DESIGN, MANUFACTURING AND SIMULATION OF FORCED CIRCULATION SOLAR WATER HEATING SYSTEM

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ABSTRACT

Forced circulation solar water heaters are renewable energy systems that make use of freely available solar energy to heat water. In this project, a forced circulation solar water heater has been designed based on Alkharj solar energy with capability of heating 200 liters of water at different flow rates. The design was assembled, and experiments were conducted to obtain heating profiles. The same system was simulated using Systems Advisor Model (SAM) software and the results were also compared to the heating profiles obtained experimentally.

OBJECTIVES

- Design of the forced circulation solar water heating system.
- Experimental analysis of the forced circulation solar water heating system.
- Simulation of the forced circulation solar water heater system using SAM software.
- Comparison between experimental and simulation results.

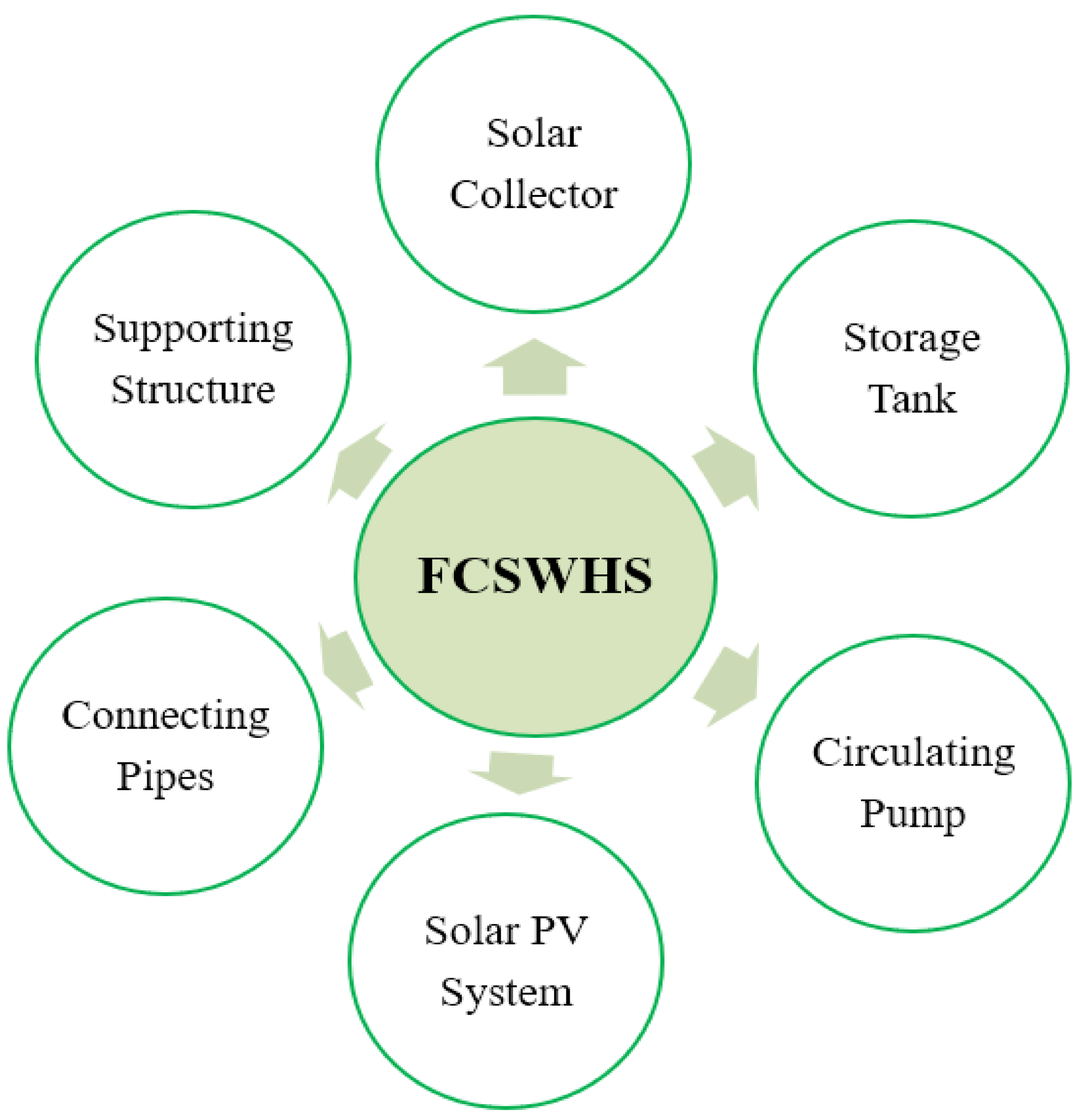
CONSTRAINTS

This study takes in consideration the following constraints:

- Economy
- Ethical
- Safety
- Sustainability
- Environment
- Political
- Social
- Technical

DESCRIPTION

The forced circulation solar water heating system (FCSWHS) designed in this project consist of six main parts:

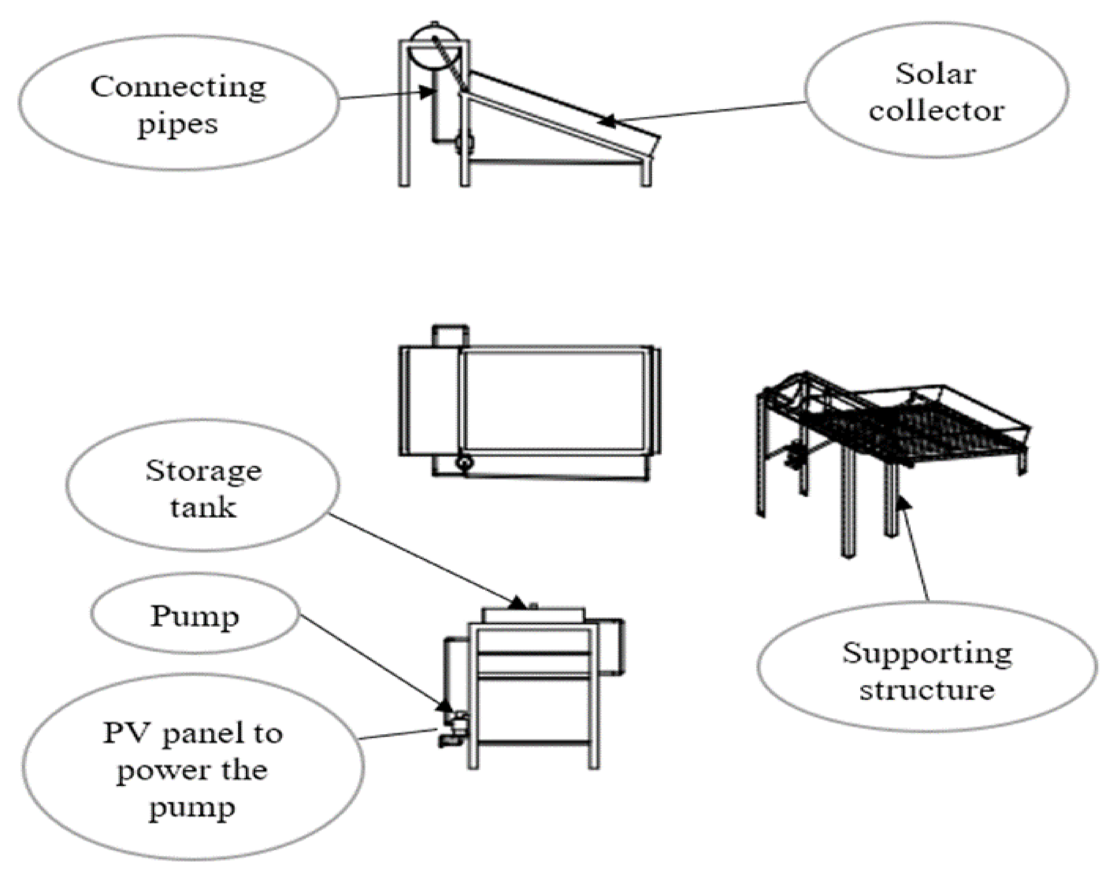


Main components of solar water heater

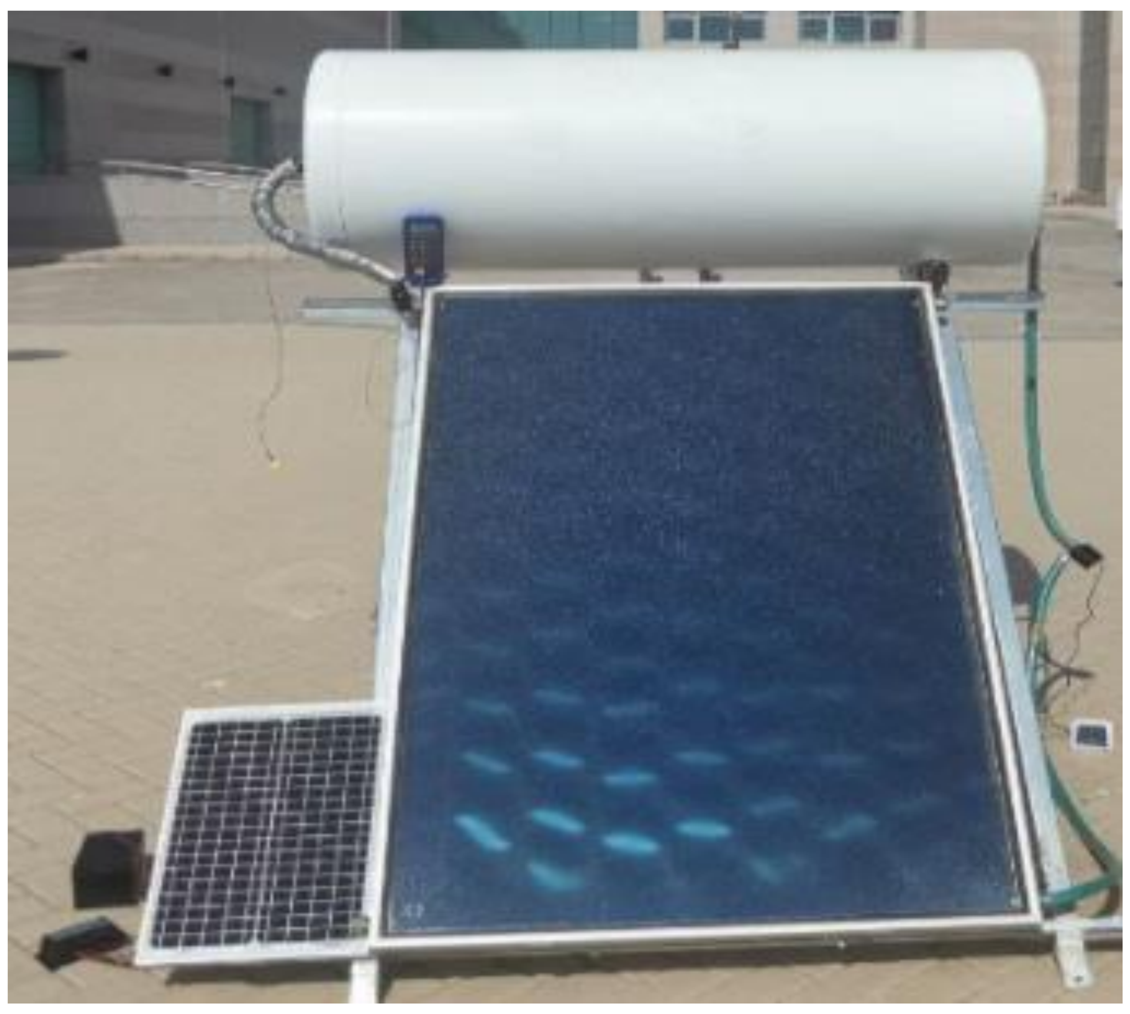
DESIGN

The design considerations of the system:

- Desired hot water temperature.
- Solar energy availability at the location.
- Mass flow rate.
- Heat transfer characteristics.
- Cost. Etc.



Concept of the FCSWH system.



Forced circulation solar water heater assembly

MATHEMATICAL MODELING

- The collector energy balance is given by:

$$\dot{Q}_u = A_c F'[I_T(\tau\alpha) - U_L(T_{fm} - T_a)]$$

- The collector efficiency factor F' is given by:

$$F' = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L[D+(W-D)F]}+\frac{1}{C_b}+\frac{1}{\pi D_i h_{f,i}}\right]}$$

- The overall loss coefficient U_L is given by:

$$U_L = U_b + U_e + U_t$$

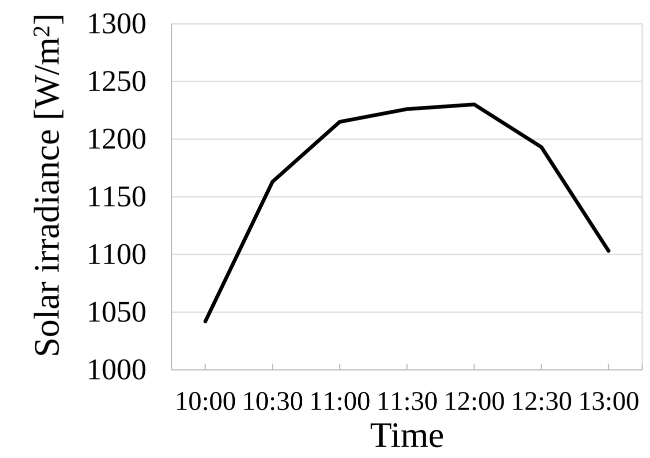
$$U_e = (k/L)_{edg} * Pt/A_c \; ; \quad U_b = k/L$$

$$U_t = \left(\frac{N}{\frac{C}{T_{pm}}\left[\frac{T_{pm}-T_a}{N+f}\right]^e} + \frac{1}{h_w}\right)^{-1} + \frac{\sigma (T_{pm}+T_a)(T_{pm}^2 + T_a^2)}{\frac{1}{\varepsilon_p + 0.00591\, N h_w} + \frac{2N + f - 1 + 0.133\, \varepsilon_p}{\varepsilon_g} - N}$$

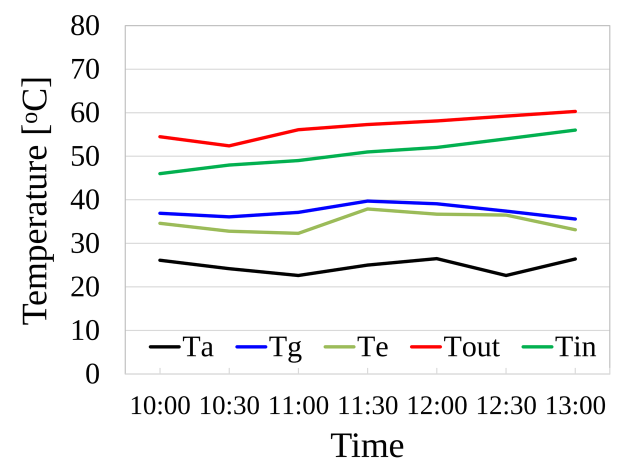
- Mass flow rate: $\dot{m} = \dot{Q}_u/[C_p(T_{out} - T_{in})]$
- Collector thermal efficiency: $\eta_c = \dot{Q}_u/I_T A_c$
- Collector pressure drop: $\Delta p = f\,\frac{\rho V^2}{2}\,\frac{\Delta l}{D} + K\,\frac{\rho V^2}{2}$

EXPERIMENTS

The experiments were conducted using the system shown in system assembly in November 2021. The parameters measured were solar irradiance, water ambient air temperatures on half hour basis.



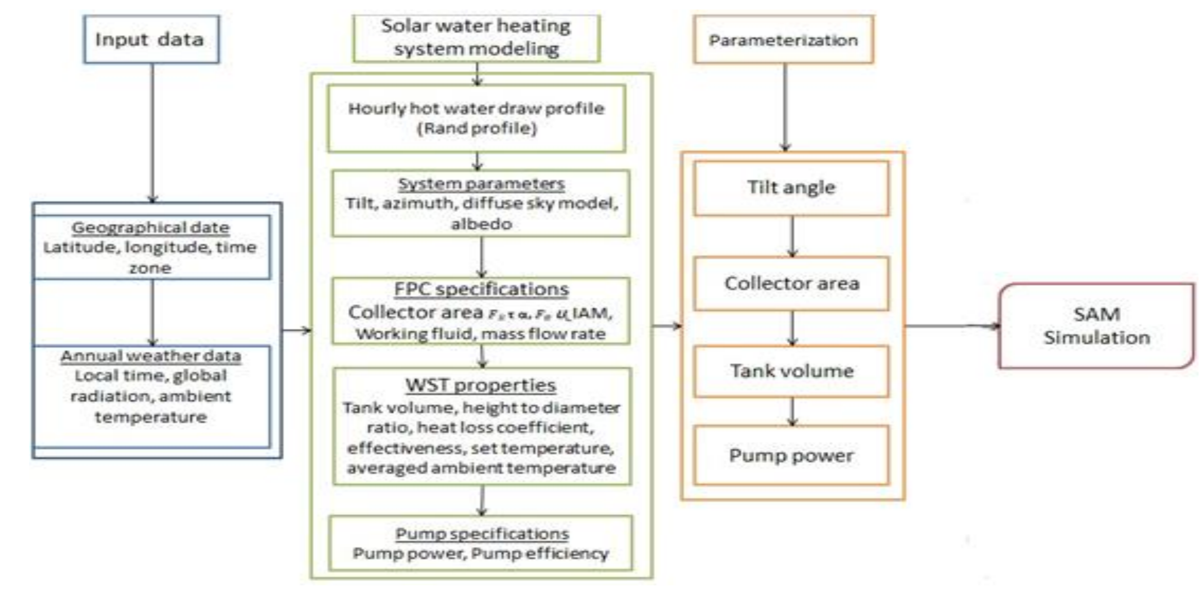
Measured solar irradiance.



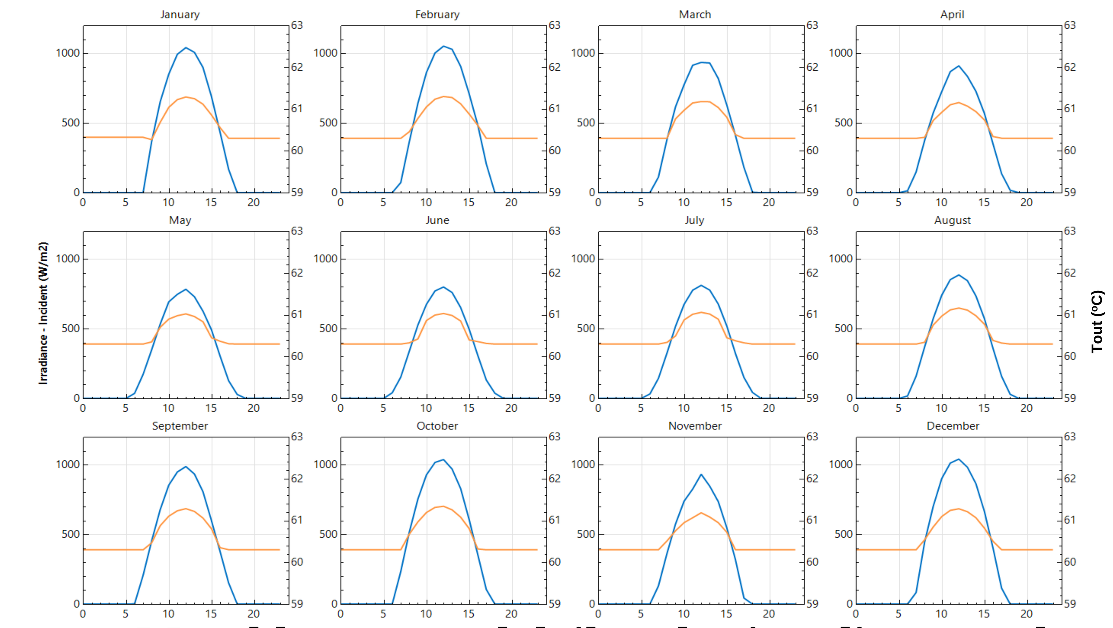
Measured temperatures.

SAM SIMULATION

SAM is a free techno-economic software model for renewable energy analysis. A typical meteorological year of Alkharj, KSA, was used for the simulations.



Simulation steps in SAM.



Monthly averaged daily solar irradiance and collector outlet temperatures.

COST ANALYSIS

the solar collector and the storage tank are the most contributing part of the cost. The total cost of the system was **2,450 SAR**.

CONCLUSIONS

- The theoretical thermal efficiency of the collector was about 77%.
- The simulated solar incidence irradiations were lower than the measured values by about 20%.
- The hourly incidence solar irradiance on the collector were highest in four months (January, February, October and December) and lowest in the summer months (May, June and July).
- Safety was considered by isolating the FCSWHS.

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