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Article

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Educational solar energy tool in Matlab environment

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Abstract

In this work, an educational tool to be used in solar energy courses is proposed. It consists of software, named Softsun, with educational purposes, which allows performing some tasks applicable to solar thermal and photovoltaic systems. Among other things, this software allows: obtaining the I–V curve of diode models using data from manufacturers, calculating solar radiation components to use the f-chart or utilizability methods for solar thermal and photovoltaic systems, and dealing with economic aspects. This software was developed within Matlab, being able to simulate several processes with a user-friendly platform. Softsun also has other functions, such as support, theories, conversion units and reports, if required by the user. The main purpose is an educational tool in the area of solar energy, which helps the teaching and learning process commonly used in engineering.

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Keywords: Education; Learning process; Software; Solar energy and teaching

1. Introduction

In the last decades, there was an increase in the utilization of computational tools to solve complex equations of energy systems used in research, teaching and learning processes, reducing the time taken to obtain the solutions [1,2]. Considering engineering systems that use solar energy, the determination of solar radiation components that are needed to apply the f-chart or utilizability methods to solar thermal and photovoltaic systems, generally consume a lot of time.

This work proposes an educational tool for a solar energy course, which helps the teaching and learning process, while reducing the time for the solution of equations. With this education tool, named Softsun, the I–V curve from one and two diode models using manufacturers' data [3], the equations of solar geometry, solar radiation, solar thermal systems and photovoltaic systems, among others, can be applied. The solar thermal systems that may be

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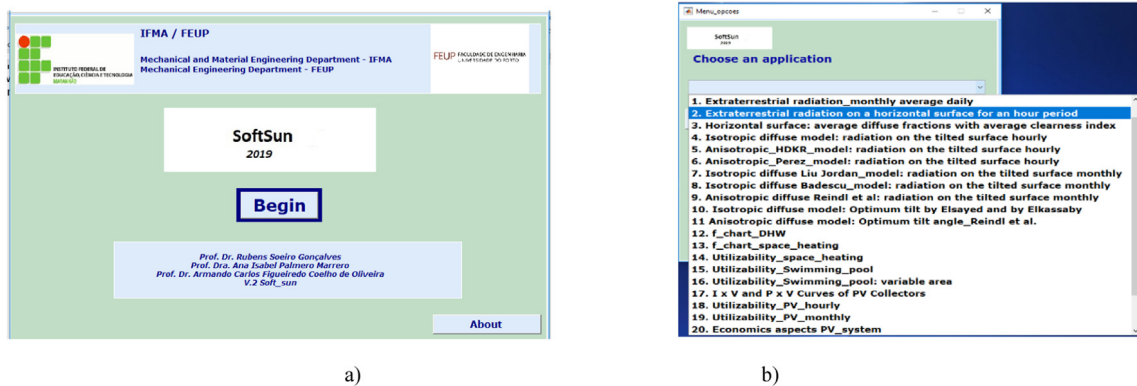


Fig. 1. Examples of the Software V2 interface: (a) initial interface and (b) interface to choose the application.

calculated are: domestic hot water heating, swimming pool water heating, space heating (heat distribution through water or air), space cooling (absorption system) by using f-chart or utilizability methods [4].

Beyond that, the Software Menu provides Help, Theories (regarding specific topics), Unit converter and Calculation reports to obtain the solution of the chosen system. It is important to emphasize that the proposed educational software ought not to replace in any moment the direct resolutions made by the student during the process of learning. For teachers in the solar energy field, Softsun software will increase the velocity of calculus and the possibility to provide more flexibility and objectivity in the analyses of results. The main advantage lies in the process of solving exercises for various applications, which usually require a lot of time to obtain results. In addition, this tool allows the discussion of the different results with the student in the classroom, when the different parameters or inputs are changed in the proposed applications. This software was developed within Matlab, being able to simulate several processes with a user-friendly platform.

2. Presentation of the Softsun software

In this section, some characteristics of the Softsun software are presented. Fig. 1a shows the Initial Interface. By selecting the button “Begin”, Softsun opens a new window (Fig. 1b) with an Interface that allows choosing an application from several available. The option “About” will display general information, the main characteristics and applications.

The SoftSun software is under development and already has, until now, 20 applications. Presently, it is possible to estimate: solar radiation, I–V curves of PV modules, solar fraction using f-chart and utilizability ($\bar{\phi}$) methods and economic aspects. The SoftSun software is flexible and new tools and applications can be easily incorporated. Regarding the solar radiation, the hourly, daily or monthly extraterrestrial radiation, as well as beam, diffuse and ground reflected components of radiation can be calculated. The radiation on a titled surface can be obtained using an isotropic model [5,6] or anisotropic models ([7–10]). Regarding the optimum tilt angle to obtain the maximum incident global solar radiation, a correlation was used in terms of clearness index, latitude, Julian day, according to Elsayed [9]. Also, the monthly optimum tilt angle can be calculated in terms of latitude and Julian day, according to Elkassaby [10].

Both solar thermal systems and photovoltaic systems can be calculated using f-chart and utilizability methods. Specifically, in swimming pool water heating or space heating applications using the utilizability method, the calculation for several cities at the same time is possible; the selection between two models ([11] or [12]) is also possible.

Regarding economic aspects, Levelized Cost of Energy, Payback and Energy Savings can be calculated for solar thermal and photovoltaic systems.

3. Results and discussion

To explain the utilization of this education tool, two exercises for different applications were chosen and the results are shown in this section.

Table 1. Some input parameters to calculate the solar fraction with the f-chart method.

Input parameters	Values
$U.A$ — building overall energy loss coefficient-area product	463 [W/°C]
Heat exchanger efficiency	0.69
A_C — collector area	50 [m ²]
$F_R(\tau\alpha)_n$ — optical efficiency	0.74
$F_R.U_L$ — loss coefficient	4 [W/m ² /°C]
β — collector slope from horizontal (south orientation)	60°
$\bar{\tau\alpha}/(\tau\alpha)_n$ — ratio of the transmittance–absorptance product (considered constant during simulations) ^a	0.96
Collector-heat exchanger correction factor	0.97
$V_{storage}/A_C$ (storage capacity/square meter of collector area)	150 [l/m ²]
City (latitude; longitude)	Madison, USA (43°N; 89°W)

^aThis ratio can be calculated month by month, if desired.

Table 2. Monthly performance of the solar DHW + space heating system (without correction).

Month	H_β [MJ/m ²]	T_a [°C]	Q_{load} [GJ]	X	Y	f_i	Q_{usef} [GJ]
Jan	13.702	−8	36	1.5588	0.40651	0.28	10.163
Feb	17.236	−5	30.4	1.621	0.54696	0.39	11.929
Mar	15.794	1	26.7	1.9266	0.63181	0.44	11.727
Apr	14.83	9	15.7	2.9146	0.97634	0.62	9.6863
May	17.142	14	9.2	4.8572	1.9901	0.97	8.9581
Jun	17.321	19	4.1	9.9343	4.3667	1 ^a	4.6894
Jul	17.462	22	2.9	13.976	6.4314	1 ^a	4.7752
Aug	17.829	20	3.4	12.226	5.601	1 ^a	4.5206
Set	15.589	15	6.3	6.7845	2.5577	1	6.4936
Out	15.175	11	13.2	3.5034	1.2279	0.73	9.6136
Nov	11.35	2	22.8	2.1614	0.51453	0.34	7.648
Dec	12.714	−5	32.5	1.6787	0.41782	0.28	9.2525

^aThese points have coordinates outside of the range of the f-chart correlations.

- First exercise: Performance of Liquid Heating System using the f-chart method.

In the first exercise, the solar fraction (f) for a combined domestic hot water (DHW) and space heating system using the f-chart method is calculated. This is a liquid heating system. Table 1 shows some input data for the f-chart method.

The monthly solar fraction (f_i) is given as a function of two dimensionless variables (X and Y) as shown in [4]. Table 2 shows the monthly performance of the system without corrections in storage capacity and load heat exchanger. In this exercise, H_β (monthly average daily radiation incident on collector surface per unit area) is calculated from the input horizontal radiation data; T_a (monthly average ambient temperature) is an input; Q_{load} (monthly total heating load for hot water) is an input; X , Y , f_i and Q_{usef} (useful energy delivered by the solar heating system) are calculated. For this application, there are still options to choose a constant or variable collector area, and also to use the heating load as input data or to be calculated. In this simulation a constant collector area was selected and the heating load was set as input data. The annual solar fraction (f_{annual}) was 0.443 without corrections and 0.441 with corrections. The results also display the months with coordinates outside the f-chart correlation (June, July and August in this case).

The results of the simulation can be presented in different formats. Figs. 2 and 3 show solar fraction as a function of X and Y , with and without corrections, in 3D. Fig. 4 shows the monthly solar fraction (in 2D) with and without correction. Different presentation forms discussed by the teacher in the classroom, varying the sensible parameters, help the student in the understanding of the results in complex solar systems increasing the velocity of calculus and the possibility to provide analyses of results in the classroom. Afterwards, the student can compare the simulation results with those obtained with a hand calculator.

- Second exercise: Performance of Liquid Heating System using the utilizability method ($\bar{\phi}$).

In the second exercise, the teacher should analyze the annual performance of a liquid solar heating system for space heating, using the utilizability method ($\bar{\phi}$). After, the student may compare the simulation results obtained in the classroom with those obtained during home work.

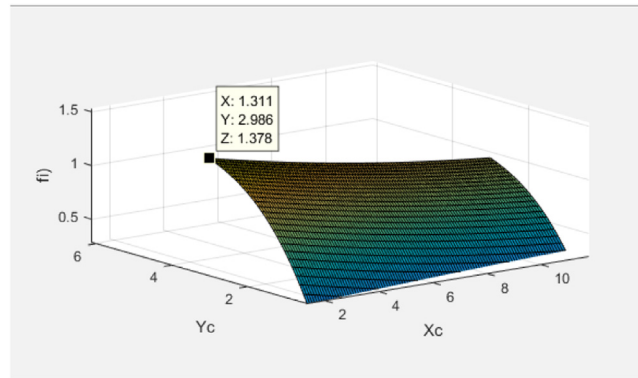


Fig. 2. Monthly solar fraction (f_i) depending on X_c and Y_c (with corrections).

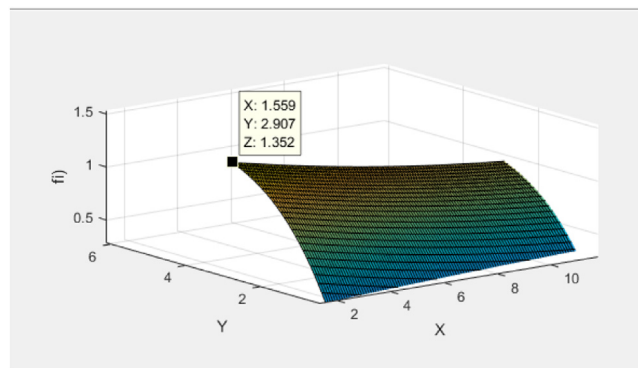


Fig. 3. Monthly solar fraction (f_i) depending on X and Y (without corrections).

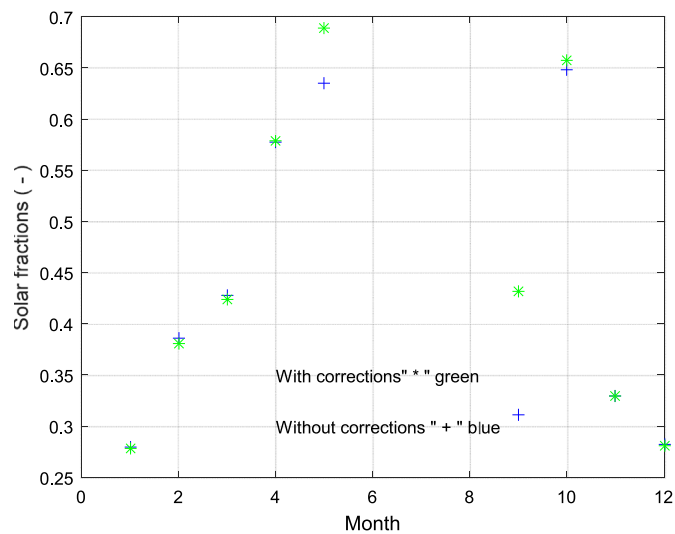


Fig. 4. Monthly solar fraction with and without corrections.

Table 3. Some input parameters to use the $\bar{\phi}$ method for a space heating exercise.

Input parameters	Values
A_c	50 [m ²]
β	60°
Latitude	43°N
T_{ground}	7 [°C]
$(UA)_s$ storage tank	30 [W/°C]
$(UA)_h$ building	200 [W/°C]
$F_R \cdot U_L$	4.55 [W/m ² /°C]
$F_R (\tau \alpha)_n$	0.78
V_{storage}	250 [m ³]

Table 4. Monthly performance of a space heating system using the $\bar{\phi}$ method.

	\bar{T}_a [°C]	DD [°C day]	H_β [MJ/m ²]	\bar{R}	Q_{usef} [GJ]	\bar{K}_T	\bar{X}_C	$\bar{\phi}$	$T_{\text{stor,f}}$ [°C] ($T_{\text{stor,i}} = 1$ °C)	$T_{\text{stor,f}}$ [°C] ($T_{\text{stor,i}} = 20$ °C)
Jan	−6	828	5.85	2.032	6.46	0.437	0.442	0.468	38.451	38.452
Feb	−5	695	9.13	1.692	9.97	0.485	0.287	0.615	28.550	28.551
Mar	1	602	12.89	1.289	12.65	0.495	0.225	0.688	25.091	25.106
Apr	9	340	15.88	0.922	12.11	0.470	0.190	0.735	25.852	25.863
Mai	15	194	19.79	0.802	13.91	0.502	0.175	0.753	30.405	30.413
Jun	21	79	22.11	0.753	13.48	0.529	0.199	0.720	38.673	38.677
Jul	23	50	21.96	0.773	12.42	0.541	0.270	0.629	47.885	47.888
Aug	22	60	19.39	0.874	10.70	0.539	0.343	0.544	55.776	55.779
Set	17	140	14.75	1.070	8.08	0.512	0.435	0.455	61.263	61.265
Out	12	282	10.34	1.441	7.43	0.494	0.467	0.429	62.643	62.644
Nov	4	508	5.72	1.685	3.15	0.391	0.712	0.291	60.817	60.818
Dez	−4	743	4.42	1.918	2.79	0.371	0.738	0.283	51.452	51.453

This method can be applied because there is a very large storage volume (seasonal storage is used).

Since the storage tank is very large, its temperature will not significantly change throughout each month, and so an average collector inlet temperature can be assumed, and the $\bar{\phi}$ method can be used [4]. The input data are displayed in Table 3. This exercise is proposed in [4, pp.697].

Table 4 shows the long-term energy performance. In this application there are two approaches to calculate the utilizability: according to Evans et al. [11] or to Klein [12]. To carry out the final result an iterative process is used.

The initial step is to guess a tank temperature for any month, usually the lowest tank temperature which is easy to estimate. Once the tank temperature is known at the beginning of the month, the tank temperature at the end of the month is guessed. The average tank temperature for the month is used to calculate the collector output and tank losses. The tank energy balance equation is used to determine the tank temperature at the end of the month. This calculated temperature is compared with the assumed value, and if they agree, the calculation continues with the next month. If they disagree, another monthly average temperature is estimated and a new final tank temperature is calculated. The procedure is repeated for all 12 months, and the final tank temperature is compared to the initial guess made. If they match, the calculations are complete; if they disagree, the calculations must be repeated, Duffie and Beckman [4]. To solve this exercise with a simple calculator in the classroom, the student would spend a long time; with this Softsun software the calculations are very quick, facilitating learning and interpretation of the solar energy system.

In this simulation the utilizability was calculated according to Klein [12], and the tolerance to find the final storage temperature at the end of the month was taken as 0.1 °C.

Table 4 shows in the last columns, two results of the final storage temperature ($T_{\text{stor,f}}$): with initial storage temperature ($T_{\text{stor,i}}$) equal to 1 °C and with $T_{\text{stor,i}} = 20$ °C. Similar values were obtained, independently of the initial storage temperature.

4. Conclusions

An educational tool for solar energy applications was developed, which can be used to determine solar radiation, and apply f-chart or utilizability methods to solar thermal or photovoltaic systems, and also to assess economic aspects. This tool, named Softsun, presents a user-friendly platform. The results obtained until now have been numerically tested for all applications available and were satisfactory, as showed in the two chosen applications: f-chart method applied to domestic hot water heating and utilizability method applied to space heating. Regarding the pedagogical aspects of Softsun, it quickly and accurately reproduces the contents treated in the classroom, in terms of mathematical models, as well as facilitating the learning of the contents of the solar energy course. It also has a teaching function to enable the student to identify the main simulation parameters. For the teachers of solar energy courses, the Softsun software will increase the velocity of calculus and the possibility to provide more flexibility and objectivity in the analyses of results.

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References

- [1] Sinha Sunanda, Chandel SS. Review of software tools for hybrid renewable energy systems. *Renew Sustain Energy Rev* 2014;32:192–205.
- [2] Bollinger Andrew L, Dorer Viktor. The ehub modeling tool: A flexible software package for district energy system optimization. *Energy Procedia* 2017;122:541–6.
- [3] Ishaque K, Salam Z, Taheri H. Simple, fast and accurate two-diode model for photovoltaic modules. *Sol Energy Mater Sol Cells* 2011;95(2):586–94.
- [4] Duffie JA, Beckman WA. *Solar engineering of thermal processes*. fourth ed.. Wiley; ISBN: 978-0-470-87366-3, 2013.
- [5] Liu BYH, Jordan RC. The interrelationship and characteristic distribution of direct, diffuse and total solar radiation. *Sol Energy* 1960;4(3):1.
- [6] Badescu V. A new kind of cloudy sky model to compute instantaneous values of diffuse and global irradiance. *Theor Appl Climatol* 2002;72:127–36. <http://dx.doi.org/10.1007/s007040200017>.
- [7] Perez R, Seals R, Ineichen P, Stewart R, Menicucci D. A new simplified version of the perez diffuse irradiance model for tilted surfaces. *Sol Energy* 1987;39(221).
- [8] Reindl DT, Beckman WA, Duffie JA. Diffuse fraction correlations. *Sol Energy* 1990;45(1).
- [9] Elsayed MM. Optimum orientation of absorber plates. *Sol Energy* 1989;42:89–102.
- [10] Elkassaby MM. Monthly and daily optimum tilt angle for south facing solar collectors: theoretical model, experimental and empirical correlations. *Solar Wind Technol* 1988;5(6):589–96. [http://dx.doi.org/10.1016/0741-983X\(88\)90054-9](http://dx.doi.org/10.1016/0741-983X(88)90054-9).
- [11] Evans DL, Rule TT, Wood BD. A new look at long term collector performance and utilizability. *Sol Energy* 1982;28(13).
- [12] Klein SA. Calculation of flat-plate collector utilizability. *Sol Energy* 1978;21(393).