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Variation of reflected radiation from all reflectors of a flat plate solar collector during a year

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ABSTRACT

In this paper the impact of flat plate reflectors (bottom, top, left and right reflectors) made of Al, on total solar radiation on a solar collector during a day time over a whole year is analyzed. An analytical model for determining optimum tilt angles of a collector and reflectors for any point on the Earth is proposed. Variations of reflectors' optimal inclination angles with changes of the collector's optimal tilt angle during the year are also calculated. Optimal inclination angles of the reflectors for the South directed solar collector are calculated and compared to experimental data. It is shown that optimal inclination of the bottom reflector is the lowest in December and the highest in June, while for the top reflector the lowest value is in June and the highest value is in December. On the other hand, optimal inclination of the left and right side reflectors for optimum tilt angle of the collector does not change during the year and it is 66°. It is found that intensity of the solar radiation on the collector increases for about 80% in the summer period (June–September) by using optimally inclined reflectors, in comparison to the collector without reflectors.

1. Introduction

Solar energy is recognized as one of the primary renewable energy sources. The most common use of solar energy includes its transformation either to thermal energy by means of thermal (T) collectors or to electrical energy by means of photovoltaic (PV) collectors. In order to obtain higher solar radiation intensity on the absorbing plate of solar collector, reflectors with various geometry (flat, spherical, parabolic, etc.) are added to the collector's assembly [1–30]. Flat reflectors are widely utilized in both thermal and photovoltaic systems, due to their simple geometry and low-cost implementation. These reflectors are particularly suitable for the integration into facades or roofs of modern buildings. Consequently, a considerable research effort is made towards their design and characterization.

A pioneering analysis of the enhanced solar energy collection using mirrors-fixed flat plate solar collector combination was presented by Tabor [1]. Further contributions were given in Refs. [2–14] and their comprehensive summary was given in Ref. [15]. The solar thermal collector with spectral selective absorber without and with flat plate top and bottom reflectors was investigated by Kostić and Pavlović [15]. Their results have shown an average energy gain of about 40% in the summer period for thermal collector with reflectors. Tanaka presented theoretical analysis of a solar thermal collector with flat plate top [16] and bottom [17] reflectors. He determined the optimum inclination of the collector and reflector throughout the year at 30° N latitude and studied the effect of the size of the top reflector on the daily solar radiation absorbed on the absorbing plate of the collector. A tilted wick solar still with a flat plate top [23] and bottom reflector [24] was also considered.

The PV module with low concentration ratio reflector was considered by Huang and Sun [18], while PV system had been analyzed by Tina and Scandura [19]. The electrical and thermal output of PV/T systems can be also increased by using reflectors of solar radiation. The effect of plane booster reflectors on the performance of a solar air heater with solar cells suitable for a solar dryer was studied by Garg et al. [20]. Brogren et al. [21] presented the results from a water-cooled PV/Thermal system with 4X CPC reflectors that yielded the yearly electric output increase by 20%. Hybrid PV/Thermal experimental models based on commercial PV modules were investigated by Tripanagnostopoulos et al. [22]. They showed that the improvement of the system performance could be

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Nomenclature

α	solar altitude angle (°)
α_1	angle of the bottom reflector to the horizontal plane (°)
α_2	angle of the top reflector to the vertical plane (°)
β	collector's tilt angle (°)
γ_1	angle of the left side reflector to the horizontal plane (°)
γ_2	angle of the right side reflector to the horizontal plane (°)
δ	declination of the sun (°)
χ_1	incident angle from the bottom reflector (°)
χ_2	incident angle from the top reflector (°)
ω	sun hour angle (°)
ϕ	latitude of the solar collector (°)
ρ_{Al}	reflectance from the aluminum sheet
ρ_g	reflectance from the ground
σ_1	incident angle from the left side reflector (°)
σ_2	incident angle from the right side reflector (°)
θ_z	solar zenith angle when a surface is facing South (°)
AM	optical air mass
D	daylight saving time (h)
e	root mean square deviation (°)
EOT	equation of time
G_{dif}	diffuse solar radiation on horizontal surface (W m^{-2})
G_0	solar constant (1366 W m^{-2})
G_{dif_col}	total diffuse solar radiation (W m^{-2})
G_{dif_sky}	sky-diffuse solar radiation (W m^{-2})
G_{dir_col}	direct solar radiation on collector surface (W m^{-2})
G_h	global solar radiation on horizontal surface (W m^{-2})
G_{in}	global solar incident radiation (W m^{-2})
G_{in_r1}	incident solar radiation on the bottom reflector (W m^{-2})
G_{in_r2}	incident solar radiation on the top reflector (W m^{-2})
G_{in_sr1}	incident solar radiation on the left side reflector (W m^{-2})
G_{in_sr2}	incident solar radiation on the right side reflector (W m^{-2})
G_{ref_gr}	reflected solar radiation from the ground (W m^{-2})
G_{ref_r1}	reflected solar radiation from the bottom reflector which reached the collector surface (W m^{-2})
G_{ref_r2}	reflected solar radiation from the top reflector which reached the collector surface (W m^{-2})
G_{ref_sr1}	reflected solar radiation from the left side reflector which reached the collector surface (W m^{-2})
G_{ref_sr2}	reflected solar radiation from the right side reflector which reached the collector surface (W m^{-2})
G_{net_col}	net incoming solar radiation on the collector surface without the additional solar input from reflected solar radiation from reflectors (W m^{-2})
G_{tot_col}	total solar radiation on the collector surface (W m^{-2})
H	altitude above the sea level (m)
L_{loc}	longitude of the solar collector (°)
L_{STM}	local standard time meridian (°)
LST	local solar time (h)
LT	local time (h)
N	day number of the year
r	correlation coefficient

achieved by using a booster diffuse reflector to increase electrical and thermal output.

The results of the influence of reflectance from flat plate top and bottom reflectors made of aluminum sheet and aluminum foil on energy efficiency of PV/Thermal collector were given by Kostić et al. [25]. They also presented experimental and analytical results on determination of the optimal position of the top and bottom reflectors during the day time over the whole year period [26].

Kumar et al. considered the general case of a collector with four reflectors. They gave an analytical model for study of the effect of an individual reflector on the collector. Numerical calculations were carried out for the South faced system and collector tilt $\beta = 0°$ for May and December in Delhi [27].

The objective of this paper is to present an extended model suitable for calculation of the optimal inclination of four flat plate reflectors: top, bottom, left and right reflectors of South oriented solar collector. Section 2 describes the development of the model in detail. Section 3 contains a short description of an experimental setup used for the model verification. Calculated results and experimental data are presented in Section 4 and discussed in terms of the model accuracy.

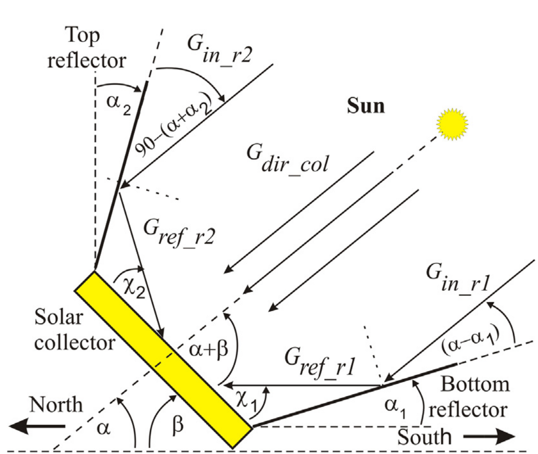

Fig. 1. Schematic diagram of the solar collector with top and bottom flat plate reflectors.

2. Analytical model

The model is developed for the South directed flat plate solar collector at tilt angle β with respect to the horizontal plane. In order to get more solar energy, four aluminum sheet made flat plate solar reflectors are mounted on the collector, as shown in Figs. 1 and 2.

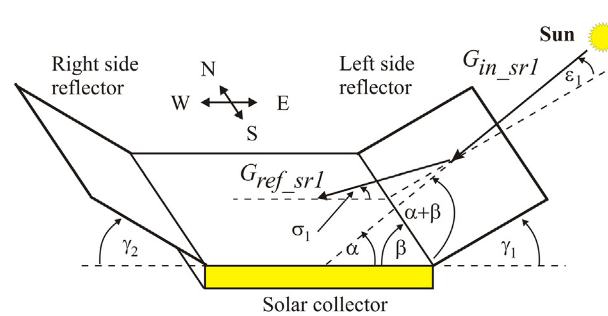

Fig. 2. Schematic diagram of the solar collector with left and right side flat plate reflectors.