Technical and Financial Feasibility Study of Solar Water Heating System Installation in Students' Mess in Bhutan

Gom Dorji

College of Science and Technology
ede2011008[at]gmail.com

Abstract: ***This paper gives the technical and financial feasibility study of installing solar water heating system (SWHS) in students' mess of three colleges of the Royal University of Bhutan. The two colleges are located in the West and one in the East. For technical feasibility studies, data like solar irradiance, temperature, and daily hot water demand are collected. The technical data are fed as input to System Advisor Model (SAM) software and simulated and found technically feasible to install the SWHS in selected sites. The annual energy saving from SHWS is 5293 kWhr, 9257 kWhr, and 6304 kWhr for College of Natural Resources (CNR), Paro College of Education (PCE), and Jigme Namgyel Engineering College (JNEC) respectively. The final energy saving from SWHS is taken for financial analysis. Considering the project period of 15 years, the financial feasibility study is also conducted. This report also includes the unit cost of energy.***

Keywords: solar irradiance; temperature; energy demand; heating system

1. Introduction

Bhutan is heavily dependent on hydropower energy. The dependent on hydro-dominated power involves the future risk of energy due to rapid climate change and the yearly increase of electricity tariff rate in Bhutan. Fig.1.1 shows the past few years of power generation from hydropower plants in Bhutan.

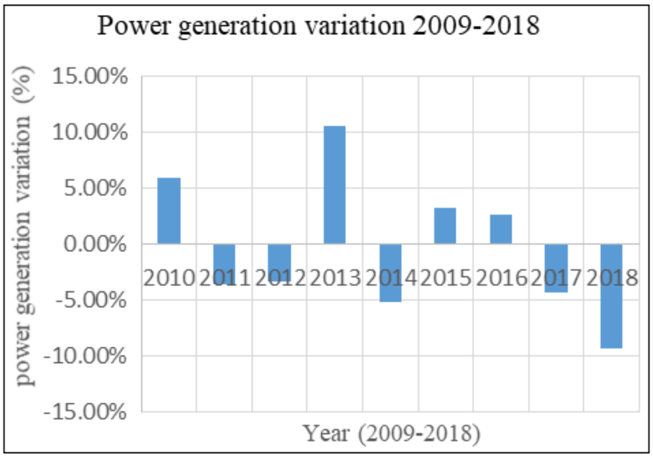

Figure 1.1: Power generation variation [1]

The variation of power generated from the year 2009 to 2018 is -0.00358%, which signifies a huge drop in power generation.

The power generated under DGPC, 70% is exported to neighboring country India and remaining is consumed within the country. Fig 1.2 also shows the rapid increase in domestic power demand and power import from the neighboring country during lean power generation seasons from the year 2009 to 2018.

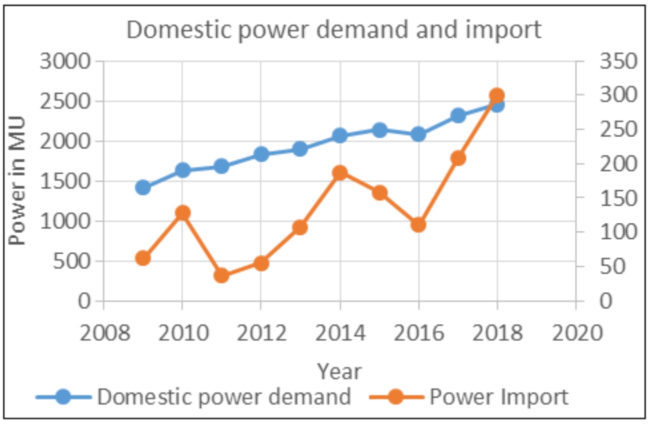

Figure 1.2: Power demand and import curve 2009-2018

Observing Fig.1.1-1.2, it is never late to move in harnessing free energy which will at least minimize the power import during the lean season. Bhutan is known to have an abundance of wind and solar energy. The World Bank report states that Bhutan receives an average of 4kWh of solar irradiance [2]. Solar energy is free and its opportunity lies on the individual how one uses it. Also, with the approval of the Alternative Renewable Energy Policy on 5th February 2013 by the government, the doors were open to a new world of opportunities for a more diversified and independent energy system through the development of alternative Renewable Energy solutions for the provision of electricity especially in the remote areas of Bhutan.

To support the above policy, researchers are working for the goal, and the College of Science and Technology (CST) alone has installed 38.7kW (on-grid and off-grid) with various funding and also installed the equivalent of 7 kW prototype solar water heating system [3] (SWHS) in students' mess estimating annual energy saving of 7500 units, which is the key to the policy target of 20 MW by 2025 by renewable energies [4].

Similarly, other colleges of the Royal University of Bhutan (RUB) receive equal solar irradiance like CST region and there is good potential of harnesing solar energy in any form like lighting and heating purposes. In all RUB colleges have mess facilities, which leads to consumption of huge electricity energy for heating the water for cooking purposes. This research aims to design the SWH systems concerning various locations using that particular place's weather data. If the design of the SWH system is installed, it will help in harnessing free solar energy to preheat the water used in college students' mess. This in return will reduce the annual electricity demand and reduction of heating time of the water for cooking.

Other than energy saving, solar energy is also clean energy, releasing less carbon-di-oxide comparing to other sources of energy generation [5]

2. Methodology

2.1 Technical data collection

Data from three different Colleges (College of Natural Resources (CNR), Paro College of Education (PCE), and Jigme Namgyel Engineering College (JNEC)) under the Royal University of Bhutan has collected. The required data for this research are monthly average temperature, solar radiation, and quantity of hot water demand per day concerning the number of students and time. The means of heating water in Jigme Namgyel Engineering College is electricity with 4x2.6 kW rating cookers. The average cooking hours in a day is 8-9 hours and the amount of hot water demand for cooking three meals and tea for boarding students per day is 450 L. In Paro College of Education, they also use electricity for heating 500-600 L water daily for 380 students using college mess. Under few circumstances, they use liquefied petroleum gas (LPG) for heating water. Since the usage of LPG is very less, the analysis is taken only for the quantity of water heated by electricity in this research. College of Natural Resources also uses electricity to heat 400 L of water per day as shown in TABLE 2.1.

The annual average solar irradiation data for three colleges, JNEC, PCE, and CNR are 4.89 kWh/m^2/day, 5.29 kWh/m^2/day, and 5.05 kWh/m^2/day respectively. The one year monthly average solar irradiation data is shown in fig.2.1. Also, the annual average temperature data for three selected colleges JNEC, PCE, and CNR are 22.29^{o}C, 14.25^{o}C, and 23.49^{o}C respectively. Fig. 2.2 shows the monthly average temperature data [6].

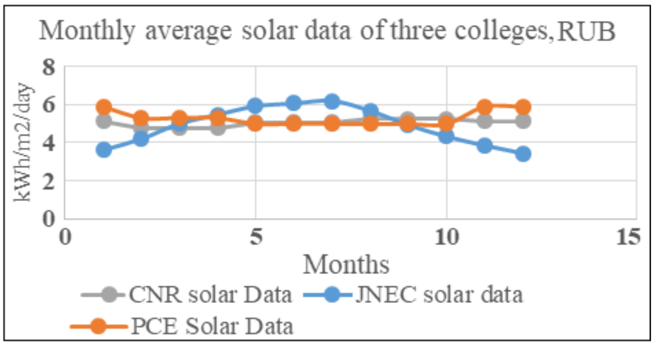

Figure 2.1: Monthly solar irradiance data

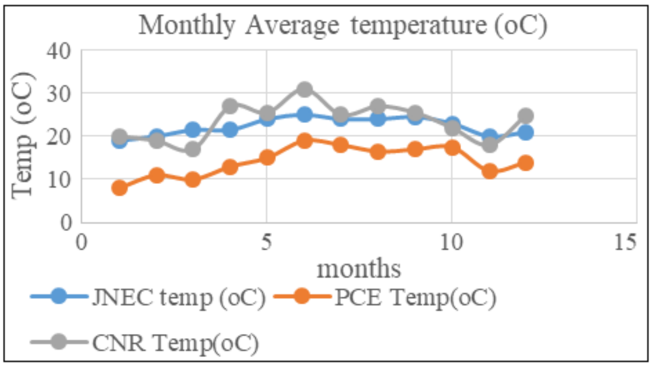

Figure 2.2: Monthly average temperature data.

Table 2.1: Hot water demand profile

Name of college	*Quantity of hot water demand (L)/day*	*Means of heating water (electricity/ firewood /LPG)*
College of Natural Resources	400	Electricity
Paro College of Education	550	Electricity/LPG
Jigme Namgyel Engineering College	450	Electricity

2.2 System Sizing

Each college mess is using an electric boiler and an electric cooker. These electric boilers and cookers not only consume energy but also takes a lot of time to boil the water. The boiled water is used for cooking breakfast, lunch, evening tea, and dinner. A small amount of hot water is also used for washing kitchen utensils. To save energy for heating the water and saving heating time, a solar water heating system will preheat the water and make it ready for use. The sizing of the system depends on surrounding temperature, annual solar irradiation received, and volume of hot water demand. The primary component required in SWHS is the collector area. For the system sizing, the following assumptions are made;

- The temperature of hot water in the kitchen is expected to be 60°C.
- Specific heat capacity (C_p) of water is considered as 4186 J/kg ^{o}C or 0.00116 kWh/kg. K.
- Overall system loss is taken as 15% of total energy demand.
- The density of water is 1000 kg/m^3

The energy demand for heating the water per day is calculated using the available solar irradiance and temperature data and results are obtained as shown in table 2.2.

Table 2.2: Energy demand per day

College	*Energy demand (kWhr/day)*
CNR	20
PCE	34
JNEC	23

Accordingly, the solar collector is also sized and shown in TABLE 2.3 assuming collector efficiency as 69%.

Table 2.3: Collector area

College	*Collector Area (m^2)*
CNR	6
PCE	10
JNEC	7

3. Simulation Results

The above system sizing results are exported to System Advisor Model (SAM) free open-access software for simulation.

3.1 College of Natural Resources result

College of Natural Resources is located at the latitude of 27.55° and longitude of 89.85°. The weather data collected are from weather station ID 75465, NSRDB, and NREL 2017. The SAM simulation uses global irradiance data as shown in fig 3.1.

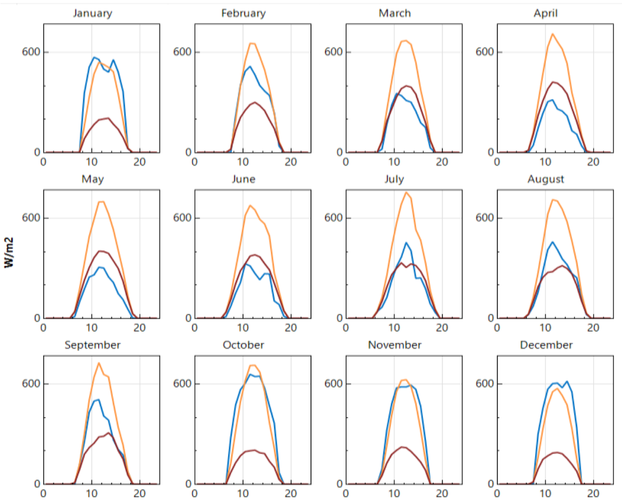

Figure 3.1: Three different irradiance data

The theoretically calculated shows the amount of energy required to heat 400 L of water every day in a year is 7200 kWh. The simulated value gives an energy consumption of 8376.9 kWh annually to heat 400 L of water every day. Some of the months, the solar radiation is not enough to heat water to set 60°C where energy from electricity is used to meet the set temperature. The annual energy saving from using SWHS is 5293 kWh. The monthly system energy generation as obtained from simulation is also shown in fig.3.2

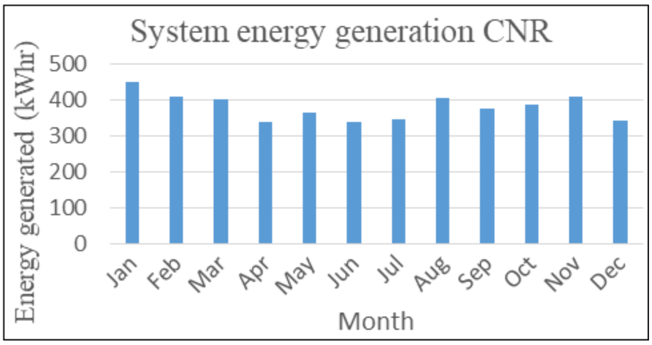

Figure 3.2: System energy generation.

3.2 Paro College of Education result

Paro College of Education is located at 24.403° Latitude and 89.425° Longitude with 2234 m above sea level. The weather data collected are from weather station ID 433990, NSRDB, and NREL 2017. Fig. 3.3 shows the monthly system energy generation for the designed system in SAM software. The annual energy consumption to heat 550 L of water every day at PCE is 10448.3 kWh and 10800 kWh for simulation result and theoretical calculation respectively. With the design of SWHS, it is expected to save annually energy of 9257 kWh. Some of the energy generated is also lost to surrounding while transferring hot water to the kitchen outlet.

In the cold winter season, ambient temperatures are close to the freezing point, and a lot of energy is required to heat water at 60°C. This demands huge energy from electricity as solar radiation is not enough to cater to the required energy.

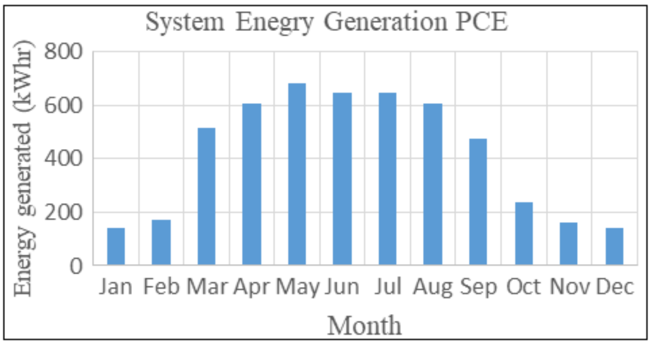

Figure 3.4: Monthly system energy generation

3.3 Jigme Namgyel Engineering College result

Jigme Namgyel Engineering College is located at 27.50° Latitude and 90.55° Longitude. The weather data collected are from weather station ID 77774, NSRDB, and NREL 2017. Fig. 3.5 shows the monthly energy generated from the designed solar water heating system

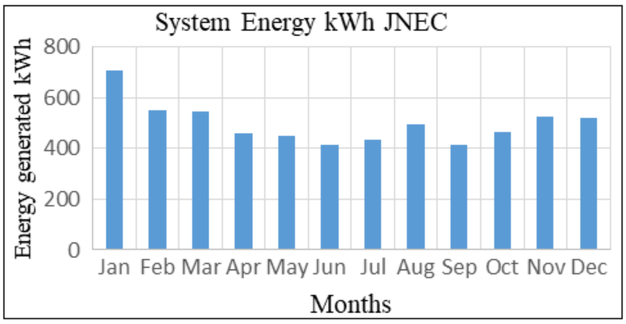

Figure 3.5: Monthly system energy generation

The theoretical calculation of energy required to heat 450 L of water every day in a year requires 8280 kWh annually. The simulated value gives energy of 9421 kWh annually to heat 450 L of water every day. Some of the months' solar radiation is not enough to heat water to set 60^0 C where energy from electricity is used to meet the set temperature.

The annual energy saving from using SWHS is 6304 kWh. Fig. 3.6 shows the SWHS's hourly average hot water temperature profile in one of the months.

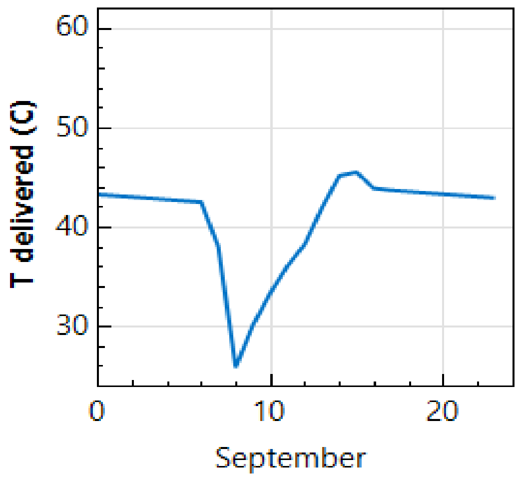

Figure 3.6: Hourly hot water temperature profile

4. Discussion

Result Analysis

The simulated results are presented in TABLE4.1 -4.3.

Table 4.1: CNR simulation data

Annual energy saved (year1)	5293 kWh
Solar fraction (year 1)	0.63
Aux with solar (year 1)	2985.1 kWh
Aux without solar (year 1)	8376.9 kWh

Table 4.2: PCE simulation data

Annual energy saved (year1)	9257 kWh
Solar fraction (year 1)	0.89
Aux with solar (year 1)	1090.7 kWh
Aux without solar (year 1)	10448.3 kWh

Table 4.3: PCE simulation data

Annual energy saved (year1)	6304 kWh
Solar fraction (year 1)	0.67
Aux with solar (year 1)	3015.6 kWh
Aux without solar (year 1)	9420.7 kWh

The comparison of results between simulated and theoretically calculated are also shown in TABLE 4.4 and percentage error is also presented.

Table 4.4: Result comparison

Colleges	*Simulated kWh p.a*	*Theoretical kWh p.a*	*% Error*
CNR	8377	7200	14.05%
PCE	10448	10800	3.37%
JNEC	9376	8280	11.69%

Financial Analysis

The financial analysis is done using the latest market price and inflation rates. The main cost of the SWHS is a solar collector. The installation price is directly proportional to the area of the collector required. As PCE requires a bigger collector area, the installation cost is also high comparing to the other two colleges. The power-rated system sizes for CNR, PCE, and JNEC are 4 kW, 6 kW, and 4 kW respectively. TABLE 4.5 gives the summary of SHWS installation and operation cost in three different colleges for the project life span of 15 years.

Table 4.5: Financial Analysis

	CNR (4kW)	PCE (6 kW)	JNEC (4 kW)
	Project period	Project period	Project period
Energy Saving (kWh)	79395	138855	94560
Financial Saving (Nu.)	288997.8	505432.2	344198.4
Unit cost of Energy (Nu./kWh)	3.15	2.63	3.07

The fig. 4.1-4.3 shows the break even curve for three SHWS.

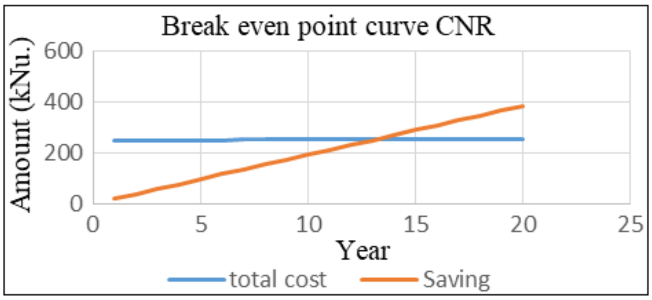

Figure 4.1: Break even curve CNR

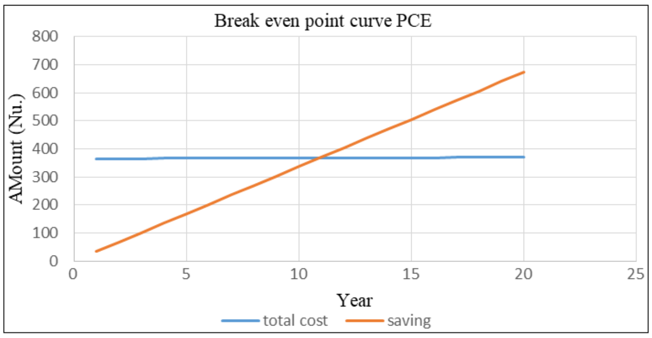

Figure 4.2: Break even curve PCE

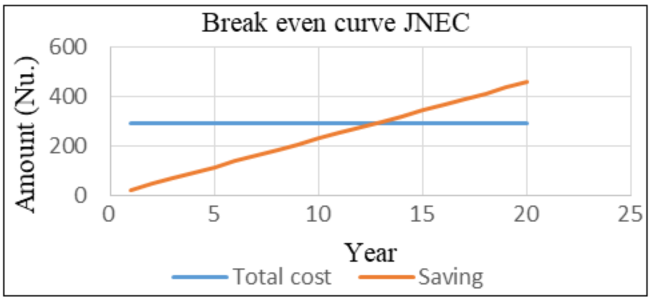

Figure 4.3: Break even curve JNEC

The payback period for CNR is between 13 to 14 years, PCE is between 11-12 years and JNEC is between 13-14 years. Considering the project life period of 15 years, SWHS installation has advantages in saving lots of energy after the payback period.

The unit cost of the energy generated is also shown in TABLE 4.5. The unit cost of energy decreases with increase in system size and vice versa.

The types of SHWS is also preferred different for different location due to difference in ambient temperature. The flat plate solar collector with a passive system is selected in all three colleges. PCE being located in higher altitude and its ambient temperature also drops below freezing point during the winter season, water cannot be used as circulating fluid.

5. Acknowledgement

Author would like to acknowledge Royal University of Bhutan (RUB) for providing Annual University Research Grant (AURG) to develop research capabilities for academicians. Also would like to acknowledge College of Science and technology (CST), Dean Research and Industrial Linkages (DRIL) office for encouraging to carry out such research, national Renewable Energy Laboratory (NREL) for providing open access System Advisor Software (SAM) and satellite data.

Author also would like to thank Mr. Karma Wangchuk, Lecturer, College of Natural Resources, Mr. Ngedup Jamtsho, B.Ed. student, Paro College of Education and Mr. Karchung, Lecturer, Jigme Namgyel Engineering College for helping in collecting data in this COVID-19 pandemic time.

References

[1] Druk Green Power Corporation Limited, Annual Report 2018.
[2] Solar Resource data. World Bank Report. Retrieved from https://solargis.com/maps-and-gis-data/download/bhutan.
[3] N.Rinzin *et al.*, “Design, Installation, and Performance Analysis of Solar Water Heating System in CST Kitchen” EE lectrical Engineering department, CST.
[4] Alternative Renewable Energy Policies. Lhengye Zhungtshog 2013.
[5] G.Dorji, *et al.,* “ A case study on PV system Performance and LCOE of 15.6 kW Hybrid Solar PV System Installed at CST” IEEE 9th Power India International Conference,2020, (pp. 1-4). Hariyana: IEEE. *Climate Data Book of Bhutan*, NCHM, 2018
[6] Detailed Report of Solar Water heating System (1000LPD) (Solapur Textile Cluster). New Delhi: Bureau of energy efficiency, 2010.
[7] A.R. Haitham, M. Mariusz and A.H. Kamal “POWER ELECTRONICS FOR RENEWABLE ENERGY SYSTEMS, TRANSPORTATION, AND INDUSTRIAL APPLICATIONs. UK.”: John Wiley & Sons Ltd.2014.
[8] Oettinger, G. H. (2012). Energy Road Map 2050. Belgium: Luxembourg.
[9] Ogueke. N.V, A. E “A review of solar water heating systems. Journal of Renewable and Sustainable Energy” (043106), 1-21.
[10] Subba, M. (2020). Hydropower generation increased by 31 percent in 2020. Thimphu: Kuensel.
[11] Vashishtha, S. (2012, April). Solar Advisory. Retrieved from Firstgreen Consulting Private Limited: https://firstgreenconsulting.wordpress.com/2012/04/26/differentiate-between-the-dni-dhi-and-ghi/