Sustainable Energy Engineering & Applied Sciences
Vol.2.Issue 2.267-276.2024
https://seeasjournal.com/

Technical Report

SAM software to simulate solar water heating (for both residential and commercial)

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KEYWORDS

Solar water
Residential
PNU
(commercial)
SWH
SAM

ABSTRACT

This Report examines the performance and the economy for residential and commercial solar water heating SWH technology, specifically flat plate collectors. Two case studies were considered: My house in Madinah al-Munawarah region (residential) and 25MW solar water heater project in prices Norah bent Abdurrahman university PNU (commercial) in Riyadh. System Advisory Model SAM was used to perform the analysis, the model input parameter is obtained from the original design of the systems and from the collectors' data sheets and some not available values are assumed reasonably or kept ad the default value of the software. The technical performance and the economics of the selected SWH system for each sites have been estimated using the SAM program by determining the delivered heat, solar fraction, the savings in energy and money, payback time, and net present value. As a result, the simulation of the two cases showed that using the SWH system in Saudi Arabia is viable, and deploying the SWH technology may cause up to 45% reduction in electricity consumption in case of The payback period for the Madinah SWH system is 7.6 years which considered to be good and promoting to be deployed. Madinah witnesses better solar radiation but also has a hotter average temperature than Riyadh, the solar fraction for residential was 0.58 which is higher than commercial of only 0.02. but the capacity factor for the commercial in Riyadh was higher of which 17%. While Madinah SWH system capacity factor is 9.5%.

1. Introduction

This report represents an analysis of solar water heater SWH for residential and commercial in the kingdom of Saudi Arabia [1-2]. The outcomes of this analysis are generally performance analysis and lifetime financial analysis. It has been built by considering case data for my house in Madinah Al-Munawarah city –residential SWH– and 25MW solar water heater project in prices Norah bint Abdurrahman university PNU –commercial SWH– in Riyadh. In this report, the analysis of residential will be more detailed considering more realistic assumptions, the reason simply because it is simpler than the first simulation and due to the availability of information since I have already owned the system [3-4]. Figure 1, Google Earth aerial satellite photo of the two usually, real-world problems or project assessment is not a direct process and could be sophisticated and huge for such reason modeling tools serves as a good solution to efficiently perform multi aspects analysis [5-6]. It offers a dynamic environment for analyzing computer models as they are running, including the ability to simulate the results data. [7-8].

System Advisor Model (SAM) is used to carry out to simulate the required cases, SAM is a free techno-economic software model that helps people in the green energy industry make decisions. It was created with funds from the

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Received: 19 June 2024, Accepted: 05 July 2024

US Department of Energy by the National Renewable Energy Laboratory (NREL) [1]. The SWH model from SAM is a one-tank water or glycol device with an auxiliary electric heater [9-10]. The value of the energy provided by the SHW system is determined by installation and maintenance costs, financial projections, and retail electricity rates. The SWH model allows to adjust the hot water load profiles, location, mains and fixed temperature profiles, heat exchanger, and collector, and solar tank characteristics.

2. Research Methodology

In the present Report, the metrological data specifically typical metrological year obtained from Photovoltaic Geographical Information System PVGIS by European Commission, then the data modified to be compatible with SAM CSV file by changing time stamp, it worked fine after some while. The TMY includes hourly data contain Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), Direct Normal Irradiance (DNI), wind speed, ambient temperature, and pressure. The SWH system for the residential model is composed of two flat plat collectors, hot water tanks and connecting pipes as shown in Figure 2. The support structure and material of collectors was an aluminum used to fix the collectors. Flat plate solar collectors from Saudi ceramics. were supposed as being typical in a thermosiphon pressurized systemOn other hand, the commercial Solar System at PNU composed of 17MWth solar thermal collectors Integration with 70MWth Diesel Boilers, consists of 3616 Large flat plate collector (10m2) was selected, manufactured by GreenOneTech – Austria, Solar system is designed based on FP large collectors of total surface gross collector area of 36,160 m², Solar system to raise the temperature of the boiler return line by a minimum of 3 degrees in winter days at an approximate capacity of 17MWth [2]. For the residential SWH system, the original design was to supply hot water for 4 people while the hot water tank capacity is 200L this satisfies that many manufactures and technical report indicate that the average daily hot water consumption is 50L per inhabitant. The hot water draw profile assumed to be constant along all days of the year, while the main tank temperature changes as the ambient temperature varies between seasons. Thus, the amount of energy to heat the water also varies. In other words, the hot water draw profile is assumed to remain constant throughout the year, while the main tank temperature changes with the ambient temperature. As a result, the energy required to heat the water also varies. As a result of this required energy system gained energy as well as the auxiliary heater energy [11]. Model input parameter for the collector is taken from the manufacturer datasheet, while others like FRUL –which is the overall loss heat transfer coefficient– and FRτα –which reflect the flat plate optical efficiency including glazing transmittance and tubed absorption– are calculated based on manufacture date. If any input parameter can't be found directly it kept as the model default value of assumed reasonably such flow rate, incidence angle modifier, and albedo. Since some design parameter has not defined previously, parametric simulation option in SAM used to assign one or more input variables value to get one or more desired output value. In other words, if any input parameter cannot be found directly, it is kept as the model's default value, such as flow rate, incidence angle modifier, and albedo. As some design parameters have not been previously defined, the parametric simulation option in SAM is used to assign one or more input variable values in order to obtain one or more desired output values. It has been used to determine the optimal tilt angle of the flat plate collector and the solar azimuth angle in the residential system in Madinah to obtain the maximum solar energy. Table 1& Table 2 summarize model input parameters and assumptions.

One of the main parameters in designing and modeling SHW is the hot water usage which directly proportional to the required thermal energy to raise its temperature from the cold tank of the main temperature to the Outlet set temperature. For the average monthly main water temperature is extracted from SAM, then it feeds into the correlation to determine the required thermal energy to heat the required amount of water which has been identifying earlier in this report. Then monthly energy usage is compiled in an excel spreadsheet and added to the same. see Figure 4

$Q\_required = m * cp * (T_{set} - T_{main})$

Where:

m: is water mass in Kg, and cp: is specific heat for water

3. Result and discussion

After completing the simulations, performance and economic analysis of residential SWH and commercial SWH have been conducted. Saudi Arabia is blessed with high solar irradiance this led to great opportunity to utilize solar thermal technologies, Figure 5 shows the annual average solar irradiance of the two sites under this report, it is noted that the average GHI in Madinah is the highest value which is 6.54 KWh/m2 day and Riyadh is 6.33 kWh/ m2 per day, and for monthly average Madinah also witnesses slightly more solar irradiation for most months. Figure 6 shows the average monthly ambient temperature for the two cities, Madinah generally has a higher average temperature for all months. while the average annual temperature in Madinah is also the higher which is 28.4°C and in Riyadh is the lower which is 25.6°C. Three major factors affect the output of the SWH system: the characteristic of components, the collector efficiency, the temperature of the water and the required temperature, and incident irradiation on the surface of the collector. A parameter that describes the rete of solar energy utilization for SWH systems is called solar fraction which defined as the ratio of the amount of solar energy divided by the total energy required to heat the water -including energy consumed in the axillary heater. It is considered 1 when all required energy delivered by solar energy to 0 if no solar energy utilization. The simulation finding for the first year is 58% for residential cases in Madinah and only 2% for commercial cases in Riyadh. The solar fraction for Madinah represents a reasonable number for such system type and size, while the PNU SWH system in Riyadh solar fraction may be very low due to model limitation or insufficient inputs data, another reason is that the main district water heating system relies on 6 diesel boilers with some help from the SWH system to rise the input if the piler from 73°C to 75°C and the low demand tor hot water in the summer season. Figure 7 illuminates, the monthly thermal energy delivered by SWH systems, and the required thermal energy to raise the water to the set temperature. It can be considered as the solar fraction; therefore, it is 63.6% in January which is the coldest month, and it reaches 92.3% in the summer in August. Similarly, Figure 8 illustrates monthly energy delivered by system vs required energy but for the commercial case in Riyadh, the solar fraction, therefore, is highest in September at 20% and it lowest in March at 9.8%. System potential to save electricity of fuel is an important evaluating term for an SHW system, which is the amount of energy that will be saved after using a solar heating system. It can be reflected on the electricity bill saving as well. Figure 9 illustrates the monthly electricity bill comparison between if the SWH system in Madinah presents or not. Cost in $ the left y-axis and the potential percentage savings for the whole project on the right y-axis. The maximum saving found in February which a 33% reduction in the bill. The average annual electricity saving per year is 224$ and the average monthly bill reduced from 297$ to 73$. For the PNU case, the monthly saving represented information about electricity usage in MWh. Figure 10 shows the monthly electricity usage in PNU SWH plant usage comparing with or without the system. Energy in MWh on the left y-axis and the potential percentage reduction for electricity usage in a project on the right y-axis. The maximum saving found in May which a 46% reduction. The annual electricity usage without the SWH is 10.9 GWh and with SWH is 3.4 GWh which results in a 31% annual reduction in the electricity usage. As mention before in this report, SAM capable to conduct performance and economic analysis, some of the most important outcomes of the two cases simulation are summarized and tabulated as shown in Table 3. For the performance parameters, the Annual energy saved is the total energy saved by the SWH system per annum, equal to the total system power generated values, the system power generated is the saved power by the system, which equal to: power generate = thermal energy without SWH (Aux only) – additional thermal energy supplied by Aux – energy consumed in pump. In the context of solar water heating (SWH) systems, the solar fraction represents the ratio of actual solar energy to the total energy supplied to the end user, essentially indicating the system's reliance on solar energy for heating purposes. Meanwhile, the capacity factor reflects the ratio of the actual output energy to the nameplate output when considering full hours of operation. It is calculated using the formula: Capacity Factor = Net Annual Energy (kWh/yr) / System Capacity (kWth) / 8760 (h/yr) [1]. Moving to financial parameters analysis, the real levelized cost is a constant unit with an adjusted value for inflation, whereas the nominal LCOE represents the current cost unit value. The choice between nominal and real LCOE depends on the specific analysis requirements, with the nominal LCOE being more suitable for near-term analyses, while the real LCOE is better suited for long-term analyses to account for inflation over many years. When it comes to residential and commercial financial models, in SAM (System Advisor Model), the electricity generated by the power system is assumed to displace the purchases of electricity to meet the electric load. The model presents the billing results with and without the power system. A critical parameter for assessing and evaluating the feasibility of a project is the payback period, which is the number of years required for the system's savings to equal the annual costs. The simple payback period considers installation and operating costs, the value of electricity generated by the system, incentives, and debt-related costs. On the other hand, the discounted payback period also incorporates the time value of money by discounting cash flows at the nominal discount rate.

4. Conclusion

In this report, the technical and economic aspects of SWH have been investigated for the residential (Madinah) and commercial (Riyadh) sectors as case studies in Saudi Arabia. The economic and technical performance of the SWH system in Madinah and Riyadh has been estimated and simulated using SAM software through determining the thermal energy delivered, solar fraction, capacity factor, the savings in energy and money, the Levelized cost of energy, and payback period. In comparison Madinah has better solar radiation but also has a hotter average temperature than Riyadh, the solar fraction for residential was 0.58 which is higher than commercial of only 0.02. but the capacity factor for the commercial in Riyadh was higher of which 17%. While Madinah SWH system capacity factor is 9.5%. the real Levelized cost of energy for a commercial system found to be 0.53$/kWh and the real nominal LCOE is 0.64$/kWh. The simple payback period for the residential SWH system is 7.6 years which considered to be good and promotive.

5. Acknowledgement

The research team extends their heartfelt gratitude and sincere appreciation to the Sustainable Energy Technologies Center for its invaluable support in conducting this research

6. References

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7. Figures and Tables:

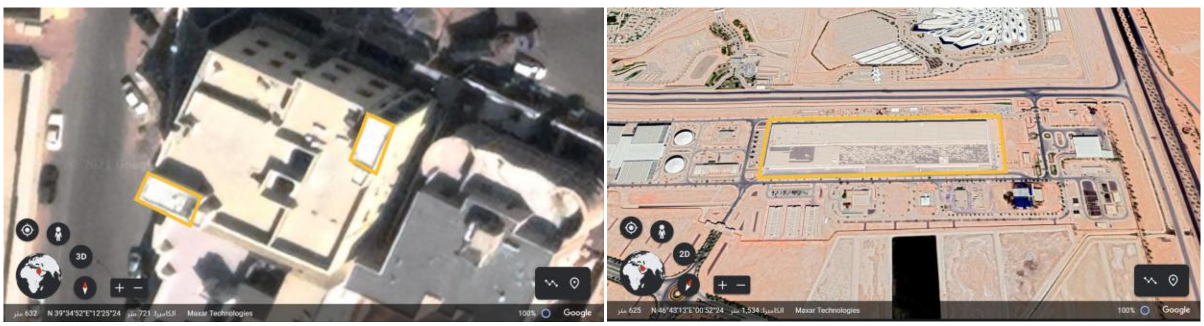

Figure.1. a) Residential SWH (Madinah city) b) commercial SWH plant at PNU in Riyadh city

Figure.3. GreenOneTech GK3100 FPC

Figure.2. 200L Saudi ceramics SWH

Table 1: Residential Case1, (Madinah) input parameter and assumption

Case1: Residential, (Madinah) location lat:24.42 long:39.581					
Parameter	**Value**	**Unit**	**Parameter**	**Value**	**Unit**
Outlet set temperature	60	°C	FR$\tau\alpha$	0.85	-
Solar tank volume	0.4	m^3	FRUL	3.5	W/m^2-°C
Azimuth	130	degrees	Heat exchanger effectiveness	1	-
Tilt	65	degrees	Storage cost	461	$/unit
Working fluid	Water	-	Collector cost	269	$/unit
Number of collectors	4	#	Balance of system	107	$
Collector area	1.3	m^2	Installation cost	187	$
Rated system capacity	**3.9 KW**		**Total system cost**	**$ 1,830**	

Table 2: Commercial Case2, PNU (Riyadh) input parameter and assumption

Case2: commercial at PNU, (Riyadh) location lat: 24.959 long: 46.702					
Parameter	**Value**	**Unit**	**Parameter**	**Value**	**Unit**
Outlet set temperature	75	°C	FR$\tau\alpha$	0.7	-
Solar tank volume	900	m^3	FRUL	0.7	W/m^2-°C
Azimuth	180	degrees	Heat exchanger effectiveness	0.8	-
Tilt	50	degrees	Storage cost	2000	$\$/m^3$
Working fluid	Glycol	-	Collector cost	600	$\$/m^2$
Number of collectors	3616	#	Balance of system	920000	$
Collector area	9.17	m^2	Installation cost	385500	$
Rated system capacity	**18.7 MW**		**Total system cost**	**$ 23 Million**	

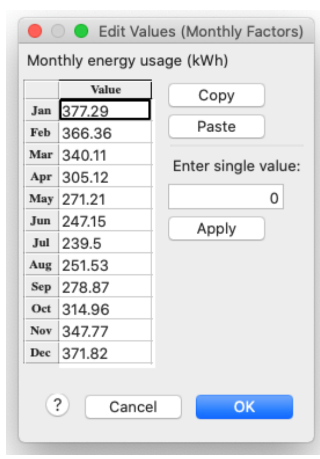

Figure.4. monthly energy usage

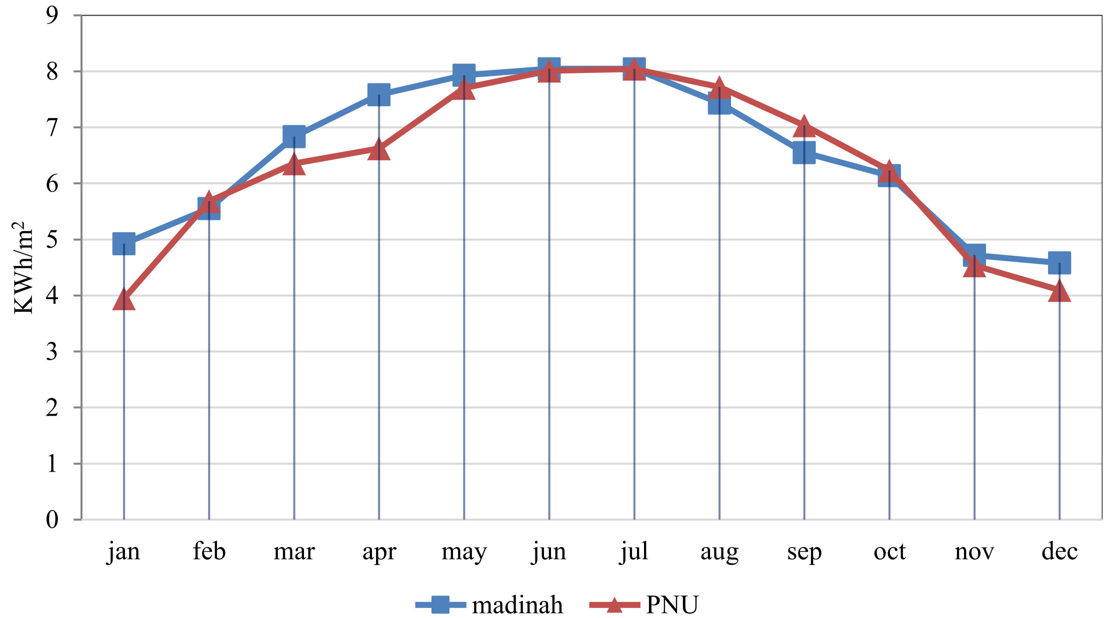

Figure.5. Average Daily solar radiation on horizontal surface

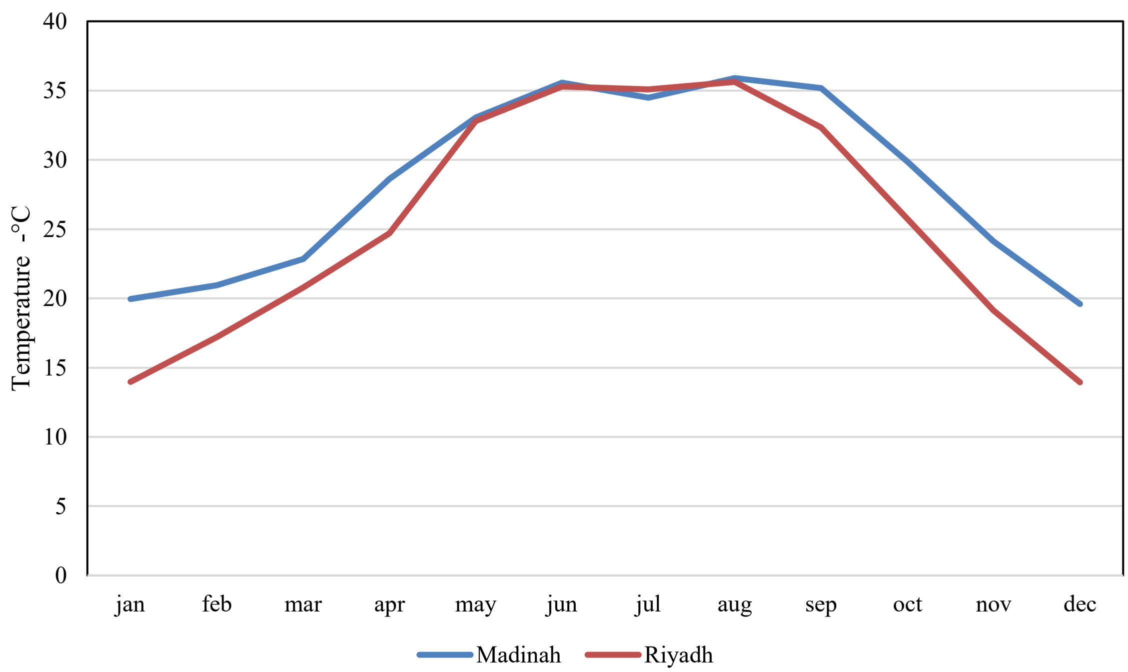

Figure.6. Average monthly ambient temperature

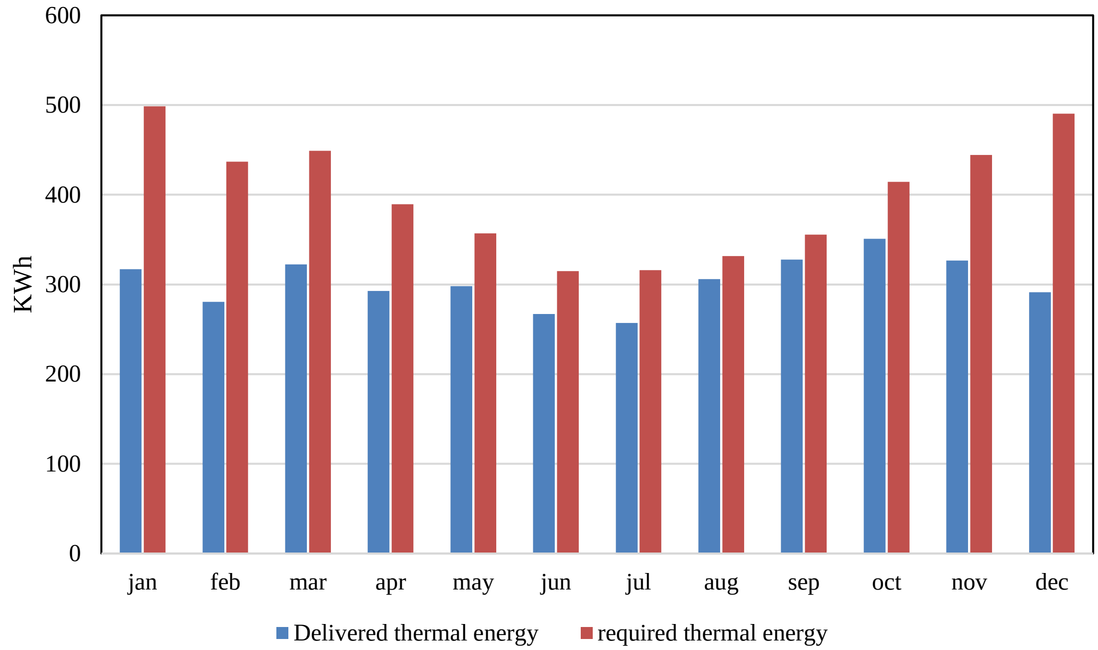

Figure.7. Monthly energy delivered by system vs required energy residential case (Madinah)

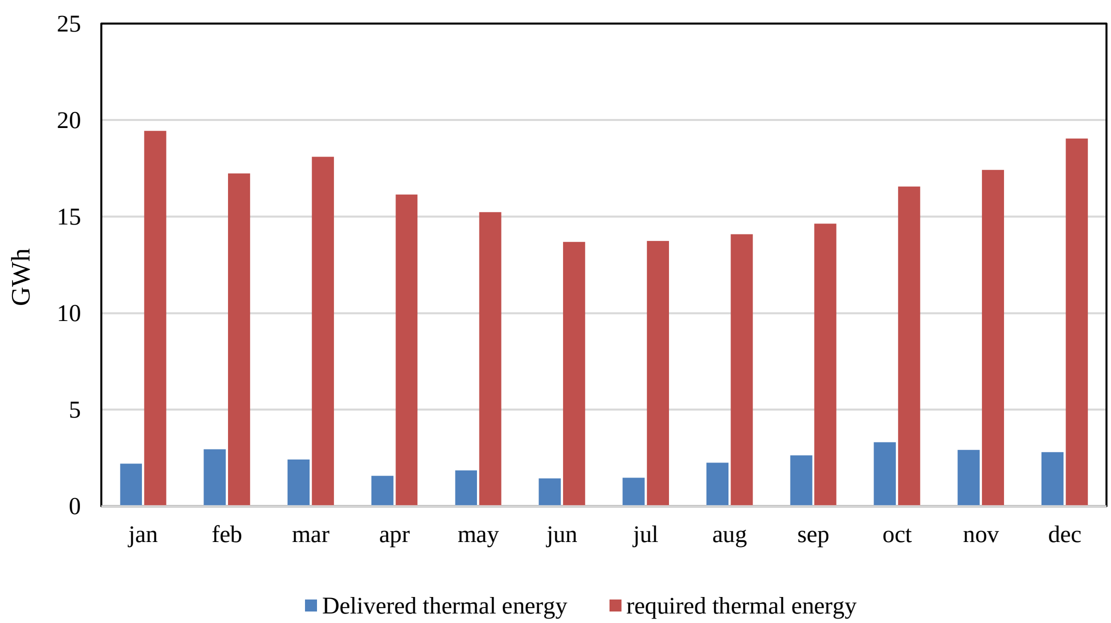

Figure.8. Monthly energy delivered by system vs required energy Riyadh

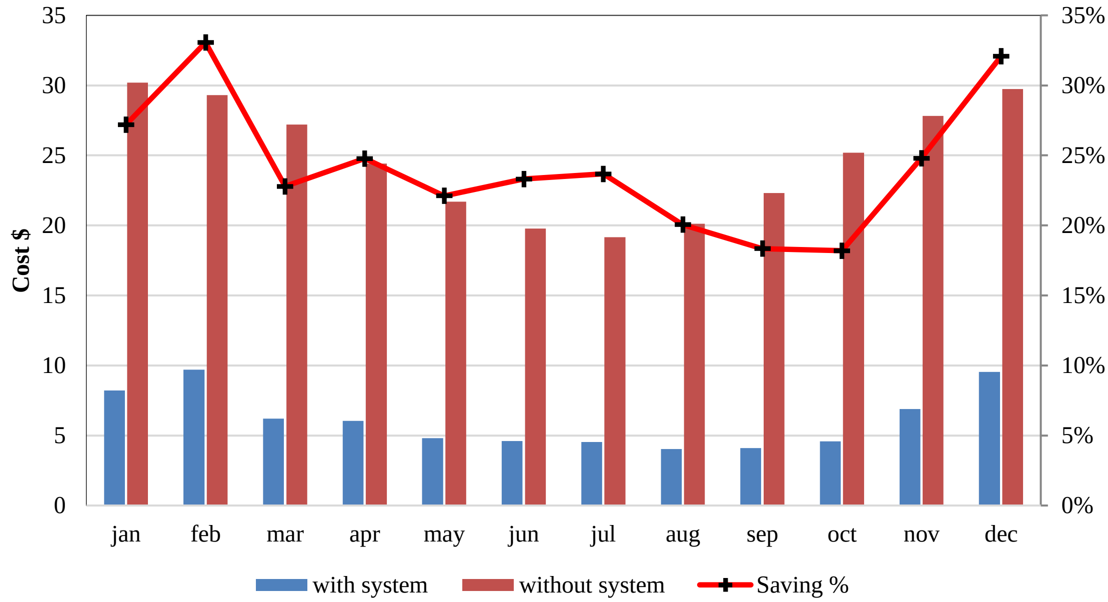

Figure.9. Monthly electricity bill comparison residential case

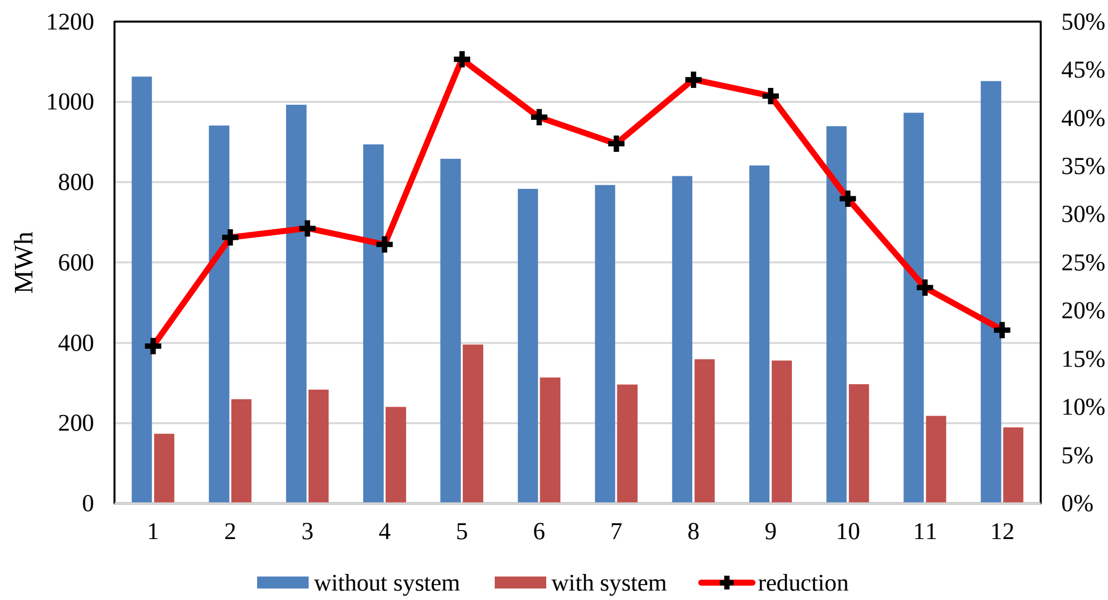

Figure.10. Monthly Electricity usage at PNU SWH plant in Riyadh

Table.3, Tabulated simulation result for first year

Parameter	**Residential**	**Commercial**
	Value	
Performance		
Annual energy saved	2,796 kWh	3,382 MWh
Solar fraction	0.58	0.02
Capacity factor	9.50%	17.00%
Aux with solar	1,194.9 kWh	167,507 MWh
Aux without solar	4,797.5 kWh	195,347 MWh
Financial		
Nominal Levelized cost of energy	-	0.64 $/kWh
Real Levelized cost of energy	-	0.53 $/kWh
Electricity bill without system	$297	$1,193,188
Electricity bill with system	$73	$1,608,613
Simple payback period	7.6 years	-
Discounted payback period	10.7 years	-