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Solar energy captured by a curved collector designed for architectural integration

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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.

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 m^2 that is placed on the building's roof.

The installation of solar energy systems in buildings typically has a visual impact due to the large size of the collectors, the need to incline the collectors to capture the maximum possible radiation and the poor options for integration. Architects are typically concerned with the visual impact of collectors on buildings and thus, some attempts have been made to integrate solar installations with buildings [5–7]. Attempts to reduce the visual impact of solar installations have had an effect on the performance of the installations [8] due to poor orientation and shadowing between buildings.

Solar collectors are designed to produce either electricity or thermal energy, so they must be oriented such that their energy production is maximized. This orientation requirement makes integration attempts difficult if performance losses are to be avoided. Attempts at integration have tried to reach the point at which both design and performance are as high as possible for the application, while assuming that some performance loss is

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Nomenclature

E	east
$E_{b,c}$	energy accumulated from beam radiation on a clear-sky day for a curved surface (J/m^2)
$E_{b,t}$	energy accumulated from beam radiation on a clear-sky day for a tilted surface (J/m^2)
$E_{d,c}$	energy accumulated from diffuse radiation on a clear-sky day for a curved surface (J/m^2)
$E_{d,t}$	energy accumulated from diffuse radiation on a clear-sky day for a tilted surface (J/m^2)
G	total radiation on a horizontal surface (W/m^2)
G_b	beam radiation on a horizontal surface (W/m^2)
$\overline{G}_{b,c}$	average beam radiation on a curved surface (W/m^2)
$G_{b,n}$	beam radiation on a plane normal to the sun's rays (W/m^2)
$G_{b,t}$	beam radiation on a tilted surface (W/m^2)
G_d	diffuse radiation on a horizontal surface (W/m^2)
$\overline{G}_c$	average total radiation on a curved surface (W/m^2)
$\overline{G}_{d,c}$	average diffuse radiation on a curved surface (W/m^2)
$G_{d,n}$	diffuse radiation coming from the sun (W/m^2)
$G_{d,t}$	diffuse radiation on a tilted surface (W/m^2)
H_c	total radiation intercepted by a curved surface over one year (J/m^2)
H_t	total radiation intercepted by a tilted surface over one year (J/m^2)
N	north
R_b	ratio between the beam radiation on a tilted surface and horizontal surface (–)
R_c	ratio between the total radiation on a curved surface and horizontal surface (–)
$R_{b,c}$	ratio between the beam radiation on a curved surface and horizontal surface (–)
r	radius of a curved surface (m)
W	west

Greek symbols

α	angle defined in Fig. 3c
α_1	angle defined in Eq. (23)
α_2	angle defined in Eq. (24)
α_p	profile angle
α_s	altitude of the sun
β	slope of a tilted or curved surface
γ	azimuth of a tilted or curved surface
γ_s	azimuth of the sun
δ	declination
θ	zenith angle of a tilted surface
θ_z	zenith angle of a horizontal surface
τ	atmospheric transmittance
ϕ	latitude
ω	hour angle (15°=1 h)

Subscripts

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

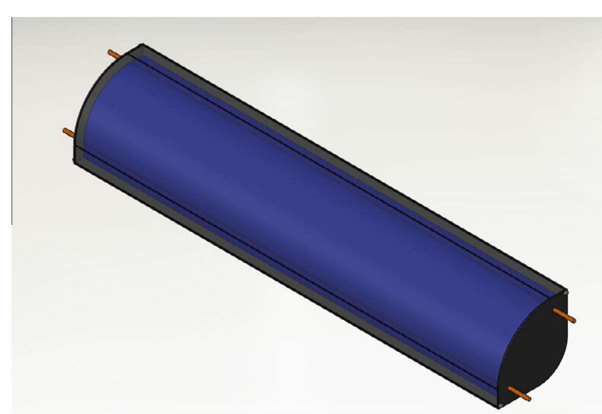

Fig. 1. Scheme of the proposed prototype with a curved geometry.