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Assessment of energy and financial performance of a solar hot water system in a single family dwelling: case study from Marjeyoun – South Lebanon

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Abstract

This paper analyzes the collected data from an installed solar water heating (SWH) system at Marjeyoun, South Lebanon. The analysis provides complete weather data for the area studied with detailed weather profiling by day and month. Average annual temperature in the studied area was 18.1 ºC and total annual solar insolation was measured to be 1510 kWh/m^2. Second, a detailed analysis of hot water consumption patterns was obtained indicating the consumer hot-water-use profile by hour, day and month. Major findings indicate that the average annual consumption of hot water is 13 m^3/person and 645 L/m^2 of built area. In addition, the thermal energy imbedded in the hot water used showed consumption of 618 kWh/person and 30.9 kWh/m^2 of built space. Third, actual solar contributions to hot water needs were quantified. The results indicate that the system contributed 3049 kWh/yr to the heating load offsetting 98.6 % of electricity needed to heat water. Total annual savings were calculated to be $195. When the analysis is done regarding the real cost of electricity incurred by the national electricity company (EDL), the actual savings are $610/yr providing for a payback period of 2 years. Average monthly tank temperatures varied from 42 ºC in winter up to 80 ºC in summer.

Keywords: Electricity, savings, consumption, financial, environmental.

List of Abbreviations

APS:	Automatic Power Supplies
ºC:	Degrees Celsius
EDL:	Electricite du Liban
h:	Hour
kWh:	Kilo Watt hour
L:	Liters
LCECP:	Lebanese Center for Energy Conservation Project
LIBNOR:	Lebanese Standards Institution
MEW:	Ministry of Energy and Water
RFQ:	Request for Quotation
SWH:	Solar Water Heater

TOR:	Terms of Reference
UPS:	Uninterruptible Power Supply
UNDP:	United Nations Development Program
W:	Watt
yr:	year

Introduction

Solar water heating applications have long been known to be effective energy saving applications; however, exact quantification of the savings has been studied in some countries [1-3] but no such results have been reported for the climatic conditions of Lebanon. Some testing has been conducted for such systems under regional conditions [4]. Furthermore, guidelines for such studies have been indicated by various authorities and energy management programs [5-6]. SWH potential for saving Green House gas emissions has been studied at NREL [7]. This work separates itself from the rest in being based on actual in situ measurements for a household with an average family living in it. The results are indicative of a normal living pattern rather that artificial testing conditions or theoretical analysis.

Project Background

On December 15th 2003, the Government of the People's Republic of China donated 500 solar thermal units to the Lebanese Government as part of an aid package dedicated for South Lebanon. Upon the decision of the Lebanese Council of Ministers in September 2005, the custody of the donated 500 solar thermal units was transferred to the Ministry of Energy & Water, who in turn, assigned the Lebanese Center for Energy Conservation Project (LCECP), a project funded by the Global Environment Facility (GEF) and managed through the United Nations Development Programme (UNDP) in Lebanon, to carry out the duty of ensuring the proper installation of the solar units and their satisfactory results. LCECP supported MEW in the selection of the beneficiaries, technical supervision, training activities, assignment of the specialized contractors, and the identification of pilot installations for further measurement and research to be used for future data dissemination on the benefits of installing solar thermal units on the national level.

MEW hosted a national training workshop at its facilities for a one week in February 2006 for several engineers, consultants and contractors on the various technical aspects of the donated solar water heaters. The training was conducted by two Chinese solar experts on theoretical and practical issues related to the design and installation aspects. This was done in preparation for an RFQ to be sent to all.

MEW & LCECP assigned qualified installers with previous experience in solar thermal units systems especially with collectors of the evacuated-tube type. LCECP arranged for the necessary subcontracting bidding documents with prequalification requirements that can be utilized for selecting the experienced subcontractors. The installers were responsible for the various works that are necessary to install the solar units to the MEW and LCECP satisfaction. The cost of the installation was covered by the beneficiaries directly and paid to the installers upon successful testing and commissioning of the units and approval of MEW & LCECP.

In order to bring the solar project to successful completion, LCECP provided, from its own resources allocated from UNDP/GEF, the necessary funds to cover the logistics such as local transportation to the south, warehouse, insurance, training, site engineer supervision and measurement equipment. As of 12th July 2006, LCECP had installed, commissioned and handed over to the beneficiary around 450 solar water heaters at various areas in the South through the assignment of 5 qualified solar contractors. As a result of the July 2006 war with Israel several systems were destroyed and Table 1 provides a quick picture of the status of the installed solar units as of the date of report preparation.

Table 1: Installed SWH systems and their current status after the July 2006 war

Location	Installed	Destroyed	Remaining
Bint Jbeil	156	114	42
Jezzine	40	1	39
Hasbaya	89	0	89
Sour	75	30	45
Marjeyoun	110	45	65
Nabatiyeh	18	0	18
Total	**488**	**190**	**298**

All of these systems are installed as one system per household except for two sites having a collective system: Salah Ghandour Hospital in Bint Jbeil with 16 units installed, and Sheikh Raghib Harb Hospital in Nabatiyeh with 18 units.

Due to the need to disseminate scientific data for the support of national comprehensive awareness campaigns, LCECP chose to procure measurement devices to be coupled to selected solar units over a one year period of time at four pilot sites for the purpose of monitoring and measuring these necessary performance data, taking into consideration the location type and altitude of these sites.

SWH System Specifications

The donated 500 solar thermal units are composed of storage tanks, solar collectors, support frames, controllers and spare parts. The donated solar units are based on the latest solar technology i,e Evacuated Glass Tubes Solar Collectors and are manufactured by Beijing Tsinghua Solar Co., Ltd, one of the known and specialized Chinese company in solar water heaters application. Each system constitutes of a 208 L storage tank which is also equipped with a 2 kW auxiliary electric heater. The system contains 28 Evacuated tubes (SL-I-1500) with a total aperture of 2.8 m^2. The reported daily efficiency is >58% with a heat loss coefficient of 9.5 $W/m^2.K$.

Marjeyoun Site

Located at 33º 21.720' N and 35º 35.309' E at an altitude of 753 m, the studied site is a separate house with an area of 100 m^2. The house has five residents living in five rooms and has two bathrooms. It is connected to the electricity mains with a 20 Amp meter and suffers from a six hour blackout on average. A supplementary town generator provides 5 Amp during outages. The system was installed in April 2006. The beneficiary paid $250 for SWH system installation costs in addition to another $200 for raising the existing water tank. Residents indicated that they stay home during weekends and rarely receive guest over dinner and never have sleep over guests. They have had a new baby born in May 2007. Table 2 details the house occupancy patterns

On the maintenance side the system did not require any maintenance; however it was observed that the system had one broken evacuated tube almost since the time of installation but the system was still working perfectly well without it. They also mentioned that water temperatures of 99ºC were reached 2-3 times with significant boiling occurring in the tank making loud noises necessitating covering of the evacuated tubes. They did not indicate any other special problems.

Table 2: Marjeyoun house residents (weekends indicate Saturday and Sunday)

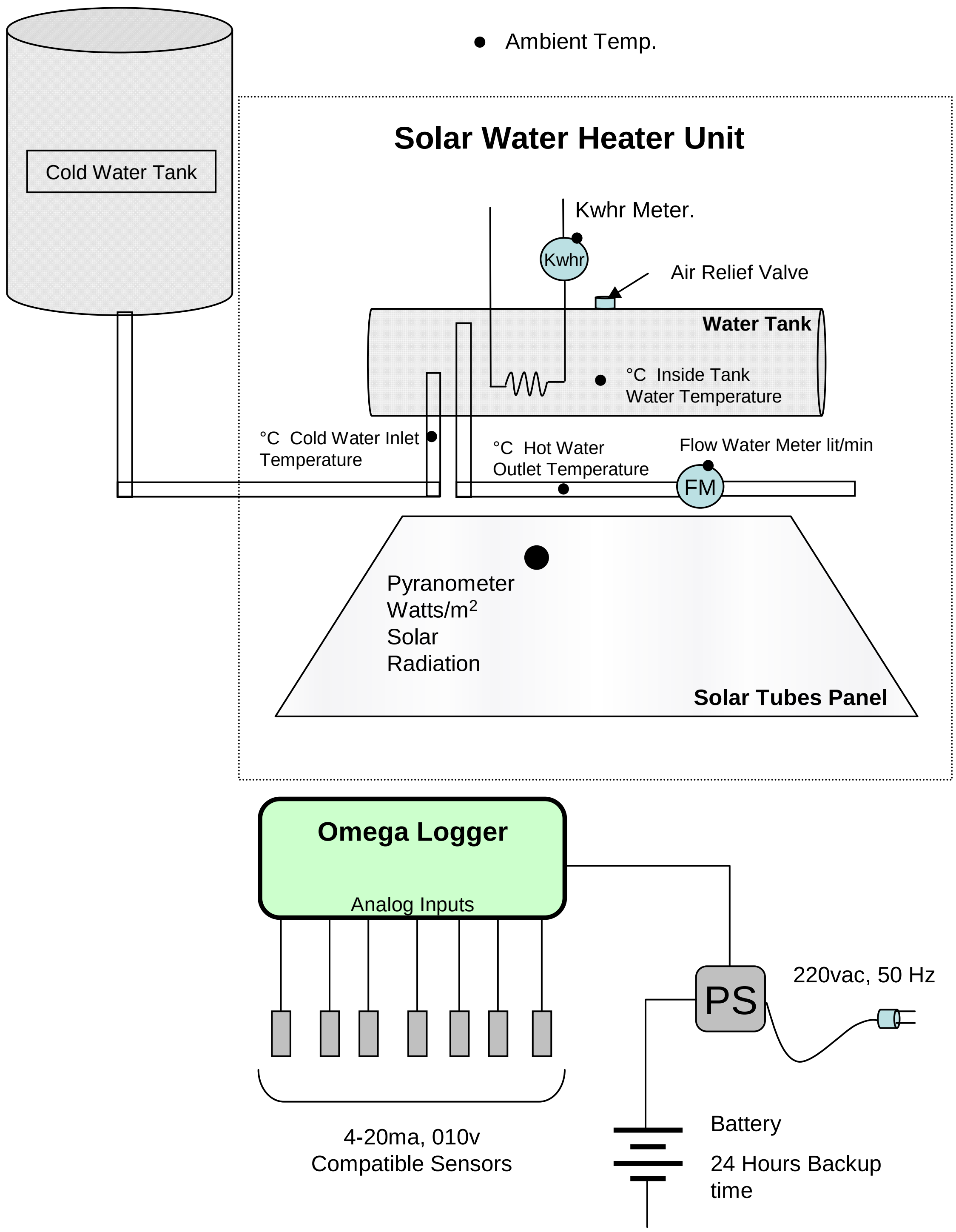
Age	Gender	Occupation	Hours away from the house on weekdays	Hours away from the house on weekends
54	M	Employee	9:00-5:00	None
44	F	House wife	None	None
14	M	Student	7:30 – 2:30	None
12	M	Student	7:30 – 2:30	None
0.6	M	---	None	None

Selection of Data to be Acquired

The data acquired in this stand-alone setup covered the following points within the system:

1. The ambient temperature in degrees Celsius is taken through the use of a thermocouple placed in an appropriate copper well (straw type well).
2. The insolation reading (W/m^2) is taken by a pyranometer placed horizontally just above the system.
3. The flow of water in the outtake hot water pipe is read through the use of an inline flow meter to read the amount of hot water delivered in liters to the household within a certain period of time. The flow meter is of the nature that gives out pulse ticks reading to indicate the passage of 2.5 liters at every pulse tick registered by the logger.
4. The electrical energy dissipated by the heating element inside the water tank is read through the use of a voltmeter placed to measure the voltage across the heating element (resistance) inside the water tank. Based on the relation $E = V^2/R$ x time, the watt-hr (Wh) is simply carried out by computer calculation. The resistance of the heating element was registered at 25.1 Ω.
5. The temperature at the cold water intake, and at the hot water outtake in degrees Celsius, are taken through the use of a thermocouple placed inside a well welded in an inline T type connection, custom made to suit the purpose.
6. The temperature inside the water tank is measured in degree Celsius, read through the use of a thermocouple also penetrated in the built-in well along the heating element.

All of these sensors/transducers are connected to the Omega data logger, which takes the reading on a sampling rate of one minute. Data are logged and downloaded approximately every 4 weeks. The logger is equipped with an uninterruptible source of supply with autonomy of at least 24 hours. Monitoring units setup is shown in the following schematic diagram.



Scheme 1: Schematic of the monitoring equipment placement

Data and Results

Relevant Weather Data

The obtained data has facilitated drawing a complete picture of the weather patterns in the selected sites. The following tables show the relevant weather data including solar insolation.

Table 3: Various monthly weather data for Marjeyoun

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Temperature(°C)	9	11.1	13.9	17.1	22.3	24.8	25.8	24.5	22.8	21.4	13.6	10.2	18.1
Heating Degree Days (18) (°C.d)	244.8	193.4	97.6	34.4	3.3	0	0	0	0	0.9	114.1	217.6	906.1
Cooling Degree Days (21) (°C.d)	0	0	0.9	0.4	73.5	117.6	148.9	88.2	23.9	39.1	0	0	492.5
Global (horizontal) radiation (kWh/m^2)	77.2	87.5	100.7	92.3	187	227.7	220.6	155.7	66.8	133.5	83.4	77.8	1510

Quantification and Patterns of Hot Water Consumption

The data obtained also provides some unique insight on hot water consumption patterns of the residents. This consumption has been analyzed regarding the hourly, daily and monthly consumption patterns. These results will serve to match residential water consumption to solar system yields in order to provide some guidelines for raising awareness among potential SWH customers to raise system efficiency by changing consumer behavior.

Monthly consumption patterns are shown in Fig 1. These patterns show a wide variation of hot water consumption through the months, with the highest consumption being in May and the lowest in July. The consumption spike observed in May could be attributed to the arrival of a new born to the family. The results also show most importantly an annual hot water consumption of 64.5 m^3/residence, 12.9 m^3/person and 645 L/m^2. These results are extremely important regarding the estimation of residential hot water consumption. These values indicate a 35 L/person per day of hot water consumption, which falls within the international standards for hot water consumption (30-50 L/person.day). In addition, thermal heat consumed for hot water was found to be 3092 kWh or 618 kWh/person per year.

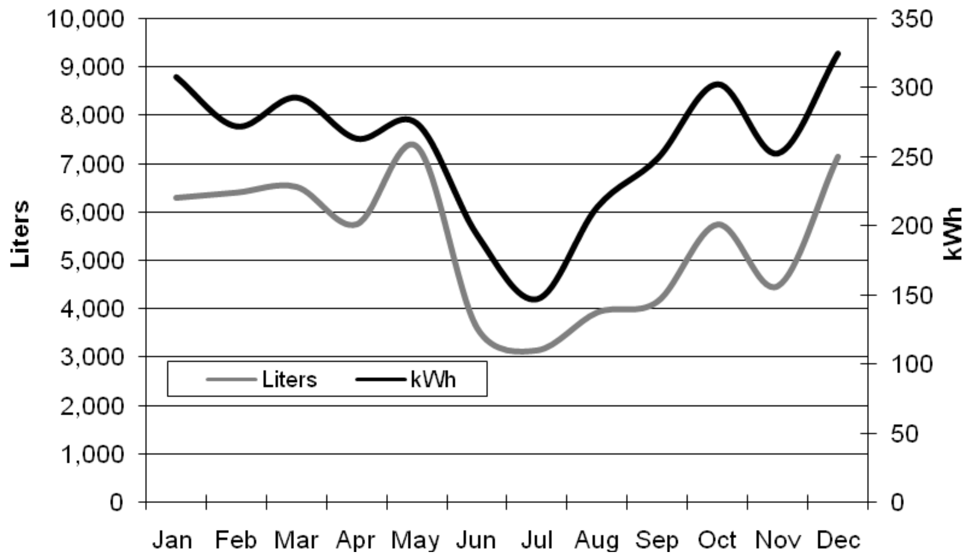


Fig 1: Plot of Monthly hot water consumption and kWh consumption

Analysis of weekly patterns averaged over the year is shown in Fig 2 and shows two distinct consumption peaks on Saturdays and Wednesdays. The total weekly consumption was found to be 1225 L and 58 kWh.

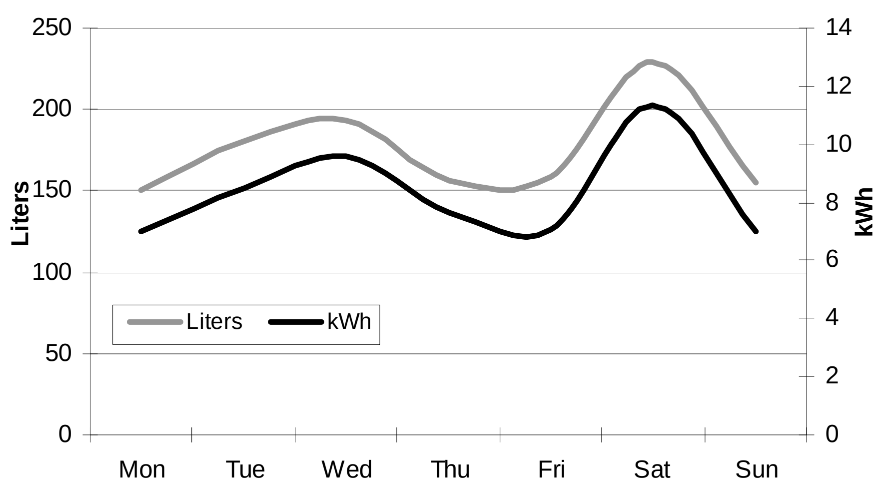


Fig 2: Plot of the weekly consumption patterns

Hourly consumption of hot water was also analyzed through out the seasons. The data obtained are shown in figure 3 for consumption in liters, and figure 4 for consumption in kWh. Two distinct peaks can be observed in the morning and the evening with a higher consumption pattern in the spring that cold also be attributed to the newborn.

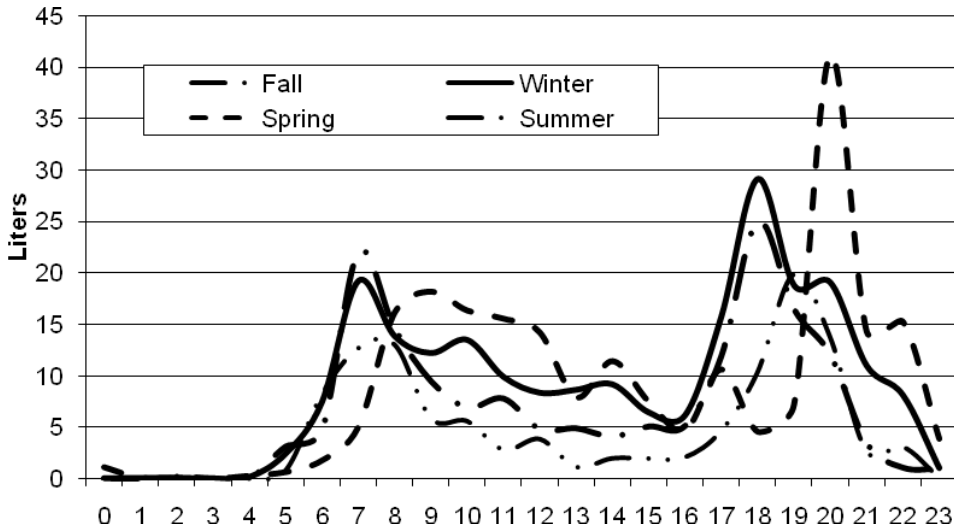


Fig 3: Plot of the hourly seasonal variations in the hot water consumption

Solar Contribution to Total Hot Water Consumption

Of the 3092 kWh of thermal energy consumed by the household throughout the year, 3049 kWh were from solar energy and only 43 kWh from the electric heater. SWH was able to supply almost all the hot water needs between the months of April and October. A mere 1.4% of the energy was contributed by the electric heating component.

Actual Savings on Bills Attained by System at Marjeyoun

The following graph illustrates the actual monthly savings realized by the installation of the SWH system as indicated by the obtained electricity bills. In financial terms, the system saved $105 for this family and 1776 kWh over the period of one year; percentage savings are 39% and 42% respectively. This is significantly higher than the expected savings of 21% based on previous studies showing that 26.6% of electricity consumption is used for water heating

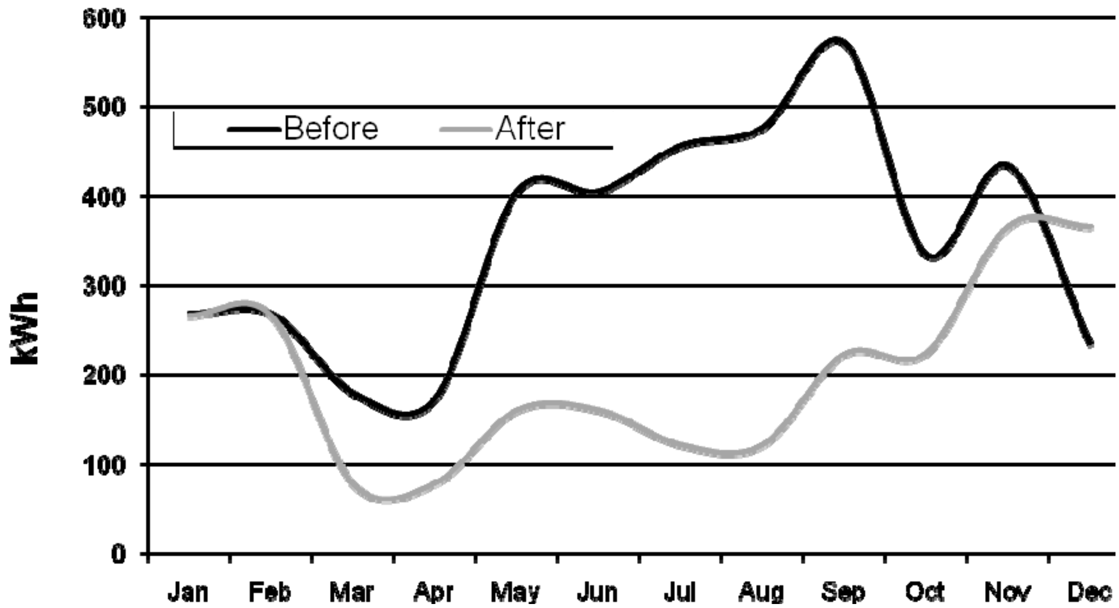


Fig 4: Plot of electricity consumption (kWh) before and after SWH system installation

Potential Savings from the Adoption of SWH Systems in Lebanon

The clear savings obtained point to the necessity of installing SWH systems all over the Lebanese territories. With the drastic weather variations across Lebanon, the current system will be taken as an acceptable average. Around 290,000 systems are needed to offset the need for a 100 MW power plant (876 GWh/yr, without accounting for technical and non technical losses on the grid). Moreover, and with closer scrutiny of the data, these systems will save a significant amount of energy in the summer months when electric loads are at a maximum, shaving off demand peaks during these times and eliminating the need for further investment in the electricity sector.

The actual current value of generating 1 MWh at EDL is currently around $200. This means that an installed system will save EDL $415/yr as the difference between actual generation cost and bill payment by customers. It may be to the advantage of EDL to promote the installation of such systems since it is currently losing money for every kWh generated at the current tariffs. Subsidizing such systems may actually save money in the long term.

For example, in the current case of Marjeyoun, the total electricity consumption of the household was 4204 kWh and total electricity cost was about $270, which means that the average cost was $0.064/kWh indicating a running loss for EDL of $0.136/kWh. With an annual savings of 3049 kWh, EDL can save $415/yr per system. This means that EDL can subsidize the price of SWH with $415 a year, or $800 (in lieu of 2 years) as a one time payment for system purchase and installation without losing money. Alternatively, EDL may opt for carrying the burden of long term financing in return of system installation. A long term loan of sixty months (5 years) for a $1200 system will cost the house owner a mere $20 per month. Paying the interests of this loan by EDL and carrying the processing burden for that period will be to its advantage from year one.

Conclusion

A comprehensive set of data has been obtained and presented within the context of the LCECP project and the 500 SWH donation form China project. The data is the first of its kind to be obtained in Lebanon and the results reported promise to be a stepping stone for any research and development in the field. Future plans for the introduction of SWH systems in Lebanon will depend on the results obtained to predict system performance and economic viability. In addition local capacity building for the installation of instrumentation, data collection and analysis has been developed.

The data obtained clearly shows that there is a clear limit as to the savings possible from these systems. Payback periods are long in the rural setting and may not necessarily justify personal investment in SWH on a financial basis only. In addition, it was shown that the solar system in question exceeds the needs for a single household during the summer. Accordingly, it is recommended that future installations be directed towards consumers with significant electricity bills, who might be able to make use of the hot water generated during all seasons, rather than rural homes with limited usage. Such consumers will generally be located in urban settings where collective systems are more justified, or in service complexes such as schools and hospitals. A significant change in the promotion strategy of SWH installation may be warranted. Regardless, payback period numbers currently used will have to be revised based on the actual data obtained.

Acknowledgement

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