Ultra Low Cost Solar Water Heater

Engineering Analysis

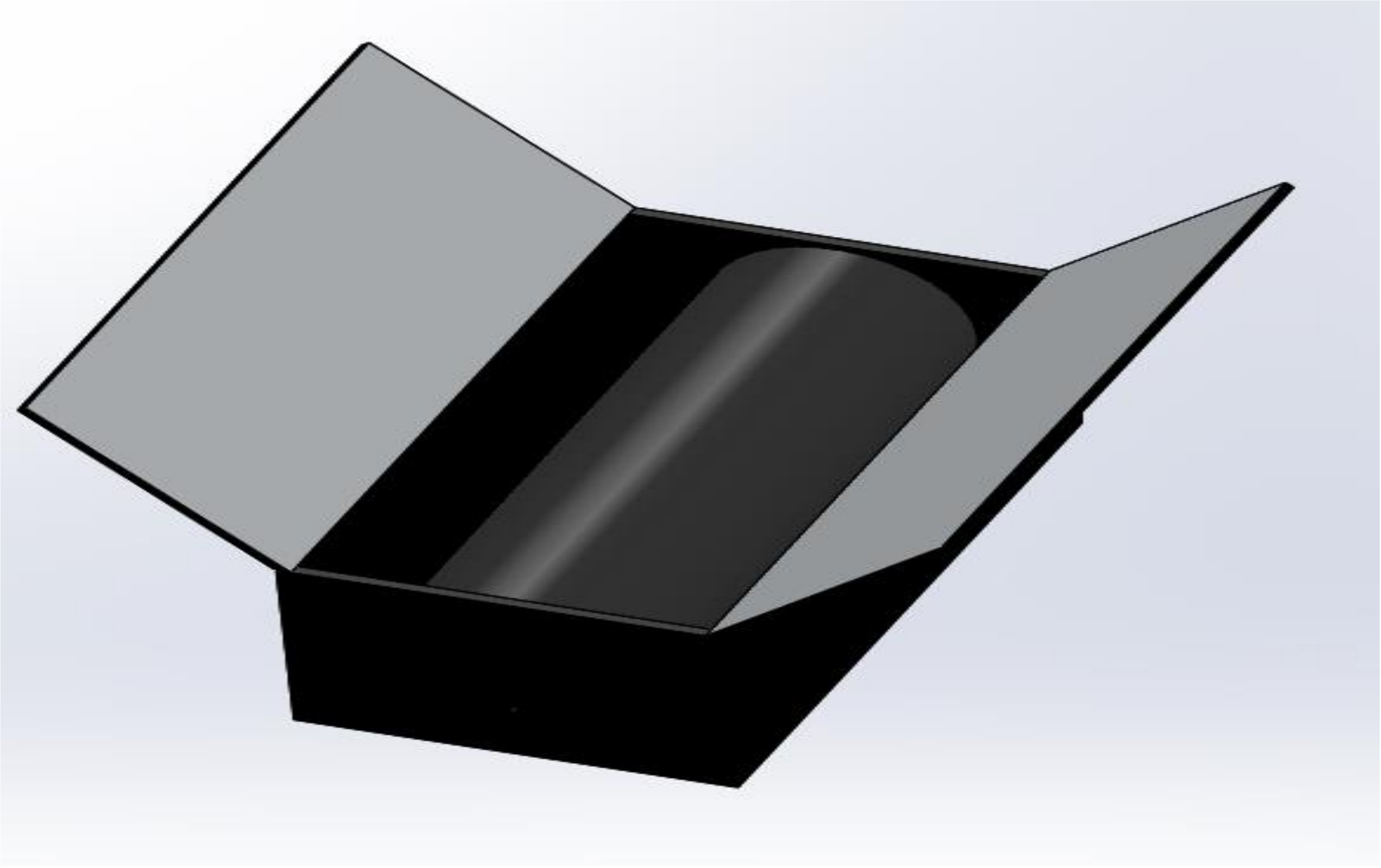
11/19/13

Saleh Alsadiq, Matt Beckham, Austin Chott, Thomas Griffin, Chris Heine

Overview

- Bread Box Collector Analysis
- Parabolic Collector Analysis
- Flat Plate Collector Analysis
- Results
- Timeline
- Conclusion

Bread Box Collector

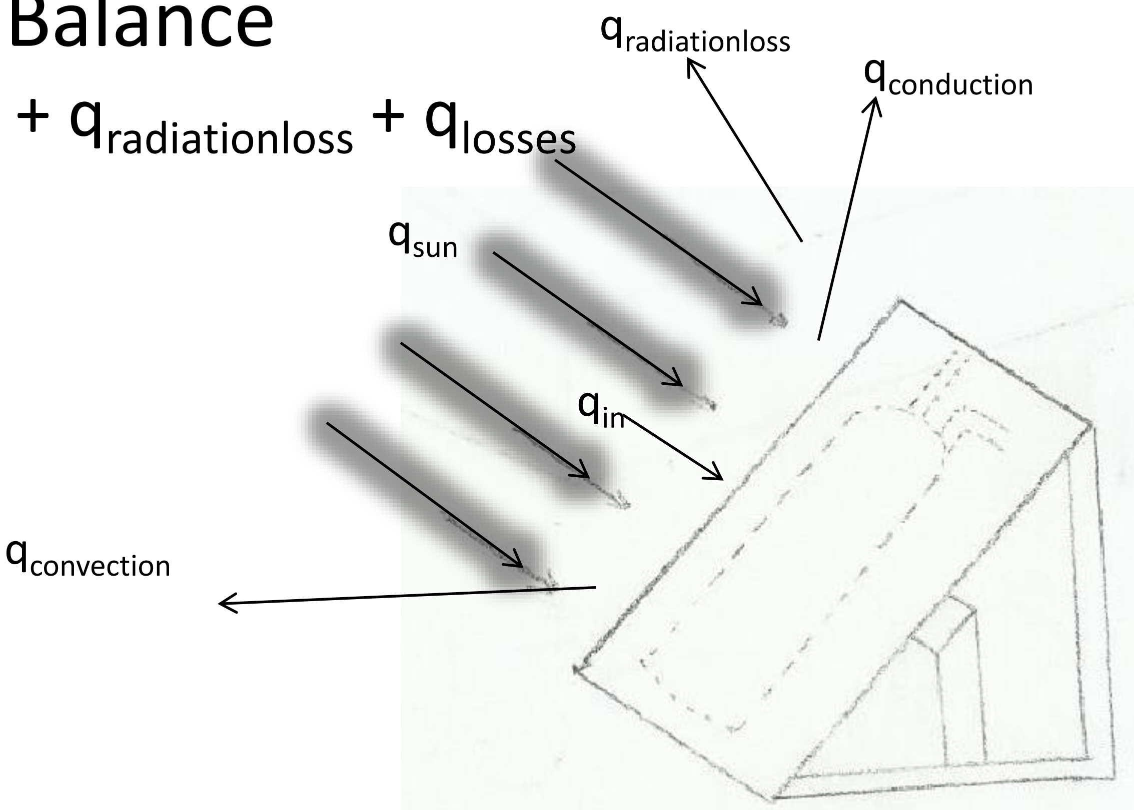


Bread Box Collector Analysis

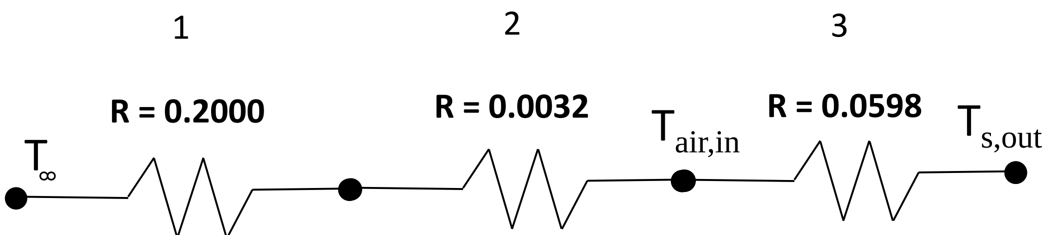
Energy Balance

$q_{sun} = q_{in} + q_{radiationloss} + q_{losses}$

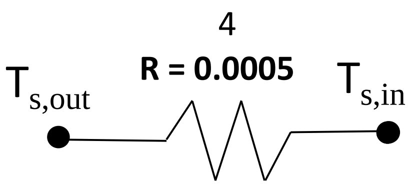
$$q = \frac{\Delta T}{R}$$



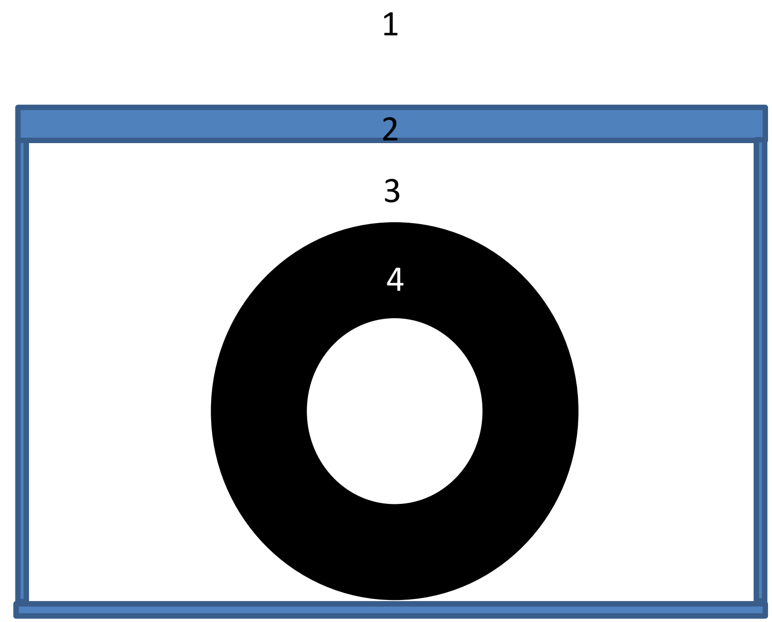
Resistance Network



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



$$R_{cyl,wall} = \frac{r_2/r_1}{2\pi kL}$$



Calculations

$q_{sun} = q_{in} + q_{radiationloss} + q_{losses}$

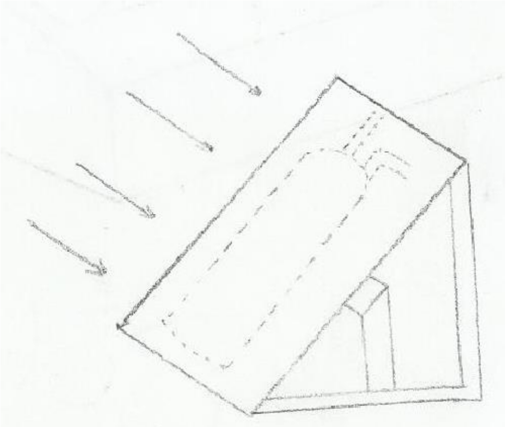
$$q_{sun} = \frac{T_{s,out} - T_{s,in}}{R_{pipewall}} + A\varepsilon\sigma(T_s^4 - T_{surr}^4) + \frac{T_{air,in} - T_\infty}{R_{conv} + R_{cond} + R_{conv}}$$

Key Assumptions: Some temperature values, heat transfer coefficient values

Plug in values to get: $$1309.83 = \frac{378K - T_{s,in}}{.0005} + 52.05 + \frac{378 - 293}{0.2000 + .0032 + .0598}$$

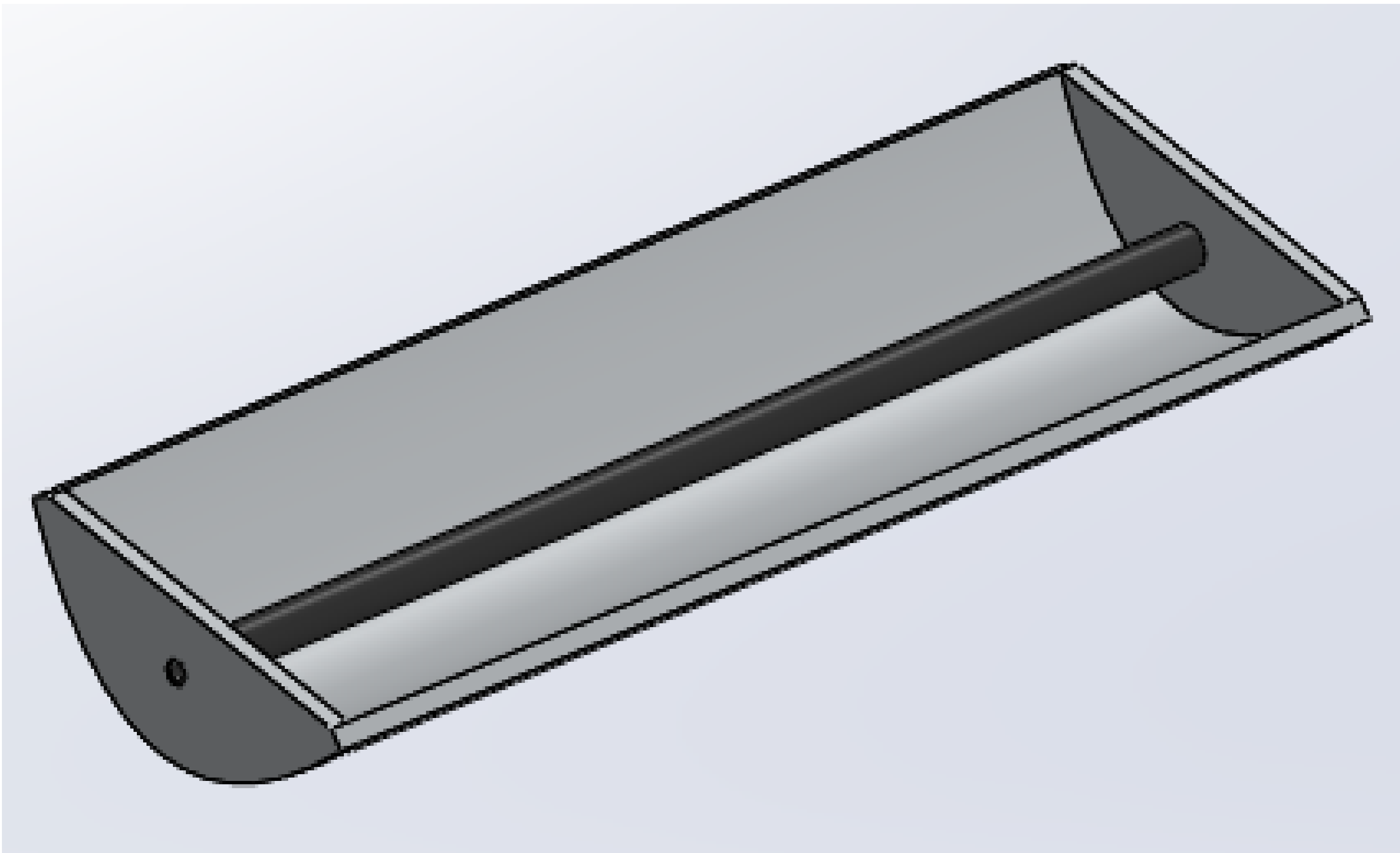
Now: $T_{s,in} = 104.6K$

Solve: $q_{in} = \frac{T_{s,out} - T_{s,in}}{R_{pipewall}}$



Final Value: $$q_{in} = 776.7W$$

Parabolic Collector



Parabolic Collector

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

- Energy Balance:

$$q_{solar} = q_{radiation} + q_{convection,out} + q_{in}$$

Parabolic Collector

- Radiation losses

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

- Convection out

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

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

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

Parabolic Collector

- q in

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

- Resistances

$$R_{conv,i} = \frac{1}{\overline{h_i} 2\pi r_i L} = 0.024223$$

$$R_{cond} = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k_{steel} L} = 6.68 * 10^{-5}$$

Parabolic Collector

- Solving for Ts,I

$$q_{solar} = A_s \varepsilon \sigma \left(T_{s,o}^4 - T_\infty\right) + \frac{(T_{s,o} - T_\infty)}{R_{conv,o}} + \frac{(T_{s,o} - T_w)}{R_{conv,i} + R_{cond}}$$

$$T_{s,o} = 318.53°K$$

- Substituting back in to q in

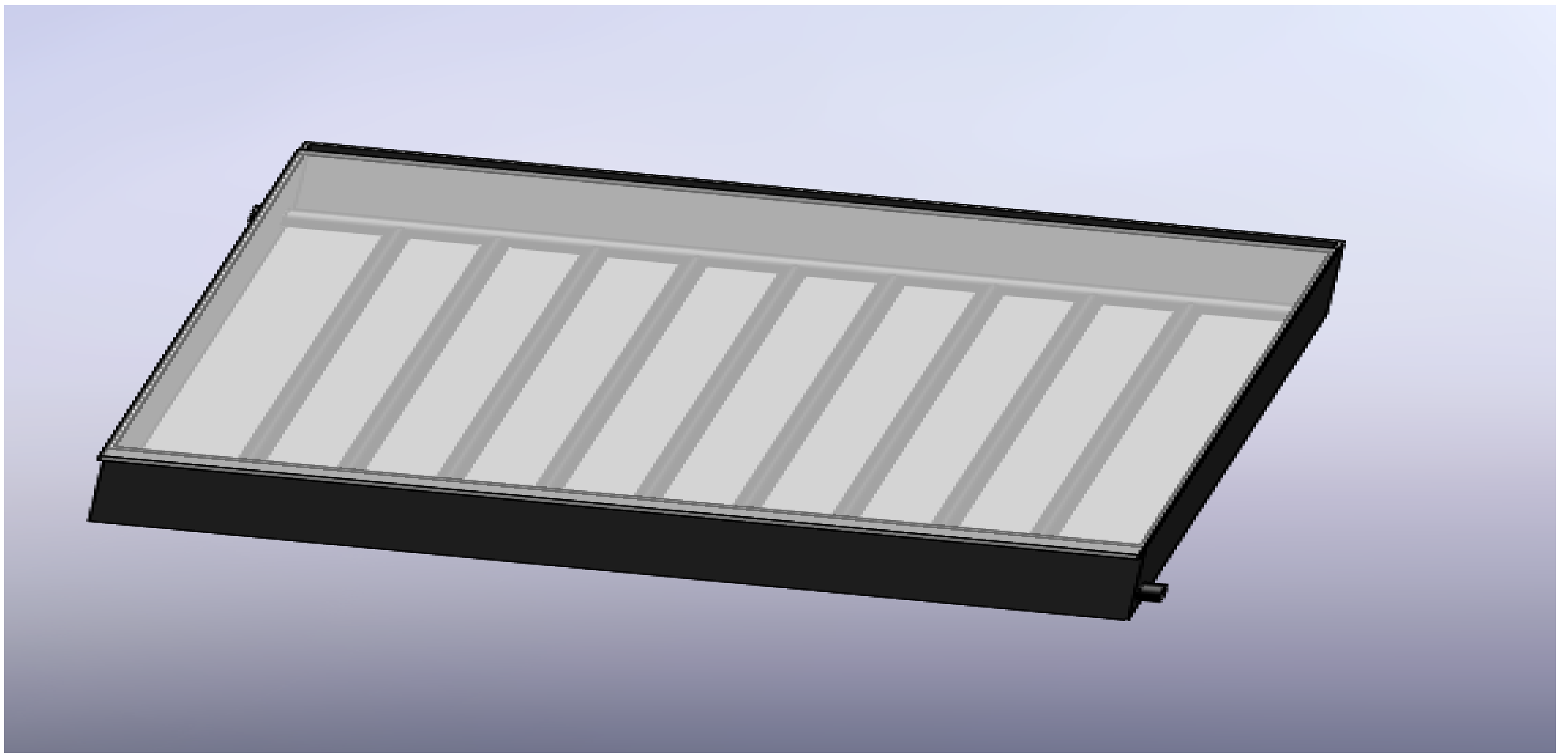
$$q_{in} = \frac{(T_{s,o} - T_w)}{R_{conv,i} + R_{cond}}$$

$$q_{in} = 737.0396 \text{ W}$$

$$q_{in} = 514 \text{ W.}$$

Flat Plate Collector

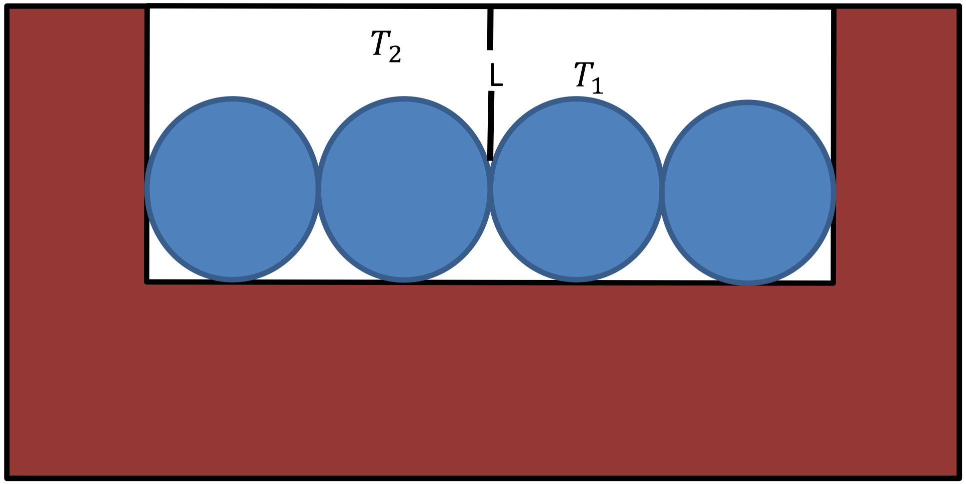
- $q''_{solar} = q''_{into\ water} + q''_{radiation\ loss} + q''_{other\ losses}$



Flat Plate Collector Analysis

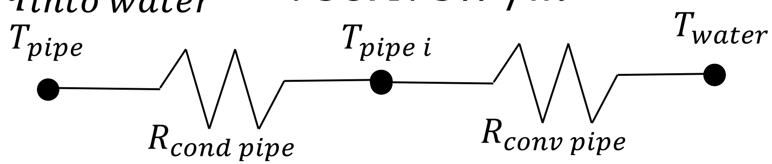
$$Ra_L \stackrel{\text{def}}{=} \frac{g\beta(T_1 - T_2)L^3}{\alpha\nu} > 1708$$

The Rayleigh number was found to be 647 with a gap of 5mm between the pipes and the glass

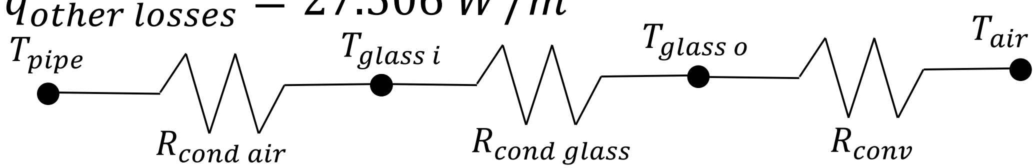


Flat Plate Collector Analysis

$$q''_{into\ water} = 738.475 W/m^2$$



$$q''_{other\ losses} = 27.506\ W/m^2$$



$$q''_{solar} = 765.99\ W/m^2$$

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

$$q''_{radiation\ loss} = 1.222\ W/m^2$$

$$q''_{radiation\ loss} = \sigma\varepsilon A(T_s^4 - T_{surroundings}^4)$$

**Calculations on this side provided for Galvanized pipe covered by glass

Flat Plate Collector Analysis

$$T_{mo} = T_{mi} + \frac{q''_{into\ water} PL}{\dot{m} C_p} \cong 284^{\circ} K$$

Mass flow rate was chosen so the pipe system would be replaced every minute. Using tabulated inlet temperatures the final temperature can be calculated at the exit of the solar collector

Average Water Inlet Temperature in Phoenix Arizona: 82.3 degrees Fahrenheit

Results

Absorption/area/$:

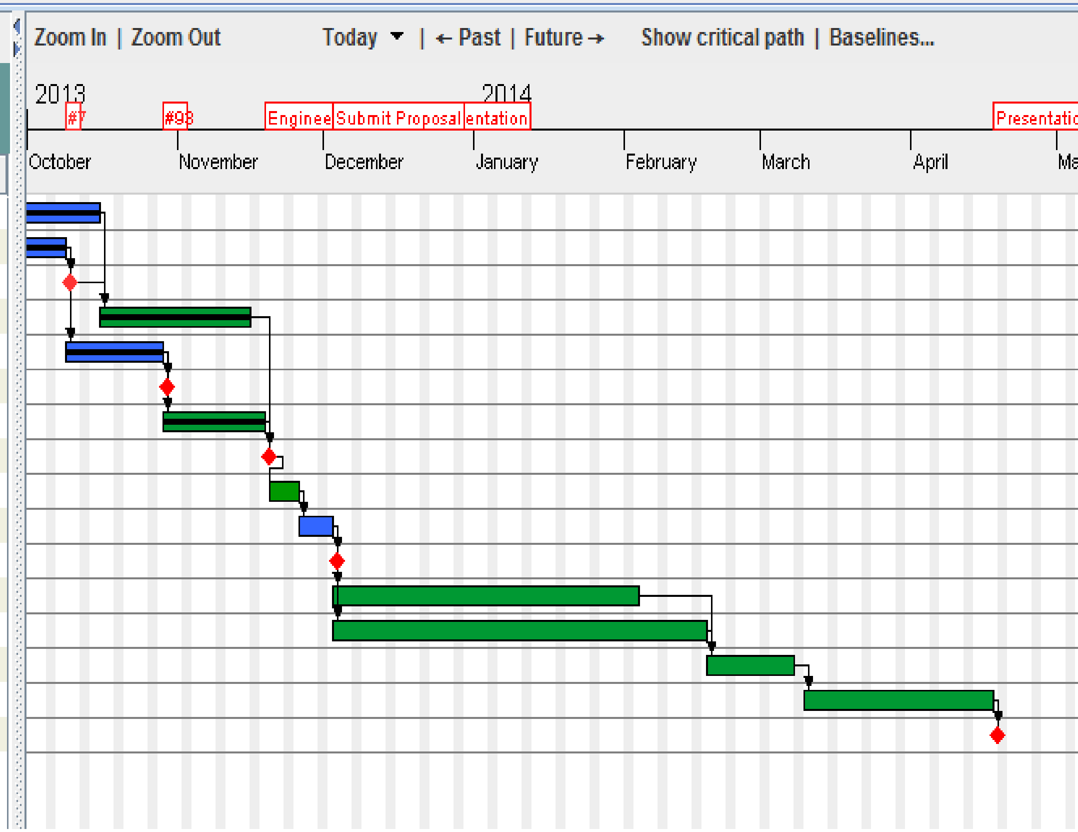
- Bread box: Best design used glass as a cover and cost $201.36 (with circulation) based on 1.67 m^2. A/A/$ comes out to **2.31**.
- Parabolic: Best design used galvanized, black painted pipes and cost $260.23 (with circulation) based on 1.16m^2. A/A/$ comes out to **2.44**.
- Flat plate: Using galvanized piping with no spacing and cost $488.41 (with circulation) based on .93m^2. A/A/$ comes out to **1.63**.

- It is most likely that we will use the **parabolic collector** with galvanized, black painted pipes based on this analysis.

Timeline

Gantt Chart

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 Presentation	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 Presentation	10/29/13	10/29/13
Collectors Engineering Analysis	10/29/13	11/18/13
Engineering Analysis Presentation	11/19/13	11/19/13
Circulation Engineering Analysis	11/20/13	11/25/13
Prepare Proposal	11/26/13	12/2/13
Submit Proposal	12/3/13	12/3/13
Build Components	12/3/13	2/3/14
Analyze Performance	12/3/13	2/17/14
Build Prototype	2/18/14	3/7/14
Prototype Analysis	3/10/14	4/17/14
Presentation at P3 Expo	4/18/14	4/18/14



Conclusion

- In summary, the analysis of the bread box, parabolic, and flat plate collectors showed that the parabolic collector had the highest A/A/$.
- Our next step will be the circulation analysis which will be completed on the 25th of Nov.
- The proposal will be finalized on the 3rd of Dec.

References

- M. Raisul Islam, K. Sumathy and S. Ullah Khan, "Solar water heating systems and their market trends," *Renewable and Sustainable Energy Reviews,* vol. 17, pp. 1-25, 1, 2013.
- U.S. Department of Energy (DOE). (2005). *Residential Energy Consumption Survey 2005*. Washington, DC: Energy Information Administration. http://www.eia.doe.gov/emeu/recs/. Accessed October 2013.
- Energy Information Administration (EIA). (2005). *Office of Energy Markets and End Use, Forms EIA-457 A-G of the 2005 Residential Energy Consumption Survey.* Washington, DC: EIA.
- American Society of Heating and Air-Conditioning Engineers (ASHRAE). (1987). *Methods of Testing TO DETERMINE THE SOLAR PERFORMANCE OF SOLAR DOMESTIC WATER HEATING SYSTEMS*. Atlanta, GA: ASHREA Standard- 95.
- American Society of Heating and Air-Conditioning Engineers (ASHRAE). (1987). *Methods of Testing to Determine the Performance of Solar Collectors*. Atlanta, GA: ASHREA Standard- 93.
- M. Raisul Islam, K. Sumathy, Samee Ullah Kahn. (2012). *Solar water heating systems and their market trends*. Atlanta, GA: Renewable and Sustainable Energy Reviews. http://www.elsevier.com/locate/rser/. Accessed October 2013.
- Database of State Incentives for Renewables and Efficiency (DSIRE). (2012). *Arizona Incentives/Policies for Renewables and Efficiency*. Raleigh, NC: North Carolina State University. http://www.dsireusa.org/incentives/index.cfm?re=0&ee=0&spv=0&st=0&srp=1&state=AZ/. Accessed October 2013.
- U.S. Department of Energy (DOE). (2012). *Building Codes and Regulations for Solar Water Heaters*. Washington, DC: U.S. Department of Energy. http://energy.gov/energysaver/articles/building-codes-and-regulations-solar-water-heating-systems/. Accessed October 2013.
- U.S. Department of Energy (DOE). (2012). *Building Energy Codes Program*. Washington, DC: U.S. Department of Energy. http://www.energycodes.gov/adoption/states/. Accessed October 2013.
- Energy Protection Agency (EPA). (2013). *P3:People, Prosperity, and the Planet Student Design Competition for Sustainability .* Washington, DC: EPA. http://www.epa.gov/P3/. Accessed October 2013