

Solar energy captured by a curved collector designed for architectural integration



D. Rodríguez-Sánchez^{a,b}, J.F. Belmonte^{a,c}, M.A. Izquierdo-Barrientos^d, A.E. Molina^{a,c}, G. Rosengarten^b, J.A. Almendros-Ibáñez^{a,c,*}

^a Renewable Energy Research Institute, Section of Solar and Energy Efficiency, CL. de la Investigación s/n, 02071 Albacete, Spain

^b RMIT University, School of Aerospace, Mechanical and Manufacturing Engineering, 3053, Carlton, Victoria, Australia

^c Escuela de Ingenieros Industriales, Dpto. de Mecánica Aplicada e Ingeniería de Proyectos, Castilla-La Mancha University, Campus Universitario s/n, 02071 Albacete, Spain

^d Universidad Carlos III de Madrid, ISE Research Group, Thermal and Fluid Engineering Department, Avda. de la Universidad 30, 28911 Leganés, Madrid, Spain

HIGHLIGHTS

- We present a new prototype of solar collector for architectural integration.
- Equations of the solar radiation on a curved surface.
- We compare the energy intercepted by the prototype with the energy intercepted by conventional collectors.
- The prototype can be competitive compared with conventional collectors.

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ABSTRACT

In this paper we present a prototype for a new type of solar thermal collector designed for architectural integration. In this proposal, the conventional geometry of a flat solar thermal collector is changed to a curved geometry, to improve its visual impact when mounted on a building facade or roof. The mathematical equations for the beam and diffuse solar radiation received by a collector with this geometry are developed for two different orientations, horizontal and vertical.

The performance of this curved prototype, in terms of solar radiation received, is compared with a conventional tilted-surface collector for different orientations in Madrid (Spain). The comparison is made for typical clear-sky days in winter and summer as well as for an entire year. The results demonstrate that the curved collector only receives between 12% and 25% less radiation than the conventional tilted-surface collectors when oriented horizontally, depending on the azimuth of the curved surface, although these percentages are reduced to approximately 50% when the collector is oriented vertically.

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1. Introduction

Energy consumption in buildings comprises an important fraction of the total worldwide energy consumption [1,2]. Heating and domestic water production represent 50–75% of the energy consumption of the residential sector, depending on the climate [3]. Solar thermal collectors are one suitable option for cleanly providing houses with that needed energy. The incorporation of solar thermal collectors or photovoltaic (PV) panels to decrease fossil energy consumption in the residential sector is becoming more common every day [1,4]. Most thermal collectors consist of a flat plate of approximately 2 m² that is placed on the building's roof.

* Corresponding author at: Renewable Energy Research Institute, Section of Solar and Energy Efficiency, CL. de la Investigación s/n, 02071, Albacete, Spain. Tel.: +34 967599200.

E-mail address: jose.almendros@uclm.es (J.A. Almendros-Ibáñez).

Nomenclature

E	east	$R_{b,c}$	ratio between the beam radiation on a curved surface and horizontal surface (-)
$E_{b,c}$	energy accumulated from beam radiation on a clear-sky day for a curved surface (J/m^2)	r	radius of a curved surface (m)
$E_{b,t}$	energy accumulated from beam radiation on a clear-sky day for a tilted surface (J/m^2)	W	west
$E_{d,c}$	energy accumulated from diffuse radiation on a clear-sky day for a curved surface (J/m^2)	<i>Greek symbols</i>	
$E_{d,t}$	energy accumulated from diffuse radiation on a clear-sky day for a tilted surface (J/m^2)	α	angle defined in Fig. 3c
G	total radiation on a horizontal surface (W/m^2)	α_1	angle defined in Eq. (23)
G_b	beam radiation on a horizontal surface (W/m^2)	α_2	angle defined in Eq. (24)
$\overline{G}_{b,c}$	average beam radiation on a curved surface (W/m^2)	α_p	profile angle
$G_{b,n}$	beam radiation on a plane normal to the sun's rays (W/m^2)	α_s	altitude of the sun
$G_{b,t}$	beam radiation on a tilted surface (W/m^2)	β	slope of a tilted or curved surface
G_d	diffuse radiation on a horizontal surface (W/m^2)	γ	azimuth of a tilted or curved surface
\overline{G}_c	average total radiation on a curved surface (W/m^2)	γ_s	azimuth of the sun
$\overline{G}_{d,c}$	average diffuse radiation on a curved surface (W/m^2)	δ	declination
$G_{d,n}$	diffuse radiation coming from the sun (W/m^2)	θ	zenith angle of a tilted surface
$G_{d,t}$	diffuse radiation on a tilted surface (W/m^2)	θ_z	zenith angle of a horizontal surface
H_c	total radiation intercepted by a curved surface over one year (J/m^2)	τ	atmospheric transmittance
H_t	total radiation intercepted by a tilted surface over one year (J/m^2)	ϕ	latitude
N	north	ω	hour angle ($15^\circ=1\text{ h}$)
R_b	ratio between the beam radiation on a tilted surface and horizontal surface (-)	<i>Subscripts</i>	
R_c	ratio between the total radiation on a curved surface and horizontal surface (-)	b	beam radiation
		c	curved surface
		d	diffuse radiation
		n	day of the year
		t	tilted surface
		$\beta = \pi/2$	vertically positioned curved surface

acceptable if the architectural integration is adequate. In some cases, the installation's performance loss can be compensated for by the addition of additional solar collectors. This solution increases the installation's size and may even be forbidden by local regulations [9] although these laws occasionally allow for certain performance losses to make integration possible.

Thus, assuming certain performance losses, several architectural integration options can be considered such as colored thermal absorbers [10–12], making the collectors active components of the facade [2,3,7,11,13,14] or even changing the size of the collectors [2,3]. Each of these cited examples insists on the necessity of a lower installation efficiency if the collectors are to be used as active components of the building. The architects, installers or final users must decide whether it is worth increasing either the installation's cost or the building's fossil energy consumption to integrate the collectors with the building.

Flat-plate solar thermal collectors are normally difficult to integrate with facades if reasonable performance is required. This difficulty is why novel technologies such as Fresnel collectors, have been tried for facade installations [15]. This type of technology is particularly interesting for solar cooling, but the temperatures achieved by the system are too high for domestic water heating requirements.

For those buildings where only domestic water or space heating is required, a novel thermal solar collector with a curved shape especially designed for its high esthetic value on facades is presented. The curved shape provides a pleasant appearance to the collectors when mounted on facades without orienting them in positions that reduce performance considerably. An example of performance-reducing installation is the installation of flat-plate solar collectors on facades.

In the following section the curved prototype is described. Then, equations for the beam and diffuse radiation intercepted by the curved surface are described in detail. Using these equations, the

energy captured by the prototype is compared with the radiation captured by a conventional tilted surface. Then, the results are discussed, and in the last section, the conclusions of the study are summarized.

2. Description of the prototype

The design consists of a solar thermal collector without concentration. The collector structure is similar to that of a common flat thermal solar collector, but with its absorber forming a 90° curve (one quarter of a cylinder) in an attempt to create a pleasant shape that is easy to integrate with facades and roofs [16]. Clearly, the glass must also be curved to offer the desired visual appearance. The box and insulation are similar to those of a typical flat solar

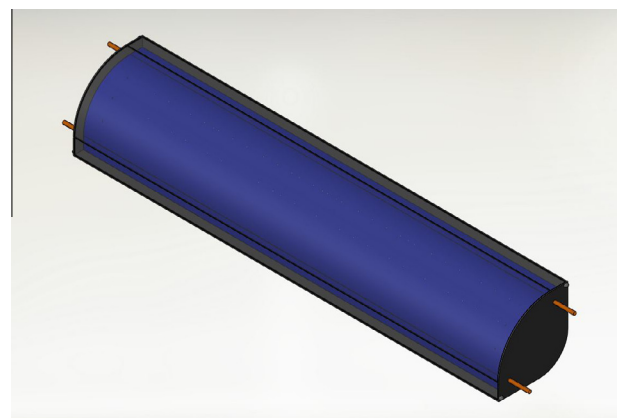


Fig. 1. Scheme of the proposed prototype with a curved geometry.

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