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A new look at the long-term performance of general solar thermal systems

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Abstract

This work addresses the problem of evaluating the long-term performance of solar thermal systems, which is quantified through the monthly or seasonal/annual solar fraction. It is shown that for a general solar system it may be expressed as a function of monthly utilizabilities, calculated for two different temperature (radiation) levels, which correspond to minimum and maximum operating temperatures. Both systems without storage and with storage are considered. Examples for solar cooling and solar cogeneration systems are shown.

Keywords: Solar thermal systems; Long-term performance; Solar fraction; Utilizability

1. Introduction

The theoretical evaluation of the long-term performance of solar thermal systems is possible through different approaches. When solar systems started to appear – back then most of the domestic hot water type – the estimation of long-term performance was done through simplified calculation methods. The first ones to be available, like the f-chart method (Beckman et al., 1977), allowed the calculation of system monthly solar fraction (ratio of useful solar energy to thermal load) through correlations with some system parameters, including collector area, collector efficiency and thermal load. These correlations were obtained by performing computer simulations with detailed simulation programs that then could only run in mainframe computers. Other methods followed this one, like the ϕ, f-chart method (Klein and Beckman, 1979; Braun et al., 1983; Duffie and Beckman, 1991), based on the concept of utilizability (Klein, 1978; Collares-Pereira and Rabl, 1979). Other simplified calculation methods were, on the other hand, based on analytical calculations with some simplifying assumptions, like Collares-Pereira et al. (1984), Gordon and Zarmi (1985) or Baer et al. (1985). These methods also used the concept of utilizability – monthly average value – in order to assess the long-term system performance. Although these simplified methods were sometimes developed with different applicability ranges or conditions, they had the advantage of identifying the main system parameters, usually expressed in non-dimensional form. This allowed the designer to have an insight on the most important factors affecting system performance. Simplified methods were also developed for passive solar buildings (Monsen et al., 1981, 1982; Oliveira and Fernandes, 1992). Again, utilizability – in this case non-utilizability or un-utilizability – played a major role.

The other approach to evaluate long-term system performance is based on detailed simulation, using dedicated computer programs like TRNSYS (Solar Energy Laboratory, 2004), or others, which need hourly climatic data as

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Nomenclature

Roman letters

a	dimensionless utilizability parameter, function of location, month, collector orientation and inclination (–)
A	area (m^2)
c	correction coefficient/factor
c_p	specific heat (J/kg/K)
COP	coefficient of performance
E	electrical energy
f	solar fraction, monthly or seasonal (–)
F_R	collector heat removal factor, based on collector inlet temperature (–)
F'_R	modified collector heat removal factor, taking into account heat exchanger efficiency (–)
$\dot{I}$	instantaneous incident solar radiation (W/m^2)
$\bar{\dot{I}}$	monthly average of instantaneous solar radiation (W/m^2)
$\bar{I}$	monthly average daily solar radiation (J/m^2/day)
M	mass (kg)
N	number of days in the month
$\dot{Q}$	instantaneous heat (W)
Q	heat (J)
SLR	solar to load ratio (–)
t	time (s)
T	temperature (°C)
$\overline{T}$	monthly average temperature (°C)
U	heat loss coefficient ($W/m^2/K$)
X	dimensionless parameter equal to monthly heat losses in the collectors divided by monthly load (–)
Y	dimensionless parameter equal to monthly solar gains in the collectors divided by monthly load (–)

Greek letters

$\Delta t_{1\text{day}}$	duration of one day (s)
$\bar{\phi}$	monthly average utilizability (–)
η_0	collector optical efficiency for solar radiation at 0° incidence angle: product of cover transmissivity and plate absorptance (–)
$\bar{\eta}_0$	monthly average collector optical efficiency (–)

Subscripts

abs	absorbed solar energy (in the collectors)
amb	ambient air
aux	auxiliary energy
c	condenser
col	collector
crit	critical level
e	evaporator
ej	ejector
exc	excess
ext	external
L	load
min	minimum level
max	maximum level
ref	reference
stor	storage (thermal)
ti	turbine inlet
β	at collector inclination angle β

input. This involves some degree of specialisation – knowledge of the program details – and requires some computing time as well. This approach became more popular with the dissemination of more powerful and low cost personal computers.

The use of simplified calculation methods has maintained its popularity and usefulness, and recently a few more developments have been added to this line of approach (Brinkworth, 2001; Joudi and Abdul-Ghafour, 2003a,b; Colle and Vidal, 2004). By identifying the most important parameters governing system performance, these methods are most useful for system design, as they provide a means of evaluating the effect of changing system parameters during the design process. This is not so easy with detailed simulations, as the change in some input variables does not necessarily have a significant effect in system long-term performance and does not show the "complete picture" – note that a high number of individual input variables are present in solar thermal system simulation.

The main disadvantage of simplified methods is that they are not applicable to a general active solar thermal system. Some of them were developed for domestic hot water (DHW) systems (like f-chart) and, thus, are not applicable to different types of systems, like solar cooling systems. Others, like ϕ–f or analytical based methods, have restrictions that do not allow its generalised application. A more general approach is attempted in this work, starting from a definition of the general operating temperature levels of an active solar system, and using their relation with utilizability values. After reviewing some of the most important features of existing methods, and stressing some of their limiting factors, the new approach will be discussed considering systems with no thermal storage and then systems with storage.

2. Review of the main features of existing simplified methods

Historically the first simplified method was the f-chart (Beckman et al., 1977). It was developed for water or air collectors, and is applicable to water heating (DHW) or space heating systems. In the case of space heating it is