e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:04/Issue:04/April-2022 Impact Factor- 6.752 www.irjmets.com

# SIMULATION AND COST-BENEFIT STUDY OF IMPLEMENTING ACTIVE SOLAR WATER SYSTEM IN THE SCHOOL MESS

**Thinley Tobgay*1, Chimi Dem*2, Dheynay Zangmo*3**

*1,2,3Department Of Electrical Engineering, Jigme Namgyel Engineering College, Samdrup Jongkhar.

## ABSTRACT

As the world becomes more conscious regarding climate change, people are looking more toward producing energy in greener ways to curb the production of greenhouse gas emissions. In addition, it has become vital for consumers to exercise conscious energy consumption through the usage of energy-efficient appliances in homes. One such approach is the installation of a solar water heating system for residential and commercial buildings. This paper discusses the implementation of an active solar water heating system and its cost-benefit for school mess located at Garpawong Middle Secondary School, Dewathang, Samdrup Jongkhar. The main aim here is to implement an active solar water system to maintain water temperature up to $50^0$ C and calculate the cost-benefit of the system. The system comprises five basic elements mainly a solar collector that collects solar radiation, a pump to circulate working fluid, a storage tank to store water, a backup system to compensate for the heat requirement, and a controller system. With available solar irradiance data, it was seen that the water temperature could be maintained at $80^0$ C in the summer and $55^0$ C in the winter. In addition, it is observed that the breakeven point of the total cost incurred in procuring the system is reached within six years of operation. The study also concludes that a total of 1033 kg of $CO_2$ can be avoided with the implementation of this system in the school mess.

**Keywords:** Active Solar Water Heating, Storage Tank, Solar Collector, Irradiance, Payback Period.

## I. INTRODUCTION

The Garpawong Middle Secondary School is in the southeast part of Bhutan. The school provides education facilities to approximately three hundred students from the nearby locality. Although all the students in the school are day scholars, the school administration provides lunch to the admitted students. It is observed that a significate amount of electrical energy is used in heating water to prepare the lunch menu in the school mess. Due to this, the school administration is required to pay a huge electrical bill every month. It was, necessary to find an alternative means to preheat the water using solar energy to reduce the net electrical energy required for preparing lunch for almost three hundred students.

Solar water heaters (SWH) are basically a system that uses the sun radiations to heat water which can be used for domestic and industrial purposes. It is not a new technology since its usage date back to 200 BC when Romans used this concept to heat their public baths, wherein the water storage tanks were painted black to absorb solar energy. The commercial development of these solar water heating systems came into reality in 1891 and was introduced by Clarence Kemp [1]. Since then, the solar water system got its popularity, and just in the year 2012, 78 million units of SWH were installed for various utility purposes all over the world [2].

## II. AN OVERVIEW OF ACTIVE SOLAR WATER HEATING SYSTEM

An active water heating system consists of electric pumps, valves, a storage tank, a controller, and other components miscellaneous components for the proper operation of the system as shown in figure 1. The operation of the system is such that the heat transfer fluid is actively pumped from the storage tank through the collector and back into the tank. In doing so, the heat transfer fluid carries the heat energy collected by the collector panels and delivers it to the water in the tank. These types of solar water heating systems are normally expensive and are efficient in heating up the water. Unlike its counter passive solar water heating system that depends on gravity for the flow of fluid, the location of storage tank placement doesn't matter as the fluid is pumped using the electric pump. This makes the placement of the storage tank independent of gravity.

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:04/Issue:04/April-2022 Impact Factor- 6.752 www.irjmets.com

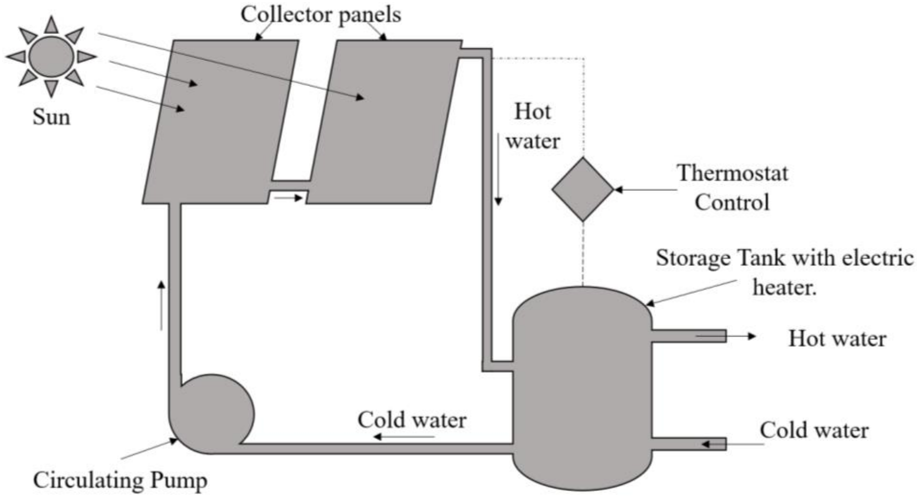


**Figure 1:** Active Solar Water Heating System

**Direct Solar water heating (Open-loop heating scheme)**

In places where the temperature normally remains above subzero, an open-loop heating scheme is preferred. Open-loop systems employ pumps to circulate the water through the collector and the heated water in the collector delivers the heat to the water in the storage tank. The auxiliary heating system in the tank further heats up the water to desired temperature [3]. These systems are not feasible in regions whose temperature drops below freezing point as the issue of pipe damage occurs due to the expansion of water in the pipe when it freezes. The system becomes much cheaper compared to other active solar water heating systems due to the usage of water as the working fluid in the refrigerant loop.

This system is simple and easy to operate. As the temperature in Dewathang never drops below freezing point and to save some project costs, the direct solar water heating system is used in Garpawong Middle Secondary School to preheat the water in the mess for the preparation of the lunch menu.

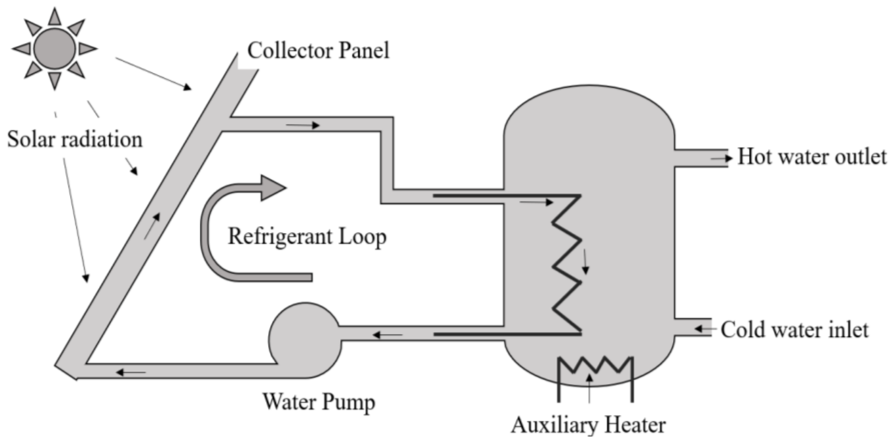


**Figure 2:** Direct solar water heating system

## III. INSTALLATION DESIGN OF ACTIVE SOLAR WATER HEATING SYSTEM

To install active solar water heating system, it is important to precisely study the technical requirements. The main components required for the proposed system are: 1) Solar Collector (Evacuated Tube) 2) Water storage/ heat exchanger with auxiliary heater 3) Controller 4) Pump 5) Pipes with insulation and 6) Valves and other miscellaneous. The design requirement for the proposed site is to preheat the water to at least 500 C before the water is being used for cooking purposes to reduce electrical energy consumption.

**Sizing of storage tank**

The storage tank stores both cold and hot water. Normally the cold water settles at the bottom due to its weight and warm water floats. The combination of an auxiliary heating source and solar energy maintains the desired temperature in the storage tank. The determination of the adequate storage tank capacity volume requires the estimation of the monthly and annual value according to volume changes. The required volume of hot water to be produced can be obtained from equation 1.

$$V_{st} = 1.2(B \cdot O \cdot D_{HW} + D_k) \quad \text{Equation 1}$$

Where, B is the number of consumers, O is the percentage occupation, $D_{HW}$ is hot water demand per person and DK is the hot water demand. Table 1 shows the data for storage size calculation.

**Table 1:** Variables determining storage size of the tank

| Sl No. | Variable | Symbol | Value |
|---|---|---|---|
| 1 | Number of consumers | B | 300 |
| 2 | Percentage Occupation | O | 80% |
| 3 | Hot water demand per person | $D_{HW}$ | 0.50 |
| 4 | Total hot water demand | $D_K$ | 300 |

Using equation 1 with variables determining the size of the storage tank from Table 1, the size of the storage tank is calculated to be 504 L. Looking at the availability of the tank size in the market, 500 L tank capacity is the closed match for the application.

**Sizing of solar collector**

The solar collector is the core of any solar water heating system that utilizes the suns radiation energy to increase the temperature of the working fluid. The heat is transferred by this working fluid to the heat exchanger to heat the water in the storage tank so that the electricity consumed in heating the water is reduced significantly.

The type of collector that is to be used in the proposed site is an evacuated tube solar collector as it can be used in any climatic condition, it has higher efficiency, is easy to install, and the less affected by the wind and temperature variation. However, it has a high initial cost compared to other types of collectors.

Evacuated tube collectors (ETCs) do not shed snow as the surface is not always warm, the tubes are the insulator in nature and the collector surface is irregular which lets the snow stick on tubes for a long time. As the glass tubes are fragile, it is not possible to scrap the accumulated snow which makes the system ineffective. So, care must be taken while using ETCs in extremely cold conditions.

The layout plan for the evacuated solar collector was prepared and the energy supplied by these tubes were calculated for the proposed site as shown in figure 3. The energy demand for heating the given volume of water i.e 300 L is obtained by using equations 2 and 3.

$$Q_{HW} = \frac{m \cdot \Delta T \cdot C_p}{3600} \quad \text{Equation 2}$$

$$Q_d = 365 \cdot [(1 + k) \cdot Q_{HW} + Q_{HL}] \quad \text{Equation 3}$$

Where k is the assumed loss factor in percentage, m is the mass of water to be heated in kg, $C_p$ is the specific heat capacity of water in kJ/kg-$^0$K, ΔT is the required temperature rise in $^0$K, $Q_{HW}$ is the domestic hot water in kWh/day, $Q_{HL}$ is the standby heat loss in kWh/day.

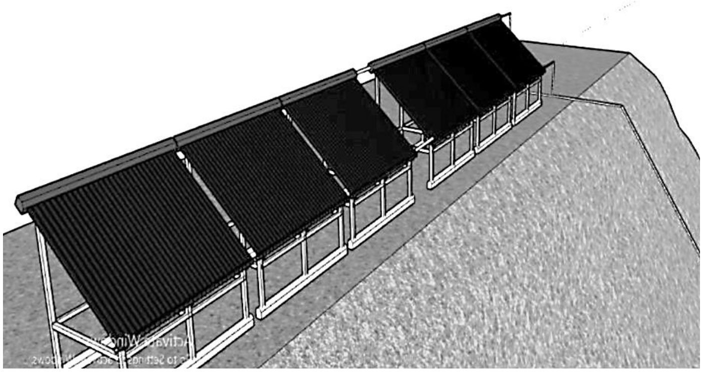

**Figure 3:** Solar Collector array layout for the proposed site

After calculating the energy demand, the number of solar collectors required for the proposed site is calculated using equations 4 and 5.

$$Q_S = Q_d \times \delta_{fn} \quad \text{Equation 4}$$

$$A_C = \frac{Q_S}{A_r} \quad \text{Equation 5}$$

Where $\delta_{fn}$ is the solar fraction usually 83.5 %, $A_C$ is the area of solar collector, $Q_S$ is the solar energy required to heat the given amount of water, and $A_r$ is the solar irradiance per surface area. It was calculated that the number of solar collectors required for the proposed site was six after taking in all the design considerations.

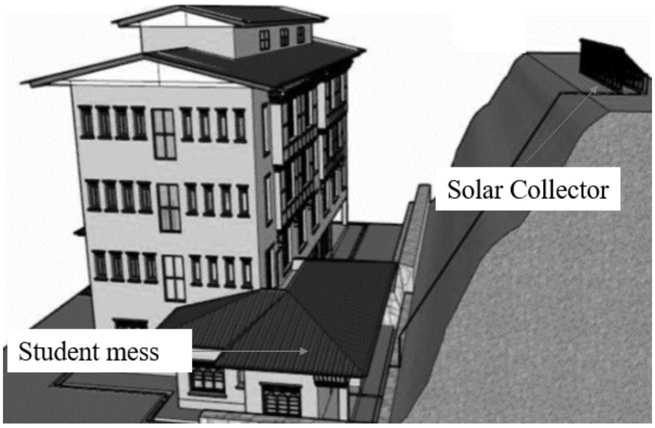


**Figure 4:** Location of the collector array and school mess

**Collector Efficiency**

Like any other practical machine, the solar collector suffers from various energy losses. Due to these losses, the efficiency of the collector is greatly affected. The efficiency of the solar collector is calculated using Equations 6 and 7.

$$Q_u = A_c F_R [G_T t_\alpha Q_{AV} - \Delta T \cdot U_L] \quad \text{Equation 6}$$

$$\eta = \frac{Q_u}{A_C \cdot G_T} \quad \text{Equation 7}$$

Where $Q_u$ is the rate of solar energy collected, $F_R$ is the collector's heat factor, $U_L$ is the overall heat transfer coefficient. $G_T$ is the incident of radiation and $t_\alpha$ is the absorbed solar radiation. In this calculation, we used the value of the annual daily average incident solar energy in Dewathang, which is about 4.893 kWh/m$^2$/day of the collector's heat removal factor $F_R$ is approximately 70%. The absorbed solar radiation $t_\alpha$ is about 0.96 for the subtropical region and the overall heat transfer coefficient $U_L$ is approximately 2 W/m$^2$°C.

The losses of the tank and pipe can be calculated by first assuming them to be well-insulated. The storage tank is assumed to be of the high insulated type. In this project, from international best practices, we will be taking 4 % of the daily heat energy as heat loss in the tank and 1% of the daily heat energy as the heat loss in the pipe.

**Determination of pump capacity**

A centrifugal pump uses a rotating impeller to increase the pressure and flow rate of the fluid. As the liquid radiates outward, the velocity increases due to centrifugal force. The benefits of a centrifugal pump are its flat flow, uniform pressure in the discharge pipe, low cost, and high operating speed. The power imparted to the water by the pump is called waterpower. to calculate the water pump, the flow rate and the pump head must be known. The pump power required in the system can be calculated using equation 8

$$P = \rho g Q h \quad \text{Equation 8}$$

Where P is the power of the pump in kW, ρ is the density of working fluid in kg/m$^3$, g is the acceleration due to gravity, Q is the flow rate of the working fluid, and h is the differential head in m.

In this design, the flow rate for heat transfer fluid is 0.01 $m^3/s$, the differential head was measured to be 10 m, and for water as working fluid, the density is 997 $kg/m^3$. The pump power was calculated to be approximately 977.06 W. Hence, the pump capacity of 1 kW is required for water circulation in the solar water heating system.

**Study of solar irradiance data of Dewathang**

The study of solar irradiance data was performed using the Meteosyn platform. The analysis showed that Dewathang receives the maximum amount of solar radiation during the summer months and the least during the winter months. The average daily and annual solar radiation value of the proposed site floats at 3.06 $kWh/m^2$ and 4.893 $kWh/m^2$ respectively. This radiation energy is sufficient to produce electricity and heats the water. The graph in figure 5 shows the average daily solar irradiance received by the proposed site.

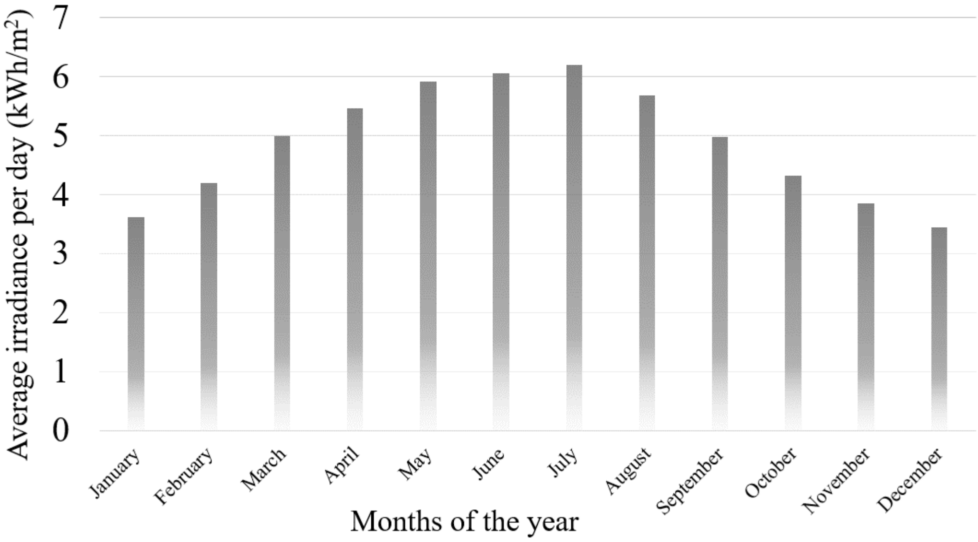


**Figure 5:** Moth wise daily average solar irradiance of Dewathang

**Simulation of the proposed solar water heating system**

The simulation of the proposed active solar water heating system was performed using TSOL software based on the weather data of Dewathang. The solar collectors are placed at an angle of $30^0$ facing the sun to shorten the pipes as possible to avoid the loss of energy during heat transportation.

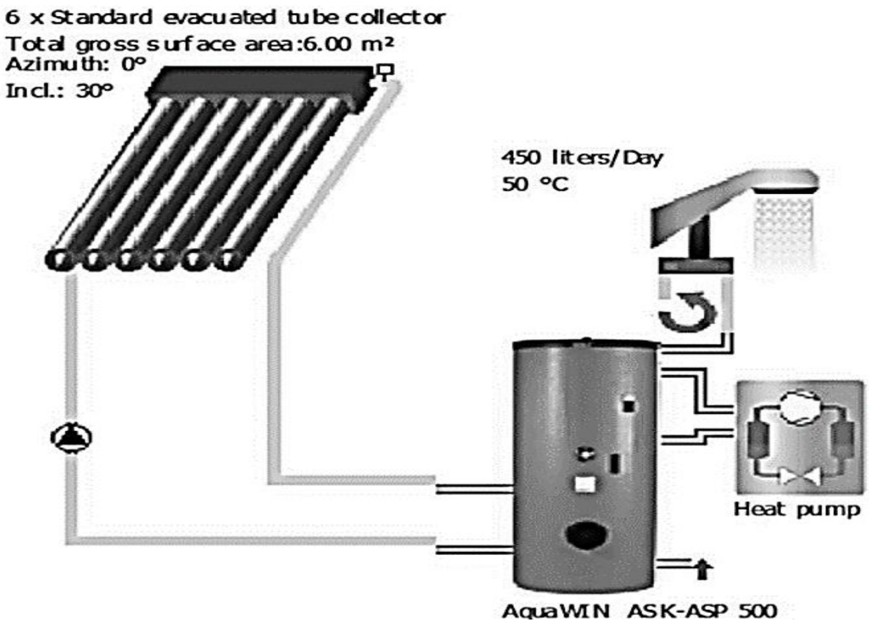


**Figure 6:** Simulation Circuit in TSOL

The simulation showed that the temperature values vary from one day to another depending on the weather change, but overall, the maximum values can be seen during July, August, September, and October with a value of more than 70-80 °C in several days of those months. As for the minimum it can be seen during the cold months from December to January with values than can reach less than 55°C.

In addition, the simulation also showed the data for $CO_2$ emission avoided for the implementation of this heating system.

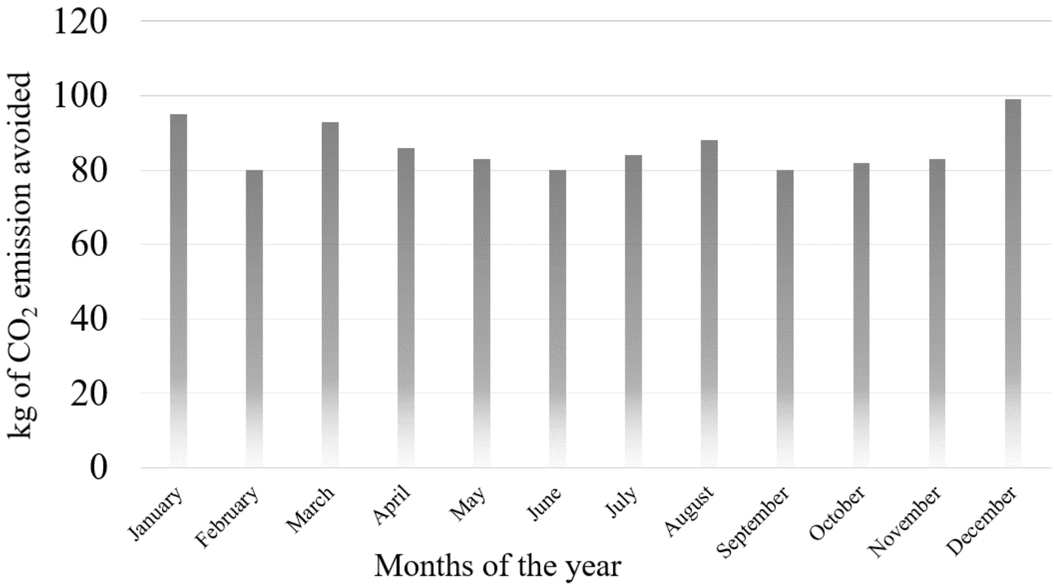


**Figure 7:** $CO_2$ Emission avoided

Figure 7 shows that the cumulative $CO_2$ emission avoided for its operation duration of one year is approximately one ton.

**Cost-benefit study of installing active solar water heating system**

The cost of water heating in the kitchen is mainly due to electric boilers. The cost of electricity is around Rs. 6420.96 per month, which sums up to Rs. 77051.52 in one year for operating these electric boilers to heat the water in the student mess.

The cost of procuring and installing a direct scheme active solar water heating system is Rs. 418,526. The maintenance cost per year for the heating system while operating is Rs. 3,600. Therefore, the total investment of Rs. 422,126 is incurred to install and operate the water heating system in the school. The annual net saving is calculated as the difference between the total electric bill for heating the water and the electrical bill for the operating pump, auxiliary heater, and controller. The net saving was calculated to be Rs. 74520.87. The cost-benefit and payback period of the proposed heating system is calculated using equation 9

$$P_{PB} = \frac{T_{inv}}{A_{sav}} \quad \text{Equation 9}$$

Where $P_{PB}$ is the payback period in years, $T_{inv}$ is the total investment and $A_{sav}$ is the annual savings from operating the solar water heating system in the student mess. The payback period as calculated using equation 9 comes out to be six years.

**Table 2:** Annual Maintenance Cost of the solar heating system

| Sl No. | Item | Cost (Rs.) |
|---|---|---|
| 1 | ETC Collector | 2000 |
| 2 | Plumbing | 1000 |
| 3 | Storage tank | 100 |
| 4 | Differential thermal controller | 200 |
| | Total | 3600 |

The solar thermal market in Bhutan is not well developed. Estimations for cost regarding equipment and installations, therefore, become uncertain. Instead, the payback has been made backward. 20 years is used here as the expected lifetime of the solar thermal system. The amount of money saved per year can be calculated which can then be used to arrive at the price of a system with a payback of 6 years. If a payback time falls outside these 20 years, it will not be economically viable.

## IV. CONCLUSION

Garpawong Middle School administration had to make huge payments only for heating water to prepare the lunch menu for day scholar students from the nearby locality. This research proposed a direct scheme of active solar water heating systems to address the difficulty faced by the school administration. While carrying out the study, it was found that the temperature of the water could be maintained within the average desired range of $50^0$ C. The school administration will save Rs. 74520.87 after the first six-year of operation of the system. The system would also avoid the $CO_2$ emission of one tonne annually as an added benefit to environmental protection.

## V. REFERENCES

[1] J. Perlin and K. Butti, “Early Solar Water heaters.,” in A golden tread, New York, Van Nostrand, 1979, pp. 27-117.

[2] Y. Kuang and S. K, “Study on directed expansion solar assisted heat pump water heating system,” Int J Energy Res, vol. 5, no. 27, pp. 48-531, 2003.

[3] G. J and S. K, Active Solar Water Heating Systems, North Dakota: North Dakota State University, 2013.

[4] S. R. Samo and A. A. Siyal, “Analysis of active and passive solar water heating system,” in Sixteenth International Water Technology Conference, Istanbul, 2012.

[5] H. M. Steinhagen, “Applications of Solar water heaters for temperatures ranging from 50-2000 C,” in 5th European thermal-sciences conference, Netherlands, 2008.

[6] G. Morrison, “Analysis of horizontal mantle heat exchangers in solar water heating systems,” Sol Energy, vol. 64, no. 1-3, pp. 19-31, 1998.

[7] I. Pillai and R. Banerjee, “Methodology for estimation of potential for solar water heating in a target area,” Sol Energy, vol. 81, no. 2, pp. 72-162, 2007.

[8] S. Kalogirou, “Solar thermal collectors and applications,” Prog Energy Combust Sci, vol. 30, no. 3, pp. 95-231, 2004.

[9] M. Rommel and W. Moock, “Collector efficiency factor F' for absorbers with rectangular fluid ducts contacting the entire surface.,” Sol Energy, vol. 60, no. 3-4, pp. 199-207, 1997.

[10] Y. Kim and T. Seo, “Thermal performances comparisons of the glass evacuated tube solar collectors with shapes of absorber tube,” Renew Energy, vol. 32, no. 5, pp. 95-772, 2007.

[11] H. MS, “Review on solar water heater collector and thermal energy performance of circulating pipe,” Renew Sustain Energy Rev, vol. 15, no. 8, pp. 12-3801, 2011.

[12] A. A, “Experimental and numerical investigation of flat plate solar collector,” Energy, vol. 35, no. 9, pp. 16-3707, 2010.

[13] P. TC, K. JJ, and W. CP, “Effective solar radiation based benefit and cost analyses for solar water heater development in Taiwan,” Renew Sustain Energy Rev, vol. 16, no. 4, pp. 82-1874, 2012.