Application of utilizability computation methods to Europe and Africa

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► To cite this version:

Maria Joao Carvalho, Bernard Bourges. Application of utilizability computation methods to Europe and Africa. Intersol Eighty Five, Pergamon, pp.2439-2443, 1986, 9780080331775. 10.1016/B978-0-08-033177-5.50459-2 . hal-00949145

HAL Id: hal-00949145

<https://hal.science/hal-00949145>

Submitted on 6 Jul 2021

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ABSTRACT

KEYWORDS

INTRODUCTION

UTILIZABILITY AND AVAILABLE ENERGY

1

"Utilizability" defined as $\bar{g}(I_c) = \int_{\Delta t} (I - I_c)^+ \cdot dt / nH_T$

The Utilizability $\bar{g}(I_c)$ is the fraction of solar radiation nH_T incident upon a collector's aperture during a certain period Δt (month or year), that lies above the specific threshold irradiance I_c . The product $\bar{g} \cdot nH_T$ is sometimes called the "available solar energy above the threshold I_c " (for the period).

UTILIZABILITY CALCULATION METHODS

Various methods have been published for utilizability computation and reviewed recently (7). Six of these methods have been considered in the present work (1-6). The first four methods only need as climatological input the mean daily global radiation value on a horizontal plane, H_H , and on the collector plane, H_T (This last value may be also computed from H_H with method (8), if it is not known). They have been derived as fits to North-American data vs the "clearness index" $K_T = H_H/H_0$ which is the parameter used to indicate the dependence of $\bar{g}$ with climate. The two last methods require an additional parameter I_{max} , maximal irradiance on the considered plane.

Collares-Pereira/Rabl method (1) includes in the same step computations of $\bar{g}$ and H_T from H_H ; it is also suitable for concentrating collectors. Clark's method (2) is the only hourly-based utilizability method. Evans method (3) proposes three different correlations of $\bar{g}$ suitable for flat-plate solar collectors; only one of them is reported here, after transformation into function of I_c and K_T' (related to K_T)

$$\bar{g} = 1 - 1.07 \cdot 10^{-3} \cdot I_c / K_T' + 3.02 \cdot 10^{-7} \cdot (I_c / K_T')^2$$

Gordon and Zarmi's method (5) is an analytical approach to the Utilizability concept, with the semi-empirical form for flat-plate collector

$$\bar{g}(I_c) = (1 - I_c / I_{max})^{1/\nu}$$

with $1/\nu = I_{max} \cdot t_p / H_T$ and t_p is the time between sunrise and sunset.

In method (6), "utilizability" is derived from Cumulative Frequency Curves (CFC) of solar irradiance incident on the collector. CFC's are defined as curves giving the time nH (mean daily number of hours) during which the solar radiation is above some threshold I_c . Correlations have been developed from a Principal Components Factor Analysis to give the Coefficients of a 5th order polynomial CFC fitting from the parameter $\nu = H_T / (I_{max} \cdot t_p)$.

AVAILABLE DATA AND METHODOLOGY

Solar radiation data used in the present analysis are summarized in Table 1. Three to seven years of solar global radiation measured hourly values have been collected for horizontal planes or south-oriented tilted planes (without ground-reflected diffuse radiation).

Table 1: Solar Radiation Data Used in the Present Analysis

Station	Country	Tilt	Latitude	Longitude	Altitude	Period
Nice	France	0°	43.7°N	7.2°E	10 m	1970-75
Millau	France	0°	44.1°N	3.0°E	720 m	1970-75
Carpentras	France	0°	44.1°N	5.1°E	99 m	1970-75
		45°-90°				1979-81
Lisboa	Portugal	0°	38.7°N	9.1°W	77 m	1975-77
Trappes	France	0°	48.8°N	2.0°E	167 m	1970-75
		45°-90°				1979-81
Kilkenny	Ireland	0°	52.7°N	7.3°W	64 m	1969-75
Maputo	Mozambique	0°	25.9°S	32.6°E	44 m	1965-69

Available data may be combined in three groups: 1. Southern Europe (Nice, Carpentras, Millau, Lisboa) 2. Northern Europe (Trappes, Kilkenny) 3. Tropical Africa (Maputo)

The considered quantity is not Utilizability, but the monthly available energy above given thresholds, $\bar{H}_T$. That makes possible the comparison of methods for which precise definition of "utilizability" is not exactly homogeneous (1-2) with the others. Available energy above various critical intensities is computed, first from these original measured data for thresholds $I_c = 0, 100, 200$ to 600 W/m^2 and, secondly, using various utilizability methods (only taking, as an input, the mean monthly sum of global irradiation on a horizontal plane and, if available, on the tilted plane). For a given location, plane and period (one month or the whole year) different comparison criteria have been selected: Mean bias error (all thresholds) and Root mean square error (RMSE) (or Standard-deviation of errors) (all thresholds). Both these parameters are given as relative values (divided by the mean available energy for all thresholds from 0, 100 to 600 W.m^{-2}). The relative error on the available energy is also given for one specific threshold (200 W.m^{-2}).

RESULTS FOR HORIZONTAL PLANES

Results are quite homogeneous within each group. Four methods (1,2,4,6) give very satisfactory results in group 1 (Southern Europe): Mean yearly bias error for all thresholds within 2%; relative errors for monthly available energy within 3 to 8% at low thresholds (Tables 2-3); largest errors in winter. Algorithms (3) and (5) show important discrepancies (10 to 20% in average; large errors in winter, up to 30% for (3)). For the third group (Maputo), all methods seem acceptable (with the exception of (3) in winter), but with systematic underestimate. For group 2 (characterized by more cloudy conditions and small values of clearness index K_T), method (6) gives good results; methods (1-2) offer a satisfactory accuracy, although with some systematic overestimate (within 10% at low thresholds). Methods (3,5) show larger errors.

RESULTS FOR TILTED PLANES

Two types of comparison have been made: first, using only as input the mean monthly irradiation on a horizontal surface; the mean monthly irradiation on the tilted plane is computed by (8), except for method (1). Second, the right value on the tilted plane is introduced, except for (1). Bourges method (6) has not been tested.

In the first case, errors are important, due to a systematical underestimation

Fig. 1: Available energy $\bar{H}_T$ (MJ/m²/day) above threshold irradiance I_c .

Table 2: Computation of Available Solar Energy above Threshold Radiation Intensities from 0 to 600 W.m⁻² (Horizontal plane) using different methods. This table gives, for each method, the mean relative bias error and the monthly root mean square error (between brackets) (in % of the average Available Energy).

Station	Col.Per /1/	Clark /2/	Evans /3/	Klein /4/	Gordon /5/	Bourges /6/
Nice	-1.6 (2.3)	0.9 (2.6)	8.4 (6.8)	1.1 (2.7)	-5.5 (5.2)	-0.9 (1.8)
Millau	-1.8 (2.4)	0.2 (1.7)	5.6 (6.5)	1.2 (2.7)	-6.2 (5.2)	-0.8 (1.3)
Carpentras	-1.9 (2.3)	0.5 (1.6)	8.4 (6.6)	0.5 (2.6)	-5.1 (5.0)	-0.2 (1.9)
Lisboa	-0.3 (1.7)	2.2 (2.5)	8.6 (7.2)	1.9 (2.0)	-2.8 (2.6)	1.7 (1.7)
Trappes	3.3 (6.5)	4.3 (4.3)	7.2 (7.0)	6.9 (6.6)	-6.0 (6.2)	0.3 (1.7)
Kilkenny	4.2 (6.1)	4.5 (4.7)	10.6 (9.5)	7.2 (7.3)	-4.0 (4.5)	2.7 (3.2)
Maputo	-4.8 (2.8)	-2.1 (2.8)	1.7 (7.3)	-2.5 (2.8)	-6.7 (4.6)	-2.7 (2.4)

Table 3: Relative errors (%) on the computed value of available energy above the threshold irradiance $I_c = 200 \text{ W.m}^{-2}$.

Station	Period	/1/	/2/	/3/	/4/	/5/	/6/
Nice	Year	-2.3	-0.1	7.3	0.6	-5.7	-0.6
	June	-1.9	-1.3	3.7	0.9	-5.6	-1.9
	Dec.	-7.7	-3.1	32.1	-4.7	-17.6	-3.5
Kilkenny	Year	1.3	5.7	15.1	8.4	-4.9	2.7
	June	1.3	3.9	10.6	7.7	-3.3	1.7
Maputo	Year	-5.8	-3.7	-0.3	-3.0	-7.1	-3.5
	June	-6.9	-5.0	9.0	-6.2	-8.7	-3.2
	Dec.	-4.6	-3.3	-3.4	-1.4	-6.1	-3.4

of the mean monthly irradiation (3 to 17%, the biggest in winter, see Tab. 4). For low thresholds values ($I_c = 200 \text{ W.m}^{-2}$), errors are within 25% for method /2/, within 30% for /1/. All other methods show errors within 50% or larger, particularly for vertical planes (Table 5).

When the correct average irradiation value is introduced, results are better (Tab. 5): e.g. for /2/ the mean bias error for all thresholds is reduced by 6 to 11 %, but monthly errors for a given threshold ($I_c=200$) are still important (10% at 45°; 20% to 25% for vert. surfaces). Methods (3-5) cannot be applied for vert. planes. Method (5) seems to be more reliable for sunny climates.

CONCLUSIONS

As a general result, all methods have significant errors when the mean monthly irradiation value on the considered plane is not known: within 30% for reasonably low thresholds, with systematical underestimation for methods /1/ and /2/; still larger for other methods. When this value is known, available energy may be computed on a more accurate way, but nonnegligible errors still remain (within 20%, with the most general, and also the most complicate, method /2/). Method (3) (developped for inclined surfaces with tilt angle close to some optimum) and methods (4) and (5) are acceptable for tilt-angles close to

the latitude, but are not quite reliable for other angles. Some additional work seems to be necessary in order to get a simple method for computing the mean monthly irradiation on a tilted plane and simple empirical utilizability formulas of a general use, for any south-oriented surface.

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Table 4: Relative error (%) on the computed value of the mean daily irradiation on tilted planes.

		/1/				/8/			
		Year	June	Marc	Dec.	Year	June	Marc	Dec.
Trappes	45°	-7.2	-2.9	-6.0	-8.4	-6.5	-2.4	-4.8	-8.5
Trappes	90°	-9.5	-7.8	-3.9	-7.7	-7.4	-1.4	-2.6	-7.9
Carpent.	45°	-8.9	-5.6	-7.9	-14.6	-8.2	-4.9	-7.0	-14.3
Carpent.	90°	-12.7	-13.9	-7.3	-16.9	-10.8	-6.8	-6.2	-16.6

Table 5: Relative errors (%) on the computed value of available energy above the threshold irradiance $I_c = 200 \text{ W.m}^{-2}$ on tilted planes, according to the type of input data: H_m (monthly average of daily global irradiation on a horizontal plane) or H_r (idem on tilted plane).

			Input data:					Input data:				
Station	Tilt	Period	/1/	/2/	/3/	/4/	/5/	/2/	/3/	/4/	/5/	H_r
Trappes	45°	Year	-10.4	-8.6	-2.4	-13.2	-11.5	-2.4	4.3	-7.3	-5.5	
		June	4.6	6.3	12.7	6.3	10.0	8.9	15.5	9.0	12.8	
		Dec.	-0.4	-5.2	-6.8	-34.6	-49.2	3.5	1.9	-28.5	-45.4	
Trappes	90°	Year	-17.3	-20.6	5.1	-31.8	-20.5	-13.9	13.9	-26.3	-13.8	
		June	10.3	8.4	78.3	11.4	59.7	9.9	80.7	13.0	62.0	
		Dec.	-0.5	-15.8	-4.3	-49.0	-58.0	-8.6	3.8	-44.6	-54.7	
Carpent.	45°	Year	-13.8	-12.1	-6.3	-15.1	-8.5	-4.4	1.9	-7.6	-0.5	
		June	-6.3	-6.5	0.9	-10.8	1.2	-1.6	6.1	-6.2	6.4	
		Dec.	-25.4	-20.5	-17.8	-26.5	-20.7	-7.2	-4.1	-14.3	-7.5	
Carpent.	90°	Year	-23.0	-20.9	2.0	-30.6	-9.1	-10.8	-14.5	-21.6	2.2	
		June	-22.9	-15.1	59.7	-46.4	53.2	-8.9	71.3	-42.5	64.3	
		Dec.	-29.8	-25.3	-18.4	-32.7	-25.3	-10.4	-2.3	-19.3	-10.4	