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Payback period for residential solar water heaters in Taiwan

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A B S T R A C T

Taiwan is a leaf-shaped island straddling the Tropic of Cancer with abundant and reliable supply of solar energy. Under the individual circumstances (solar radiation, ambient temperature and hot water consumption pattern), solar heating could be economically competitive with conventional heating fuels (electricity, natural gas or liquefied petroleum gas). In this context, the market of residential solar water heaters (SWHs) in Taiwan has been highly developed with subsidy programs offered by the government of Taiwan so far. Next, the economic viability of residential SWHs is determined by the life-cycle savings. This study develops a procedure for estimating the payback period of residential SWHs in terms of operation cost and effective energy savings over conventional heating fuels. A case study in southern Taiwan indicates that the increase in daily load volume per area of solar collector installed has a beneficial effect. An end user should determine the economically optimal solar collector area of an SWH according to the hot water consumption pattern of each household. Payback period is shorter when the substituted conventional fuel is electricity. With the subsidy program, an SWH is in a favorable situation when compared with an electrical water heater. Findings of the present study would assist partially system design of residential SWHs and help accrue more monetary benefit to the end users.
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Contents

1. Introduction

Renewable energy is receiving increasing support due to its environmental advantages, and solar thermal applications have been acknowledged among the leading alternative solutions. SWHs have proven to be cost efficient for both domestic and industrial applications [1]. Taiwan has depended almost exclusively on imported fossil fuels to fulfill its energy needs. The ratio of indigenous energy to total energy supply in Taiwan was 2.1% in 2011 [2]. Other than the issue of global climate change [3], the use of renewable energy is critical in national economic development. Significant efforts have been made toward the development and dissemination of biomass energy, geothermal energy, ocean energy, photovoltaic energy, solar thermal energy and wind power generation in Taiwan during the past two decades [4–7]. For solar thermal energy, SWHs, which can provide hot water at

Abbreviations: BEMOEA, Bureau of Energy, Ministry of Economic Affairs; CPI, consumer price index; EWHs, electrical water heaters; GWHs, gas water heaters; LPG, liquefied petroleum gas; LNG, liquefied natural gas; SC, solar collector; SWHs, solar water heaters

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Nomenclature

A_{sc}	area of solar collector installed
C_n	operation cost
E_{ei}	actual daily solar energy gain
E_i	daily available solar energy
E_o	net annual heat output
G	solar radiation per square meter
g_m	inflation rate
IC_o	initial cost
L	daily load volumes
m	annual maintenance cost
n	years of operation
Q_i	daily energy demand for hot water production
R_n	total savings

Greek symbols

ΔIC	difference in operation cost
η	thermal efficiency
γ	subsidy ratio as a percentage of initial cost

temperatures ranging from 40 to 80 °C, for domestic or industrial use,
are one of the most common applications. With the subsidy programs offered by the Bureau of Energy, Ministry of Economic Affairs (BEMOEA) and some regional governments, the accumulated area of solar collectors installed at the end of 2011 reached 2.13 million square meters [8].

Srinivasan [9] pointed out that a national renewable energy policy is a vital prerequisite for translating customer choice into a larger market share for non-conventional energy technologies. Financial incentives have been adopted for SWHs in many countries, including direct subsidy, performance-based subsidy, tax credits and tax deduction [10]. According to the statistical data gathered by the Taiwan Gas Appliance Manufacturers Association [11], gas water heaters (GWHs, 73.8%) dominated the market while the market share of electrical water heaters (EWHs) was 23.5% in 2011. There are approximately 0.3 million residential SWHs in operation, which represents less than 4% of the total households [12]. Most of the SWHs use natural circulation. Further, the capital cost of SWHs is considerably higher than that of GWHs or EWHs. Even with the national and regional subsidy programs [13,14], financial consideration is the key determinant in the decision process of consumer adoption. For residential SWHs in Taiwan, the average area of solar collector installed (A_{sc}) is approximately 5 m^2 and 3 m^2 (4- to 6-person household) for flat-plate type and evacuated-tube type solar collectors, respectively. The ratio of volume of storage tank to A_{sc} ranges from 50 to 80 l/m^2 [8]. Furthermore, as a rule of thumb for the system design of an SWH, the daily hot water consumption for each person corresponds to the hot water production of $A_{sc} \approx 1$ m^2. Therefore, an SWH with A_{sc} less than 2 m^2 would be used for one- or two-person households.

A residential SWH system could reduce water heating energy demand by 50–85% [15]. Payback period might be 2–4 years, depending on the type and size of the system [16]. However, the economic feasibility of SWHs is mainly determined by their initial cost, long-term efficiency and subsidy program. Islam et al. [1] demonstrated that the installation of SWHs are more feasible on a large A_{sc} compared to a small unit installed per household in terms of energy conservation and per unit energy cost over initial costs. For residential SWHs, Pan et al. [17] indicated that the payback period of SWHs in Taiwan varies from 6 to 15 years in different regions and type of heaters being replaced. However, other than the climatic conditions, the A_{sc} of a system and hot water use pattern are also among the dominant factors influencing the payback period of an SWH. In this study, the payback calculation model developed by Kaldellis et al. [18] is adopted. The operation cost of an SWH comprises its initial and maintenance costs. The annual inflation rate, taken as the consumer price index (CPI) in this study, is also taken into account. For the benefit part, the collector efficiency, effective solar radiation and hot water consumption pattern are included.

The remainder of this paper is organized as follows. Section 2 provides a brief description of the payback model. The climatic condition (global solar radiation and ambient temperature) in southern Taiwan, collector efficiency and hot water consumption pattern are employed to evaluate the effective heat gain. The historical prices of the conventional fuels (electricity, natural gas and liquefied petroleum gas) are also given. The payback period is obtained by the sensitivity analysis of major variables (unit price of a SWH, daily load volume and fuels being substituted). To consider a choice between SWHs and EWHs for an end user, economic costs of the heaters are addressed in Section 3 and conclusions are drawn in Section 4.

2. Payback period of SWHs in Taiwan

To assess the economic feasibility of SWHs in Taiwan, the payback calculation model developed by Kaldellis et al. [18] is adopted to estimate the operation cost (C_n) and total savings (R_n) due to the thermal energy offered by an SWH after n years of operation, in which

$$C_n = IC_o\left[(1-\gamma)+m\frac{1+g_m}{g_m-1}\left[\left(\frac{1+g_m}{1+i}\right)^n-1\right]\right] \tag{1}$$

where IC_o is the initial cost of an SWH; γ is the subsidy ratio as a percentage of IC_o; m represents the annual maintenance cost (=2% of the initial cost in this study, according to a general survey on local installers in Taiwan); g_m is the inflation rate; and i is the local annual capital cost.

$$R_n = E_o c_o\frac{1+e}{e-i}\left[\left(\frac{1+e}{e-i}\right)^n-1\right] \tag{2}$$

where E_o is the net annual heat output of an SWH; c_o is the present value of the effective cost coefficient of the substituted conventional energy; and e is the mean annual rate of price change in the substituted conventional energy.

2.1. Cost analysis

This analysis involves the initial and maintenance costs of a system, which are calculated using market data. For SWHs in the domestic sector, the mean annual rate of CPI (=1.38% from 2004 to 2011) and the average one-year interest rate of saving account (=0.949% from 2009 to 2011) are deemed suitable for representing the inflation rate and local annual capital cost, respectively [19]. Furthermore, the glazed flat-plate-type solar collectors with metal absorbers and glass cover are widely used in Taiwan. The average unit price (2009–2011) is 9100 and 14,000 NTD/m^2 (NTD: New Taiwan Dollar) for a system with $A_{sc} < 2$ m^2 and A_{sc}=4–6 m^2, respectively, as shown in Fig. 1. With the similar thermal output per A_{sc}, a shorter payback period can be expected for an SWH of

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