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Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions

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Abstract

New comparative tests on two different types of solar collectors are presented in this paper. A standard glazed flat plate collector and an evacuated tube collector are installed in parallel and tested at the same working conditions; the evacuated collector is a direct flow through type with external compound parabolic concentrator (CPC) reflectors.

Efficiency in steady-state and quasi-dynamic conditions is measured following the standard EN 12975-2 and it is compared with the input/output curves measured for the whole day.

The first purpose of the present work is the comparison of results in steady-state and quasi-dynamic test methods both for flat plate and evacuated tube collectors. Beside this, the objective is to characterize and to compare the daily energy performance of these two types of collectors. An effective mean for describing and analyzing the daily performance is the so called input/output diagram, in which the collected solar energy is plotted against the daily incident solar radiation. Test runs have been performed in several conditions to reproduce different conventional uses (hot water, space heating, solar cooling).

Results are also presented in terms of daily efficiency versus daily average reduced temperature difference: this allows to represent the comparative characteristics of the two collectors when operating under variable conditions, especially with wide range of incidence angles.

Keywords: Flat plate collector; Evacuated tube collector; Efficiency; Quasi-dynamic method; Daily efficiency

1. Introduction

Mainly two types of liquid solar collectors for domestic heating and hot water production are used presently: flat plate collectors and evacuated tube collectors. They are characterized by different cost and performance, so it is very important to choose the right collector for each application in order to optimize the behaviour of the whole system, the energy savings and the finance payback.

Glazed flat plate collectors usually present a metal absorber in a flat rectangular housing. The glass cover on the upper surface and the insulation on the other side limit the thermal losses. The solar energy absorbed by the plate is transferred to the liquid flowing within the collector tubes. The tubes are in good thermal contact with the absorber surface. Air is present in the space between the plate absorber and the transparent cover. In comparison, evacuated tube collectors allow to reduce the convection and the conduction thermal losses. This collector consists of glass vacuum-sealed tubes; the absorber surface is located into the inner glass tube and it can have several shapes.

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Nomenclature

A_a	aperture area of collector (m^2)	$K_{\theta d}$	incidence angle modifier for diffuse radiation (–)
a	heat loss coefficient for linear regression, Eq. (5) ($W/(m^2\,K)$)	$K_{\theta l}$	longitudinal incidence angle modifier (–)
a_1	heat loss coefficient, Eq. (4) ($W/(m^2\,K)$)	$K_{\theta t}$	transversal incidence angle modifier (–)
a_2	temperature dependence of the heat loss coefficient, Eq. (4) ($W/(m^2\,K^2)$)	$\dot{m}, m$	mass flow rate (kg/s)
b_0	incidence angle modifier coefficient for FPC and for longitudinal projection of angle θ in ETC (–)	n	number of recording time intervals (–)
b_1, b_2, b_3, b_4	incidence angle modifier coefficients in Eq. (10) (–)	$\dot{Q}$	useful power extracted from collector (W)
c	heat loss coefficient for daily linear regression, Eq. (11) ($W/(m^2\,K)$)	Q_{in}	daily irradiated energy over unitary area (J/m^2) (in the graphs (kWh/m^2))
c_1	heat loss coefficient, Eq. (6) ($W/(m^2\,K)$)	Q_{out}	daily collected energy over unitary area (J/m^2) (in the graphs (kWh/m^2))
c_2	temperature dependence of the heat loss coefficient, Eq. (6) ($W/(m^2\,K^2)$)	T_a	ambient or surrounding air temperature (K)
c_3	wind speed dependence of heat loss coefficient, Eq. (6) ($J/(m^3\,K)$)	t_a	ambient or surrounding air temperature (°C)
c_4	long-wave irradiance dependence of the heat loss coefficient, Eq. (6) ($W/(m^2K)$)	t_{in}	inlet temperature to the collector (°C)
c_5	effective thermal capacitance, Eq. (6) ($J/(m^2\,K)$)	T_m	mean liquid temperature (K)
c_6	wind speed dependence in the zero loss efficiency, Eq. (6) (s/m)	t_m	mean liquid temperature (°C)
E_L	long-wave irradiance ($\lambda > 3\ \mu m$) (W/m^2)	T_m^*	reduced temperature difference ($m^2\,K/W$)
ETC	evacuated tube collector	T_m^{*m}	daily average reduced temperature difference ($m^2\,K/W$)
F'	collector efficiency factor (–)	t_{out}	outlet temperature from the collector (°C)
FPC	flat plate collector	U	overall heat loss coefficient ($W/(m^2\,K)$)
G	global solar irradiance (W/m^2)	u	surrounding air speed (m/s)
G_b	direct solar irradiance (W/m^2)	$\Delta\tau$	time interval (s)
G_d	diffuse solar irradiance (W/m^2)	η	efficiency (–)
K_θ	incidence angle modifier for global radiation (–)	η_0	zero loss collector efficiency (η at $T_m^* = 0$) (–)
$K_{\theta b}$	incidence angle modifier for direct radiation (–)	σ	Stefan–Boltzmann constant ($W/(m^2\,K^4)$)
		$(\tau\alpha)$	effective transmittance–absorptance product (–)
		$(\tau\alpha)_{en}$	effective transmittance–absorptance product at normal incidence (–)
		θ	angle of incidence (°)
		θ_t	transversal projection of angle θ (°)
		θ_l	longitudinal projection of angle θ (°)

The evacuated tube collectors may be subdivided in two types. In the direct flow through collector the heat transfer liquid is pumped in the tubes. The second type consists of heat pipes inside vacuum sealed glass tubes. A reflector can be present to optimize the absorption of the solar radiation.

The choice of the optimal collector depends on the temperature level required by the specific application and on the climatic conditions of the site of installation. Therefore, in terms of efficiency, each collector displays features which make it most suitable to a certain application.

In conventional uses solar collectors can provide energy for domestic hot water or space heating in combination with low water temperature systems (approximately 35–50 °C), whereas this heat has to be provided above a minimum temperature of 75–80 °C in absorption cooling machines (Schmid et al., 1984). In areas with high sunshine, solar collectors could also be used in cooking process (Hussein et al., 2008) or in still plants (Badran et al., 2005).

The knowledge of the thermal performance of a solar collector is essential to make the right choice. With the publications of the European Standard EN 12975-2 a unique standard exists throughout Europe for solar thermal collector testing. This standard specifies a reproducible procedure and guarantees thus comparable results. It includes two alternative test methods for the thermal performance characterization of solar collectors: steady-state and quasi-dynamic tests.

Some studies on the performance of flat plate collectors following EN 12975 (Kratzenberg et al., 2005; Fisher et al., 2004) and the comparison of uncertainty calculation methods of this performance (Kratzenberg et al., 2006) can be found in the literature. Comparative studies between different normalized test methods for flat plate collectors are also reported in Rojas et al. (2008) and Cucumo et al. (2008). Instead, limited results are available on transient test methods applied to evacuated tube collectors. In (Rönnelid et al., 1997) data from outdoor testing has been used for characterizing the behaviour of a CPC collector with incidence angle; in Perers (1997) the extended MLR procedure is applied to quasi-dynamic method for characterization of evacuated tube collectors