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An experimental investigation of the performance boundaries of a solar water heating system

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ABSTRACT

This paper presents the performance characteristics of a solar water heating system consisting of a 3 m^2 flat plate collector and a 68 L tank, from readings taken over a period of 2 years under real weather conditions. It focuses on the characteristics and the behavior of the system, its response to solar radiation and hot water flow rate through the collector under no load conditions and in the evaluation of the errors associated with the system performance measurements. The system behavior proved to be linear with small relative standard deviations (less than 15%) within the values of the calculated errors and also relatively insensitive to solar radiation fluctuations ranging from 800 to 1100 W/m^2. Flow rate variations from 0.07 and up to 0.25 L/s did not produce any noticeable effects on the energy collected in the storage tank of the system under investigation. The calculated absolute errors in the system instantaneous efficiency ranged from 34% for low flow and up to 20% for the high flows.

1. Introduction

The use of solar energy for thermal applications constitutes today one of the most popular engineering applications in the world. According to the European Solar Thermal Energy Industry Federation [1], the average installed capacity in the EU27 and Switzerland in 2006 was 27 kWth per 1000 capita, showing a spectacular growth of 47%. Cyprus with more than 530 kWth per 1000 capita is the distant leader while Austria with 225 and Greece with 208 are in second and third place. Currently, the most widespread solar application is for residential water heating. Today, systems for hot water production in single-family houses are dominant as they are proving economically feasible and viable [2]. The thermal behavior of a solar water heating system, however, constitutes a complex problem involving a number of interrelated parameters such as the solar radiation and other weather conditions, the water flow rate through the collector, the storage tank configuration, the effectiveness of the heat exchanger, and the thermal load. Based on the great number of such systems in operation today a number of researchers have examined the environmental impact of such systems and life cycle assessments have been performed [3,4].

An integrated collector/storage solar water heater was first patented in 1891 [5]. Due to its rather simple and concise structure, this type of system offers a value for money approach to permit the wide scale domestic adoption of solar water heating. Arthur [6] illustrated that a simple cylindrical shape offers a practical solution to maximizing the storage volume to exposed surface area, while Lindsay and Thomas [7] demonstrated that it is necessary to maintain thermal stratification within the store system for an attractive system. Lavan and Thompson [8] indicated that vessels with low aspect ratios promote internal mixing and vessels with a north–south alignment have higher aspect ratios and thus maintaining higher levels of thermal stratification.

Reiss and Bainbridge [9] suggested that 'long thin vessels are more suitable than short squat vessels' and simulations conducted by Eames and Norton [10] showed that an aspect ratio of 3:1 was a good value to use. Tiller and Wochatz [11] suggested that 'storage volume/glazing ratio of 51–69 L/m^2 operate better for systems in cooler climates'.

Theoretical analyses of reflector/collector combinations [12–16] suggest that use of a concentrator improves significantly the system thermal efficiency. As suggested, concentrating reflector increases the solar energy collection of a cylindrical vessel, with a low surface area to volume ratio.

The thermal stratification in the storage tank is also an important aspect that affects the system performance and is a desirable phenomenon that improves the collector efficiency since the collector inlet fluid temperature is lower than mixed mean storage temperature. Smyth et al. [17] dealt with the design of the storage itself by examining a number of sleeve design configurations, and proposing an optimized one, while Eames and Norton [10] undertook and experimental investigation of the thermal performance of

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