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Numerical and experimental study of a corrugated thermal collector

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ABSTRACT

The present work proposes a design for solar thermal collectors and also a numerical simulation analysis procedure to evaluate the collector performance. The performance of this collector is compared with the performance of other two commercial ones by observing both the numerical modeling study and experimental test results. Benefits of using the corrugated parallel approach, in terms of yield, are shown applying a new alternative approach of numerical modeling. A better performance is observed for the corrugated parallel collector, which provides a higher yield using an energy-absorbing surface. Moreover, the proposed numerical methodology could be used to evaluate the performance of other thermal collector configurations.

1. Introduction

The energy that a society consumes and its use and transformation effectiveness are criteria that characterize the development degree of a country. In fact correlations between the energy consume and the life quality levels have been defined and reported [1]. The development of the welfare society progress in parallel with the increasing energy consumption; for instance, the eighteenth century energy consumption per person was estimated about 3 kW h per day in buildings while nowadays is approximately 350 kW h per day in buildings, according to González [2]. This increasing consumption is causing sustainability, environmental, social and political problems. The described situation obviously requires corrective actions. Accordingly, the European Union has set a target for 2020 to reach the objective 20–20–20 (20% emissions reduction, 20% of energy provided by renewable energies, and 20% for saving energy). Focusing in an illustrative case, Spain is a paradigmatic example. In fact, this country is completely dependent on energy supply from abroad, importing the 75.6% of total consumption [3]. For correcting this, a contribution of renewable energy to gross final consumption of about 22.7% is expected to reach in 2020 [4]. Therefore, for achieving these objectives the design of increasingly efficient renewable devices in buildings as solar collectors is

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Nomenclature

$(\tau\alpha)$	transmittance-absorptance product
$\dot{m}$	collector flow rate (kg/s)
η	efficiency
η_i	instantaneous efficiency
$\mathbf{n}$	unit normal vector to the boundary (positive outward)
ρ	density, (kg/m^3)
a_1	linear heat loss coefficient, (W/(m^2 K))
a_2	quadratic heat loss coefficient, (W/(m^2 K^2))
A_c	collector area, (m^2)
C_p	specific heat, (J/(kg K))
D_h	hydraulic diameter, (m)
NU_D	diameter Nusselt number
e_c	collector thickness, (m)
e_{in}	insulation thickness, (m)
ε	emittance
h_f	fluid-to-tube heat transfer coefficient, (W/(m^2 K))
k	thermal conductivity, (W/(m K)) and number of ducts
k_{in}	insulation thermal conductivity, (W/(m K))
L	length duct section, (m)
N	number of glass covers
P_c	perimeter collector, (m^2)
q_I	incident solar irradiance on tilted surface, (W/m^2)
q_S	absorbed irradiance, (W/m^2)
T	temperature, (°C)
t	time, (s)
T_a	ambient temperature, (°C)
T_{fi}	inlet fluid temperature, (°C)
T_{fm}	mean fluid temperature, (°C)
U_i	back loss coefficient, (W/(m^2 K))
U_l	edge loss coefficient, (W/(m^2 K))
U_t	top loss coefficient, (W/(m^2 K))
w	fin width, (m)

needed. Accordingly, the aim of this work is the proposal of a new solar thermal corrugated collector with parallel configuration for buildings that improves other commercial panel efficiency.

The tube and plate absorbers have been studied by analytical methods by several authors [5–8]. The study of Hottel and Woertz is a pioneer work in the field [5]. Duffie and Beckman [6] presented the theory of flat-plate and concentrating collectors relating this topic with solar process economics and solar heating design. Eisenmann et al. [7] focuses on the correlations between the efficiency factor and the material content of absorber and tubing for flat-plate collectors with the fin-and-tube geometry, and Eismann and Prasser [8] calculated the efficiency of non-ideal absorbers using two-dimensional simulations and proposed new correlation for the fin efficiency to provide accurate efficiency/cost optimization. Moreover, numerical analysis is nowadays an essential tool to evaluate these types of devices [9–20]. Namely, in [9] block-oriented simulation technique was applied to obtain the solution of the dynamic model performed to describe the thermal behavior of solar collectors, while in [10] new transfer functions based on a validated collector model were performed to control collectors used in domestic applications. In these studies, mathematical models are developed to simulate numerically the collector performance using Matlab and FEM. The numerical simulation permits to know the collector yields without performing additional experimental tests. It is indispensable to predict the collector performance under a wide variety of conditions, in different operating scenarios. In addition, in the most of these works the simulations have been validated by experimental measurements.

Otherwise, the application of statistical learning tools is needed to properly estimate the collector characteristics from experimental data. Inference techniques applied to regression model are absolutely necessary to estimate dependence relationships and then make predictions [21,22]. Namely, multiple linear regression models (black-box type model) are proposed to describe the transient collector processes precisely [23]. However, the application of nonparametric models is not as common in this field. They are more flexible and simple ways to estimate regression functions. In the present work, a smoothing method that uses a spline function to fit a set of noisy observations is used [21,24]. Moreover, the uncertainty of experimental observations can be nowadays obtained by bootstrap techniques [25–27] and thus can be applied to thermal collector measurements. Bootstrap is a simple and straightforward way to estimate confidence intervals, variance,

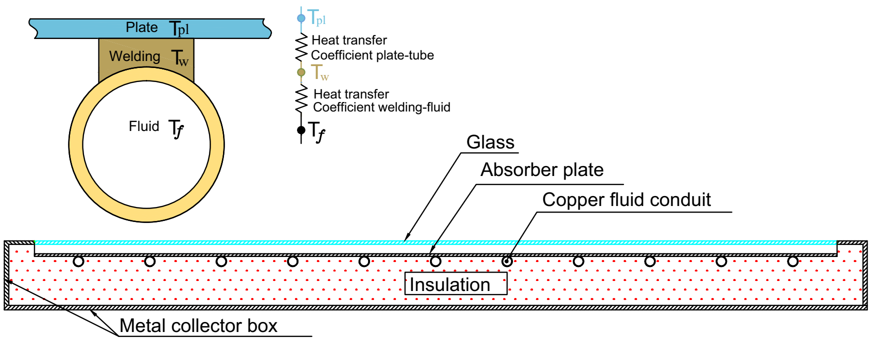

Fig. 1. Scheme of a standard flat-plate solar collector.