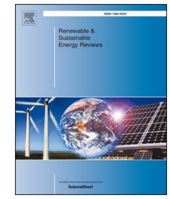
Renewable and Sustainable Energy Reviews 91 (2018) 741–753

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



Decision-making tool for the optimal selection of a domestic water-heating system considering economic, environmental and social criteria: Application to Barcelona (Spain)

Maria del Mar Casanovas-Rubio*, Jaume Armengou

Universitat Internacional de Catalunya, 22 Immaculada, 08017 Barcelona, Spain

ARTICLE INFO

Keywords:
Sustainability
Domestic water-heating systems
Solar collectors
Multi-criteria decision analysis
Indicators
Environmental impact

ABSTRACT

The research presented in this paper has two main objectives. First, it aims to generate an assessment tool for ranking and selecting the most sustainable domestic water-heating system (WHS) (with the lowest economic, environmental and social impact) that could be applied in any location and with any demand. Second, it aims to ascertain which WHS is the most sustainable in places with a climate and solar radiation like that of Barcelona, Spain, where a minimum solar contribution to domestic water heating is compulsory for new buildings and significant renovations. Multi-criteria decision analysis was employed to create the optimised flexible assessment tool. The Delphi method was followed to perform the surveys, and to provide the objectivity required in the identification of impacts, the definition of indicators and the assignment of weights. The most relevant criteria were determined: annual cost, material consumption, energy consumption, GHG emissions, space requirement, visual impact and occupational risks. The resulting tool was tested by analysing twelve domestic WHS, including two conventional systems, and ten combinations of five solar thermal technologies with two conventional systems as backup for a changing room in a sport centre located in Barcelona. The two conventional WHS studied were a natural gas-fired condensing boiler and an electric water heater. The five solar thermal technologies were: a flat plate with a harp design, a flat plate with a serpentine design, a heat-pipe evacuated tube, a direct-flow evacuated tube, and a direct-flow evacuated tube with CPC. The dynamic thermal simulation programme T*SOL was used to dimension the solar thermal systems. Two sensitivity analyses were carried out: one on weights and one on references. The tool proved very useful in the assessment of these systems, and could also help in decision-making processes to select the most sustainable WHS for other locations and domestic hot water demands.

1. Introduction

The final energy consumption of the residential sector in the European Union (EU) accounted for 26.8% of the total energy consumption in 2013. This was the highest percentage of all sectors; even slightly above that of road transport or industry [1]. Water heating was responsible for about a quarter of this energy consumption [2]. Furthermore, households accounted for 19% of greenhouse gas (GHG) emissions in the EU in 2012 [1]. Residential energy consumption in Spain accounted for 18.5% of the total energy consumption in the same country, and 5.4% of the total residential energy consumption in the EU (28 countries) in 2015 [3]. Household GHG emissions in Spain accounted for 20.4% of the total GHG emissions in the same country, and 7.5% of the total household GHG emissions in the EU in 2014 [4]. Thus, the appropriate choice of a domestic water-heating system (WHS) can largely reduce energy consumption and operational costs, and protect the environment [5].

Domestic solar water heating is a well-developed technology that is used to reduce energy consumption for domestic hot water (DHW) supply [2]. Its potential for significantly reducing domestic energy consumption is recognised [2]. Legislation on buildings is progressively introducing domestic solar WHS. Consequently, the total installed capacity is increasing every year, and reached 33.3 GWth in operation in 2015 in the EU 28 and Switzerland, which generated an estimated 23.5 TWhth of solar thermal energy while contributing to a saving of 6.3 $MtCO_2$ [6]. In the case of Spain, the total installed capacity in operation in 2015 was 2296 MWth [6].

All three pillars of sustainability, economic, social and environmental factors, must be considered in decisions on the most appropriate WHS for a given location and demand, to obtain a comprehensive view of the system. In fact, sustainability consists of finding a balance between these three dimensions, and is therefore an interdisciplinary

* Corresponding author. Present address: Universitat Politècnica de Catalunya, Jordi Girona 1-3, 08034 Barcelona, Spain.
E-mail address: mar.casanovas@upc.edu (M.d.M. Casanovas-Rubio).

https://doi.org/10.1016/j.rser.2018.04.040
Received 15 March 2017; Received in revised form 20 December 2017; Accepted 14 April 2018
1364-0321/ © 2018 Elsevier Ltd. All rights reserved.

problem. If an analysis is limited to one or two dimensions, the view of the problem will only be partial. However, in the literature review presented in the next section, few studies were found that compare types of solar collector systems including flat plates, evacuated tubes and conventional systems for producing DHW from a complete, sustainable, multi-criteria perspective that includes social, economic and environmental aspects. Further comparative studies of solar and conventional commercial WHS are needed to help policy makers, installers and users to make decisions on the most sustainable WHS [7].

The research presented in this paper has two main objectives: (1) to develop a multi-criteria decision-making tool applicable to any location and demand that enables prioritisation and selection of the best WHS, including solar and conventional systems and considering the three dimensions of sustainability, and (2) to illustrate the use of the tool with a case study and determine the best WHS to be used in a sport centre located in Barcelona, Spain.

This research extends knowledge by providing a multi-criteria tool for sustainable decision making on WHS. It is innovative as it applies multi-attribute utility theory (MAUT) to a new area: selection of the best domestic WHS. It explores the interdisciplinary connection between fields of knowledge in solar and conventional WHS. It connects engineering with economy, environment and society, in other words, it looks at engineering from the perspective of sustainability; and sustainability is fundamental for present and future generations.

According to the present study and under the studied climatic and hot water demand conditions, policies that encourage the installation of flat plate solar WHS are justified, particularly in a society that increasingly recognises the value of the environment and calls for a reduction in GHG emissions and conventional energy consumption.

The rest of the paper is organised as follows. The second section presents a literature review of research on technical, economic and environmental aspects of solar WHS and multi-criteria decision analysis (MCDA) applied to the energy sector, particularly to renewable energies and domestic solar WHS. The third section develops a decision-making tool for selecting optimal domestic WHS based on MAUT and the Delphi method. In the fourth section, a case study on determining the optimal WHS out of twelve alternatives is solved by using the proposed tool and simulations with T*SOL software. The fifth and last section of the paper presents the conclusions of the study.

2. Literature review

The definition of energy policies and the selection of the best WHS should be based on evaluating the sustainability of existing technologies, considering all three pillars of sustainability, economic, environmental and social factors, in an integrated way. However, much of the current literature on solar WHS has focused on technical, economic or environmental aspects separately.

Some previous studies on solar WHS have focused on technical and economic aspects. For example, Tian and Zhao [8] and Jamar et al. [9] reviewed solar collectors for low- and high-temperature applications in terms of optical optimisation, heat loss reduction, heat recuperation enhancement and sun-tracking mechanisms. Allouhi et al. [10] studied the technical performance of flat plate and evacuated tube collectors in several locations in Morocco. Buker and Riffat [11] reviewed the current status of building-integrated solar thermal collectors. Wang et al. [12] reviewed solar WHS in terms of technical background, market potential and research questions. Gautam et al. [13] reported studies on technical advancements, economic feasibility and the overall scenario of solar WHS. Islam et al. [14] and Shukla et al. [15] discussed the design features, energy efficiency and cost effectiveness of solar WHS. Al-Badi and Albadi [16] and Benli [17] evaluated technical and economic aspects of solar WHS in Oman and Turkey, respectively. Vieira et al. [18] concluded that split systems performed better than thermosiphon in Brisbane, Australia, in terms of energy efficiency and level of service, and hence should be prioritised in energy efficiency policies.

Additionally, several recent studies have reported on environmental and economic aspects of solar WHS. For example, Ibrahim et al. [5] qualitatively reviewed the operational costs, environmental effects and performance of existing WHS. Lamnatou et al. [19] critically reviewed the existing life-cycle analyses on building-integrated solar thermal systems. Greening and Azapagic [20] quantified the environmental impact of solar WHS in regions with low solar radiation, such as the UK, while Koroneos and Nanaki [21] quantified the environmental impact and economic performance in Thessaloniki, Greece. Shaddel and Shokouhian [22] studied the payback period and the annual reduction in natural gas consumption and CO_2 emissions due to the installation of solar thermal collectors in a multiple-dwelling complex in Mashhad, Iran. Bessa and Prado [23] assessed the reduction of CO_2 emissions with the use of solar WHS in comparison with electric showers in social housing in several Brazilian climatic zones.

Cassard et al. [24] and Friedrich Ferrer [25] analysed economic aspects of solar WHS, the former in the US and the latter in South Africa (SA). Their conclusions were similar: solar WHS are only economically attractive in a few regions. The high initial cost is a primary driver of the low penetration of residential solar WHS in the US: "the life-cycle benefits often do not greatly exceed the capital cost of the system" [24]. However, solar WHS provide other "benefits such as reduced reliance on fossil fuels and reduced carbon dioxide emissions" but these are somehow "external to the consumer and difficult to quantify" [24].

In fact, the search for a logical, optimal solution to the sustainability of energy systems is a complex process that requires robust quantitative methods [26]. In this regard, MCDA could become a powerful tool for decision making on sustainable energy systems [26,27]. There are several studies on renewable energies and domestic solar WHS based on MCDA. Troldborg et al. [28] assessed the sustainability of eleven renewable energy technologies considering three environmental, three technical, and three socio-economic criteria using the PROMETHEE method. They considered uncertainty in the input information using a Monte Carlo simulation. As the assessment was performed at national level and hence was not specific, the uncertainty associated with the criteria and the ranking was high. They stated that the degree of uncertainty for actual site-specific projects would probably be lower. Stein [29] developed a model to rank nine renewable and non-renewable electricity production technologies considering financial, technical, environmental and socio-economic-political criteria using the analytic hierarchy process (AHP). A sensitivity analysis of the weights was performed considering four scenarios. It was concluded that solar, wind, hydropower and geothermal provide the most overall benefits and, therefore, policies to encourage the use of these type of energies should be expanded. Cavallaro [30] used the multi-criteria PROMETHEE method to rank twelve solar thermal technologies according to seven economic and technical criteria, and determined the weight stability intervals within which the weight of each criterion can be modified without changing the ranking. Nixon et al. [31] designed a new solar thermal collector using an MCDA including quality function development, the AHP and the Pugh selection matrix and sixteen technical, financial and environmental criteria.

Notwithstanding the increasing use of solar WHS, the improved technology, and the recognised environmental advantages in terms of energy consumption and GHG emissions, the overall sustainability (that covers all three pillars) of these methods in comparison with each other and in relation to conventional systems is not yet clear. Neither is it clear which is the best system from the perspective of sustainability for use in a specific location with specific demands. Comparative studies of all the main commercially available solar WHS configurations and types of solar collectors are needed [7]. In this area, Hang et al. [7] carried out a relevant study in which six types of domestic WHS including two types of solar collectors (flat plate and evacuated tube) in combination with two types of auxiliary systems (natural gas and electricity) and two conventional systems (natural gas and electricity) were evaluated from energy, economic and environmental perspectives.

Download English Version:

https://daneshyari.com/en/article/8111181

Download Persian Version:

https://daneshyari.com/article/8111181

Daneshyari.com