Ultra Low Cost Solar Water Heater

Final Proposal

12/10/13

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Overview

- Client
- Needs
- Objectives
- Collector Concepts
- Engineering Analysis
- Cost Analysis
- Results
- Final Design
- Timeline

Client

- Client: U.S. Environmental Protection Agency (EPA)
  - P3: People, Prosperity, and the Planet Award
  - Research, design, and develop solutions to real world challenges involving the overall sustainability of human society

Need Statement

Current solar water heaters are too expensive and it takes a long period of use to make them financially sensible, therefore current solar water heater designs are financially impractical over a short period of use.

The solution is to design a low cost solar water heater that makes minimal sacrifices in efficiency which result in significant reduction in cost.

Objectives

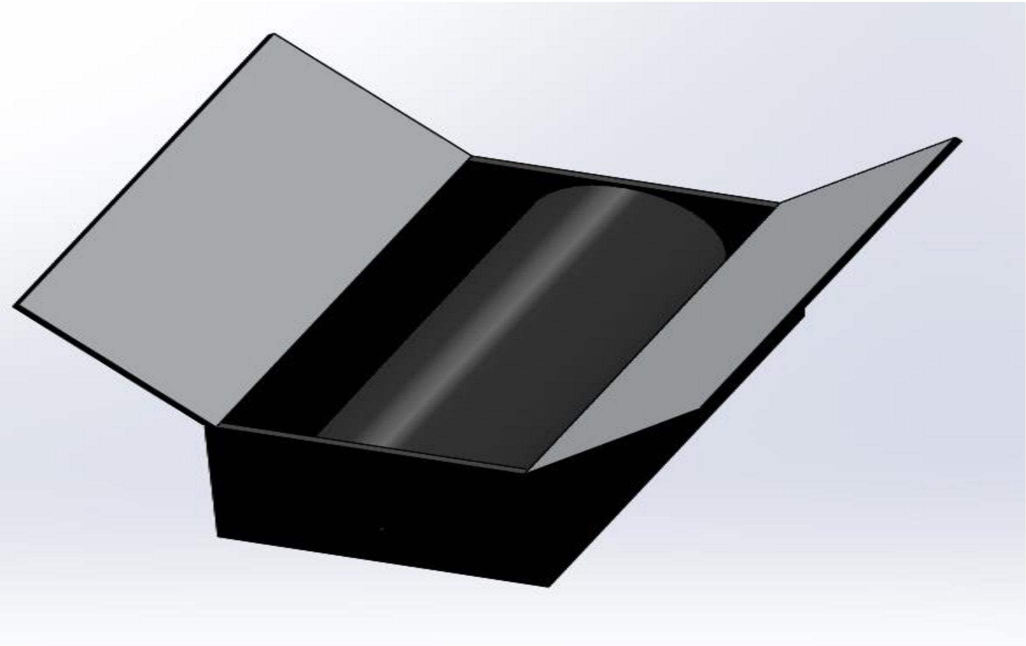
- Heats water
- Weather resistant
- Low initial cost
- Quick financial return
- Easily integrated into existing system
- Safe
- Reasonable size

Collector Concepts

- Parabolic Collector
- Flat Plate Collector
- Bread Box Collector

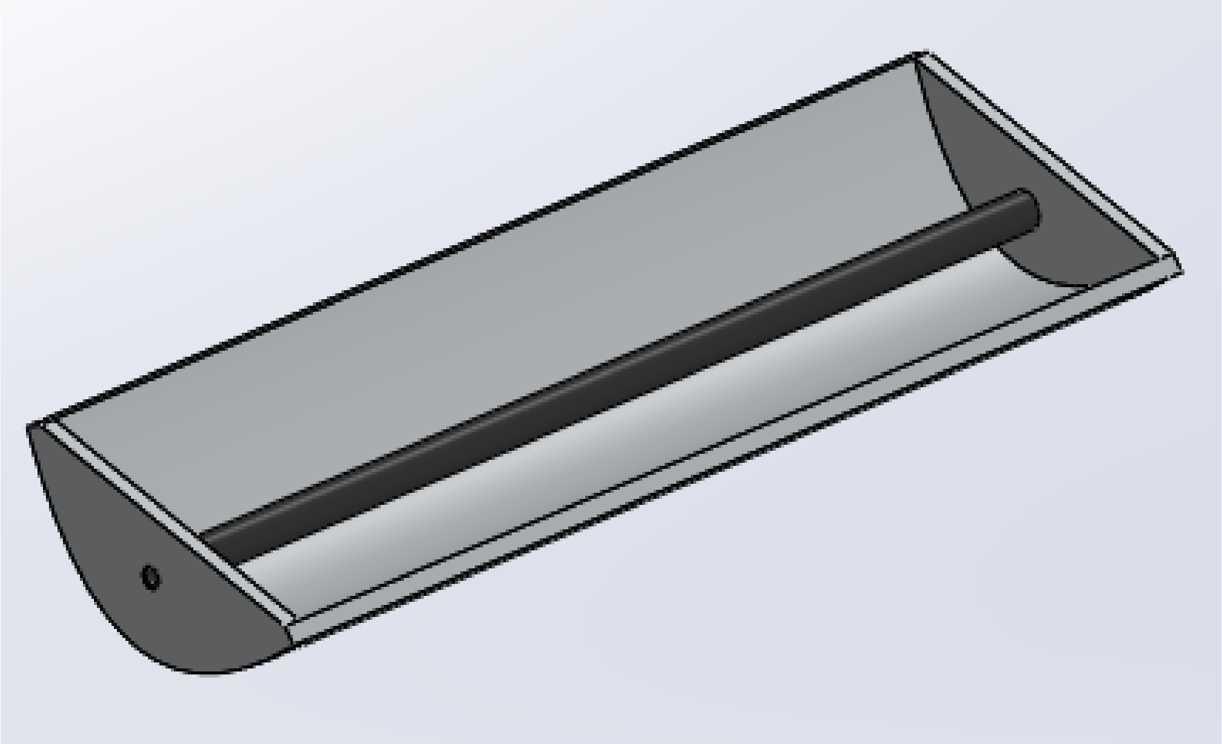
Bread Box Collector

- Large black water tank
- Tank sits inside a fully insulated box
- Dual pane glass sits on top to capture solar radiation



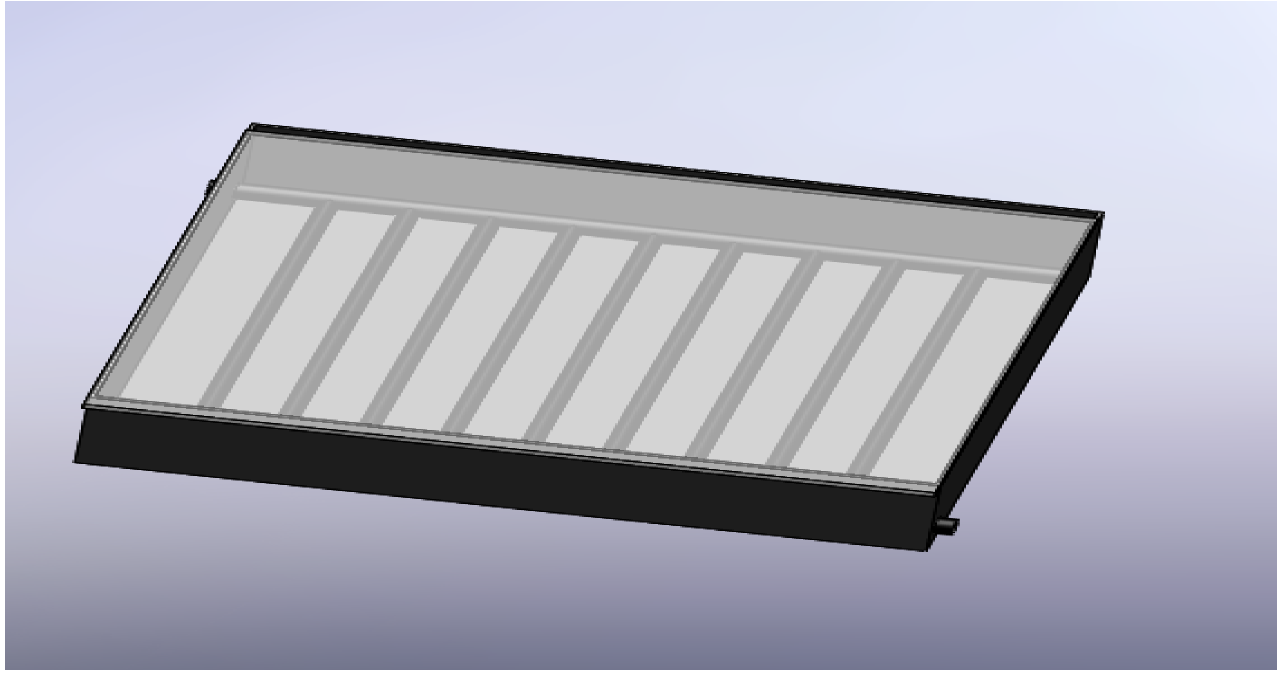
Parabolic Collector

- The parabolic dish provides additional surface area and concentrates the solar energy onto the pipe

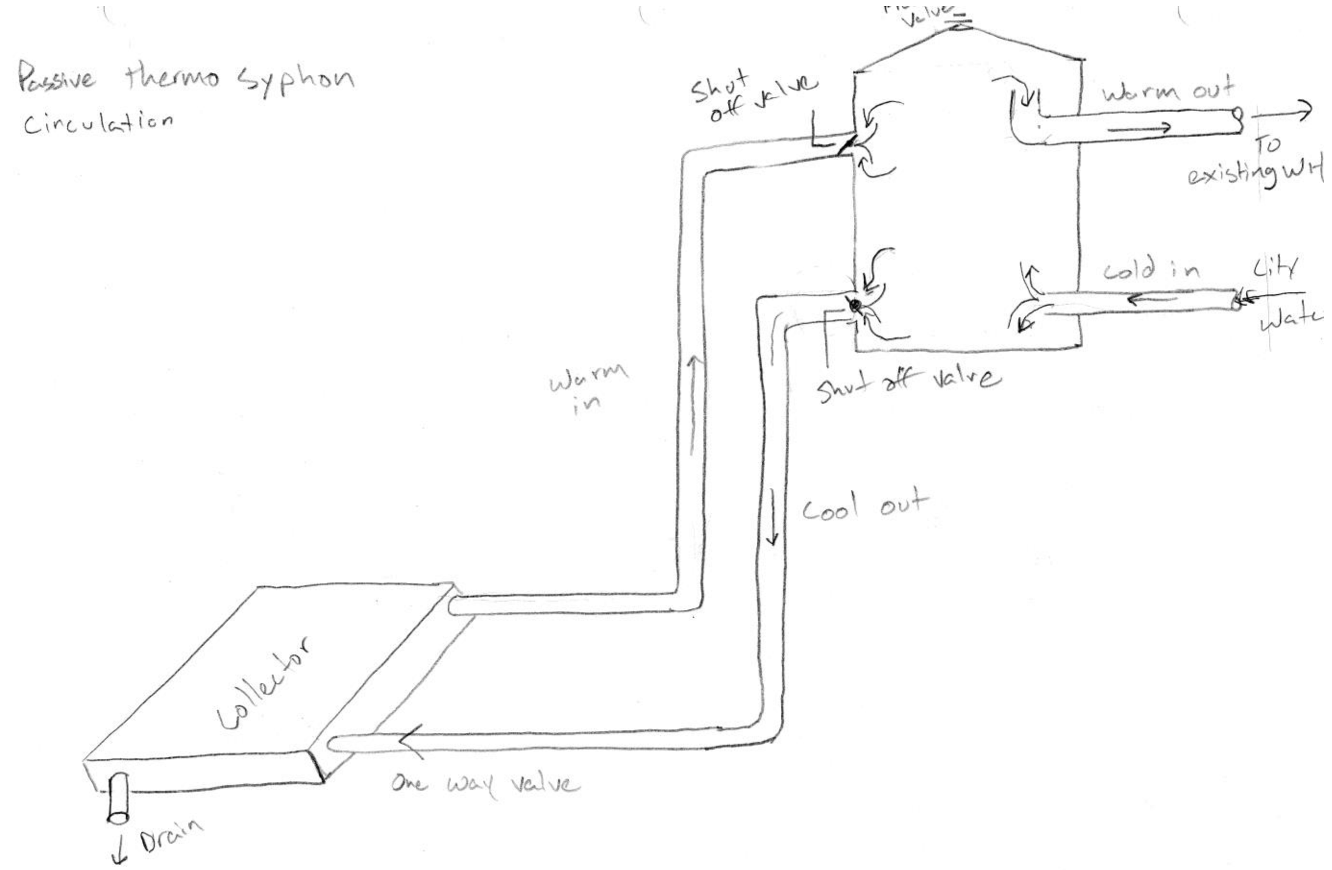


Flat Plate Collector

- Black pipes or flat background absorb radiation
- Possibly modular design
- Active or passive circulation

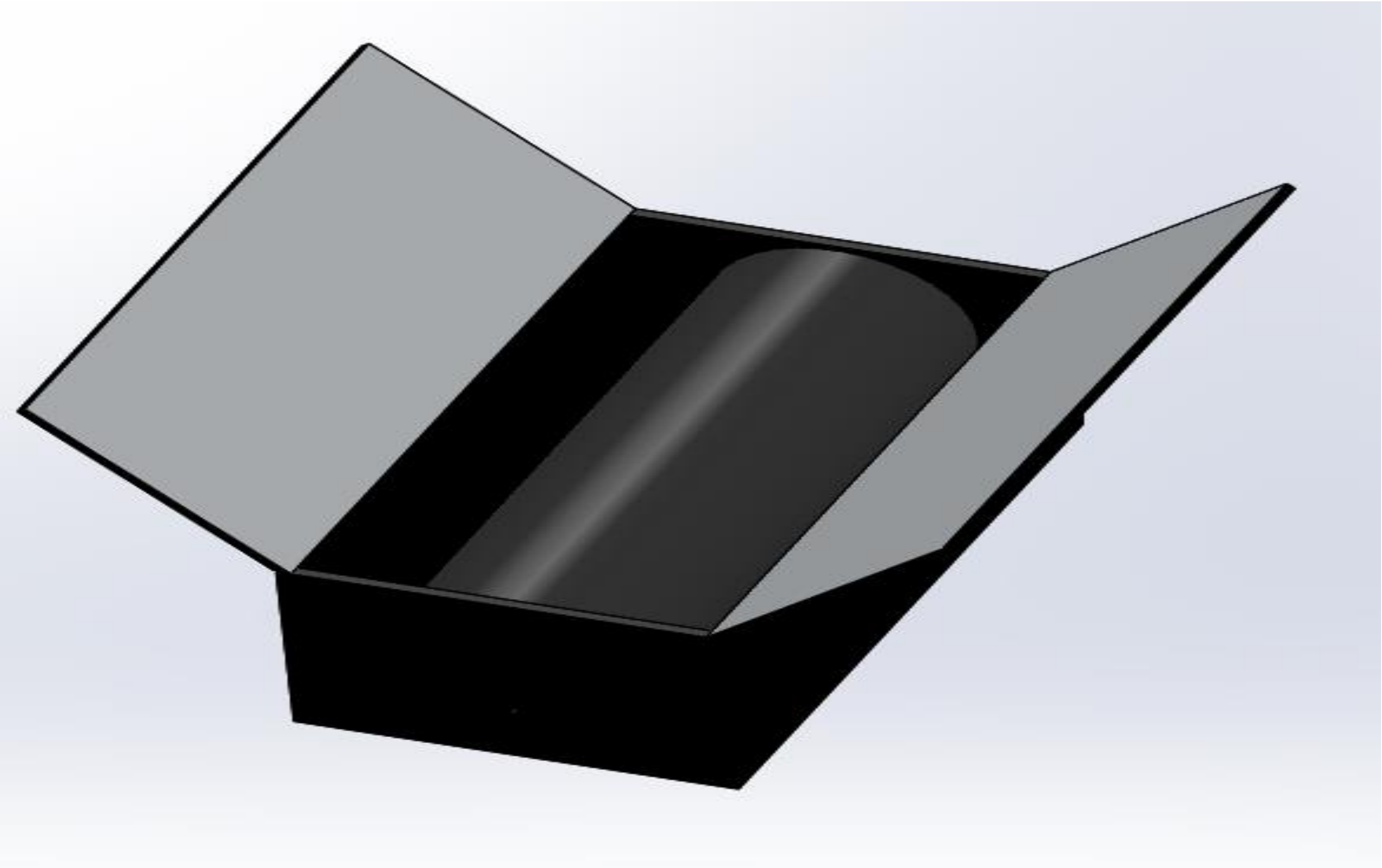


Passive Circulation



- Thermosyphoning is used to circulate water

Bread Box Collector Analysis

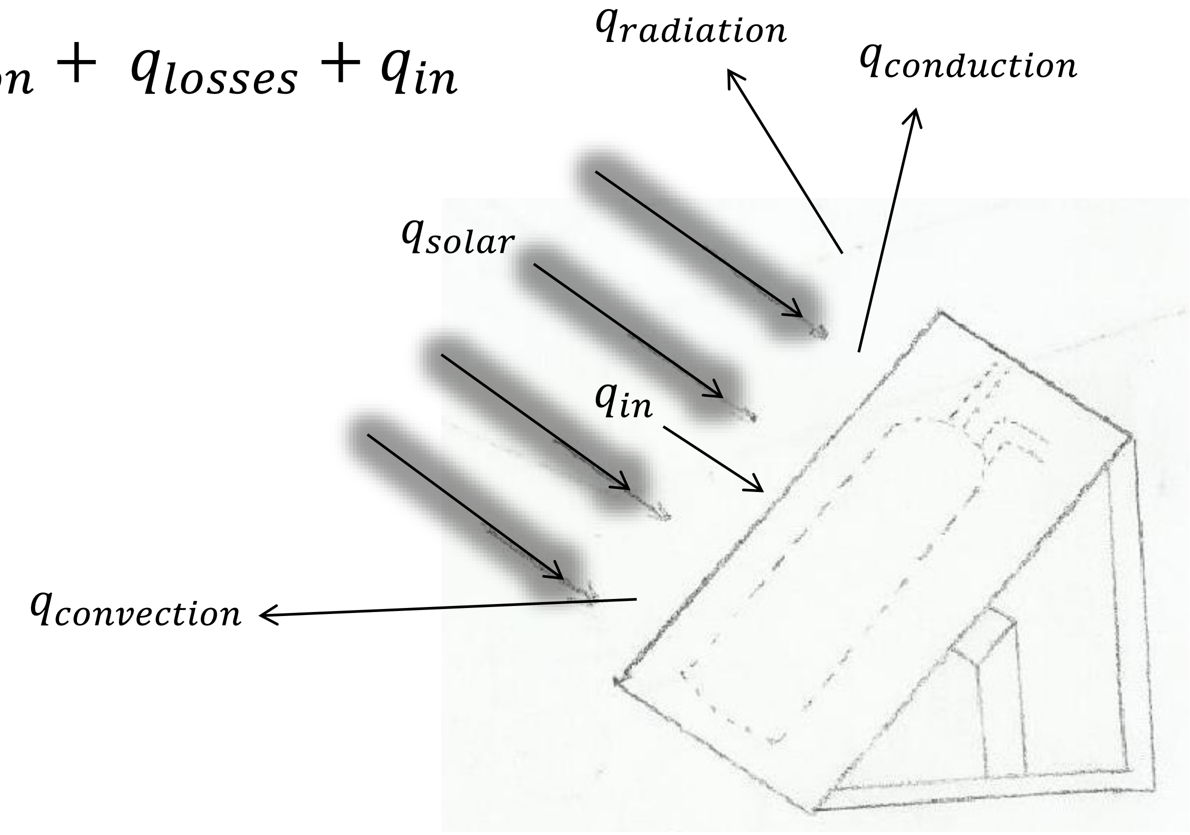


Bread Box Collector Analysis

- Energy Balance

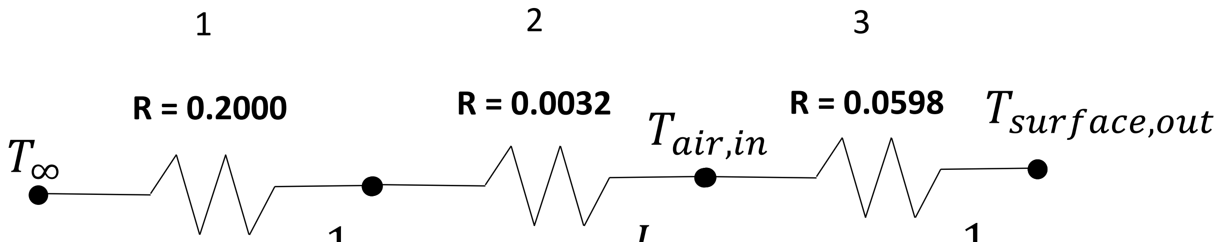
$$q_{solar} = q_{radiation} + q_{losses} + q_{in}$$

$$q = \frac{\Delta T}{R}$$



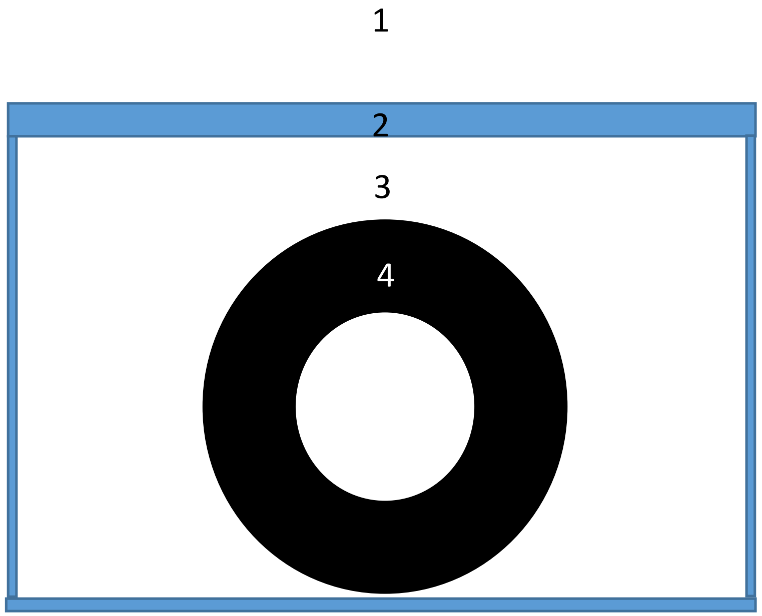
Bread Box Collector Analysis

- Resistance network



$$R_{conv} = \frac{1}{hA_c} \qquad R_{cond} = \frac{L}{kA} \qquad R_{conv} = \frac{1}{hA_c}$$

$$R_{cond} = \frac{r_o/r_i}{2\pi kL}$$



Bread Box Collector Analysis

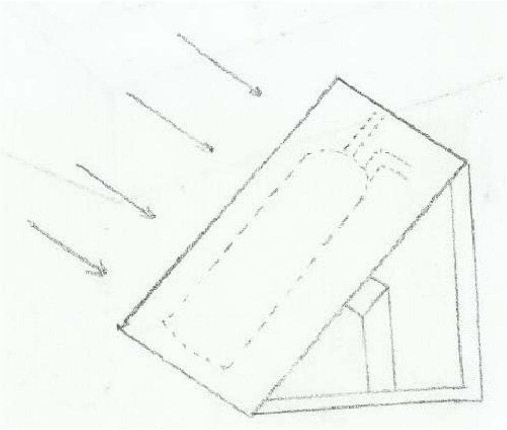
- Solving for $T_{s,o}$

$$q_{solar} = q_{radiation} + q_{losses} + q_{in}$$

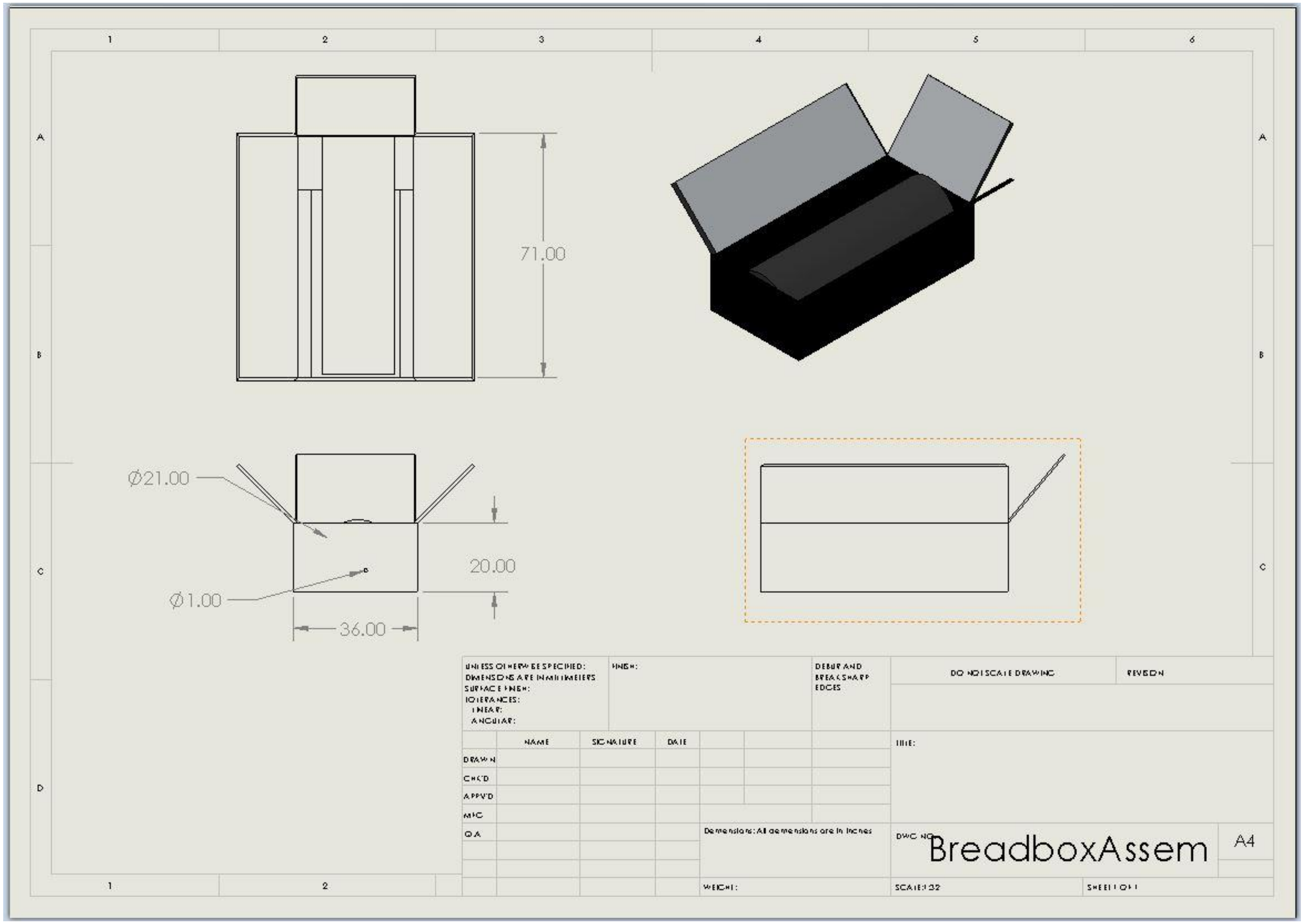
$$q_{solar} = \tau\varepsilon\sigma(T_{s,o}^4 - T_\infty) + \frac{T_{s,o} - T_{air,o}}{R_{conv,o} + R_{cond,glass} + R_{conv,i}} + \frac{T_s - T_{water,i}}{R_{pipe} + R_{water}}$$

- Substituting back in to q_{in}

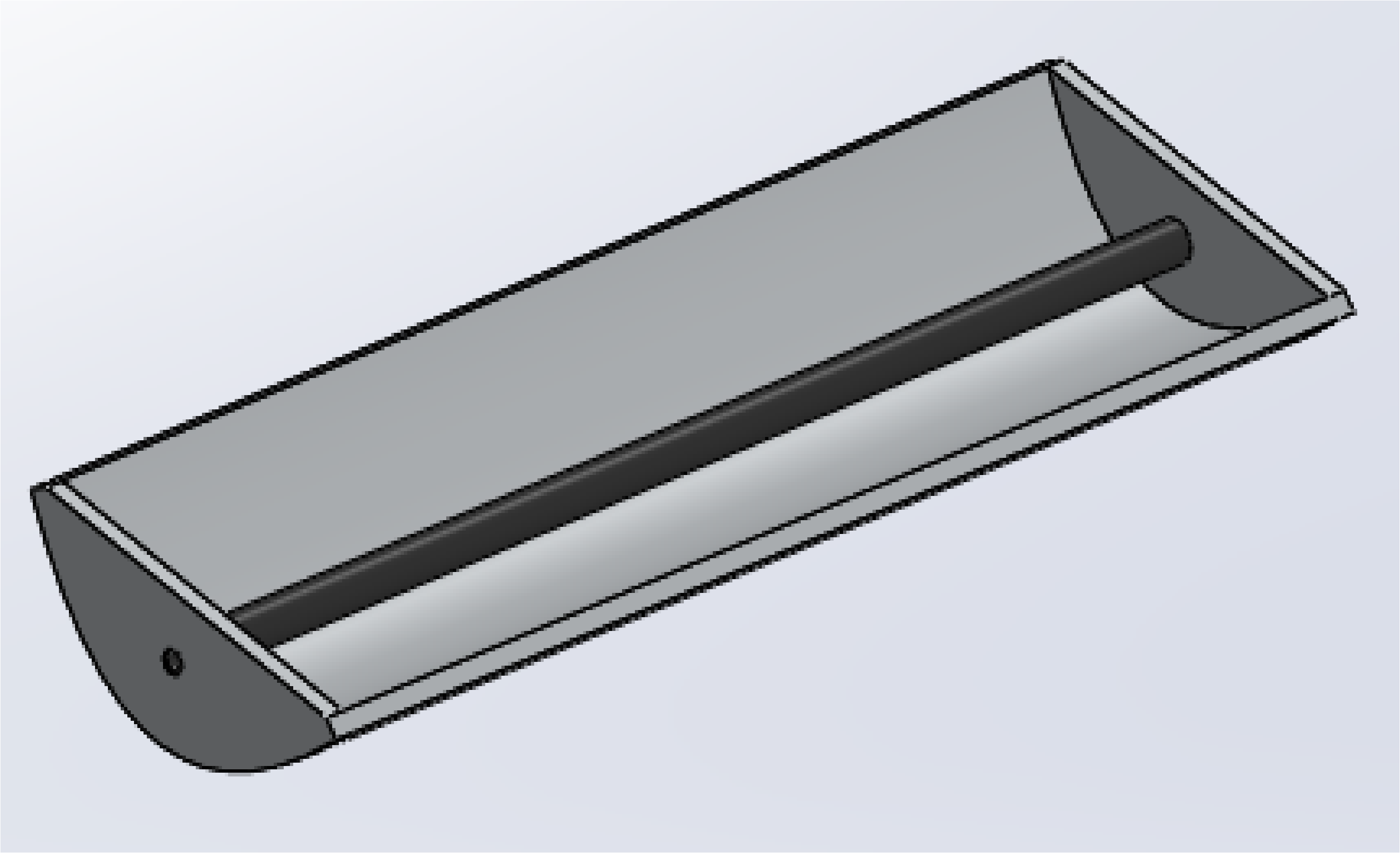
$$q_{in} = \frac{T_s - T_{water,i}}{R_{pipe} + R_{water}}$$



Bread Box Collector



Parabolic Collector Analysis



Parabolic Collector Analysis

- Solar radiation:
  - 1070 W for painted galvanized steel pipe
  - 717 W for unpainted galvanized steel pipe

- Energy Balance:

$$q_{solar} = q_{radiation} + q_{losses} + q_{in}$$

Parabolic Collector Analysis

- Radiation losses

$$q_{radiation} = A_s \varepsilon \sigma (T_{s,o}^4 - T_\infty)$$

- Convection out

$$q_{conv,o} = \frac{(T_{s,o} - T_\infty)}{R_{conv,o}}$$

$$\overline{Nu_D} = \frac{\overline{h_o} D_o}{k_{air}} = C Re_D^m Pr_o^{1/3}$$

$$R_{conv,o} = \frac{1}{\bar{h} 2\pi r_o L}$$

Parabolic Collector Analysis

- q_{in}

$$q_{in} = \frac{(T_{s,o} - T_{water})}{R_{conv,i} + R_{cond}}$$

- Resistances

$$R_{conv,i} = \frac{1}{\overline{h_i} 2\pi r_i L}$$

$$R_{cond} = \frac{\ln(r_o/r_i)}{2\pi k_{steel} L}$$

Parabolic Collector Analysis

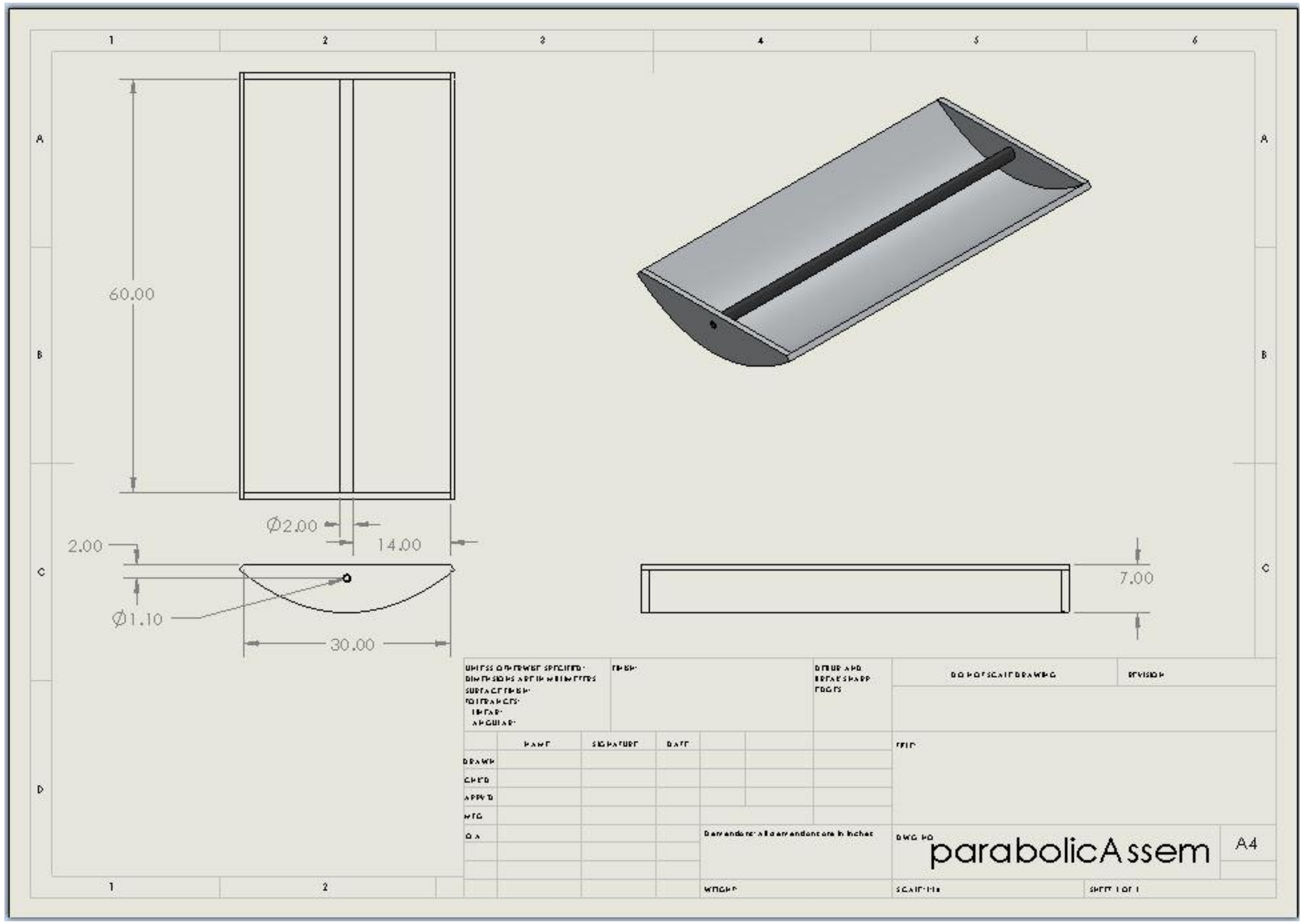
- Solving for $T_{s,o}$

$$q_{solar} = \tau\varepsilon\sigma(T_{s,o}^4 - T_\infty) + \frac{T_{s,o} - \ T_{air,o}}{R_{conv,o} + R_{cond,glass} + R_{conv,i}} + \frac{T_{s,o} - T_{water,i}}{R_{pipe}}$$

- Substituting back in to q_{in}

$$q_{in} = \frac{\left(T_{\ s,o} - T_{water}\right)}{R_{conv,i} + R_{cond}}$$

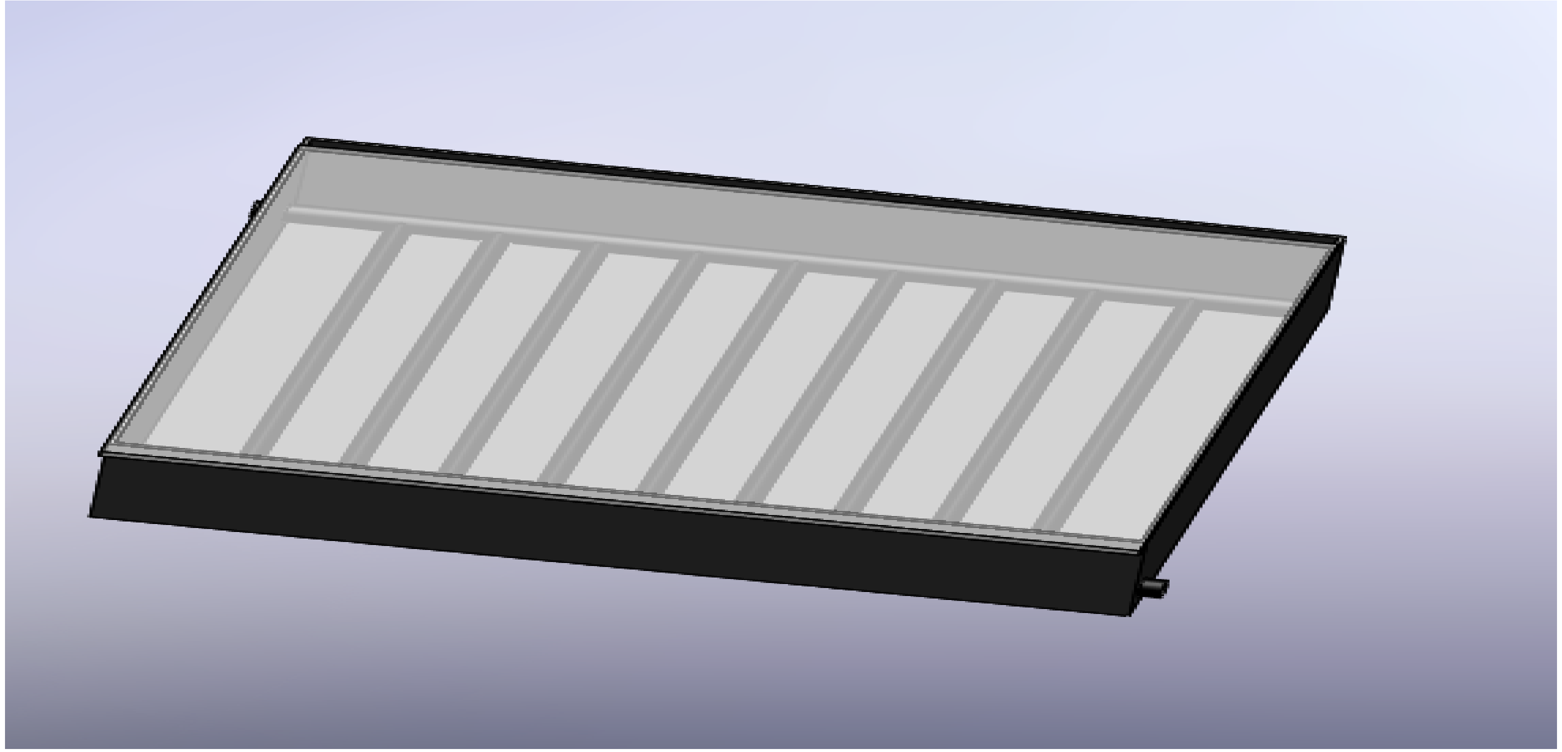
Parabolic Collector



Austin Chott

Flat Plate Collector Analysis

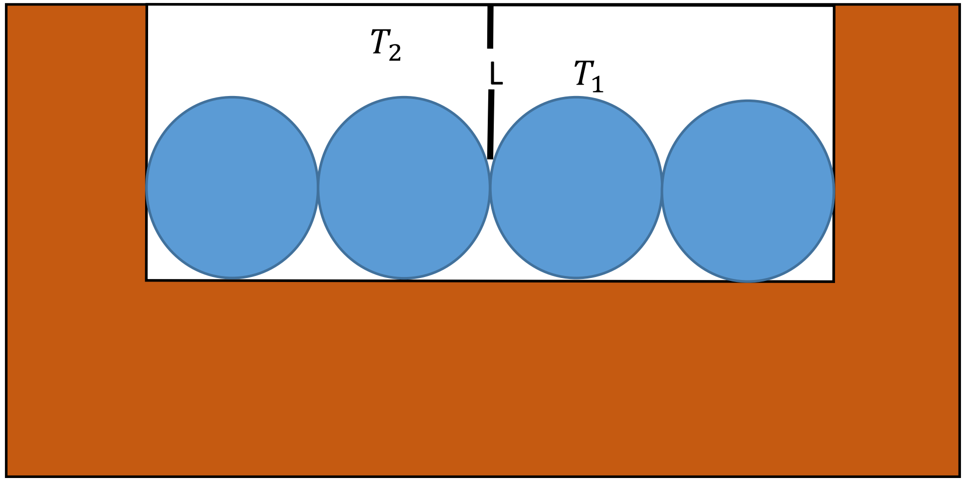
$$q_{solar} = q_{radiation} + q_{losses} + q_{in}$$



Flat Plate Collector Analysis

- Rayleigh number

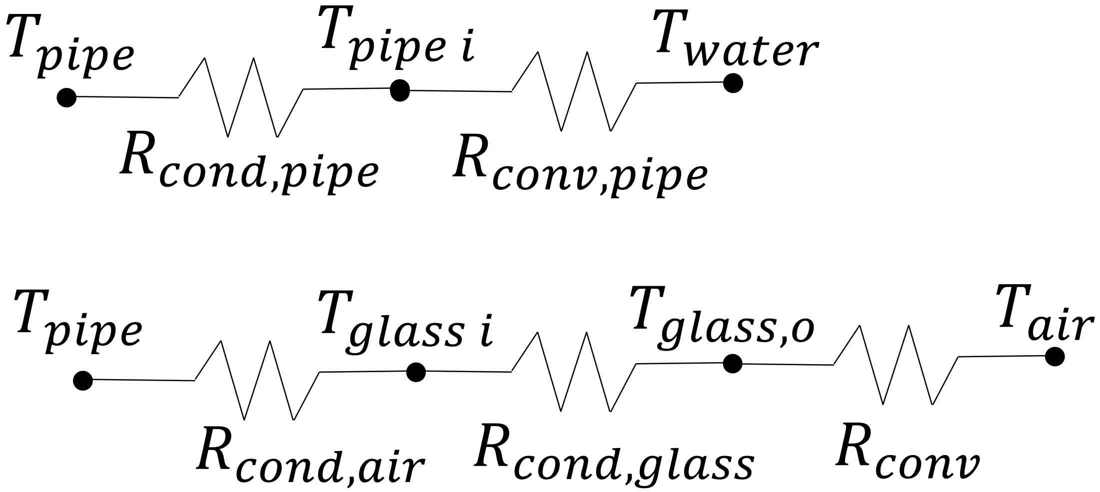
$$Ra_L \stackrel{\text{def}}{=} \frac{g\beta(T_1 - T_2)L^3}{\alpha\nu} < 1708$$



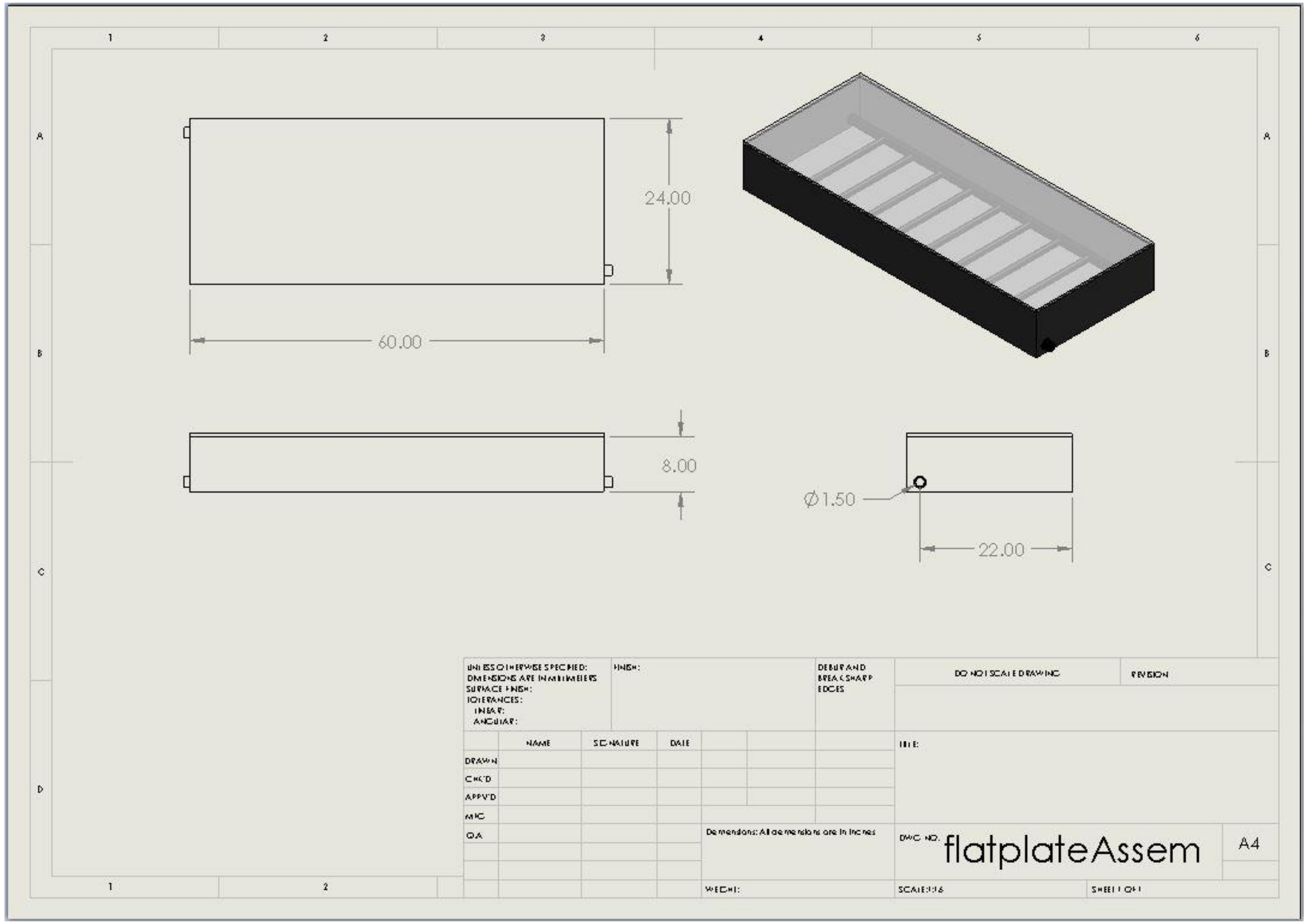
Flat Plate Collector Analysis

- Resistance network

$$q''_{solar} = \rho\tau\alpha G$$



Flat Plate Collector



Bread Box Collector Cost Analysis

Material	price	% used	# req	cost
Mylar sheeting 25'x50"	$ 37.15	50%	1	$ 18.58
Box	$ 8.50	100%	1	$ 8.50
Insulation	$ 10.48	100%	4	$ 41.92
1" X 10' PVC	$ 3.67	100%	1	$ 3.67
Paint	$ 3.00	100%	3	$ 9.00
Insulation	$ 10.48	100%	2	$ 20.96
Glass	$ 82.11	100%	1	$ 82.11
Misc fittings	$ 5.00	100%	5	$ 25.00
			Total	$ 209.74

- Green indicates easily scavenged
- Orange indicates difficult items to scavenge

Parabolic Collector Cost Analysis

Material	price	% used	# req	cost
Mylar sheeting 25'x50"	$ 37.15	25%	1	$ 9.29
Plywood 4'x8'	$ 18.45	100%	2	$ 36.90
Flat black paint	$ 3.00	100%	1	$ 3.00
1" x 10' PVC	$ 3.67	100%	1	$ 3.67
Misc fittings	$ 5.00	100%	5	$ 25.00
			Total	$ 77.86

- Green indicates easily scavenged
- Orange indicates difficult items to scavenge

Flat Plate Collector Cost Analysis

Material	price	% used	# req	cost
Plywood 4'x8'	$ 18.45	33%	1	$ 6.09
Paint	$ 3.00	100%	1	$ 3.00
Glass Sheet	$ 10.38	100%	2	$ 20.76
insulation	$ 10.48	100%	1	$ 10.48
1" X 10' PVC	$ 3.67	100%	12	$ 44.04
Misc fittings	$ 5.00	100%	5	$ 25.00
			Total	$ 109.37

- Green indicates easily scavenged
- Orange indicates difficult items to scavenge

Circulation System Cost Analysis

Passive Circulation System Cost with pressure		Amount	Total
Piping 10ft X 1in	$ 3.38	4	$ 13.52
Drain Valve	$ 6.97	1	$ 6.97
Pressure Release	$ 6.49	1	$ 6.49
Shut off valve	$ 8.97	2	$ 17.94
Water heater tank	$ 50.00	1	$ 50.00
Total			$ 94.92

- Green indicates easily scavenged
- Orange indicates difficult items to scavenge

Matt Beckham

Results

Collectors	Area (m^2)	Purchased Cost (USD)	Scavenged Cost (USD)	Everything Scavenged (USD)	Absorption (W)
Bread Box	1.672	304.66	134.69	52.58	628.67
Parabolic	1.161	186.30	37.29	37.29	691.83
Flat Plate	0.929	198.79	28.00	28.00	371.08

Collectors	Absorption/Area/$ Purchased Cost ($W/m^2/\$$)	Absorption/Area/$ Scavenged Cost ($W/m^2/\$$)	Absorption/Area/$ Everything Scavenged ($W/m^2/\$$)
Bread Box	1.23	1.90	2.95
Parabolic	3.20	4.36	4.36
Flat Plate	2.01	3.11	3.46

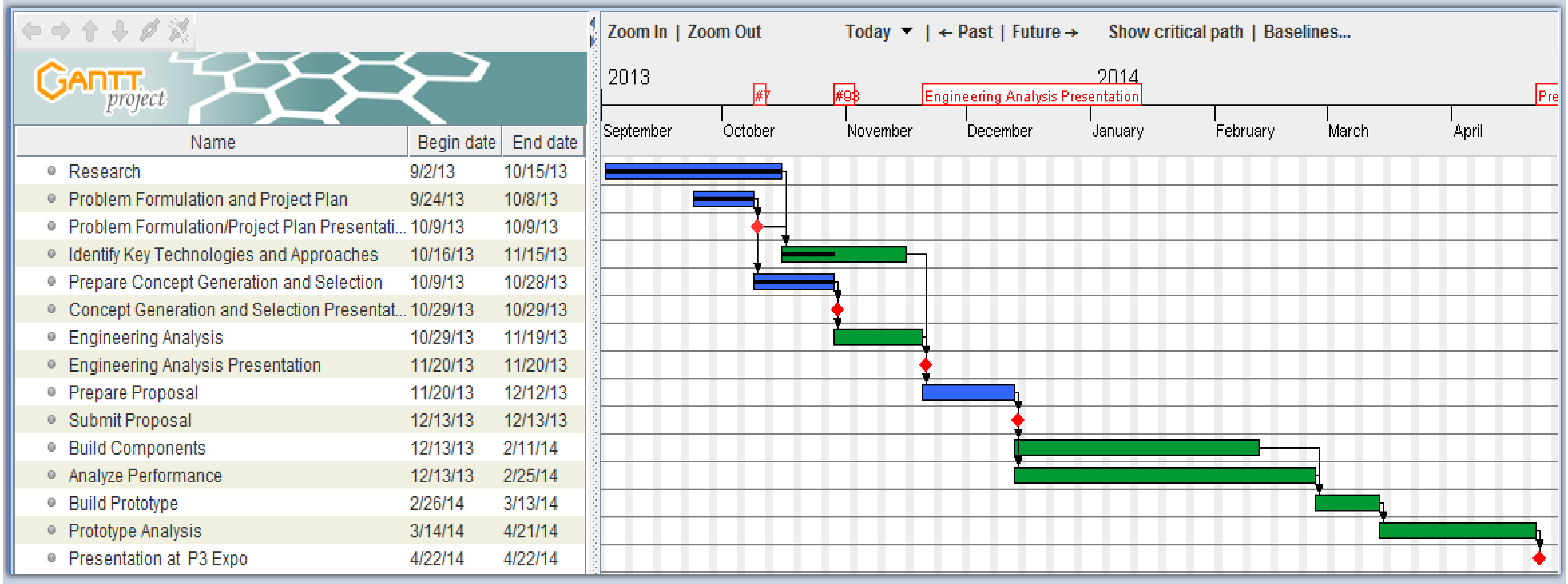
* Results are based on optimal collector performance

Final Design

- Based off of the absorption per area per dollar analysis the parabolic collector will be our final design for next semester.
- We will make a parabolic collector using as much scavenged material as possible.

Collectors	Absorption/Area/$ Purchased Cost ($W/m^2/\$$)	Absorption/Area/$ Scavenged Cost ($W/m^2/\$$)	Absorption/Area/$ Everything Scavenged ($W/m^2/\$$)
Parabolic PVC	3.20	4.09	4.09
Parabolic Galvanized	2.20	3.10	3.10
Parabolic Painted Galvanized	3.11	4.36	4.36

Timeline



Name	Begin date	End date
Research	9/2/13	10/15/13
Problem Formulation and Project Plan	9/24/13	10/8/13
Problem Formulation/Project Plan Presentati...	10/9/13	10/9/13
Identify Key Technologies and Approaches	10/16/13	11/15/13
Prepare Concept Generation and Selection	10/9/13	10/28/13
Concept Generation and Selection Presentat...	10/29/13	10/29/13
Engineering Analysis	10/29/13	11/19/13
Engineering Analysis Presentation	11/20/13	11/20/13
Prepare Proposal	11/20/13	12/12/13
Submit Proposal	12/13/13	12/13/13
Build Components	12/13/13	2/11/14
Analyze Performance	12/13/13	2/25/14
Build Prototype	2/26/14	3/13/14
Prototype Analysis	3/14/14	4/21/14
Presentation at P3 Expo	4/22/14	4/22/14

Questions

References

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