Freeze Protection		For Burst Protection	
	Volume % DOWTHERM SR-1	Volume % DOWTHERM 4000	Volume % DOWTHERM SR-1	Volume % DOWTHERM 4000
20 (-7)	16.8[1]	17.3†	11.5[1]	11.9[1]
10 (-12)	26.2	27.1	17.8[1]	18.4[1]
0 (-18)	34.6	35.7	23.1[1]	23.8[1]
-10 (-23)	40.9	42.2	27.3	28.1
-20 (-29)	46.1	47.6	31.4	32.5
-30 (-34)	50.3	51.9	31.4	32.5
-40 (-40)	54.5	56.3	31.4	32.5
-50 (-46)	58.7	60.6	31.4	32.5
-60 (-51)	62.9	64.9	31.4	32.5

← Table from DOW Products, which is specific to their formula of Ethylene Glycol (Includes corrosion inhibitors & other additives)

Recommendations from EG Manufacturers

Due to possible slush creation, ethylene glycol and water solutions should not be used in conditions close to freezing points.

For freeze protection, the required concentration of inhibited glycol fluid in the system depends on the operating conditions of the system and the lowest expected ambient temperature. To obtain adequate freeze protection, the glycol solution must maintain a freezing point at least 5°F below the lowest anticipated temperature. See the links below for concentrations of Dow heat transfer fluids required for freeze protection at different temperatures.

mixture ratio of the glycol. For example if a coolant loop or system is being winterized and temperatures will fall down to -10°F at the lowest, a mixture of 30% propylene glycol to 70% water will be enough to protect the system. 30% propylene glycol has a freeze point of 8°F but the burst point is -18°F. This system will be protected but the coolant will be slushy. By definition, freeze point is the temperature where ice crystals begin to form. The fluid will become slushy but will not expand. The burst point of a fluid is the temperature where the fluid will freeze solid, expand, and break pipes or damage other parts of the equipment.

- Based on all of these recommendations, I believe that, for our system, an Ethylene Glycol concentration of 40% will be a minimum. However, for a safety factor, we may want to go with a 45-50% concentration. This way, the ethylene glycol will never freeze and likely never slush. This would be beneficial because, not only would our system not freeze, but it would never be "too cold" to run the system.

July 17 More Ethylene Glycol Research

Specific Heat

- While adding more EG to our system provides better freeze protection, it also lowers the specific heat and system performance.

Specific Heat - c_p - (Btu/lb.°F)

Temperature (°F)	Temperature (°C)	Ethylene Glycol Solution (% by volume) 25	30	40	50	60	65	100
-40	-40	1)	1)	1)	1)	0.68	0.703	1)
0	-17.8	1)	1)	0.83	0.78	0.723	0.7	0.54
40	4.4	0.913	0.89	0.845	0.795	0.748	0.721	0.562
80	26.7	0.921	0.902	0.86	0.815	0.768	0.743	0.59
120	48.9	0.933	0.915	0.875	0.832	0.788	0.765	0.612
160	71.1	0.94	0.925	0.89	0.85	0.81	0.786	0.64
200	93.3	0.953	0.936	0.905	0.865	0.83	0.807	0.66
240	115.6	2)	2)	2)	2)	2)	0.828	0.689
280	137.8	2)	2)	2)	2)	2)	2)	0.71

- Due to this performance loss, the flow rate of the system must be increased in order to provide the same cooling capacity. Below is a 50% EG solution compared to clean water at certain temperatures.

Fluid Temperature (°F)	Fluid Temperature (°C)	Flow Increase (%)
40	4.4	22
100	37.8	16
140	60.0	15
180	82.2	14
220	104.4	14

Note! The specific heat of ethylene glycol based water solutions are **less** than the specific heat of clean water. For a heat transfer system with ethylene glycol the **circulated volume must be increased** compared to a system only with water

- This substantial difference in required flow rate will need to be taken into account when sizing pumps. We do not want to get a pump that does not provide a high enough flow rate for the amount of heat transfer that we need in our system.
- However, we have to make this performance trade-off in order to protect our system from freezing. Better to run at a higher flow rate than have to shut system off entirely.

18 July 17 | Instructor/Team Meeting #5

- Weather data - has dry bulb, wet bulb, rel hum, & other data
  - hourly
- Presentation will be in Facilities management building
- Meeting (Instructor) on Thursday next week @ noon
- Problem statement & specs slides in presentation
  - Initial charge
- Use specific titles → designed with new vs designed with reused
- BOM & costs for each design
- Will need to purchase pump
- Timeline/schedule in powerpoint
- Current cost vs cost of our system (energy & maintenance)
- Highlight important decisions in design review
- Q & A after design review - facilities engineering group
- V_{econ} = 4-8 ft/s for corrosion & erosion purposes
- Scott getting ROM pricing for PFHX
- Need to plan for presentation
  - ↳ prepare for questions
  - ↳ plan for who says what
- Presentation ≈ 25 mins long

Action Items

- Scott will send weather data & get quotes for PFHX
- Kevin will make necessary changes to the design review powerpoint
- Frank will work with Scott to ~~a~~ fix floor plan
- Justin and myself will assist in the above tasks when necessary.

Reflection

Today's meeting went quite well and we are moving along nicely on the path to a finalized design. At this point, we are mainly working on nailing down the specifics and sizing the equipment we will need to purchase

Sizing Piping for the System

We know that the economic velocity for our system is in the range of 4-8 ft/s

- This is the optimal range for fluid flow that minimizes both corrosion and erosion of the inside walls of our piping
- Direction changes in the system (wyes, tees, etc) are the most prone to erosion.

From the economic velocity, along with the expected average volumetric flow rate of the system, a range for the economic diameter can be calculated.

- To acquire this range, we will determine the economic diameter at 4 ft/s and 8 ft/s
- $\dot{V} = 350 \text{ gpm} = .78 \text{ ft}^3/\text{s}$

$$V_{econ} = \frac{4\dot{V}}{\pi D_{econ}^2} \qquad V_{econ_4} = \frac{4(.78 \text{ ft}^3/\text{s})}{\pi D_{econ_4}^2} \approx 6''$$

$$V_{econ_8} = \frac{4(.78 \text{ ft}^3/\text{s})}{\pi D_{econ_8}^2} \approx 4''$$

The above calculations yield an economic diameter range of 4-6". However, it would be most ideal to go with 6 nom sch 40 steel pipe for our system.

- The reason that it is better to go with a larger size pipe is the fact that there would be less friction, and, in turn, less pressure/head loss within our system.
- Less head loss means that the pumps within our system will not have to work as hard to move our fluids, resulting in higher overall system efficiency
- The higher cost of larger piping is offset by operational savings

24 July 17 — Updating Wikipage #1

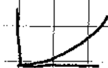
For this update, I mainly focused on the "Project Design" section of the page. Tasks I completed included: updating the decision table, adding some additional text to clarify images and tables, and general editing for understanding & easy to [redacted] comprehend structure. I also added "Team Members" and "Document Archive" sections. Code for some of these tasks below.

```
==Project Design==
The following information provides evidence and reasoning for the decisions that we made during the design of our system.
[[File:2017_FreeBreezeBrothers_HXs.JPG|center|600px|thumb|left|Potential Heat Exchangers for System]]
[[File:2017_FreeBreezeBrothers_Hxtable.JPG|center|500px|thumb|left|Heat Exchanger Comparison]]
Above is a comparison of two potential heat exchangers for use in our system, along with a table of important values from a hypothetical test system.
{| class="wikitable" style="text-align: center;"
|+ Decision table
|-
! Decision
! Selection
! Justification
|-
| Conventional Cooling Tower vs Dry Cooler
| Dry Cooler
| The dry cooler meets all of the specifications for this project. These include: 1) Keeping the coolant from freezing. 2) Keeping the coolant from being exposed to the environment. 3) Utilizes cold ambient air or "Free Cooling" to chill coolant instead of refrigeration cycle.
|-
| Shell and Tube vs Plate and Frame Heat Exchanger
| Plate and Frame
| The plate and frame heat exchanger is a much better fit for our project due to its efficiency, space requirement, and ability to be easily modified by adding or removing plates, for different cooling loads. Also, it is much easier to clean and maintain opposed to a shell and tube.
|-
| Conventional Pump vs VFD Pump for Coolant Loop
| VFD Pump
| Due to the fact that our systems uses ambient air, which has a large temperature range, our system will require a VFD pump to vary the flow through the coolant loop i.e. less flow when ambient temps are lower and more flow when ambient temps are higher.
|-
| Water vs Ethylene Glycol in Coolant Loop
| Ethylene Glycol
| Since our system will be operating in sub-freezing temperatures, it is important that our coolant fluid does not freeze. An ethylene glycol solution has a lower freezing point than water, so this added safety factor against freezing makes sense for our system.
|-
| Free vs Forced Convection in Dry Cooler
| Forced Convection
| Based on our calculations, forced convention is much more feasible for the system. With free convection, the size of dry cooler necessary is very large and expensive. Additionally, forced convection gives us much greater control of system efficiency and performance.
|-
| Top vs Bottom Mounting of Dry Cooler Fans
| Top Mounting
| For our system, it makes more sense to have the bottom side of the heat exchanger open and have the fans draw air through the system. All we will have to add is a method for protecting the fans from ice and snow. Lastly, most manufacturers produce the dry coolers with top mounted fans, and it would likely be an added cost, if even possible, for underside mounting of the fans.
|-
| New PFHX vs Repurposing Old PFHX
| Repurpose Old PFHX
| Because we have access to a PFHX in good condition that we can reuse, it was a simple decision to go this route instead of buying new.
|-
| New Dry Cooler vs Repurposing Old Dry Cooler
| Repurpose Old Dry Cooler
| The university already owns a dated dry cooler that has been put out of service. However, by repurposing components from this piece of equipment, we can recycle it into a functioning dry cooler that will be proficient for our system. This way, we save the cost of purchasing a new dry cooler and salvage an otherwise abandoned component.
|}
Below are two schematics of our system, the first being a general system outline that shows all of the main components and the second being a floor plan of the actual installation location with options for placement of our system.
[[File:2017_FreeBreezeBrothers_SystSchem.JPG|center|1150px|thumb|left|System Schematic]]
[[File:2017_FreeBreezeBrothers_FloorPlan.jpg|center|750px|thumb|left|Floor Plan]]

==Team Members==
{| class="wikitable" style="text-align: center;"
|-
!
! Name
! Discipline
```

17 July 17 Instructor/Team Meeting #6

- System runs - mid-october - March
- ≈ $4200 for our system - will be less due to commercial power cost
- For Chiller ≈ $17,000 for 4 months of power
- When ambient temp = glycol in temp - heat will be added to system ≈ 60 °F
- Could look at only running @ night for certain parts of year
- Lowest temp recorded ≈ -18 °F
- VFD fans - smooth curve non-VFD - step curve

- Flow through Dry Cooler - how many hours do you need a certain flow (in each batch) then multiply by power consumption
- Payback period comparisons - cost of doing nothing
  - project for free cooler install cost
  - monthly cost of operating system
- Do simple payback
- ≈ $1000 per year for maintenance ≤ 5 year payback
- Repurposing parts saving lots of money/initial capital
- Need to know how many hours/24 hours system could be used
- For each month, # of hours below certain temperature
  - plot for each month
- Be general in presentation, more specific in Q & A.
- Meeting Tomorrow @ 4 pm

Action Items

- Kevin will complete payback period for system
- Frank will complete histograms for weather data
- I will flesh out schedule for rest of project

Reflection

Today's meeting went quite well and we are almost prepared for our design review on Monday. (≈ 90% ready)

28 July 17 | Preliminary Design Review Preparation

Today we will be reviewing the slides and handouts that will accompany our presentation on July 31st

Goals

- Decide who is speaking and when
- Decide what slides to have in main presentation versus backup slides to help answer potential questions
- Decide if all members are speaking or if only select members will speak
- Complete weather data analysis to give duty cycle chart for system

Economic Diameter @ < 200 gpm econ dia = 2.5 - 3"
@ 200 gpm economic diameter = 3-4.5"

- Bring excel files of EES results
  - ↳ No EES on presentation computer

[redacted]

Presentation

- Frank will present floor plan & weather data
- Kevin will discuss the two different designs
- I will discuss the problem statement & deliverables / specs
- If Justin wants to, he can present pump sizing & Ethylene Glycol Selection

Slides

- We went over the presentation slides with Scott and got his overall approval
- A few changes/additions will need to be made in order to have the presentation completely ready for Monday

Action Items

- Kevin will fix presentation & distribute it to all members
- All members will go over their assigned slides and be ready to present on Monday.

Reflection

I feel that we are adequately prepared for our presentation on Monday and that we will be able to effectively present our project

-17 Lecture 5 Notes

Snapshot
Expected outcomes: System Design & Data & Prototypes
- Team has developed idea for final design, taking into account client needs
- Team has created relevant prototypes and has assembled data/evidence that the conceptual design will work.

Preparation:
- update project portfolio - Bring all codes/models
- Pin-up poster
  - Team name
  - Team members
  - sponsor
  - problem statement
  - Table of specs
  - Major areas of project learning
  - Illustrate that design will work
  - Effectively communicate the final product
  - list unresolved issues and the plan for solving them
  - schedule/plan for project completion
- Can supplement poster with laptop

Delivery:
- Business attire
- Advance clean-up of station
- early set-up of location
- Make logbook entries with lessons from own project
- Take notes on other teams

Due by Friday, August 4th
- portfolio
- updated Wiki page
- Team member citizenship form
- Logbook review form
  - Do not staple review form into logbook

Meeting with team Wednesday, August 2nd @ noon to create poster for Snapshot and go over snapshot presentation schedule.

- No instructor/Team meetings this week due to design reviews being scheduled on these days

31 July 17 — Preliminary Design Review

Today, we presented our designed system to UI facilities and a few of our classmates. Overall, I feel that the presentation went very well and that we effectively conveyed our design, and the reasons we chose that design, to the audience. While there were many things that we took away from this review, below is a list of some of the major ideas/issues that we are planning on addressing in the Fall semester.

1) Provide a controls document for the end user of the system
   - ↳ simple if-then scenarios i.e. if the weather is going to be above 50°F for an extended period of time, shut off and drain system

2) Provide VFD pricing for pumps & fans
   - ↳ During review, it was roughly estimated that VFD for the pumps would be ≈ $1,200

3) Decide upon VFD or sequenced fans
   - ↳ We will have to work with Scott on this issue and it will be dependent on the dry cooling unit that we actually repurpose

4) Determine shipping costs for items we are ordering
   - ↳ Most important for large items like pumps and dry cooler (if we have to purchase a new ones)

5) Acquire expected life cycles of our components
   - ↳ This is to see if it is worth chasing small windows of cooling potential or not

6) Determine piping / valve / bypass placement
   - ↳ Has to do with water tower logistics/operation

Preliminary Design Review Results

ORGANIZATION 4.0/5.0
S: Outline followed a logical sequence
S: Provided a thoughtful summary of accomplishments/lessons learned to date
I: The ending seemed a bit abrupt -- take time to remind audience of your accomplishments
I: It would be a good idea to list items for discussion on the concluding Q/A slide

DELIVERY 4.0/5.0
S: Speakers were well-prepared and spoke with well-founded confidence
S: Voices were steady and clear
I: There was confusion about when to advance a couple of slides
I: Pace may be been a little fast (slow down and give audience time to read/fully assimilate each slide)
I: Strive to get all members involved in the presentation/discussion, inviting them to contribute

COMPLETENESS & ACCURACY 4.0/5.0
S: System components appeared to be well-researched and justified with vendor data
S: Multi-year Moscow weather data was used to define your duty cycle
I: More details could have been given about your EES model and its role in design decision-making

VISUAL AIDS 3.5/5.0
S: Visually attractive slides that piqued audience curiosity
S: Handouts with component specs and cost data provided for easy reference
I: Some of the fonts were small and hard to read
I: Label EXCEL sheets so it is clear what design case they represent

AUDIENCE INTERACTION 4.0/5.0
S: Good questions were generated by the presentation and Q/A lasted nearly as long as the talk itself
S: Took time to listen before responding to questions
I: Consider moderating the Q/A portion so more of the facilities staff can weigh in
I: Invite all group members (at appropriate times) to engage in the Q/A

DESIGN 4.0/5.0
S: Two relevant design options were considered
S: Nice deployment of engineering modeling tools in equipment sizing
S: Detailed design of ethylene glycol system, including suggested water/EG mixture
S: Very compelling return on investment (especially with repurposed equipment)
S: Conservative economic analysis was employed to insure that design was not oversold
I: Pump costs (including VFD) need to be made more concrete
I: Start to inventory issues that might surround equipment positioning & pipe routing
I: Make sure your fully account for costs associated with operating in the current mode
I: Have you identified special instrumentation for acquiring system performance data

PROJECT MANAGEMENT 4.5/5.0
S: Great awareness of costs and benefits
S: Strong rapport with client and his organization was evident throughout the presentation
S: Work plan for fall includes time for system installation and preliminary performance studies
I: Pass along a list of action items for Scott/UI Facilities to keep the ball moving between terms
I: Look out for potential set-backs en route to installation

Reflection

As shown in the results above, we did very well on our preliminary design review and I am very proud of what we have accomplished. We definitely worked hard to get to this point.

2 August 17 | Updating Wikipage #2

For this update, my main focus was on the "project design" section. I added "system modeling," "off the shelf design," "repurposed design," and "final design" subsections for better overall flow and organization. I also added pictures to display the components for each of the designs. Lastly, I added another chart to "system modeling."

[[File:2017_FreeBreezeBrothers_Specs.JPG|frameless|center|650px|]]
==Project Design==
The following information provides evidence and reasoning for the decisions that we made during the design of our system. Additionally, both of the designs that we produced for the system are presented.
===System Modeling===
[[File:2017_FreeBreezeBrothers_HXs.JPG|center|600px|thumb|left|Potential Heat Exchangers for System]]
[[File:2017_FreeBreezeBrothers_Hxtable.JPG|center|500px|thumb|left|Heat Exchanger Comparison]]
Above is a comparison of two potential heat exchangers for use in our system, along with a table of important values from a hypothetical test system. Shown below is a graph of system cooling capacity versus ambient air dry bulb temperature.
[[File:2017_FreeBreezeBrothers_SCC.JPG|center|500px|thumb|left|System Cooling Capacity versus Ambient Air Temperature]]

===Off the Shelf Design===
For this design, we decided to use completely new parts and components throughout the system. This design is also a representation of a worst case scenario that provides a maximum for the total cost if we decide to construct the entire system from scratch. The following pictures are of some of the new components that have been selected for this design.
{| class="wikitable" style="text-align: center;"
|-
|[[File:2017_FreeBreezeBrothers_NPFHX.JPG|300px|thumb|left|New Plate and Frame HX (M6-FD) Source: Alfa-Laval]]
|[[File:2017_FreeBreezeBrothers_NDC.JPG|500px|thumb|left|New Dry Cooler (AVR-158) Source: Dry Coolers Inc.]]
|}

===Repurposed Design===
This design involves the integration of components owned by the University that we are able to repurpose for use within our system. By salvaging these old units, we will save a large sum of money over a new purchase. The two main components that will be reused in this design are the plate and frame heat exchanger and the dry cooler, which happen to be the most expensive components to buy new. Pictures of the recycled components of this design are shown below.
{| class="wikitable" style="text-align: center;"
|-
|[[File:2017_FreeBreezeBrothers_PFHX.JPG|300px|thumb|left|Plate and Frame HX with Repurpose Potential]]
|[[File:2017_FreeBreezeBrothers_ODC.JPG|500px|thumb|left|Dry Cooler with Repurpose Potential]]
|}
It is important to note that, for the designs above, pumps, valves, and piping will have to be purchased. Also, pipe size and pump sizes are exactly the same for both.

===Final Design===
The following information provides justification for design choices and finalized schematics for our system.
{| class="wikitable" style="text-align: center;"
|+ Decision table
|-
! Decision
! Selection
! Justification
|-
| Conventional Cooling Tower vs Dry Cooler
| Dry Cooler
| The dry cooler meets all of the specifications for this project. These include: 1) Keeping the coolant from freezing. 2) Keeping the coolant from being exposed to the environment. 3) Utilizes cold ambient air or "Free Cooling" to chill coolant instead of refrigeration cycle.
|-
| Shell and Tube vs Plate and Frame Heat Exchanger
| Plate and Frame
| The plate and frame heat exchanger is a much better fit for our project due to its efficiency, space requirement, and ability to be easily modified by adding or removing plates, for different cooling loads. Also, it is much easier to clean and maintain opposed to a shell and tube.
|-
| Conventional Pump vs VFD Pump for Coolant Loop
| VFD Pump
| Due to the fact that our systems uses ambient air, which has a large temperature range, our system will require a VFD pump to vary the flow through the coolant loop i.e. less flow when ambient temps are lower and more flow when ambient temps are higher.
|-
| Water vs Ethylene Glycol in Coolant Loop
| Ethylene Glycol
| Since our system will be operating in sub-freezing temperatures, it is important that our coolant fluid does not freeze. An ethylene glycol solution has a lower freezing point than water, so this added safety factor against freezing makes sense for our system.
|-
| Free vs Forced Convection in Dry Cooler
| Forced Convection

LOGBOOK REVIEW FORM #2

Engineer	Reviewer	Date
Alex Leppek		2 August 17

STEP 1: Inventory your six best logbook entries and rate each one using the rubric given to the right.

1 – Missing
2 – Incomplete, minimal long-term value to author
3 – Complete, clear long-term value to author
4 – Exemplary, considerable long-term value to others

Entry	Date	Rating (circle one)
Ethylene Glycol Research	13 July 17	1 2 3 (4)
More Ethylene Glycol Research	17 July 17	1 2 3 (4)
Sizing Piping for the System	20 July 17	1 2 3 (4)
Updating WikiPage #1	24 July 17	1 2 (3) 4
Preliminary Design Review Preparation	28 July 17	1 2 (3) 4
Preliminary Design Review	31 July 17	1 2 (3) 4

STEP 2: Self-assess your logbook in the areas below using the scales provided (*circle one*).

Project Management (in the context of ME 410, consider your client to be mentors, staff, and instructors)

Goals	1 – missing	2 – vague	(3) – multiple/divergent	4 – focused & strategic
Action Items	1 – missing	2 – minimal	3 – clear & sequenced	(4) – tasks remove bottlenecks
Team/Client Notes	1 – missing	2 – minimal	3 – moderate	(4) – extensive
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

Design Development

Notes & Analysis	1 – missing	2 – sparse	3 – relevant	(4) – detailed, extensive
Decisions	1 – missing	2 – random, sparse	3 – highlights	(4) – comprehensive, justified
Illustrations	1 – missing	2 – unclear, messy	3 – basic w/o discussion	(4) – detailed w/ discussion
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

Assessment (of self & team)

Reflection	1 – missing	2 – little awareness	3 – occasional	(4) – regular & effective
Strengths	1 – missing	2 – little awareness	(3) – moderate	4 – detailed knowledge
Improvement	1 – missing	2 – little awareness	(3) – some areas cited	4 – detailed action plan
OVERALL RATING	1 – insufficient	2 – sub-standard	(3) – good	4 – excellent

Organization

Entries	1 – insufficient	2 – on demand, sparse	3 – regular	(4) – regular & spontaneous
Labels	1 – missing	2 – sparse & generic	3 – consistent	(4) – informative
Layout	1 – unclear	2 – haphazard	3 – readable	(4) – clear, structured, helpful
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

My two greatest strengths in my logbook are showing design development and project management. Showing design development adds value because it is proof of the work I have completed and shows that the design is original and unique. Project management adds value because it allows the project to stay on track and helps to avoid confusion/time wasting. My two areas for improvement are setting goals and identifying strengths and areas for improvement in my entries. These both add value because they would help me to further improve my logbook entries. I can implement these improvements by lengthening my reflections on my entries and adding these items.

3 August 17 | End of Semester Snapshot #1

- Today is the end of semester snapshot for the summer semester
- Our poster turned out very well and has all of the required parameters

Bandbeesten

Goals: • Create Sousaphone stand
• Add lights & fog to piano
• Reinforce piano

Want to complete by Oct. 7th on Stand
Will refine stand, but latest prototype functions well

Morgan Aerosport Model

Goals: Create model of Morgan Aero Supersport in CATIA

Used sketch tracer to create outline of car
Used surface fill and lofts to create majority of car
Rear of car was most difficult to design/model

Solar Tracker

Goals: Create solar panel that tracks sun

uses linear actuators to move solar panel
Will be used as experiment for MB 430
$1,700 budget
Want to test solar panels to compare to spec sheets

Senior Design Logbook Evaluation Form

Student Name	Alex Leppek
Team Name	Free Breeze Brothers

Logbook Mechanics	Assessment		Assessment
Self-Assessment (SII)	Complete	Dates	Complete
Self-Assessment (Most creative, etc.)	Complete	Blank Areas Lined Out	Complete
Ink	Complete	Correct Logbook Binding	Complete
Entries Titled	Complete		

Logbook Entry Assessment	1	2	3	4
Project Management				
Quality	○	○	○	◉
Frequency	○	○	◉	○
Design Development				
Quality	○	○	○	◉
Frequency	○	○	○	◉
Assessment				
Quality	○	○	○	◉
Frequency	○	○	○	◉
Organization				
Quality	○	○	○	◉

Overall Score	4 /4

Instructor Comments
Excellent record of project learning and design decision-making!
Helpful annotations surrounded tables and figures
Thoughtful reflections throughout
Follow through on your commitment to share your logbook more widely with others
Keep up the good work!

30 August 17 | Instructor/Team Meeting #7

- Some items have been ordered, other things have been potentially delayed
- Ask Scott for input on the P&ID
- Also ask Scott about vendors for temp & flow probes
- Send email to Scott
- Goals for team:
  - have system installed prior to winter so we can do some testing & verification
  - go over with data logging system used by facilities
    - ↳ Not simple, will require some work to figure out
  - Create simple if-then logic statements for use (Control scheme)
  - Create useful & complete P&ID
- May look at how system performance changes with changes in relative humidity
- Detailed design review will later in September
- Should add temp probes to the dry cooler
- Snapshot day on 10th of October
- Board meeting potentially on 2nd of October
- Think about snow protection for dry cooler fans

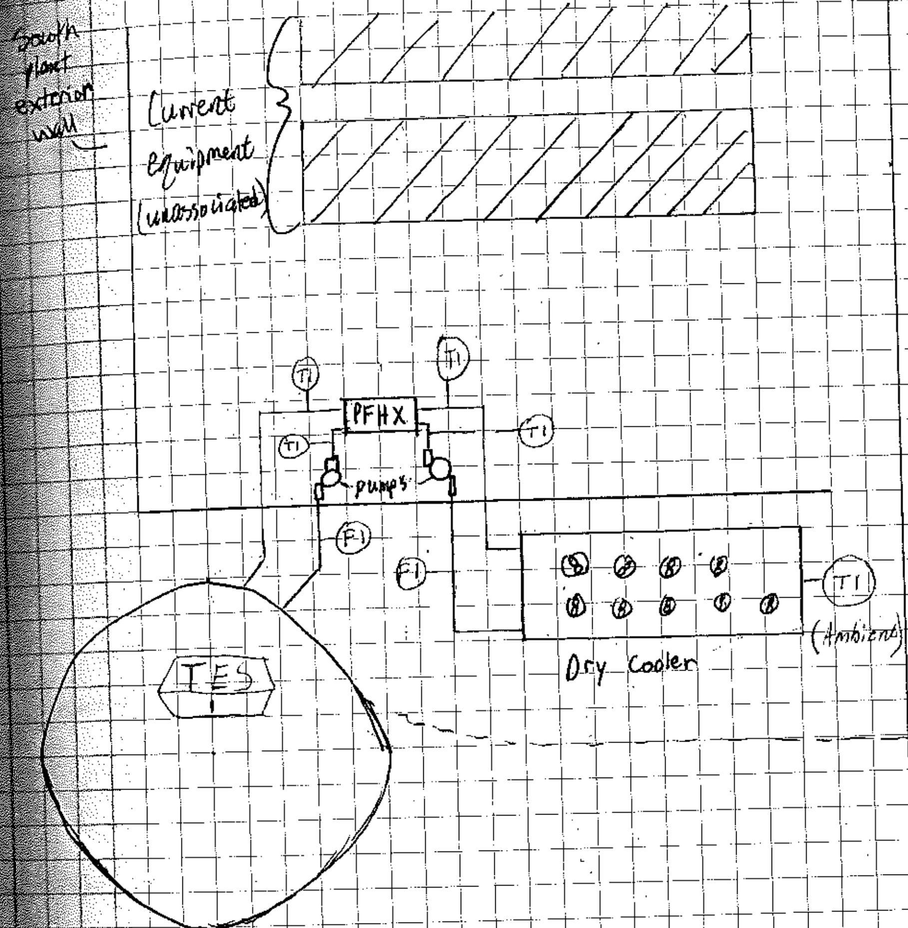
Action Items

- Kevin will complete P&ID
- I will send email to Scott with P&ID & questions about project progress
- Justin will work on the control logic scheme

Reflection

Our meeting today was productive and we set some goals that we would like to accomplish this semester. I feel that we are definitely on schedule and we will
[illegible] construction progress when Scott returns.

17 Initial P & ID



At this point in our design process, we are fairly sure of the necessary locations for our temperature and flow probes. However, when it comes to valves, we are unsure of the locations and types that we will need in our system. Additionally, since we will be hooking into the [redacted] storage tank, there will be additional valves associated with that. As can be seen above, we will need a temperature probe on all of the inlets and outlets into our plate & frame HX. We will also need a flow sensor in each of our two independent loops so that these can be monitored & adjusted if necessary.

6 September 17 — Instructor/Team Meeting #8

End Goals
- Create owners manual for system
- Create useful P&ID
- Create basic system logic including fan sequencing

Procurement update
- 5 hp - 3" inlet, 4" output - glycol loop
  - this pump has arrived
- Gives room for flow varying
- Will still be able to have wide margin with VFD
- Smaller pump is on its way
- PFHX - 158 plates
- 2 hp 2 1/2" inlet 3" output 6 1/8" impeller
- Temp & pressure sensors
  - some are in
- Two flow meters - From Florida, Accucon
  - last thing to arrive
- HX → dissassembled, cleaned, few gaskets needed replaced
- Dry cooler is in place
- Housekeeping pad will be laid → doweled rebar holds it in place
- [redacted] PFHX prone to fouling if water is not very clean
- Bottom of tank is dirtier & where we will be drawing from
- May have to add sand filter before PFHX
- 40 Micron filter on the sand filter
- Currently set up as side process → Not in line with chillers
- Will set smaller pump up as a parallel option to sand filter/pump combo
- Our system is #5
- VFD's have been ordered
- Will need to make owners manual
- Scott will send us ABB code example
- Think of sequence for new six fan cooler
- Assume fans 1 hp

Action Items
- Kevin et. all will edit the P&ID → meet Scott tomorrow @ 2 pm in rm 112 [illegible]
- Justin will create a simple logic scheme for the system

Reflection

Today's meeting was very productive and we got some good insight on where the project stands and the items we need to [illegible]

12 September 17

Lecture 6 Notes

Design Failure Mode Effects Analysis

- Necessary for creating & producing products
- Come up with all of the things in the system that can break
  - ↳ figure out which ones are most important / most catastrophic if they fail

Purpose of DFMEA

- Identify, quantify, & reduce design risk
- provides traceable document for making design decisions
- Prioritize which design activities to pursue next

DFMEA Inputs

- Product design requirements → specs & regulations
- Bill of materials → list of components
- Product definition → sketches, diagrams, description of system

DFMEA Outputs

- Risk priority number (RPN)
  - ↳ = severity × occurrence
  - ↳ High RPN → high risk items
- Select/Define remedial action based on design risk

DFMEA Method

1) List components, subsystems, & functions
2) Document symptoms of failure
3) Document potential effects of failure
4) Document potential causes & mechanisms of failure
5) Rate severity of the failure effect
6) Rate the occurance of the failure
7) Calculate the RPN of each potential failure effect
8) Classify failures by RPN
9) Select & describe remedial actions
10) Assign remedial actions
11) Reassess severity/occurrence of anticipated failures and update RPN values

- DFMEA is an ongoing process (Not one time thing)

Instructor / Team Meeting #9

- As-built → somewhat like owner's manual
  - ↳ contains all manuals from the components
- As-built must be in three ring binder
  - ↳ can have tabs & must be organized
- Review table of contents & what needs added
- Scott will feed us a list of part #'s for the as-built
- Fans on dry cooler are 1 hp
- will have to look into if partitions can be removed on dry cooler
  - ↳ will determine what we end up doing with the fans
- DFMEA is good - but may need to set scale for our project
  - ↳ less general
  - Differentiate between minor & major repair
  - Always have table of scale definitions with DFMEA
  - → Add plate failure for PFHX to DFMEA
  - → Also may add fouling for PPHX
- Valves fail wide open or completely closed (usually)
  - ↳ gate may fall into seat after falling off stem
  - ↳ sometimes designed to be either full open or fully closed when failure happens
- P&ID → only thing need to fix is jog near dry cooler
- PFHX is counter flow ☒ & electric consumption on pump
- Dry cooler fans have been cut from original circuit board
- Easiest thing to do with fans is just to turn them on & off
- Costs & benefits for fans need to be taken into account
- When system is complete, need to figure out what data we want to take

Action Items

- I will make the necessary changes to the P&ID
- Kevin will make the necessary changes to the DFMEA

Reflection

Today's meeting went very well and we have identified some areas that we need to focus on while the system is constructed. This way, we will be productive with all of the time available to us.

20 September 17 — Instructor / Team Meeting #10

- Scott is giving us a few things to put into the as-built binder
- Prices on pumps were a little lower than expected
- Bell & Gossett needed flows & head pressure to accurately spec out pumps for the system
- They come up with 1st, 2nd, & 3rd best choices for pumps
  - ↳ efficiency for our chosen pumps are quite good
- Scott will get us other manufacturers spec sheets as items are ordered
- present as-built table of contents to Scott to ensure as-built is in a good order
  - ↳ calculations should be at the end of the binder
- Governing equations should also be included
  - ↳ don't go too in depth
- Control logic should also be included
  - ↳ can be done many different ways
  - ↳ can use mapping from a set point
  - ↳ increases or decreases flow to return system to set points
  - ↳ Mapping will have to be redone with any system changes such as fouling
- Flow rate will decrease to increase cooling & vice versa
- Can set dead bands for system to "hold" within and not make changes to operating
- May try different methods for running system controls
- Snapshot day is October 10th
- plan on a display for advisory board
  - ↳ can be used for snapshot day also
- Scott's team will be doing Fall wood boiler shut down next week
- Pumps, heat exchanger, and dry cooler are in place at South Plant
  - ↳ No piping as of yet

Action items

- We will all work to prepare for the advisory board meeting & Snapshot
- As parts come in, Kevin will populate the as-built

Reflection

At this point in the project, there is not much else for us to contribute since construction is in progress. For this reason, Scott has told us to focus on our snapshot & advisory board meeting presentations.

LOGBOOK SELF-REVIEW FORM #3

...Review your previous logbook entries. Inventory ...best and rate each one using the rubric given to the ...

1 – Missing
2 – Incomplete, minimal long-term value to author
3 – Complete, clear long-term value to author
4 – Exemplary, considerable long-term value to others

	Date	Rating (circle one)
...structor/Team Meeting #7	30 August 17	1 2 (3) 4
...itial P&ID	5 September 17	1 2 3 (4)
...structor/Team Meeting #8	6 September 17	1 2 3 (4)
...al P&ID	7 September 17	1 2 3 (4)
...structor/Team Meeting #9	13 September 17	1 2 (3) 4
...structor/Team Meeting #10	20 September 17	1 2 (3) 4

...Self-assess your logbook in the areas below using the scales provided (*circle one*).

...Management

	1 – missing	2 – vague	3 – multiple/divergent	(4) – focused & strategic
...Items	1 – missing	2 – minimal	3 – clear & sequenced	(4) – tasks remove bottlenecks
...Client Notes	1 – missing	2 – minimal	3 – moderate	(4) – extensive
...ALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

...Development

...& Analysis	1 – missing	2 – sparse	3 – relevant	(4) – detailed, extensive
...es	1 – missing	2 – random, sparse	3 – highlights	(4) – comprehensive, justified
...sions	1 – missing	2 – unclear, messy	3 – basic w/o discussion	(4) – detailed w/ discussion
...ALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

...ent (of self & team)

...tion	1 – missing	2 – little awareness	3 – occasional	(4) – regular & effective
...ths	1 – missing	2 – little awareness	(3) – moderate	4 – detailed knowledge
...ement	1 – missing	2 – little awareness	(3) – some areas cited	4 – detailed action plan
...ALL RATING	1 – insufficient	2 – sub-standard	(3) – good	4 – excellent

...ation

	1 – insufficient	2 – on demand, sparse	(3) – regular	4 – regular & spontaneous
	1 – missing	2 – sparse & generic	3 – consistent	(4) – informative
	1 – unclear	2 – haphazard	3 – readable	(4) – clear, structured, helpful
...ALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

My two greatest strengths in my logbook are meaningful entries and thorough meeting minutes. Meaningful entries add value because a logbook full of useless information is not helpful for anyone and it would likely be disregarded. Thorough meeting minutes add value because it can be used by both myself and others to look back and see important highlights and decisions and when they occurred. My two greatest areas for improvement in my logbook this time are frequency of entries and noting task completion. Frequent entries add value because they provide a more clear path of project progression. Noting task completion adds value because it shows how long parts of the project took. I can implement both of these by making separate entries for completed tasks.

27 September 17 Instructor/Team Meeting #11

- Scott provided us with some of manuals for the as-built
    - ↳ flow meter
    - ↳ pressure sensor
    - ↳ pumps
- Should include diagrams, DFMEA for our snapshot day & industry board meeting
- For data collection, will need to determine the best way
    - ↳ likely daq or standalone device
- Our project will be integrated into ATS system eventually
    - ↳ however, our way of data collection will be temporary
- ABB vfds will have a output signal that we can use for [redacted] current measurements on the pumps
- DAQ does not need to be too complex
    - ↳ portable, not too expensive
    - ↳ ask Ankit & Kumar what they would recommend
- Set-up at 4:30 for design board meeting on Monday Oct 2nd
    - ↳ goes from about 4:45 - 5:15
- Next formal presentation will be final project presentation
    - ↳ at facilities again
- ABB book will have logic that we will have to explore

Action items

- We will all prepare for design board meeting on Monday and for snapshot day on October 10th
- Kevin will speak with Dr. Kumar about possibly choosing a DAQ that will be sufficient for the data that we will need to collect from our system
- Justin will look into the different methods we can use to implement logic into our system (mapping vs Sequencing)

Reflection

Today's meeting was productive and we outlined some areas to focus on for the coming weeks. At this point, and for the past few weeks, system construction is under way and we will not be directly involved in the project again until construction is complete and the system is fully operational

Senior Design Logbook Evaluation Form

Student Name	Alex
Team Name	Free Breeze Brothers

Logbook Mechanics	Assessment		Assessment
Self-Assessment (SII)	Complete	Dates	Complete
Self-Assessment (Most creative, etc.)	Complete	Blank Areas Lined Out	Complete
Ink	Complete	Correct Logbook Binding	Complete
Entries Titled	Complete		

Logbook Entry Assessment	1	2	3	4
Project Management				
Quality	○	○	○	◉
Frequency	○	○	◉	○
Design Development				
Quality	○	○	○	◉
Frequency	○	○	○	◉
Assessment				
Quality	○	○	○	◉
Frequency	○	○	◉	○
Organization				
Quality	○	○	○	◉

Overall Score	4 /4

Instructor Comments

Exemplary logbook work - this should be a tremendous asset to you on the job

Effective use of figures and diagrams

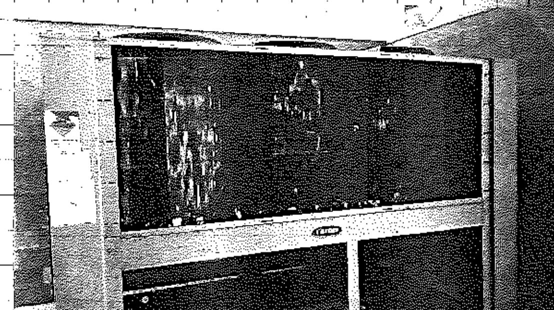
Thank you for your silent, steady leadership within the team

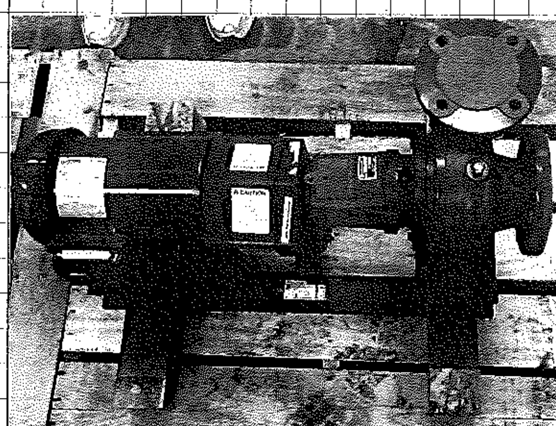
Find ways to incorporate details about testing and report development in your logbook

28 September 17 Construction Update #1

Today, we were able to visit the South facility to see how the installation was progressing and to take a few measurements. At this point, the dry cooler has been placed in its final position and has had all of the unnecessary components, such as the compressors, and wiring removed. It is now ready to have pipes and electricity run to it. The two pumps have arrived and are sitting in Bay 3 of the facility. Lastly, the PFHX is also ready, but it is still currently at the steam plant

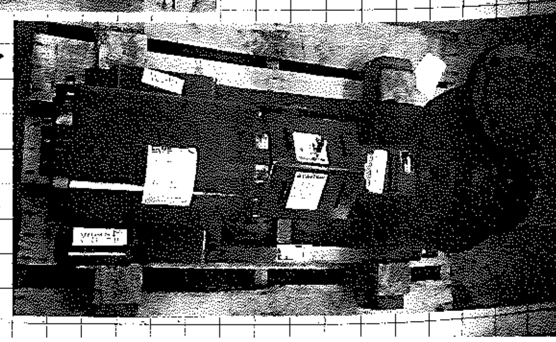
Carrier Dry Cooler →
→ stripped of unnecessary components
→ 6 fans with partitions
↳ all fans will run when system is on





← Bell & Gossett 2 hp pump
→ fully sealed
↳ motor components are not open to atmosphere, so hosing off pump will not damage it

Bell & Gossett →
5 hp pump
→ Not fully sealed
↳ motor components are open to environment and may be damaged if pump exterior was sprayed with water



Instructor/Team meeting #12

Kevin talked to Dr. Kumar about a DAQ for our system
- → PCIe was recommended
- → Need connector block
- → Board & block come as a package from NI

Computer for the board should be as portable as possible
- → doesn't need to be super powerful
- → Ankit will hold onto this system when not in use

PCIe board has 16 inputs
Thermal probes are RTD's
- → amperage signal

Need to determine if all probes can output a voltage that can be read by the connector block
- → do not want to buy something that won't work for all sensors in our system

VFD outputs will be used for outputs on pumps
- → can be selective since VFD's have may output options

Ask Dr Kumar about noise in data
- → video card could cause issues

We will use shielded wire for sensors to prevent noise
Bring DFMEA to snapshot day
Scott's team will be more focused on our project next week
- → doing boiler shutdown

During last two weeks of semester, we will give our final presentation at facilities
- → need to schedule at a good time for everyone

Action Items
- Kevin will update system curve with new calculated surface area
- We will all look into different computers and DAQs that are both suitable for our project and affordable.

Reflection

Today's meeting went well and we discussed some upcoming action items and presentations such as Snapshot. At this point, we are still mainly on hold for project input since construction is still underway and has a ways to go before completion. In all, we are ahead of the game and have the project well under control

11 October 17 Instructor/Team Meeting #13

- Will need to find out system requirements for Labview
  - ↳ this will determine if we can use the computer currently in the South Campus Chiller plant
- will need to be a computer that can be left for weeks in a safe spot
- Computer at plant now is all solid state, no moving parts
- Labview becoming more prominent in industry
- computer will need to be set up for lengthy data collection
  - ↳ no computer updates, restarts, etc
- Will use sheilded wire to run from sensors to DAQ
- Scott will order the DAQ that Kevin has speced out for data collection
  - ↳ coming from Hungary so it will be a little while before we get it
- Scott will run all sensor wires into the office, which is where our daq & computer will be located
  - ↳ we do not need to worry about long term implementation of sensors into currently system at the chiller plant
- Scott's team has been busy for the last few weeks, so no progress has been made on the system construction
- We may need to change the frequency scale on the DFMEA
  - ↳ may only need four criteria instead of five
  - ↳ break it down into days + once daily, once weekly, etc
- VFD's can be finicky at the begining, become reliable when bugs are worked out
- Once pipes are in place & not leaking, unlikely to leak for a long time

Action Items
- Justin will look into ABB logic & come up with some systems logic
- Kevin will make an outline for the final as-built manual
- I will assist in both above tasks if necessary

Reflection
Our meeting today was productive and we decided on a DAQ to order for our data collection. We are still in the waiting process for the most part, but our main focus is on documentation & deliverables

Instructor/Team Meeting #14

- Going through as-built binder
  - ↳ will only need one binder to satisfy final capstone requirement
  - ↳ will have to get Scott's input on how binder should be structured/ordered
  - ↳ content-wise, the binder is almost complete, since we have all of the user manuals and pertinent analytical calculations already in the binder
  - ↳ we are still going to keep the second portfolio for items that pertain to the capstone class moreso than the project such as meeting minutes, agendas, etc
- Beyerlein suggested that we may put a chronological pdf of our meeting minutes onto our wikipage
  - ↳ Wikipage will be updated as construction progresses and when we do some data acquisition
- Scott was unable to make the meeting, but he sent an email with a few updates.
  - ↳ pumps, VFD's, outside fans will likely be wired next week
    - ↳ contracted out to Source Electric
  - ↳ instrumentation wiring will likely be done in the next few weeks
  - ↳ will be getting new computer at the south chiller plant
- Scott also said a potential problem has arisen with differential pressure. However, he said we will not worry about it at this point.

Action Items

- Justin will continue working on ABB/system logic
- Kevin & I will assist Justin and take care of any other items that come up

Reflection

Today's meeting was somewhat productive, but only so much can get done without Scott present. Next week should be a more informative meeting.

25 October 17 | Instructor/Team Meeting #15

- Our daq has arrived and Scott gave it to us to learn how to use it
  - ↳ Ankit is setting up a computer for the South Chiller plant with Labview & all other programs that it will need
- Construction is progressing well on the project
  - ↳ electrical is in progess & scott thinks the pumps and VFD's are wired in
  - ↳ piping is also in progress & will be worked on for the rest of this week and part of next week
  - ↳ all fans on the dry cooler are working and spinning in the correct direction
- Scott has a goal of getting the construction done on November 1st
  - ↳ this date may get pushed back because Scott's team has other responsibilities
- Once construction is done, it would be nice to run the system in weather that we designed it for, ~20-30 °F, but this is dependent on what the weather does in November which is unpredictable
- Will have to figure out best combination of sensor location and system programming that is best suited for our system
  - ↳ may end up being trial & error
- For as-built
  - ↳ one-page, summary of project/Binder at beginning
  - ↳ table of contents

Action Items

- Kevin will write up summary for the as-built manual
- Justin will continue working on logic code for the system
- I will update the wikipage as soon as we can see the progress made on construction & assist in the above tasks if needed

Reflection

Today's meeting was very informative and it is good to hear that the project construction is well under way. We will soon get to see our design become a reality and be able to compare our calculations with real data. At this point, our main focus is finishing the as-built manual, the code for the system VFD's, and figuring out data acquisition

Instructor/Team Meeting #16

Construction update

- Still working on pipe work
  - ↳ getting close to the end
- Ended up buying a new computer for the South Chiller plant
  - ↳ we will use along with future Capstone groups
  - ↳ Ankit is installing Labview and other software on the computer
- Wires for sensors will be run into the office, where the computer will also be located
- Once construction is complete, we will schedule time with Scott to go up to the plant, set up the DAQ, and program Labview to collect our necessary data
- May or may not have a problem with differential pressure, since we are using liquid throughout the system, instead of a refridgerant loop
  - ↳ If this happens, there is a backup plan of putting a 3600 RPM, 5 hp motor on along with the VFD to have a larger flow potential in the system
- For final presentation, will need brief scope of project as a whole, but most of the presentation should be concentrated on M&V, results, etc
  - ↳ will be presenting to the same people as we did last time, so they will just need a refresher of the project, not an entire explanation
- Sensor wires will be ran with shielded wire so that the signals do not interfere with each other
  - ↳ need to limit noise in the system in order to get accurate results

Goals for Rest of semester

- Data acquisition
- Final report / Binder / Snapshot
- Proof of system functionality

Reflection

Our meeting today went quite well and we are getting to a point in our project that is pretty exciting, since our design is very close to becoming a reality. We are prepared to do data acquisition on the system and to finish off any other components of the project, such as the system users manual, the Wikipage, and other documentation

15 November 17 Instructor/Team Meeting #17

For final presentation, we decided to have a combined presentation at snapshot instead of two separate presentations, one at facilities and a technical presentation at snapshot

Construction update

Both loops are flooded (filled)

Pumps have been run but Scott isn't sure if there is flow through the chilled water loop

The Glycol loop is looking very good however Scott and his crew will have to troubleshoot the chilled water loop

↳ due to this, the system is not entirely ready to run at this point

For M&V, we will only need about 4-5 time snapshots in order to verify our system

we will need to send Scott the slides for our powerpoint for the Snapshot poster

↳ he will send these onto facilities so they can get a refresher on the project

Scott gave a contingency that the system may not run before the end of semester if they can't figure out the issue in chilled water loop

LOGBOOK SELF-REVIEW FORM # 4

STEP 1: Review your previous logbook entries. Inventory your six best and rate each one using the rubric given to the right.

1 – Missing
2 – Incomplete, minimal long-term value to author
3 – Complete, clear long-term value to author
4 – Exemplary, considerable long-term value to others

Entry	Date	Rating (circle one)
Construction Update #1	28 September 17	1 2 3 (4)
Instructor/Team Meeting #12	4 October 17	1 2 (3) 4
Instructor/Team Meeting #13	11 October 17	1 2 (3) 4
Instructor/Team Meeting #14	18 October 17	1 2 (3) 4
Instructor/Team Meeting #15	25 October 17	1 2 3 (4)
Instructor/Team Meeting #16	1 November 17	1 2 3 (4)

STEP 2: Self-assess your logbook in the areas below using the scales provided (*circle one*).

Project Management

Goals	1 – missing	2 – vague	3 – multiple/divergent	(4) focused & strategic
Action Items	1 – missing	2 – minimal	3 – clear & sequenced	(4) – tasks remove bottlenecks
Team/Client Notes	1 – missing	2 – minimal	3 – moderate	(4) – extensive
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) excellent

Design Development

Notes & Analysis	1 – missing	2 – sparse	3 – relevant	(4) – detailed, extensive
Decisions	1 – missing	2 – random, sparse	3 – highlights	(4) – comprehensive, justified
Illustrations	1 – missing	2 – unclear, messy	3 – basic w/o discussion	(4) – detailed w/ discussion
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) – excellent

Assessment (of self & team)

Reflection	1 – missing	2 – little awareness	3 – occasional	(4) – regular & effective
Strengths	1 – missing	2 – little awareness	(3) – moderate	4 – detailed knowledge
Improvement	1 – missing	2 – little awareness	(3) – some areas cited	4 – detailed action plan
OVERALL RATING	1 – insufficient	2 – sub-standard	(3) – good	4 – excellent

Organization

Entries	1 – insufficient	2 – on demand, sparse	(3) – regular	4 – regular & spontaneous
Labels	1 – missing	2 – sparse & generic	3 – consistent	(4) – informative
Layout	1 – unclear	2 – haphazard	3 – readable	(4) – clear, structured, helpful
OVERALL RATING	1 – insufficient	2 – sub-standard	3 – good	(4) excellent

My two greatest strengths in my logbook are extensive meeting notes and clear action items. Extensive meeting notes add value because it allows both myself and others to look back and see when decisions were made and for what reasons. Clear action items add value because it allows each team member to know exactly what they are responsible for, which reduces confusion and makes it easy for the other members to hold each other accountable for assigned tasks. In my logbook, my two greatest areas where I could improve are assessment and more frequent entries. Assessment adds value because it allows for a realization, and future action upon, areas that are lacking. Frequent entries add value because they provide a clear path of project progress. I can implement both of these by allotting more time for writing in my logbook.

Senior Design Logbook Evaluation Form

Student Name	Alex
Team Name	Free Breeze Brothers

Logbook Mechanics	**Assessment**		**Assessment**
Self-Assessment (SII)	Complete	Dates	Complete
Self-Assessment (Most creative, etc.)	Complete	Blank Areas Lined Out	Complete
Ink	Complete	Correct Logbook Binding	Complete
Entries Titled	Complete		

Logbook Entry Assessment				
Project Management	1	2	3	4
Quality	○	○	○	◉
Frequency	○	○	○	◉
Design Development				
Quality	○	○	○	◉
Frequency	○	○	○	◉
Assessment				
Quality	○	○	◉	○
Frequency	○	○	◉	○
Organization				
Quality	○	○	○	◉

Overall Score	4 /4

Instructor Comments

Great job on your logbook throughout the project - frequent & informative entries

Easy layout and labeling for rereading/reuse

Take your logbook lessons learned forward into your professional practice

Thank you for your thoughtful work as well as your leadership presence within the team

I look forward to touring the finished installation and seeing initial performance data