Optimization of flat plate solar collector angles at a latitude just outside the tropics

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Abstract

Calculations were made to determine the optimum angle of inclination (in terms of energy input) of two flat plate solar collectors when fixed throughout the year at the same angle at the latitude of Johannesburg (26°S). The result was compared with the value obtained when the collectors were both adjusted to a different angle at the equinoxes, and that when the two collectors were fixed throughout the year at different angles to each other.

Nomenclature

a	Solar altitude
A	'No atmosphere' correction factor; values given in [1]
B	'Atmosphere' correction factor; values given in [1]
d	Solar declination
h	Hour angle from noon
I	Insolation intensity (collector normal to Sun) (I', non-normal)
L	Latitude
N	Day of year (1, Jan. 1)
z	Azimuth angle
θ	Angle of inclination of collector from horizontal

Introduction

By far the majority of solar collectors are not 'tracked'. To maximise energy collection over a whole year by means of a fixed flat plate solar collector, a common rule of thumb used is to align the collector (normally facing true north or south) at an angle θ with the horizontal of (latitude $+10°$). This arrangement is intended to optimise user utility by increasing the energy collected over the winter months – when it is supposed that it is then more necessary than in the warmer summer months. In the case of Johannesburg, which lies just south of the Tropic of Capricorn at a latitude of 26° – corresponding localities are Brisbane, Karachi, and Monterey (Mexico) – this would suggest that such a collector be aligned at an angle of 36°. To determine whether two such collectors, each fixed throughout the year at a different angle, or both adjusted to a new angle at the equinoxes, would give a better energy maximum over the whole year than when they are fixed throughout at a compromise angle, calculations were made for each of the two collectors at a range of angles to determine the best arrangement.

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Optimisation of collector angles

Calculations were made of energy input over one year for all values of θ_1 and θ_2 between 0° and 90° in 10° steps for each of the two collectors to cover the following possibilities:

1. Both collectors at the same angle θ_1 throughout the year;
2. two collectors, one fixed at θ_1 and the other at θ_2 throughout the year; and
3. both collectors at a fixed angle θ_1, but changed at the equinoxes to the best 'summer' or 'winter' angle. ('Summer' is here represented by Days 1–81 and 265–365; 'winter' by Days 82–264.)

The calculations made involved use of the following equations:[2;3]

Declination:

$$d = 23.45 \sin\left(\frac{360° \times (284+N)}{365}\right) \quad (1)$$

Solar altitude:

$$\sin a = \sin d \sin L + \cos d \cos L \cos h \quad (2)$$

Insolation intensity (normal):

$$I = \frac{A}{\exp\left(B \,/\, \sin a\right)} \quad (3)$$

Insolation intensity (non-normal):

$$I' = I \sin a \cos\theta + I \cos a \cos z \sin\theta \quad (4)$$

To examine the suitability of Eq.(3) at the latitude of the exercise, Figure 1 was plotted to show the diurnal curve resulting from use of this equation for $N = 235$. To provide an actual comparison with this curve, the ordinates were then multiplied by $\sin a$ to give Figure 2a which represents the diurnal insolation received by a horizontal surface. The shape of this curve is closely similar to the plot (Figure 2b) of an actual insolation curve for $N = 235$

measured in Johannesburg [4] by means of an unshielded Eppley pyranometer having a horizontal element; however, the peak ordinate of the actual curve is about 14% higher – which may be ascribed to an altitude effect, plus other diffuse contributions. (The local height effect was not calculated in the absence of suitable data.[3])

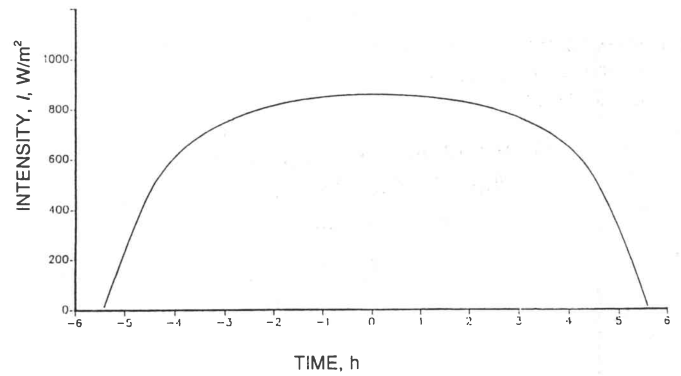

Figure 1 Theoretical I vs h
N = 235

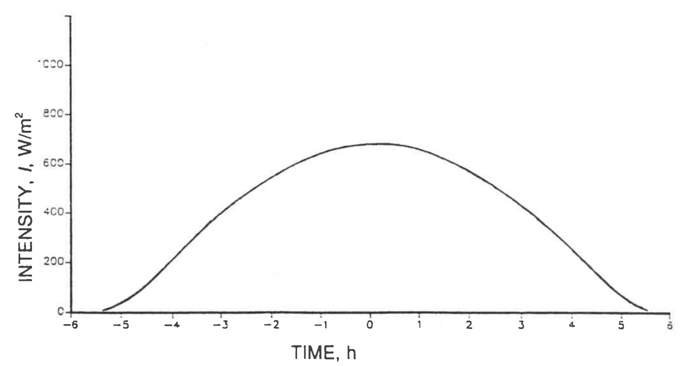

Figure 2a Direct intensity equation corrected for horizontal surface for comparison.

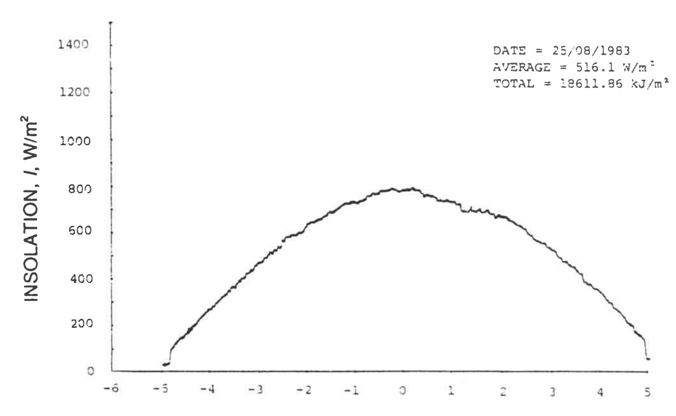

Figure 2b Eppley pyranometer plot for N = 235. (Insolation averaged over each 20 s interval and then plotted.)

[3]Data such as those referred to in [5] were not considered to be applicable to local conditions.

Results

In respect of the three possibilities listed:

1. The best angle for two collectors fixed at the same angle throughout the year was found to be 30°, with a total annual input of 4 635 kWh, as shown in Figure 3. This angle agrees with that quoted by Sayigh [6] for the best angle for a flat collector in terms of average daily radiation measured in Riyadh, of similar latitude (25°N). Under these conditions, 67.29% of the total radiation was found to be associated with the 'summer' months, and 32.71% with the 'winter' months. As a matter of interest, the total input for a fixed angle of 36° was only about 2% less.
2. No case of using different angles for the two collectors, but with both fixed throughout the year, was better than the above quoted result of 30°.
3. Changing the angle of the two collectors at the equinoxes resulted in the following optimum angles and corresponding energies for the seasons shown:

Season	θ, deg	Energy, kWh per collector
Summer	40	1 049
	10	1 205
Winter	40	1 217
	10	1 003

The maximum 'winter' input (two collectors at 40°) was thus 2 434 kWh, while the maximum 'summer' input (2 collectors at 10°) was 2 410 kWh, giving a total of 4 844 kWh. While, as expected, this exceeded the annual energy figure for two collectors at an angle constant at 30° throughout the year, it is only about 4% greater – which hardly justifies the changeover complication.

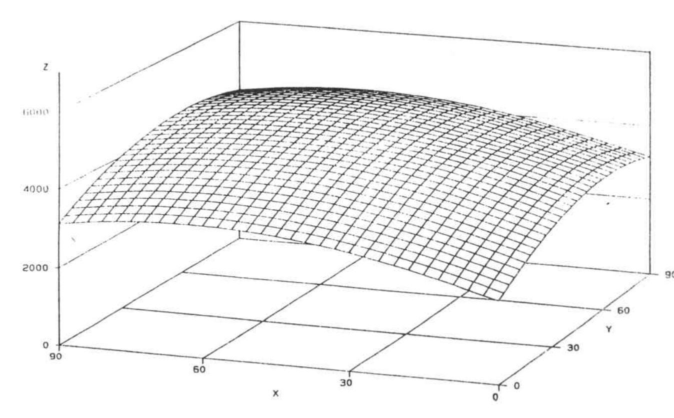

Figure 3 Insolation over the whole year as function of θ_1 and θ_2.

Conclusion

The choice of collector angles to obtain maximum energy input was found not to be critical at the latitude of 26°S. The maximum energy obtained by calculation by using different 'winter' and 'summer' angles of 40° and 10°, respectively, was found to be only slightly greater than that obtainable from collectors fixed at an angle throughout the year at 30° (= latitude + 4°), and no other choice of angle fixed throughout the year gave as good a result as 30° for both collectors. Energy values associated with the rule-of-thumb angle of (latitude + 10°) were in turn nearly as good.

References

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