Renewable Energy xxx (2015) 1–8

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Review

Thermal performance evaluation of solar water heating systems in Australia, Taiwan and Japan – A comparative review

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A R T I C L E I N F O

Article history:
Received 20 December 2014
Accepted 8 April 2015
Available online xxx

Keywords:
Solar industry
Solar water heating systems
Thermal performance rating
Subsidies
Renewable energy certificates

A B S T R A C T

The need for domestic hot water in regions with cool climate represents a significant proportion of domestic energy consumption. The steady increase in the electricity costs and environmental concern from use of fossil-based fuel raises the interest in the search for alternative energy sources. In the case of domestic hot water provision, many governments have initiated a gradual switch to more environmentally friendly systems powered by renewable energy such as solar. Solar water heating (SWH) is a mature technology and is gaining popularity in many countries with increasing number of affluent population in society. The increasing adoption of these systems and technologies is a welcome development; however the robust methods of assessment of their thermal performances are required. This paper presents a comparative study of the methods of evaluation of SWH systems' thermal performance in three countries with increasing hot water systems penetration: Australia, Taiwan and Japan. The aim of this comparative study is to discuss merits and weaknesses of each approach and to explore possible common approach that will improve the existing methodologies.

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1. Introduction

While energy efficiency has played a significant role in curbing energy consumption in many countries over the last 3 – 4 decades [1–3], ever increasing activities in all sectors and inevitable depletion of fossil-based fuel resources make it necessary to find alternative resources. The pairing of energy efficiency and renewable energy in meeting future energy demands has been hailed as the most promising pathway for energy sustainability [4].

A number of studies have carried out the technical, economic, environmental and life cycle analyses of SWH systems. The work of Morrison and his co-workers (e.g. Refs. [5–8]) dealt mainly with the research on characterisation and development of various types of SWH systems, the results of which have made their way into relevant Australian (and New Zealand) standards. Tsilingiridis et al. [9] carried out life cycle environmental analysis of a thermosyphon SWH system and found that domestic SHW systems can make significant energy saving of electrical water heater but this benefit would be significantly reduced if the system they replace are powered by natural gas. The same study showed that steel and copper used in making the SWH systems "*have the major contribution on the environmental impacts* [[9], p. 1288]. A study carried out by Kalogirou [10] revealed that the energy saving of about 79% can be attained from installing thermosyphon SHW systems which translates to a monetary payback period of 2.7 years. Furthermore, the study showed that energy used for the systems fabrication and installation could be recovered within 13 months of the system operation. A study on 30 years (1978–2007) use of domestic SWH systems in Greece [11] demonstrated the significant energy saving and greenhouse gas emission reduction due to installation of those systems.

In Australia, domestic hot water consumption represents about a quarter of the total energy consumption in residential sector [12]. In 2011 more than half (52%) of hot water systems were electric and 36% were run by mains gas [13]. SWH systems share is still relatively small at about 8%, despite a twofold increase from 2005 figure of 4% [14]. The 2010–2011 energy consumption figures show that solar hot water systems contributed 11 PJ to Australia's energy production which accounted for 4.23% of total renewable energy

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http://dx.doi.org/10.1016/j.renene.2015.04.023
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Please cite this article in press as: Halawa E, et al., Thermal performance evaluation of solar water heating systems in Australia, Taiwan and Japan – A comparative review, Renewable Energy (2015), http://dx.doi.org/10.1016/j.renene.2015.04.023

production. This is an almost twofold increase from the 2006–2007 of 6 PJ. Based on the latest figures released in September 2014, the total number of SWH systems and air source heat pumps installed in Australia within the period 2001–2014 are 881 872; of which 54 938 units were installed in 2014 [15], as shown in Fig. 1. As seen, the number of units installed peaked at 2009 coinciding with the Australian government introduction of Solar Hot Water Rebate for the systems "installed on or after 3 February 2009 until 30 June 2012" [16]. A recent study projected that total installation of SWH systems in 2014 would reach 30 520 units and would rise to 43 141 in 2016, a significant increase '*driven by rebate to be made available under the "One million solar roofs" program*' [17].

The prospect for more efficient and more environmentally friendly forms of water heating systems (including solar hot water systems) was boosted by the introduction of Australian (federal, state/territory) governments' initiative to phase out greenhouse intensive (electric) hot water system starting from 1 January 2010 [18]. Following this, all new Class 1 buildings in all states (except Northern Territory, Queensland and Tasmania) have restricted the installation of greenhouse gas (GHG) intensive hot water systems [19].

Taiwan is an isolated island and depends exclusively on imported fossil fuels to fulfill its energy needs. In 2012, the total domestic energy consumption was 100,383 $\times$ 10^3 metric ton of oil equivalent, in which the energy use in the industrial and residential sectors accounted for 38.2% and 10.9%, respectively [20]. Moreover, utilization of renewable energy sources is critical for future socio-economic development. The Renewable Energy Development Bill was promulgated in 2010 by the government of Taiwan. The total capacity for power generation by renewable energy was 3696.7 MW in 2012, including conventional hydropower (2081.3 MW), wind power (571 MW), solar photovoltaic (222.4 MW), and biomass (822 MW). The accumulated area of solar collectors for SWH systems installed in Taiwan reached 2.27 million m^2 [21]. The renewable energy accounted for 1.89% of the total energy production [20].

Taiwan, straddling the Tropic of Cancer, is situated between latitudes 22° and 25°N. Insolation ranges between 1 200 and 1 700 kWh/m^2/year. Solar thermal system has potential to help reduce domestic energy consumption of LPG, natural gas and electricity. The area of solar collectors installed per annum (ΣA_{SC}) in Taiwan is shown in Fig. 2. It can be seen that the installed area of SWHs was quite limited ($\Sigma A_{SC} < 10\ 000\ m^2$) until the mid 1980s. The significant increase in ΣA_{SC} after 1986 was due to the first subsidy program (1986–1991). The second subsidy program was initiated in 2000 [22]. The accumulated area of solar collector installed

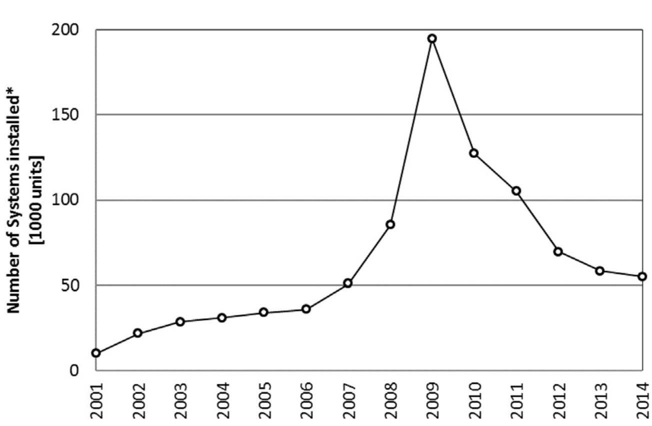

Fig. 1. Number of SWH and air source heat pump systems installation in Australia, 2001–2014 [15].

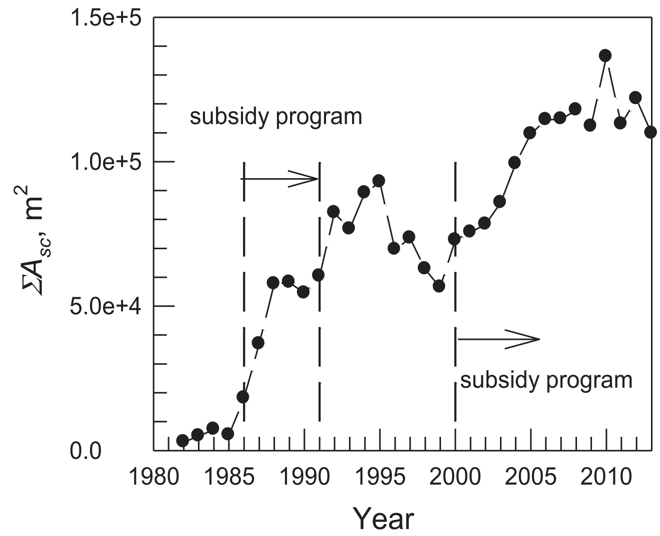

Fig. 2. ΣA_{sc} in Taiwan, 1982–2013.

(2000–2013) is approximately 1.5 million m^2. A remarkable increase in installation of SWH resulted in a price reduction in the first four years. However, the price has changed little in recent years. In terms of sale price of solar collectors for SWH, the current cost is approximately 10 500 NTD/m^2 (Chang et al.,2014[1]). A direct subsidy of 2 250 NTD/m^2, based on the area of solar collectors installed (A_{SC}), is granted to the end user who purchases a certified SWH with glazed flat-plate or evacuated-tube type solar collectors. The subsidy is 1500 NTD/m^2 for unglazed flat-plate solar collectors. It has also been noted that the noticeable increase in the sales of SWH systems in 2010 was attributed to additional regional subsidy programs by few local governments [23]. However, it is considered that the financial incentive might only be remarkably effective at the initial stage of each subsidy program [23]. Nevertheless, dissemination of SWH systems represents the most successful story of utilization of renewable energy in Taiwan.

Japan is one among 12 countries in the world with significant capacity of SWH systems in operation by the end of 2011 with 1.5% share of the world's total capacity of 223 GW_{th} [24]. However most of these systems were installed in 1970–80s and the number of new installation has continuously dropped, as shown in Fig. 3.

The history of use of solar-powered hot water systems in Japan perhaps can be traced back to the work of Ei-ichi Okamodo who founded Chiryu Heater in 1944, a solar thermal company that "*has relentlessly produced collectors and tanks since 1957*" [26].

Japan's Solar Energy Utilization and Promotion Forum (SEUPF) was established in 2009. The Forum set up 5 working groups, namely on: (1) Promotion Policies, (2) Housing Technologies, (3) Standardization, (4) Design, and (5) Commercial Technologies. The Housing Technologies Working Group is tasked to establish the methodology for rating the solar domestic hot water systems in Japan [27]. The work on systems rating was envisioned as a means of stimulating the market.

This paper presents a comparative study of methods for evaluating the thermal performance of SWH systems in Australia, Taiwan and Japan. The main objectives of the SWH systems rating are to (1) help consumers in making appropriate decision in choosing the appropriate systems, (2) verify the claimed energy performance and greenhouse gas offsets of the system, (3) provide basis for

[1] 1 USD ≈30 NTD.

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