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Quantification of energy produced from an evacuated tube water heater in a real setting

Ahmad Houri [a,*], Hussein Salloum [b], Anwar Ali [b], Abdel Karim Abdel Razik [c], Laila Houri [d]

[a] Natural Science Division, Lebanese American University, P.O. Box: 13-5053 Chouran, Beirut 1102 2801, Lebanon
[b] Lebanese Center for Energy Conservation Project (LCECP), Ministry of Energy and Water, Corniche du Fleuve, 1st Floor room #303, Beirut, Lebanon
[c] Beta Engineering, P.O. Box 14-6291, Beirut, Lebanon
[d] Faculty of Agricultural and Food Sciences, Dean's office, American University of Beirut, P.O. Box 11-0236, Riad el-Solh, Beirut 1107 2020, Lebanon

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ABSTRACT

For the first time, actual data regarding an evacuated tube SWH has been collected from an implemented system in Lebanon. The data collected was based on a number of sensors installed at various points in the system. The results indicated real hot water use of the household and operational temperatures throughout the year. The system provided more than 98% of the household needs indicating a clear over sizing of the system. Other findings include excessive heat generated in the summer, necessitating forced shadowing of the collectors. The system provided 3049 kWh/y and saved the family around $195. More significant savings are obtained by the electricity company since electricity in Lebanon is subsidized. This case study provides a reference point for the observed savings rather than estimated savings.

1. 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.

2. Methodology

2.1. Project background

Within the context of installation of 500 SWH systems in Lebanon, the Lebanese Center for Energy Conservation Project (LCECP), procured 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.

2.2. 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 about 58% with a heat loss coefficient of 9.5 $W/m^2.K$.

2.3. Marjeyoun site

Located at 33° 21.720′ N and 35° 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 (2 parents and three children, one of them born in May of the study year) living in five rooms and has two bathrooms. It is connected to the electricity mains with a 20 Amp meter and suffers from a 6 h of daily blackout on average. A

* Corresponding author.
E-mail address: ahouri@lau.edu.lb (A. Houri).

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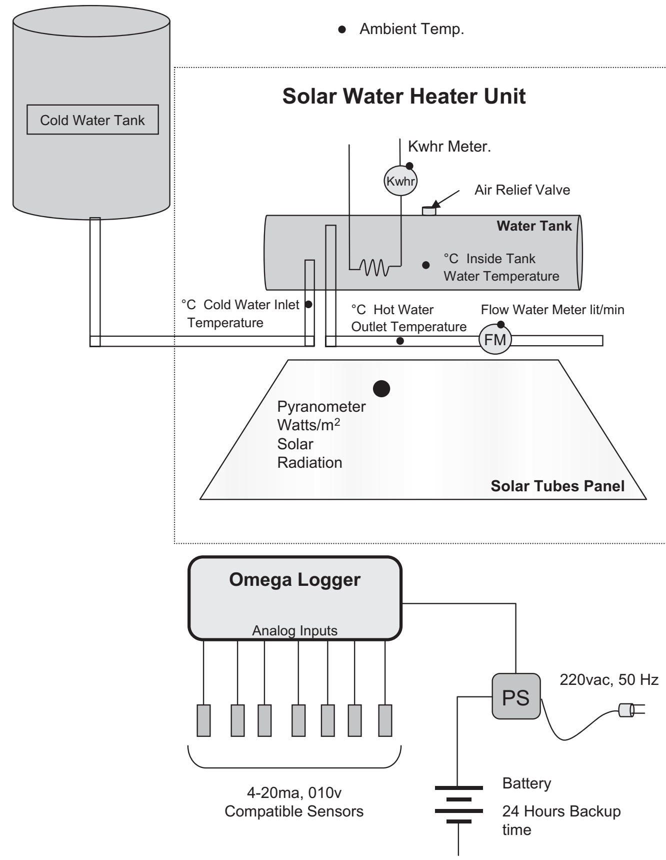
supplementary town generator provides 5 Amp during outages. The system was installed in April 2006. The beneficiary paid $250 for SWH system installation costs in addition to another $200 for raising the existing water tank. Residents indicated that they stay home during weekends and rarely receive guests over dinner and never have sleep-over guests. They have had a new baby born in May 2007. 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 99 °C 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.

2.4. 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 L 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 $E = V^2/R \times \text{time}$, 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 1 min. 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 h. Monitoring units setup is shown in Scheme 1.



Scheme 1. Schematic of the monitoring equipment placement.

3. Data and results

3.1. Relevant weather data

The obtained data has facilitated drawing a complete picture of the weather patterns in the selected sites. Table 1 shows the relevant weather data including solar insolation.

3.2. 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 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.

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

Table 1
Various weather data for Marjeyoun.

Variable	Yearly average
Average Temperature(°C)	18.1
Heating Degree Days (18) (°C.d)	906.1
Cooling Degree Days (21) (°C.d)	492.5
Global (horizontal) radiation (kWh/m^2)	1510

Hourly consumption of hot water was also analyzed throughout the seasons. The data obtained shows two distinct peaks in the morning and the evening with a higher consumption pattern in the spring that could also be attributed to the newborn.

3.3. 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.

3.4. Actual savings on bills attained by system at Marjeyoun

Fig. 1 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.

3.5. 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 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.

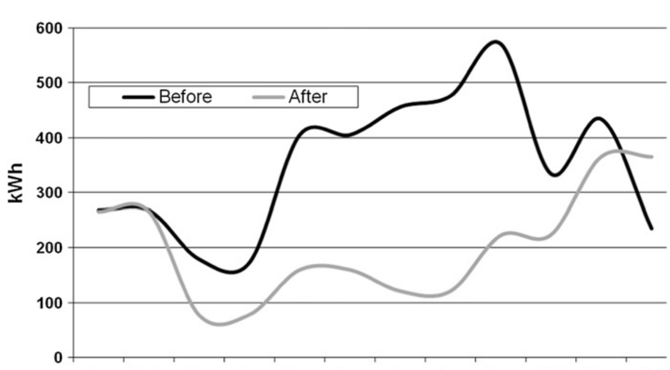


Fig 1. Plot of electricity consumption (kWh) before and after SWH system installation.

4. 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.

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