Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 115 (2015) 667–679

SOLAR ENERGY

www.elsevier.com/locate/solener

Analytical study on solar energy absorbed on elliptic curved collector

Hiroshi Tanaka [a,*], Wael M. El-Maghlany [b], Mohamed A. Teamah [c]

[a] Department of Mechanical Engineering, Kurume National College of Technology, Komorino, Kurume, Fukuoka 830-8555, Japan
[b] Department of Mechanical Engineering, Faculty of Engineering, Alexandria University, Egypt
[c] Mechanical Engineering Department, College of Engineering and Technology, Arab Academy for Science, Technology and Maritime Transport, Abu-Quir, Alexandria, Egypt

Received 23 May 2014; received in revised form 29 January 2015; accepted 14 March 2015
Available online 3 April 2015

Communicated by: Associate Editor Ursula Eicker

Abstract

A new type of solar thermal collector which can be integrated with facades and roofs to provide pleasant shapes is introduced. The solar collector has an elliptic curved shape, and ellipse aspect ratio was varied to cover all geometric shapes. The mathematical equations were developed to calculate the beam and diffuse radiation absorbed on the elliptic curved collector. Theoretical analysis was done to determine the effects of the ellipse aspect ratio and the azimuth angle of the collector on the performance of the collector, and the results were compared with a conventional tilted flat plate collector for four typical clear-sky days (spring and fall equinoxes and summer and winter solstices). The total energy received throughout the year is also compared. The elliptic curved collector is able to absorb a sufficient amount of solar radiation to be competitive with a conventional flat plate collector. One of the advantages of this study is in the mathematical expression that enables the designers to simulate not only all possible configurations but also all possible orientations of the elliptic curved collectors covering all days.

Keywords: Solar thermal; Collector; Elliptic; Curved

1. Introduction

Instead of a common flat plate solar thermal collector, various shapes and types of solar collectors have been presented to integrate with facades and roofs to offer the desired visual appearance to the buildings. Bonhote et al. (2009) introduced the solar collectors as building elements to increase the architectural admission of energy self-supplying buildings to decrease the energy cost. Kalogirou (2004) introduced the importance of solar energy as a survey of the various types of solar thermal collectors and applications. Probst and Roecker (2007) reported the results of a large web survey on architectural quality of building-integrated solar thermal systems (BIST). The various approaches in building integration of solar system and a number of successful examples were reported by Hestnes (1999). The transparent solar thermal facade collectors (TSTC) as building-integrated solar thermal system were studied by Maurer et al. (2012, 2014). A flat plate solar collector which is integrated into a rainwater gutter was presented and experimented by Motte et al. (2013). Non-rectangular solar collector (equilateral triangle and isosceles trapeze) and its examples of facade and roof integrated arrays were presented by Visa et al. (2014). A transient analysis of solar concrete collectors used for providing domestic hot water was introduced by Bopshetty et al. (1992), and a mathematical model has been developed to

* Corresponding author.
E-mail address: tanakad@kurume-nct.ac.jp (H. Tanaka).

http://dx.doi.org/10.1016/j.solener.2015.03.025
0038-092X/

Nomenclature

a	half ellipse horizontal axis (m)
b	half ellipse vertical axis (m)
E_G	total daily energy absorbed on a surface on a clear-sky day (J/m^2)
G_b	beam radiation on a tilted surface (W/m^2)
$\overline{G}_b$	average beam radiation on a curved surface (W/m^2)
$\overline{G}_{bh}$	average beam radiation on a horizontal surface (W/m^2)
G_{bn}	beam radiation on a plane normal to the sun's rays (W/m^2)
$\overline{G}_{bv}$	average beam radiation on a vertical surface (W/m^2)
G_d	diffuse radiation on a horizontal surface (W/m^2)
$\overline{G}_{dc}$	average diffuse radiation on a curved surface (W/m^2)
G_{dt}	diffuse radiation on a tilted surface (W/m^2)
G_{dn}	diffuse radiation coming from the sun (W/m^2)
$\overline{G}_G$	instantaneous average total radiation on a curved surface (W/m^2)
H_G	total yearly energy absorbed on a surface (J/m^2)
I	extra-terrestrial solar radiation (W/m^2)
m	ellipse aspect ratio
n	number of days
R_b	ratio between the beam radiation on a tilted surface and horizontal surface
R_{bc}	ratio between the average beam radiation on a curved surface and horizontal surface
r	radius of a curved surface (m)

Greek symbols

α	polar angle
α_s	sun altitude angle
β	inclination angle of a tilted or curved surface
γ	azimuth of a tilted or curved surface
δ	declination angle
θ	incident angle of beam radiation to tilted surface
ϕ	latitude angle
τ	transmittance of atmosphere
Ω	hour angle

estimate the performance of such collectors. Building integrated thermal solar system but with photovoltaic thermal (BIPVT) system has been designed by Ibrahim et al. (2014) to produce both electricity and hot water and later integrated to building. Also, a transmissive Fresnel reflector was designed by Chemisana and Rosell (2011) to match the needs of building integration for concentrating photovoltaic (PV), thermal (T) or hybrid photovoltaic/thermal (PVT) generation. Gonzalez-Pardo et al. (2013) analyzed optical performance of vertical heliostat fields integrated in building facades for concentrating solar energy. Fischer et al. (2004) presents the improved approach to outdoor performance testing of solar thermal collectors under quasi-dynamic test conditions according to the European Standard EN 12975-2. The most important effects for the all-day performance of the collector were taken into account. Tagliafico et al. (2014) introduced the different models in the simulations of the flat plat thermal collector including the computational fluid dynamic approach. Tripanagnostopoulos et al. (2000) fabricated flat plate solar collectors in order to test the performance with colored absorbers for water heating applications; this test insures that the collector is compatible with the architectural design, and also aesthetic. Recently, Rodriguez-Sanchez et al. (2014) proposed and theoretically analyzed a curved solar thermal collector, which cross-sectional area is one quarter of cylinder, for architectural integration. The mathematical equations for the beam and diffuse solar radiation received by a curved surface with this geometry were developed for two different orientations, horizontal and vertical. However, their model to calculate the solar radiation on the curved surface is limited to that of one quarter of cylinder and cannot be applied to other curved surface such as ellipse.

Therefore, in this paper, a new type of elliptic curved solar thermal collector which can be integrated with facades is presented, and the mathematical equations for the beam and diffuse radiation received on the elliptic curved surface are developed for the collector in the horizontal position. The performance of this curved solar thermal collector, in terms of solar radiation received, is analyzed for Alexandria city (Egypt). The primary objective of this study is to compare the solar energy captured by a curved surface with that captured by a conventional tilted surface, consequently; the comparison with a conventional flat plate collector is made for typical clear-sky days in spring equinox, summer solstice, fall equinox and winter solstice. Further, the total energy absorbed throughout the year is also compared.

In the following sections, equations for the beam and diffuse radiation captured by the curved surface are

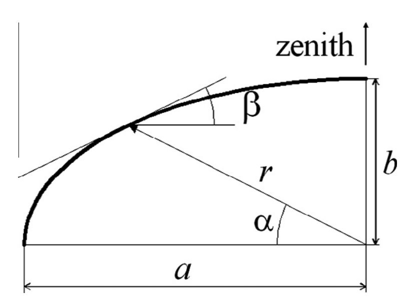

Fig. 1. A schematic diagram of the elliptic curved solar collector.