Sustainable Water Solutions

SWS

Preliminary Design Review
September 16, 2009
ME 463

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Engineers for a Sustainable World
PURDUE UNIVERSITY CHAPTER

Presentation Outline

- Team & Project Overview
- Customer Specifications & Engineering Requirements
- Preliminary Analysis
- Preliminary System Designs
  - Rainwater Harvesting
  - Solar Water Heating
- Sustainability Analysis
- Looking Forward

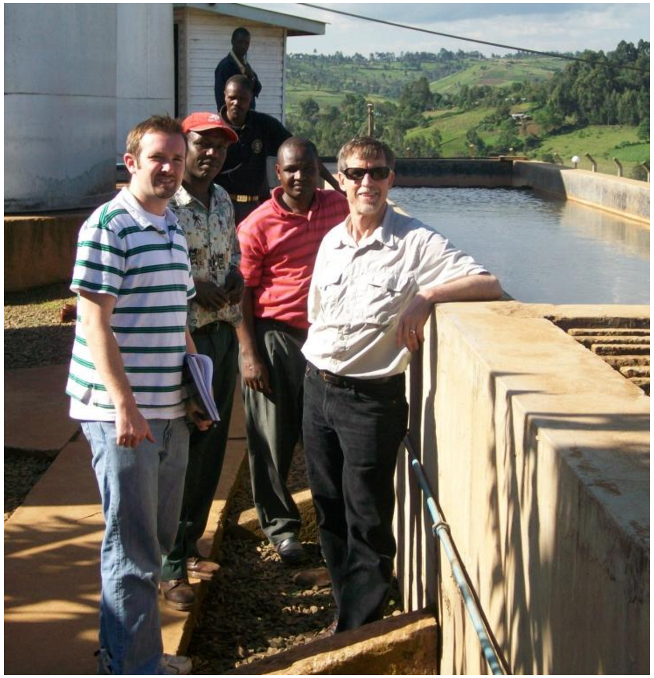
Organization Chart

Mission Statement

- Develop a sustainable, low-maintenance, rainwater harvesting system with solar water heating capability. The system will be designed to meet approximately 1/3 of the needs of the in-patient ward (~100 patients), providing 20L of water per day per person, 10L being heated water.

Project background

- Tenwek Hospital
  - Rift Valley Province
  - Bomet, Kenya
  - Missionary Hospital
  - Provides primary healthcare for 600,000 Kenyans
  - 308 beds for in-patient housing
- Assessment trip in June 2009
- System to supplement current water supply

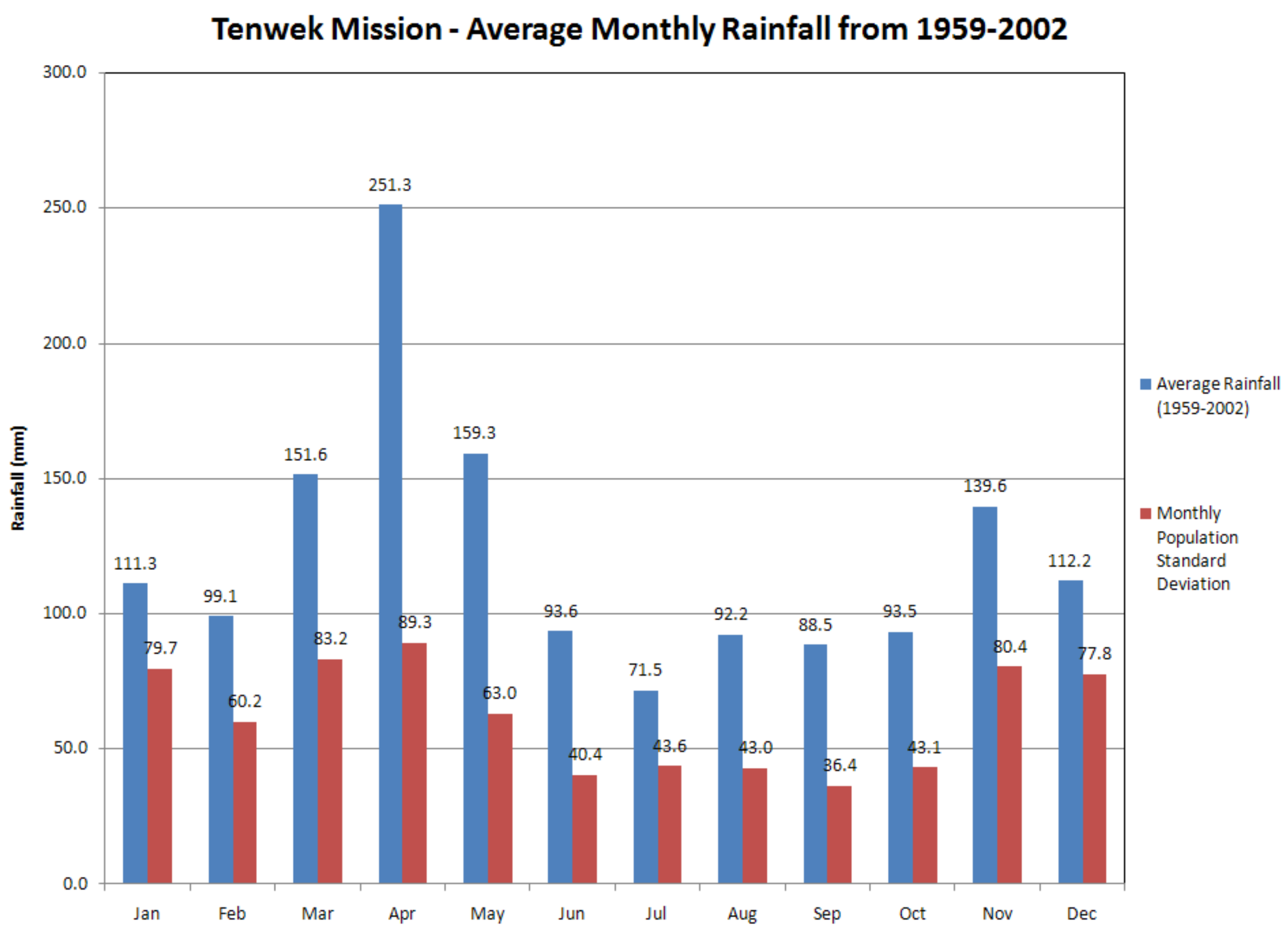


Project Location

Customer & Engineering Requirements

- Minimal Environmental Impact
- Provide 1000L/day of supplemental water and 1000L/day of heated water during rainy seasons
- Provide 500L/day of heated water year round
- Solar water heater output temperature of 45°C
- Low Maintenance
- Low Cost
- Manufactured locally from local materials
- Pump to supply solar heaters 11.5 m net positive suction head (NPSH)

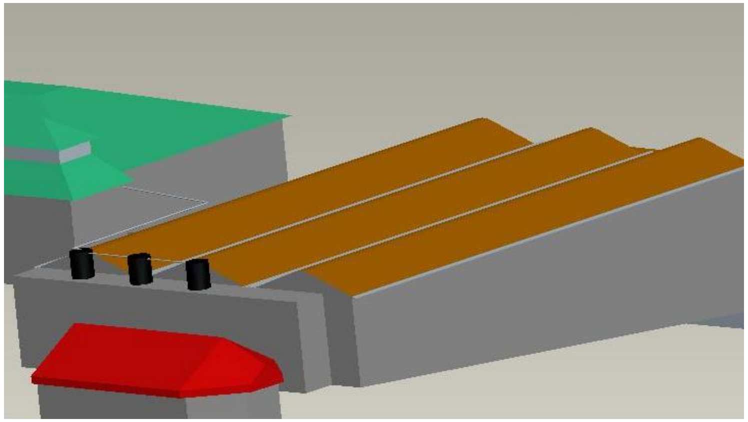
Preliminary Analysis



Joseph Kiprono, "…Hydrologic Characteristics and Management Practices…", MS, Moi University, 2005

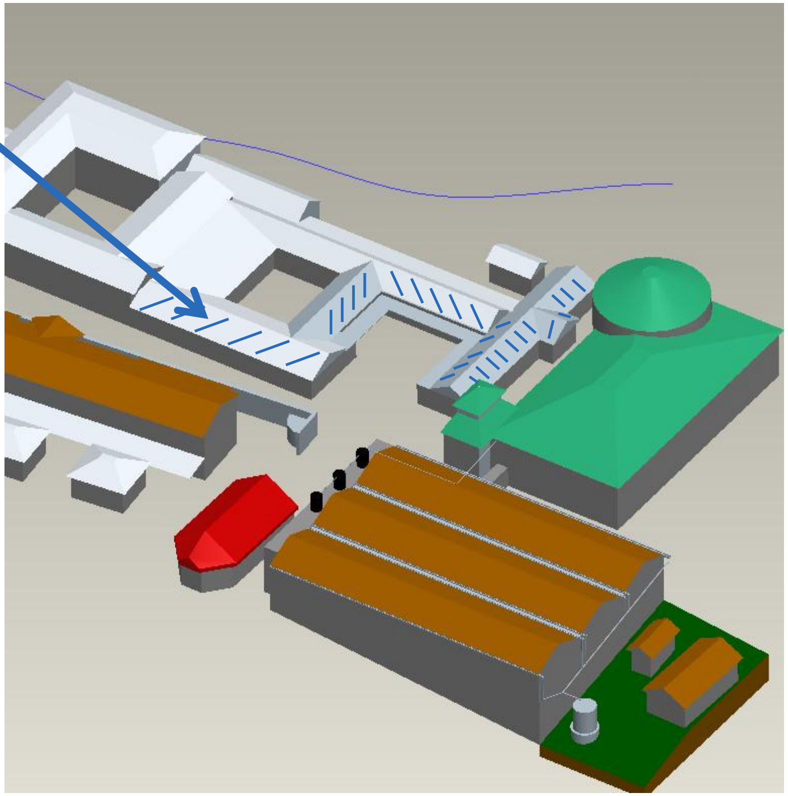
Preliminary Analysis

- In-patient Housing
  - Total roof collection area of 960m^2
  - Provide daily average of 2500L
- Tank Sizing
  - Demand Approach:
    - Assuming worst case scenario of a 30-day drought
    - 60,000 L Tank for supply trough dry seasons
      - 20L/day for 100 patients
    - 15,000 L tank for supply through dry seasons
      - 10L/day of heated water for 50 patients



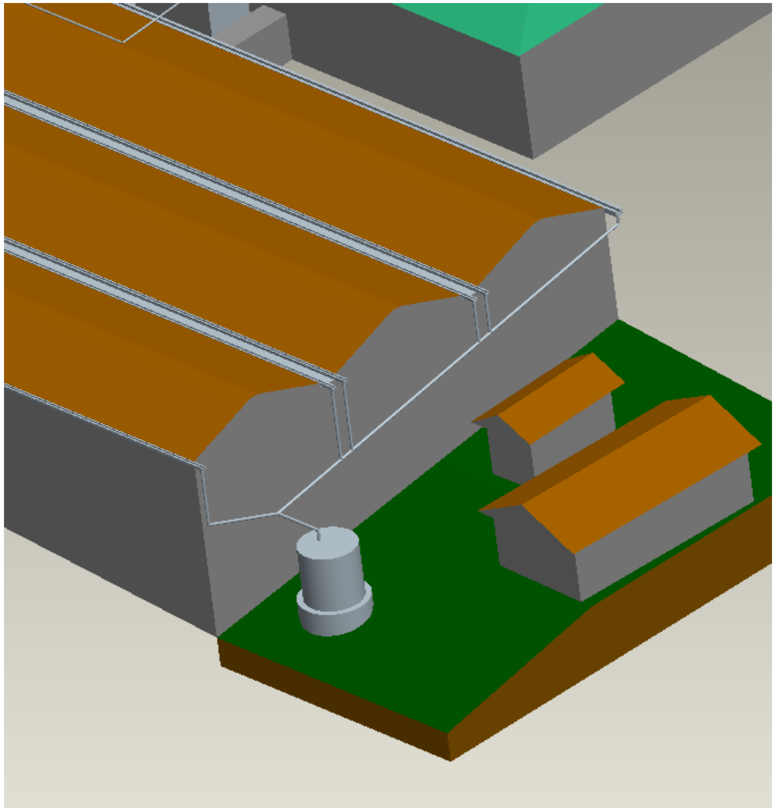
Preliminary Analysis

- Out-patient Building
  - Potential roof collection area of 410m^2
  - Provide daily average of 1,070L
  - Potential complications with water transport to the in-patient ward



Preliminary System Design: Rainwater Harvesting

- Rainwater Harvesting Collection Design
  - Water collected from in-patient housing
  - 250 m 5" Gutter system
  - 50 m 3" Piping
  - Filtration System
  - First flush diversion
  - 15,000 L storage tank
  - Tank Base

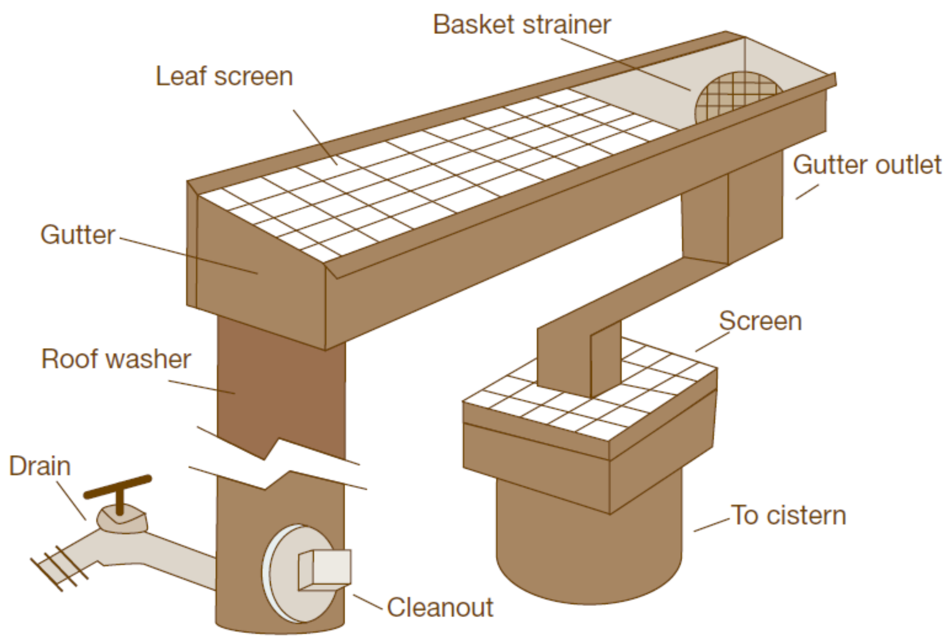


Preliminary System Design: Rainwater Harvesting

- Gutter system options
  - Aluminum
  - Vinyl (PVC)
  - Galvanized Steel
- Galvanized Steel gutters common in Kenya
  - ~1000 Ksh/m ($14.00/m)
- 3" PVC piping common for harvesting in Kenya
  - ~150 Ksh/m ($2/m)

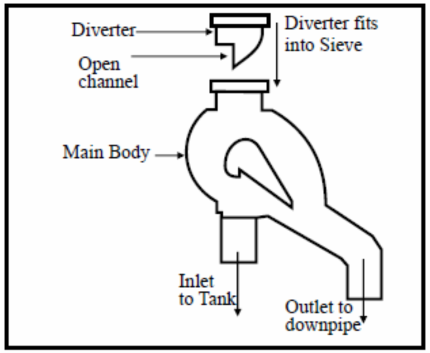
Preliminary System Design: Rainwater Harvesting

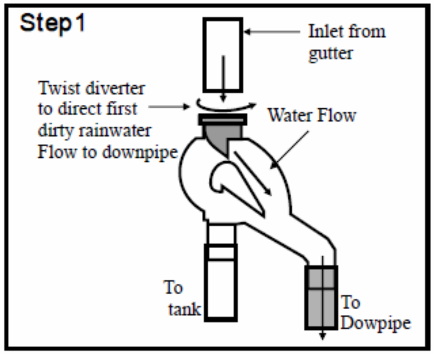
- Filtration of debris maybe needed if collecting off of buildings with trees nearby

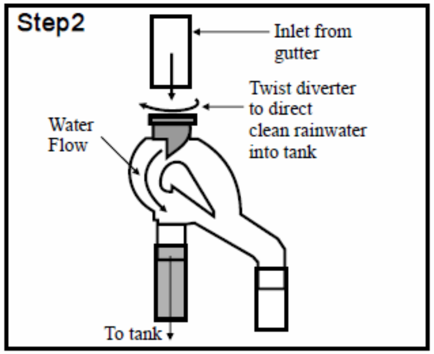


Preliminary System Design: Rainwater Harvesting

- Initial rainfall after a long dry period should not be collected due to accumulated dust
- First flush options
  - Kentank manual "Sieve" (Left)
  - Automatic water diverter (Right)







Preliminary System Design: Rainwater Harvesting

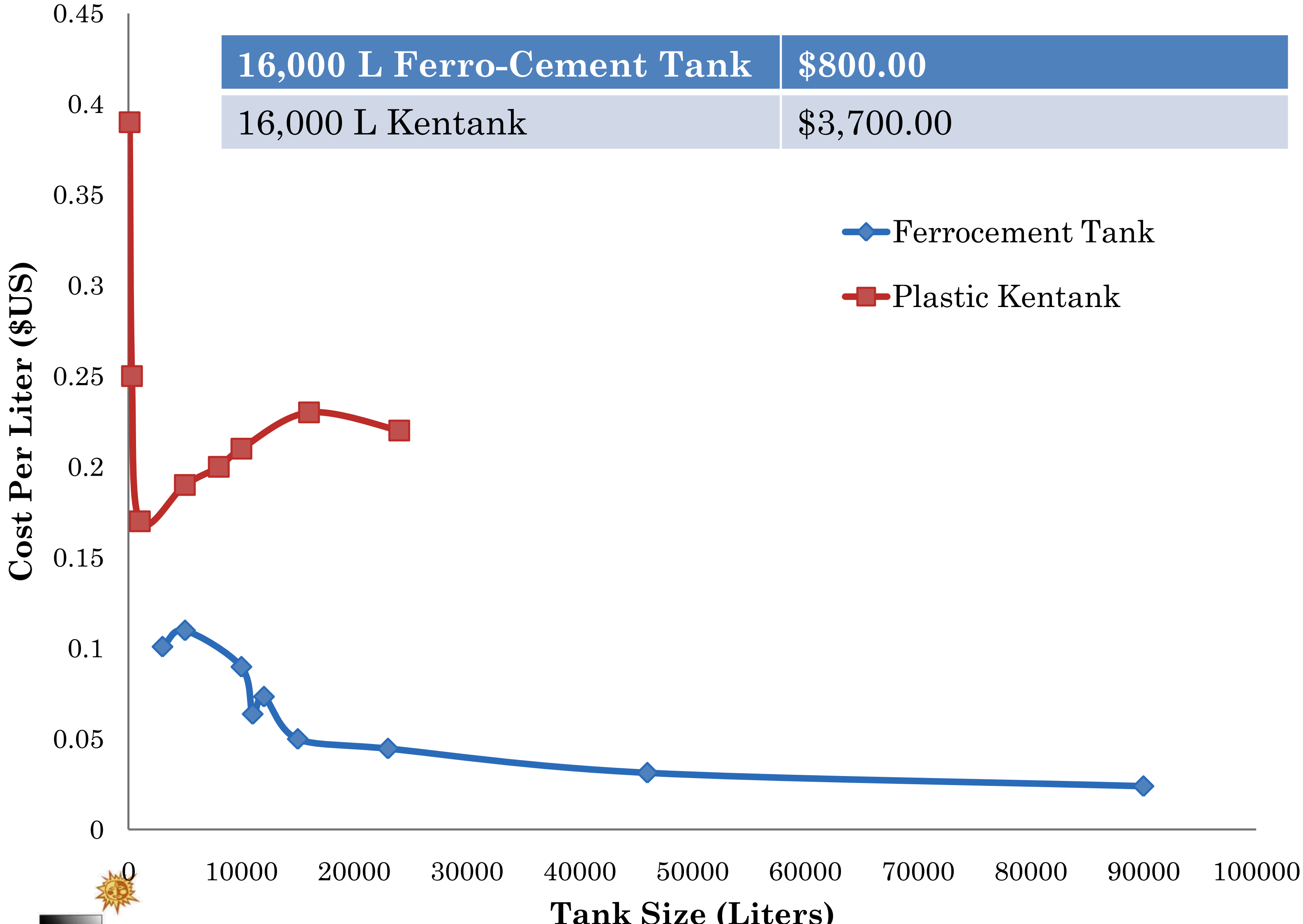
- Tank design options
  - Metal
  - Plastic
  - Ferro-cement
- Plastic and Ferro-cement tanks are feasible options

	Tank Type		
	Metal	Plastic	Ferro-cement
Cost	3	1	9
Sufficient Longevity	1	9	9
Structurally Strong	3	9	9
Remain water tight	3	9	3
Easy to clean	3	9	3
Prevent children from entering	3	3	3
Needs to block light	9	9	9
Sealed from bugs	9	9	9
Doesn't affect taste	1	9	3
Easy Access	9	9	9
Total	**44**	**76**	**66**

Weak = 1
Medium = 3
Strong = 9

Preliminary System Design: Rainwater Harvesting

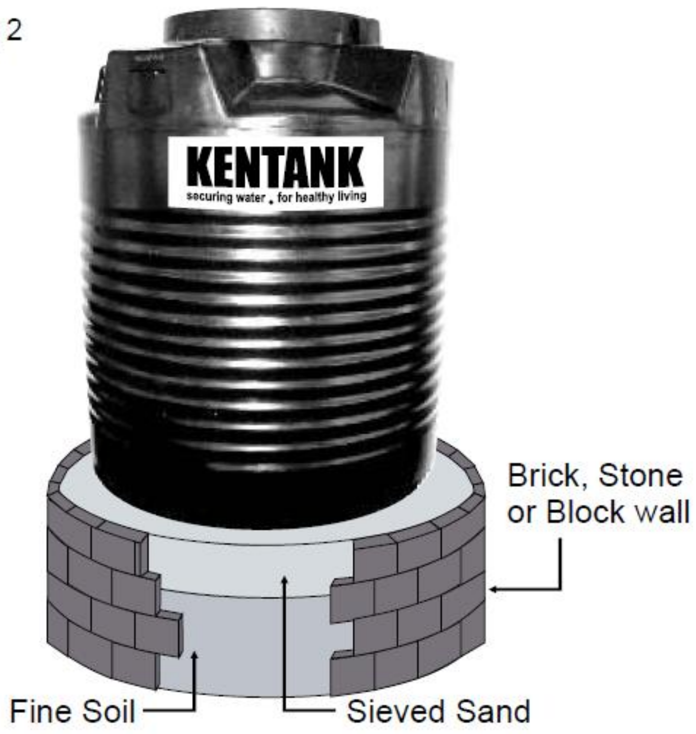
16,000 L Ferro-Cement Tank	**$800.00**
16,000 L Kentank	$3,700.00



Preliminary System Design: Rainwater Harvesting

- Kentank foundation
  - Layers of sand enclosed in brick cylinder
  - ~59,400 Ksh ($800) for given 16,000 L tank

Fig 2

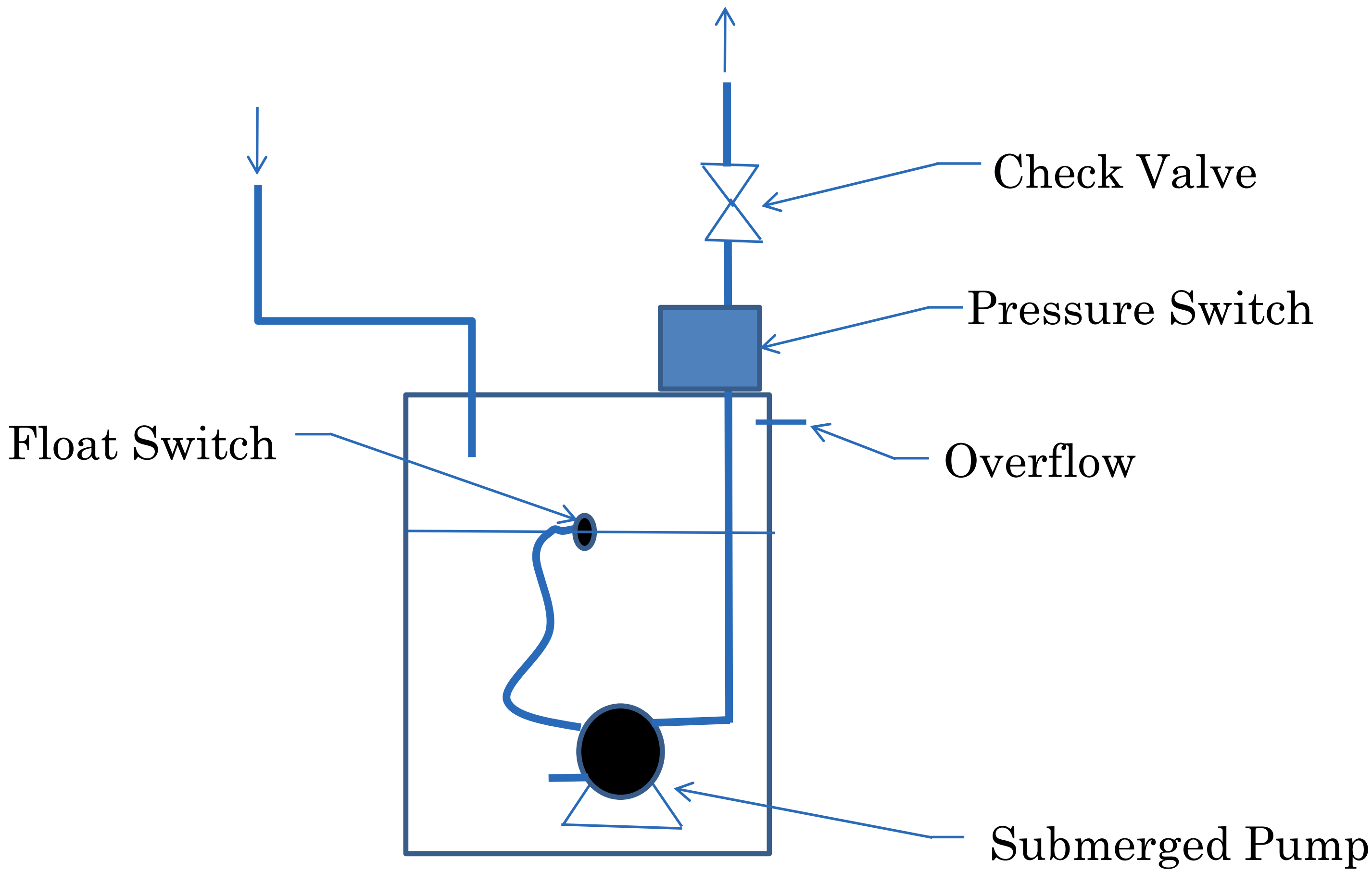


Preliminary System Design: Rainwater Harvesting

- Ferro-cement tank below ground versus above ground
  - Tenwek utilizes both above ground and below ground tanks
  - Above ground is ideal is sufficient surface area is available

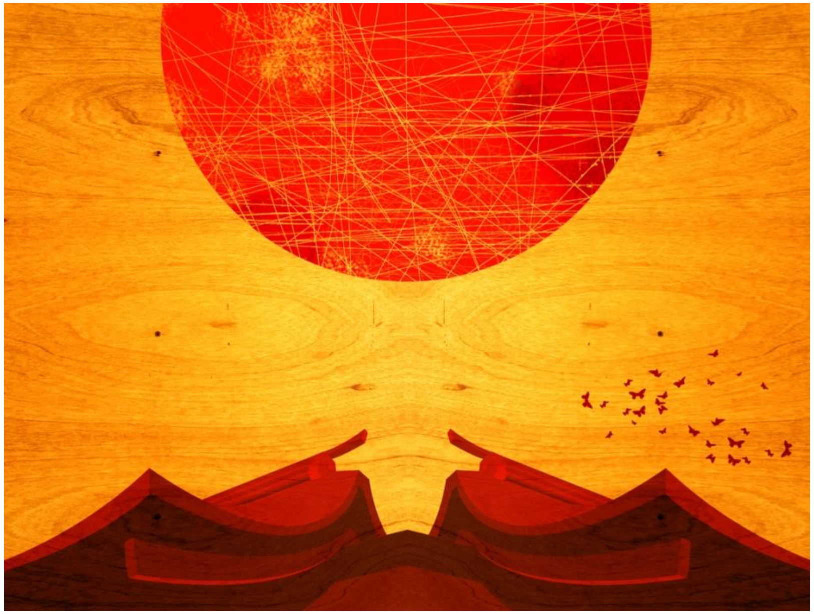
Above Ground	Below Ground
Easy to find structural problems	Can be built in heavily congested areas
Easy to maintain and clean	
Easy to draw water from	

Preliminary System Design: Rainwater Harvesting



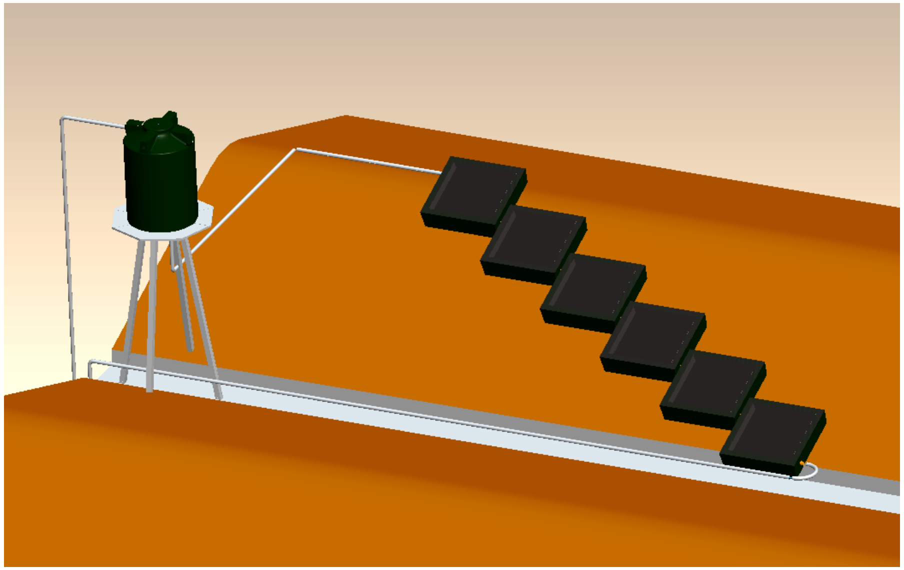
Preliminary System Design: Solar Water Heating

- Active Solar Water Heater
  - Dan
- Passive Solar Water Heater
  - Thermosyphon
    - Robb
  - Integrated
    - Stephen



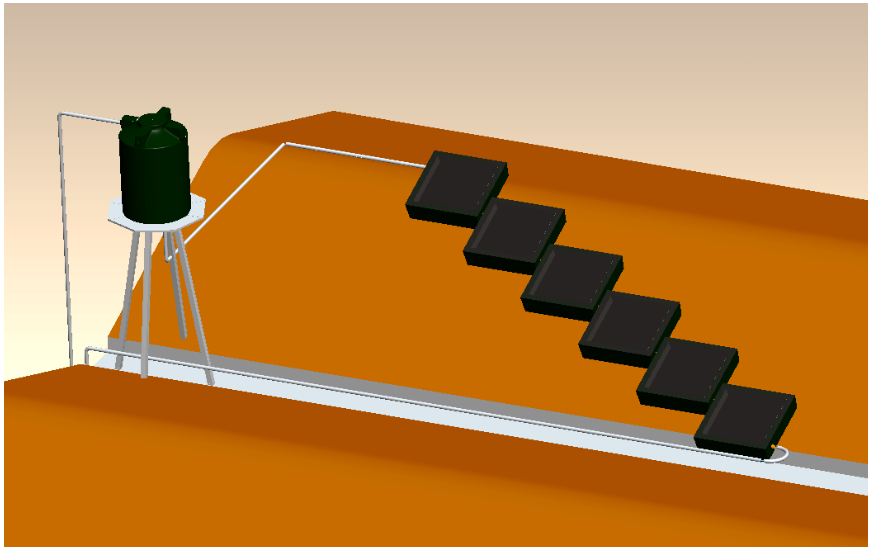
Preliminary System Design: Active Solar Water Heater

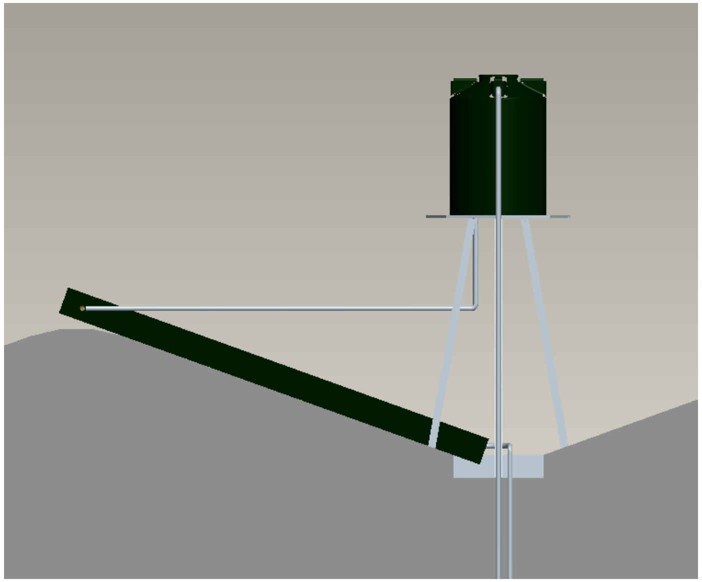
- Active Solar Water Heater
  - Direct Heat Exchange System
    - Forced flow through heat exchangers
    - No heat exchange fluid – Direct heat exchange through solar collector plates



Preliminary System Design: Active Solar Water Heater

- Six heat exchangers in series
  - Provides the necessary heat transfer surface area for the desired output temperature
- Local storage tank elevated 1m above heat exchanger
  - As tank discharges, the hydrostatic pressure decreases, decreasing the flow rate and compensating for the lower flux later in the day
  - Maintains a constant delivery temperature
- Output Options
  - On-demand thermal storage tank
    - Maintains a desired output temperature
  - Direct to spigot for use
    - Water will sit in heat exchanger until called up, increasing output temperature





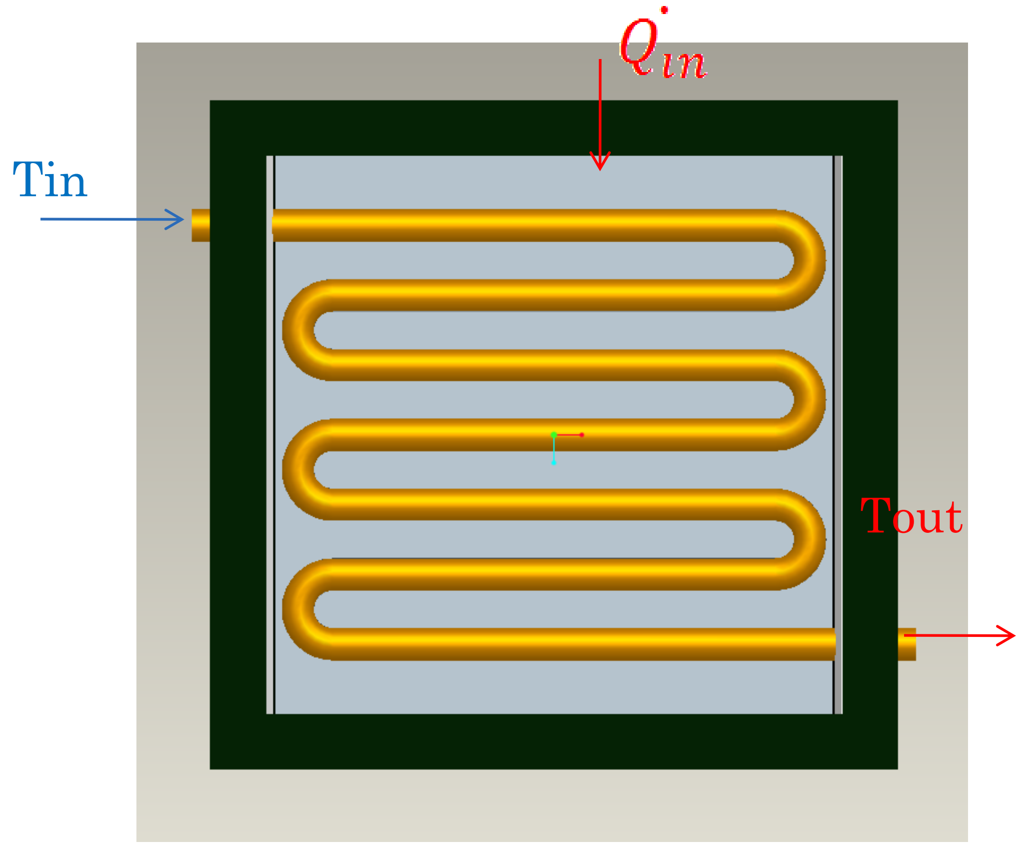
Preliminary System Design: Active Solar Water Heater

Assumptions:

- Solar Flux = 698 W/m2
- η_t=.7
- A_c=1m^2*6 Collectors
- $\dot{m} =$ 2.66e-2 kg/s
  - •1000L supply over a 10 hour day
- Tin = 20ºC

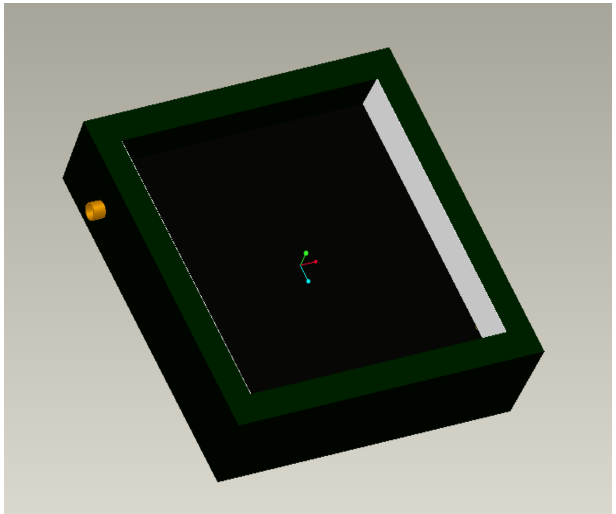
$$T_{out} = T_{in} + \frac{\dot{Q}_{in} A_c}{\dot{m} C_p}$$

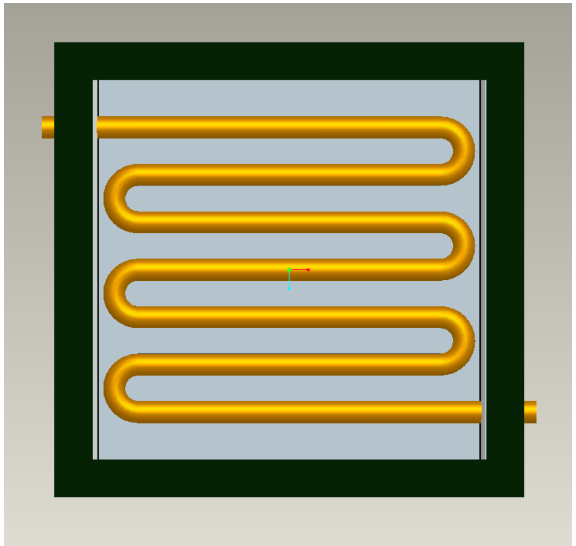
•$\underline{T_{out} = 46.3^oC}$

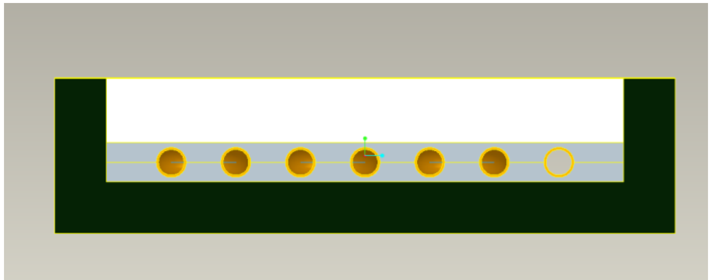


Preliminary System Design: Active Solar Water Heater

- Heat Exchanger Design
  - BOM
    - Thermoplastic Insulation/Shell
    - Copper Tubing
    - Aluminum heat Transfer plates (2)
    - Reflective material on sides to maximize incident radiation
    - High Transmissivity glass cover
      - Eliminates forced convective flow from heat transfer plates







Preliminary System Design: Active Solar Water Heater

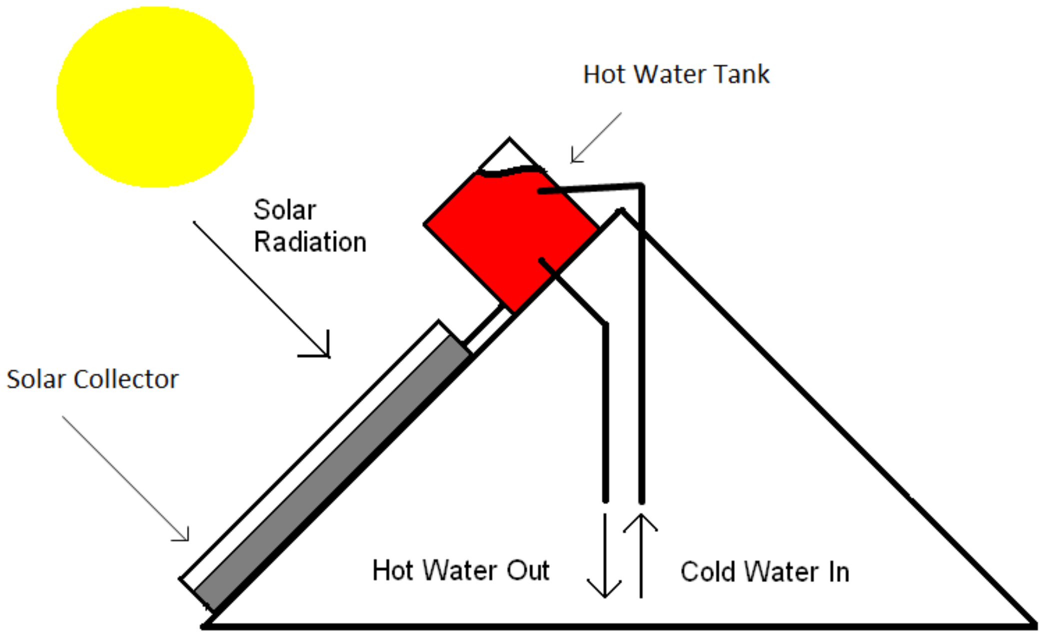
- System Evaluation
  - Pros:
    - Fast transient performance
      - Will reach desired temperature quickly
        - Heat transfer analysis will determine transient response
    - Flexibility in output temperature
      - Flow rate manipulation determines desired output temperature
    - Gravity fed throughput/output
  - Cons:
    - Initial capital cost is a concern (YTBD)
    - Potentially requires extra on-demand thermal storage tank
    - Series system may complicate troubleshooting

Preliminary System Design: Thermosyphon Passive Water Heater

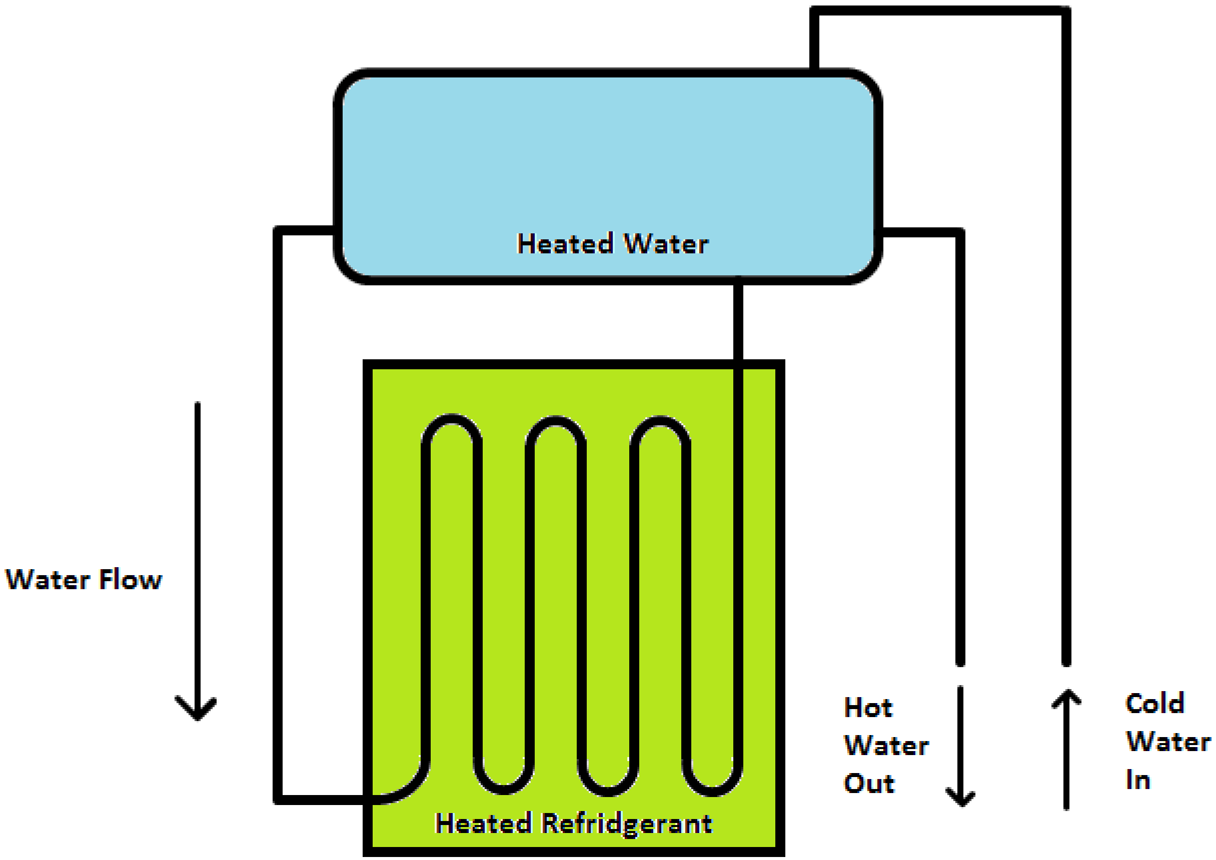
- Mass flow rate controlled by natural convection and buoyancy forces
- Utilizes a shell-and-tube heat exchanger

- Pros
  - No pump required during heating of water
  - Very simple design requirements
  - Low maintenance requirements
- Cons
  - Water must be stored above solar collector
  - Not as efficient as active water heater
  - Heat exchanger loop must be closed during heating

Preliminary System Design: Thermosyphon Passive Water Heater



Preliminary System Design: Thermosyphon Passive Water Heater



Preliminary System Design: Thermosyphon Passive Water Heater

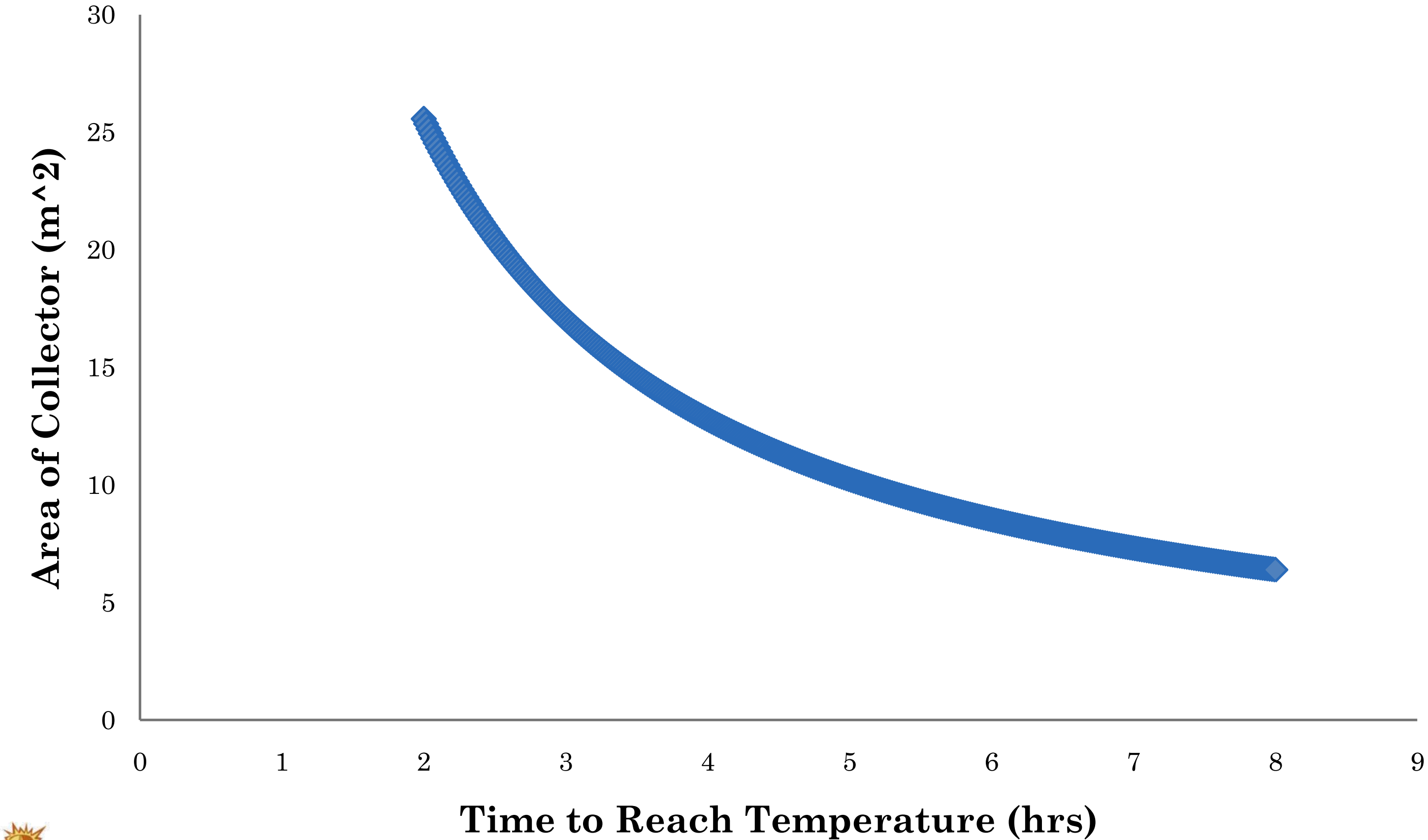
- Assumptions
  - Clear sunshine for 8 hours during the day
  - Incoming water is 20 °C
  - One dimensional flow
  - Connecting pipes feature no flow resistance
  - No water pulled from tank during heating
  - Closed loop circuit for water during heat transfer
  - 100% heat transfer from refrigerant fluid to water
  - Water mean temperature is treated as bulk object
  - Laminar pipe flow

Preliminary System Design: Thermosyphon Passive Water Heater

- Analysis
  - Average density of water = 990.7 kg/m^3
  - Amount of Water in System = 1000 L
  - Specific heat of water = 4.18 kJ/kg-K
  - Mass of water in system = 993 kg
  - Governing Equation:
    - $Q = m\ C_p\ \Delta T$
  - $Q_{req} = 10.4 \times 10^4$ kJ
  - Flux of 698 W/m^2 absorbed by solar plate
  - Transmissivity of cover plate = 0.9
  - Absorptivity of collector plate = 0.9

Preliminary System Design: Thermosyphon Passive Water Heater

- Results



Preliminary System Design: Thermosyphon Passive Water Heater

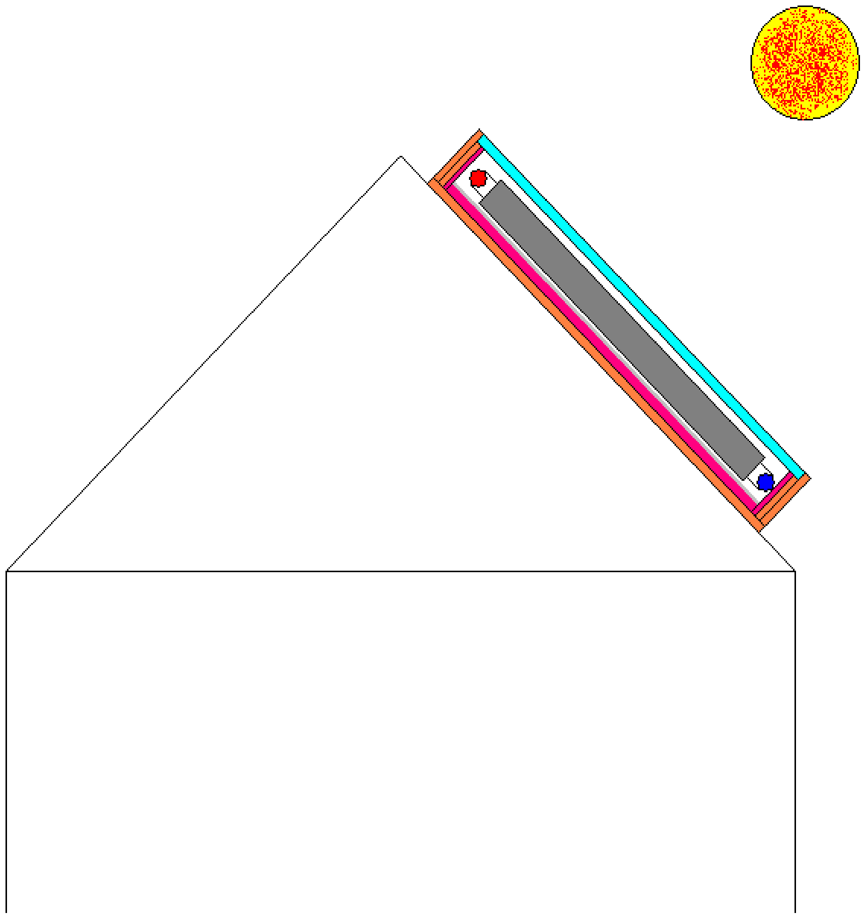
- Core Materials Needed
  - Glass Cover
  - Aluminum collector plate (coated to have absorptivity of 0.9)
  - Stainless steel liner
  - Insulation
  - Refrigerant R-410A
    - Highest latent heat, thermal conductivity, and lowest viscosity compared to other refrigerants[1]
  - Stainless steel & PVC piping
  - Storage tank

Preliminary System Design: Thermosyphon Passive Water Heater

- Conclusion
  - 149 m^2 of roof space is available
  - In order to accommodate space for water collection, only 30 m^2 of space will be allowed
  - Due to space requirements, 2 hours is minimum time required to reach operating temperature
  - Once operating temperature is reached, system will maintain and exceed needed requirements
  - Heated water will be gravity fed to locations of use
  - User must fill system once a day to 1000 L

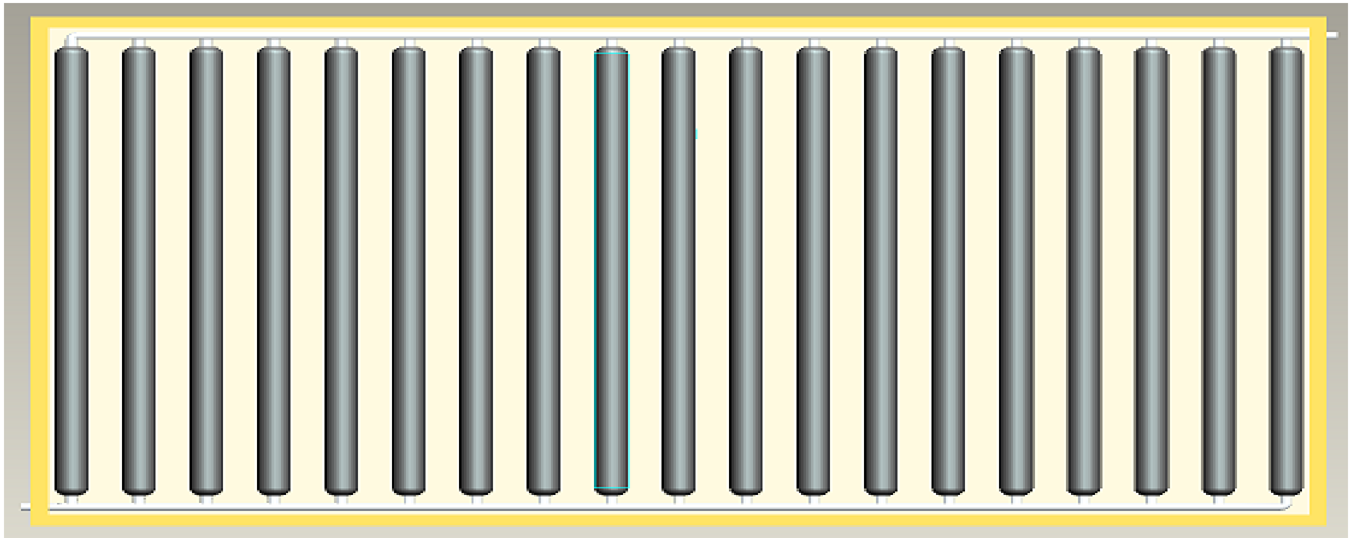
Preliminary System Design: Passive Integrated Solar Water Heater

- Integrated System
  - Heat Collection incorporated with Hot Water Storage
  - Insulated Box with Plexiglas cover
  - Hot Water Outlet on top of tanks
    - Utilize Thermal Stratification
  - Lays flat with roof facing north



Preliminary System Design:
Passive Integrated Solar Water Heater

- Application
  - Need a raised reservoir with at least twice volume of storage tank or pump
    - Required to draw hot water out of the system
  - Investigate available materials locally



Preliminary System Design: Passive Integrated Solar Water Heater

- Storage Analysis
  - Provide 1000 L of hot water daily
  - Need high surface area volume ratio
  - Optimize the ratio against the number of tanks required
  - Minimize the pressure of the system on the roof

Diameter (m)	Volume per tank (L)	Surface Area/Vol. Ratio	# Tank Req.
0.1	23.56	40.67	42.44
0.11	28.51	37.03	35.08
0.12	33.93	34.00	29.47
0.13	39.82	31.44	25.11
0.14	46.18	29.24	21.65
0.15	53.01	27.33	18.86
0.2	94.25	20.67	10.61
0.25	147.26	16.67	6.79
0.3	212.06	14.00	4.72
0.35	288.63	12.10	3.46

Preliminary System Design: Passive Integrated Solar Water Heater

- Thermal Analysis
  - Assumptions
    - Inlet Temp 20 °C
    - Design Outlet Temp 45 °C
    - Annual Mean Radiation 698 W/m^2
    - Adiabatic
  - $Q = m\ C_p\ \Delta T$
  - Heating Rate Dependent on Tank Diameter

Dia. Tank (m)	Heating Rate ($^0C/hr$)	Heat Up Time (hr)
0.1	6.97	3.59
0.11	6.33	3.95
0.12	5.81	4.31
0.13	5.36	4.66
0.14	3.56	7.03
0.15	4.65	5.38
0.2	3.48	7.18
0.25	2.79	8.97
0.3	2.32	10.76
0.35	1.99	12.56

Preliminary System Design: Passive Integrated Solar Water Heater

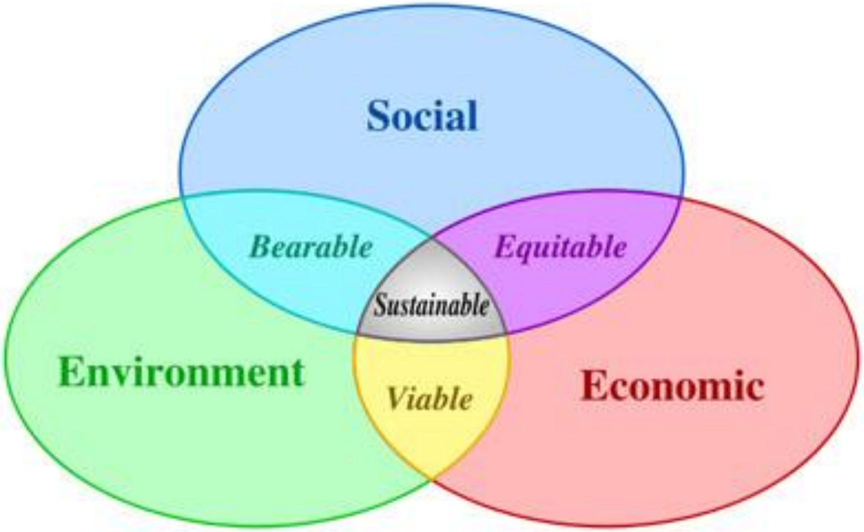
- Design Issues
  - Assuming 698 W/m^2 with 10h of sunlight, the system will take at least half of the day to reach design temp.
    - Can introduce more tanks at smaller diameter
  - Consider cascade heating if the system will be drawn on frequently after reaching temp.
    - Pending a design request from the customer
  - Potential issue with equal drawing from each tank
    - Investigate changing outlet pipe sizing
  - Possible incorporation of thermal blanket at night
    - Dependent on morning hot water requirement

Preliminary System Design: Passive Integrated Solar Water Heater

- Core Materials Needed
  - 1/8" Plexiglas sheets
  - PVC pipes
  - Black Paint
  - 19 aluminum tanks with 3 m length and 0.15 m dia.
  - 2" x 12" 's lumber
  - Insulated foam boards
  - Highly reflective sheet
  - Insulated Cover if needed

Sustainability Analysis

- Economic
  - Low initial cost
  - No annual cost
- Environmental
  - Local materials
  - Recycled materials
  - Minimal waste
- Social
  - Low maintenance
  - Minimal manpower to operate



Looking Forward

Concept Design Review – 9/21/09 ~ 10/21/09

- Performance Analysis
- Assembly Analysis

Fabrication – 10/21/09 ~ 11/18/09

- Procurement of Materials
- Scale Model of Entire System

Testing – 11/9/09 ~ 11/23/09

- System Test
- Design Improvements

Final Design Review – 11/25/09

Looking Forward

September 2009

- Involve Purdue's ESW Chapter with SWS team

November 2009

- Complete fabrication & testing of system
- Create operation, maintenance, installation, & troubleshooting manuals
- Final Design Review

Spring 2010

- Present final system design to Tenwek officials
- Re-evaluate system & make necessary design changes

Fall 2010

- Handover final system design to Tenwek officials
- Provide engineering support as necessary

Thank you for your time
Questions?

Engineers for a Sustainable World

PURDUE UNIVERSITY CHAPTER

Preliminary System Design: Active Solar Water Heater

Zerrouki, A, Boumédien, & Bouhadef, K. (2002). The natural circulation solar water heater model with linear temperature distribution. Renewable energy, 26(4), 549-559.