Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 111 (2015) 151–156
Solar Energy
www.elsevier.com/locate/solener

Figure of merit for solar domestic hot water systems

José Luis Duomarco

A.I.U, Montevideo, Uruguay

Received 4 June 2014; received in revised form 14 October 2014; accepted 19 October 2014
Available online 18 November 2014

Communicated by: Associate Editor Ruzhu Wang

Abstract

New software has been developed, adapted to International Standard ISO 9459-2, in which the daily solar domestic hot water (SDHW) system operation is modeled with a heat-limited consumption scheme, fixed by a nominal temperature, (T_{dn}), and a daily nominal hot water volume production, (V_{dn}). Solar energy is traced to its end forms; overheating in summer months, remaining in storage to be used the next day, lost through storage tank surface and drawn-off in the useful hot water. Auxiliary heat to comply with nominal settings is also calculated. For commercial reasons it is becoming more and more necessary to have an effective way of classifying SDHW systems. Our proposal is to use as figure of merit, the rate between the hot water produced in one year and the auxiliary heat needed, (L/kW h), calculated when the daily extraction is 2/3 of the storage volume, ($V_{dn} = 2/3\ V_s$) and the temperature (T_{dn}) is 60 °C. The draw-back of such a procedure results from observing that the value obtained is site-dependent. An alternative classification way is presented, based on a non-dimensional number that is totally site-independent.

Keywords: Solar domestic hot water systems; International standards; Solar systems' classification

1. Introduction

Which is the "best" solar collector? The question has not an easy answer, although it is persistently made by newcomers.

The cost of the system is usually the first thing to consider. The durability and quality of materials should be related to cost and are quite visible at a glance. Qualification test procedures are well established and are similar to other outdoor equipment tests (ISO 9806-2, 1995).

Nevertheless, calculation of energy delivered by the system over its lifetime has had several approaches. The Solar Energy Laboratory of the University of Wisconsin, UW-SEL, has developed a modular method, where each module is tested separately. The parameters obtained are then fed into especial software where annual performance is calculated. The f-chart and TRNSYS calculation procedures, works on these trends (Duffie and Beckman, 1991). The solar Collector and System Testing Group, CSTG, has followed a track quite different because no reference is made to components parameters (Belessiotis and Harambopoulos, 1993; ISO 9459-2, 1995). The system is characterized from the start as a black box with input–output parameters that are determined by an all-day test. Maybe the most important difference between the two methods is in how the store stratification event is handled. In the method of UW-SEL several analytical models are developed while in the method of CSTG, stratification is already taken into account in the experimental results.

The International Standard ISO 9459-2:1995 applies to SDHW systems operated without auxiliary boosting and for an evening draw-off. The test procedures are applicable only to systems of 0.6 m^3 of solar storage capacity or less.

E-mail address: duomarco@adinet.com.uy

http://dx.doi.org/10.1016/j.solener.2014.10.023
0038-092X/

Software that allows a volume-limited and a temperature-limited demand is given by the standard to evaluate a long-term performance prediction (LTPP). We have developed software, in which the daily demand is modeled with a heat-limited consumption scheme, fixed by a nominal temperature and a nominal hot water production (Bourgues et al., 1991; Carvalho and Naron, 2000).

For commercial reasons, it is becoming more and more necessary to have an effective way of classifying SDHW systems, from an energy preserving point of view. Some classifications are based in the annual amount of solar energy captured (FSEC, 2002; INMETRO, 2012). Our proposed figure of merit instead, is defined by the rate between the hot water volume production and the auxiliary heat needed in one year's work (L/kW h). The highest its value, the better; more hot water is produced with the unit of costly auxiliary energy. If its inverse is used, the lowest its value the better; less auxiliary energy is needed to produce the liter of hot water (kW h/L). The draw-back of all these procedures, results from observing the site-dependent nature of their final values. One would like to be able to classify SDHW systems in an intrinsic way, only dependent on the systems characteristics. An alternative classification procedure is presented, based on a non-dimensional number description of the SDHW system that is totally site-independent.

2. Method's procedures

The method is based in the ISO 9459-2 standard's experimental procedures and a new long-term-performance-prediction calculation (LTPP):

2.1. Draw-off profile tests

The temperature profile, obtained during the extraction of three times the storage tank volume of water at a rate of 10 L/min, characterizes the behavior of the storage tank, when the hot water inside, mixes with the cold water coming in from mains. Two different functions $f(V)$ and $g(V)$ are used. The first is obtained based on a draw-off profile performed at the end of each test-day and the second is based on a separate test determining the mixing draw-off profile when the tank has an initial uniform temperature, without stratification. The formula Eq. (12) gives the analytical definition of these functions.

2.2. Input–output diagram

The daily behavior of the system is characterized by a linear model defined in formulas Eqs. 5-5′. The parameters are obtained by least squares fitting of the following daily test results:

- $Q_T = Q_{T3Vs}$ – sensible energy contained in the three times the tank volume of water, drawn-off in the daily test.
- $T_S = T_{main}$ – cold water temperature during the daily test.
- T_a and G_T – maximum ambient temperature and solar irradiation on collector aperture during the daily test.

2.3. Store overnight loss coefficient

The store heat loss coefficient is obtained in an independent test, where the storage tank is left to cool down overnight, Eq. (15) is used.

2.4. LTPP

The long-term performance prediction is calculated by software given in the standard. It includes two load patterns:

- ***Load pattern 1***, determined by the volume of daily hot water consumption,
- ***Load pattern 2***, determined by a minimum useful temperature limit for the hot water consumption. When the outlet temperature is lower than this minimum value, no water is extracted from the store.

2.5. New LTPP

New software has been developed, not included in the standard, with a different load pattern:

- ***Load pattern 3***, modeled for a nominal temperature and a nominal hot water volume production, both constant during the year. According to the daily climate conditions and daily hot water extraction, the draw-off temperature and draw-off volume may be under or above the nominal values. If overheating is present, the excess energy over the nominal is calculated and discarded. If solar heating is under the nominal value, the auxiliary heat necessary to reach nominal settings is calculated. The calculation is extended only to 365 days assuming an annual periodicity, although it could be extended further, if longer daily meteorological series were available or synthetic series were used. The algorithm is formulated in the appendix A, Eqs. 1–19 with variables defined in Table 1.

3. Application to Montevideo

A case study has been conducted on two solar thermal systems, as if they were operated in the city of Montevideo, located 34°53′ South latitude and 56°09′ West longitude, with ***load pattern 3***. The climate data used was obtained from project "Surface Meteorology and Solar Energy" (NASA, 2010). Simultaneous daily global solar radiation on horizontal surface, maximum and minimum temperature series for year 2010, were used in the simulation.