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Research Article

OPTICAL PERFORMANCE INVESTIGATION OF A CLFR FOR THE PURPOSE OF UTILIZING SOLAR ENERGY IN TURKEY

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Abstract

This study provides a feasibility analysis of the performance of a compact linear Fresnel reflector (CLFR) to be used in a renewable system for the energy demand in some cities in Turkey. The main idea of this work is to investigate whether it will be beneficial or not when CLFRs are used for energy production in Turkey. For this purpose, the optical performance of a CLFR system is investigated theoretically in six of the cities of different regions. The results obtained show that for residential and even for small size commercial usage of CLFR systems could satisfy a very huge amount of solar energy. When the energy need in different processes like heating, cooling, drying is considered, it is easily said that the collected solar energy by a CLFR system would be enough for energy need in many processes.

Keywords- *Solar radiation in Turkey, concentrating solar energy, linear Fresnel reflectors, optical performance, renewable energy systems.*

1. Introduction

Today, the World is more dependent on energy than ever. Aside from the extraction and the combustion of fossil fuels having severe effect on human health, the decrease in reserves and the increase in energy prices make the renewable energy systems more popular [1]. Besides, increasing global emissions create a big concern [2]. Therefore, the use of renewable energy grows continually all over the world. For all that, the selection of the correct system for given location is still crucial. A detailed investigation of the system is a must for a considered particular location. Many similar works for different locations have been done in the literature [3-13]. In the referred works, different renewable energy systems have been considered for different locations in the world. Thus, the governments from all over the world put a target for renewable energy use in their own countries [14-29]. By having such targets many countries took big steps in renewable energy production. For instance, 114723 GWh of electricity in Germany came from renewable sources in the first nine months of 2015, which was almost double the amount produced from nuclear sources. Additionally, some electricity prices have decreased from the previous year [14]. Economic expansion, rising per capita income, positive demographic trends and the rapid pace of urbanization have been the main drivers of energy demand, which is estimated to increase by around 6 percent per annum until 2023 in Turkey. The current 70 GW installed electricity capacity is expected to reach 120 GW by 2023 to satisfy the increasing demand in the country [20].

Energy is used both as residential and commercial. It can be used for heating, cooling, drying, lighting and obtaining hot water, process steam, and electricity. For all of the purposes, energy can also be obtained through solar energy. The only concern would be the collected amount of the solar energy for these purposes.

This study provides a feasibility analysis of the optical performance of a compact linear Fresnel reflector (CLFR) to be used in a renewable system for the energy demand in some cities in Turkey. The main idea of this work is to investigate whether it will be beneficial or not when CLFRs are used for energy production in Turkey. For many domestic and even commercial but maybe not industrial applications, the solar concentration ratio of 5-15 would be enough to

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obtain the required energy. To fulfil the job in this paper, optical performance of a CLFR will be examined in detail.

2. Solar Energy Potentıal and Usage In Turkey

Turkey is located in a very advantageous geographical location with 7.2 hours/day of annual insolation duration and 3.6 kWh/m2-day of annual solar radiation [30]. Monthly solar energy potential of Turkey is given in Table 1.

Table 1. Monthly Average Solar Potential of Turkey [30].

Months	Monthly Total Solar Energy (kWh/m^2-mnt.)	Sunshine Duration (hours/month)
January	51.75	103
February	63.27	115
March	96.65	165
April	122.23	197
May	153.86	273
June	168.75	325
July	175.38	365
August	158.40	343
September	123.28	280
October	89.90	214
November	60.82	157
December	46.87	103
TOTAL	1311	2640
Average	3.6 kWh/m^2-day	7.2 hours/day

Also, solar energy potential according to the geographical regions in Turkey is given in Fig. 1.

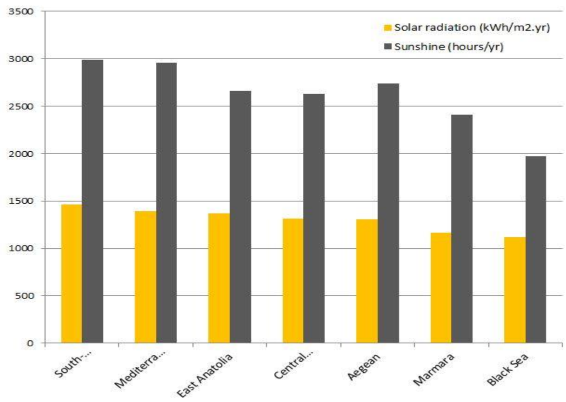

Fig. 1. Total solar radiation in the regions in Turkey [30].

Average annual total solar radiation map of Turkey is also given in Fig. 2. However it has been recognized that the existing meteorological data is lower than the actual solar energy data of Turkey. EIE (General Directorate of Renewable Energy) and DMI (Turkish State Meteorological Service) have been taking new measurements since 1992 to determine the more accurate solar energy data. Although the measurements have not been completed yet, the collected data indicates that the actual solar energy radiation values are 20-25% higher than the existing data [30].

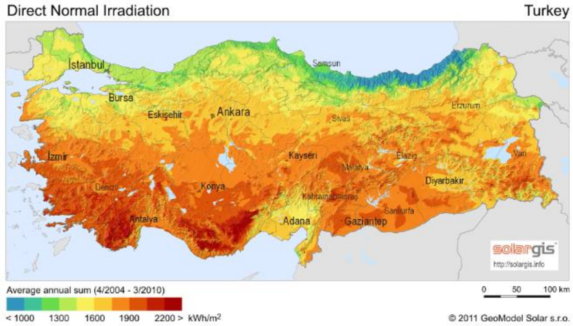

Fig. 2. Total solar radiation in Turkey [31].

Despite it seems the regions south-eastern Anatolia and Mediterranean have got the high solar energy potential in Turkey, in this study, the feasibility of using CLFR systems is evaluated for different provinces in different regions because of the changing insolation hours. For this purpose, it is desired to examine the applicability of a CLFR system in Istanbul city of Marmara region, Izmir city of Aegean region, Konya city of Central Anatolia region, Antalya city of Mediterranean region, Gaziantep city of South-eastern Anatolia and Van city of East Anatolia region. To introduce the solar energy potentials, the average monthly total solar energy (kWh/m2-month), and monthly sunshine duration hours (hours/month) are given in the following figures for the aforementioned cities in the selected regions. Since the solar radiation is not high enough in Black Sea region, this region is excluded in this study. Average monthly total solar energy potential for Izmir is given in the Fig. 3 as,

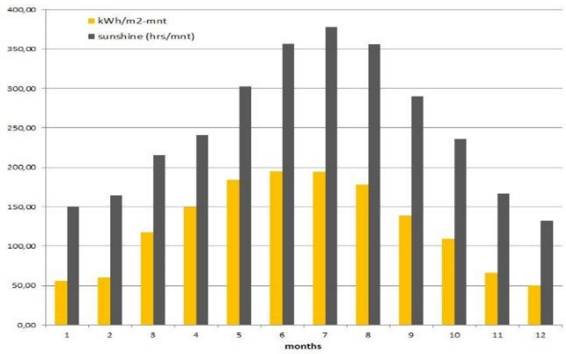

Fig. 3. Monthly total solar radiation and sunshine in Izmir [32].

Monthly solar energy potential for Konya is given in Fig. 4.

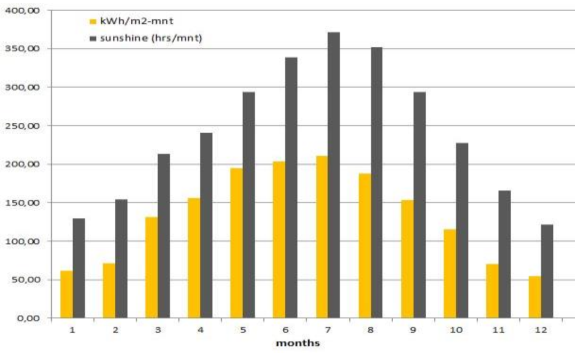

Fig. 4. Monthly total solar radiation and sunshine in Konya [32].

Monthly solar energy potential for Antalya is given in Fig. 5.

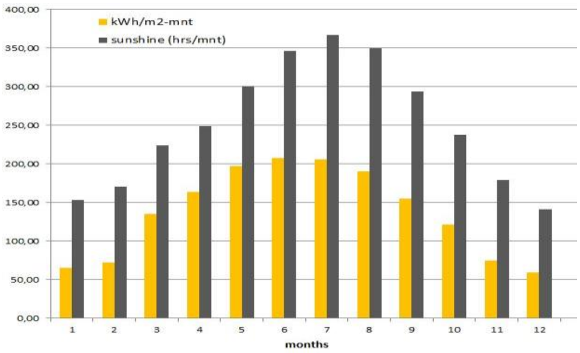

Fig. 5. Monthly total solar radiation and sunshine in Antalya [32].

Monthly solar energy potential for Van is given in Fig.6.

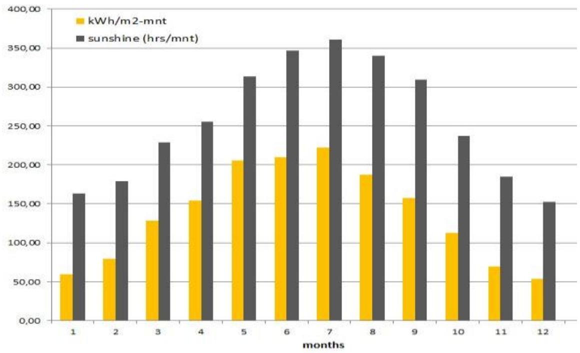

Fig. 6. Monthly total solar radiation and sunshine in Van [32].

Monthly solar energy potential for Gaziantep is given in Fig. 7.

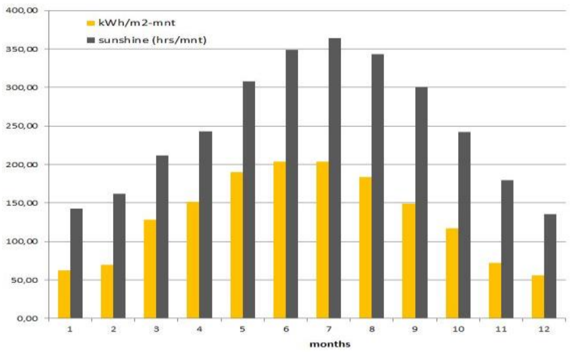

Fig. 7. Monthly total solar radiation and sunshine in Gaziantep [32].

Monthly solar energy potential for Istanbul is given in Fig. 8.

Energy demand in Turkey is mainly met by imported resources like gas and oil. The changes in the number of capita, energy demand, production and import are shown in Table 2. Although Turkey has almost all kinds of energy resources, it is an energy importing country, since these resources are limited. More than half of the primary energy consumption in the country is met by imports and the share of imports continues to increase each year [37]. On the other hand, despite there is an annual potential of over 2600 hours sunshine in Turkey, benefit from solar energy was only about 420 ktoe (about 5 TWh as heat) as of 2007 [38].

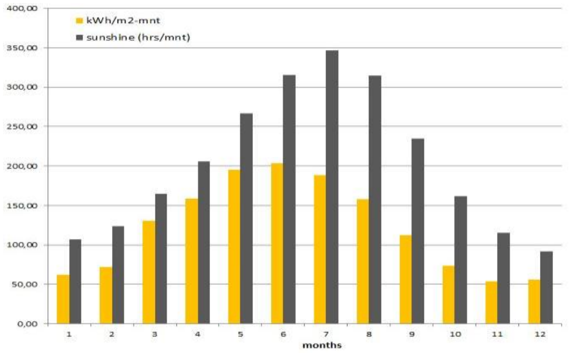

Fig. 8. Monthly total solar radiation and sunshine in Istanbul [32].

Table 2. Energy in Turkey [36].

Year	Capita (million)	Primary Energy (TWh)	Product. (TWh)	Import (TWh)
2004	71.79	952	280	677
2007	73.90	1163	317	881
2008	71.08	1146	337	843
2009	71.90	1136	352	817
2012	74.90	1360	355	1035
2013	75.77	1355	376	1008

It can also be easily said that the demand is tend to increase in the incoming decades. Therefore as a solution for this problem, renewable energy appears to be one of the most efficient and effective solutions for clean and sustainable energy development. Among all, solar power is one of the most promising and more predictable than other renewable sources and less vulnerable to changes in seasonal weather. Turkey has relatively rich solar potential. In spite of such a high potential, solar energy is not widely used, except for flat-plate solar collectors. They are only used for domestic hot water production, mostly in the sunny coastal regions. The electricity generation from the solar energy is realized by photovoltaics (PV) and solar collectors. Unfortunately, PVs have high installing costs; hence, an economical usage of them is not easily available today [39].

3. Optical Calculations for Linear Fresnel Reflectors

A compact linear Fresnel reflector system shown in Fig. 9 consists of flat mirrors forming of a parabola-like shape to reflect the incident solar rays onto a receiver tube which are placed on top of the mirror system.

Solar power on a collector-mirror is given as [33];

$$P = I_b.W.L.\sum_{i=0}^{N}\cos(\theta_i) \tag{1}$$

Where I_b is direct normal irradiance (DNI) (W/m^2), L is the length of the mirror (m), W is the width of the mirror (m), N is the number of mirror in the system and θ_i is the tilt angle of the i^{th} mirror. i=0 refers the first mirror (if there is any, otherwise refers the central point of the mirrors) in the centre of the system. All of the geometrical parameters related to a CFLR system are given as in the Fig. 10.

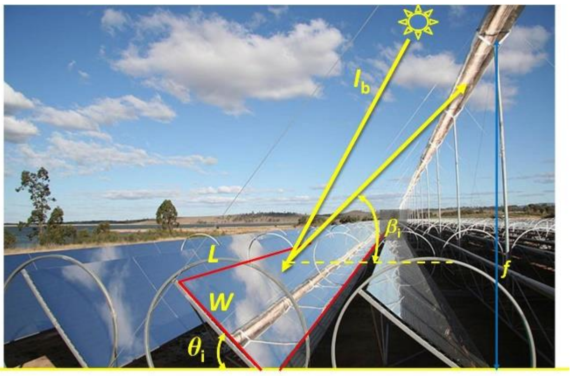

Fig. 9. Mirrors and receiver of a CLFR system

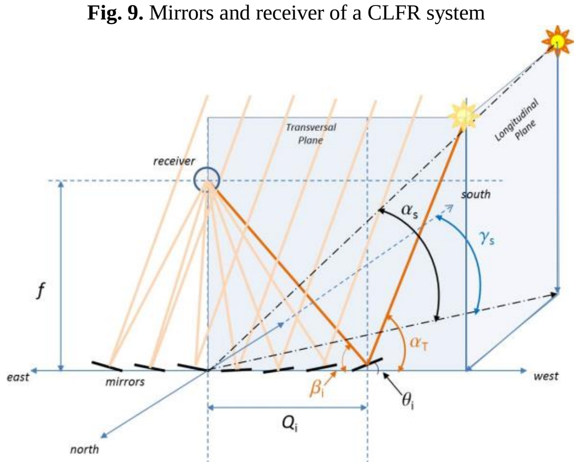

Fig. 10. Geometrical structure of an LFR system.

The tilt angle of the i^{th} mirror is defined as [33];

$$\theta_i = \frac{\alpha_T - \beta_i}{2} \qquad (2)$$

where the transversal solar altitude angle α_T and the angle β_i are defined as;

$$\alpha_T = \arctan\left(\tan(\alpha_s)/\sin\gamma_s\right) \qquad (3)$$

$$\beta_i = \arctan\left(f/Q_i\right) \qquad (4)$$

The angles α_s and γ_s refer the solar altitude and solar azimuth angles, *f* is the height of the absorber and Q_i is the distance of the i^{th} mirror from the centre of the CLFR system. The Sun's position in terms of the angles α_s and γ_s is calculated trough the following equations as [34, 35]:

$$\cos\gamma_s = \frac{\sin\delta.\cos\varphi - \cos\delta.\sin\varphi.\cos(HRA)}{\cos\alpha_s} \qquad (5a)$$

Eq.(5a) is valid when the Local Solar Time (*LST*) is smaller than 12 or hour angle (*HRA*) is negative, hence the azimuth angle for *LST*>12 or *HRA*>0 is calculated by;

$$\gamma_s = 360 - \cos^{-1}\left(\frac{\sin\delta.\cos\varphi - \cos\delta.\sin\varphi.\cos(HRA)}{\cos\alpha_s}\right) \qquad (5b)$$

$$\sin\alpha_s = \sin\delta.\sin\varphi + \cos\delta.\cos\varphi.\cos(HRA) \qquad (6)$$

where δ is the declination angle of the Sun, φ is the latitude of the location of interest;

$$\delta = 23.45^0 \sin\left[\frac{360}{365}(d-81)\right] \qquad (7)$$

$$HRA = 15^0(LST - 12) \qquad (8)$$

In Eq.(7) *d*, refers the number of the day of the year and *LST* in Eq.(8) is an adjustment of local time (*LT*) given as;

$$LST = LT + \frac{TC}{60} \qquad (9)$$

TC in Eq.(9) stands for time correction factor (in minutes) which accounts for the variation of the *LST* within a given time zone due to the longitude variations within the time zone and also incorporates the Equation of Time (*EoT*) and they are given as;

$$TC = 4(\text{longitude - LSTM}) + EoT \qquad (10)$$

$$EoT = 49.87\sin(2B) - 7.53\cos B - 1.5\sin B \qquad (11)$$

where,

$$B = \frac{360}{365}(d-81) \qquad (12)$$

is resulted in degrees. And LSTM in Eq.(10) is the Local Standard Time Meridian (LSTM) which is a reference meridian used for a particular time zone and is similar to the Prime Meridian, which is used for Greenwich Mean Time (GMT) and it is calculated as;

$$LSTM = 15^0 \Delta T_{GMT} \qquad (13)$$

where ΔT_{GMT} is the difference of the LT from GMT in hours.

A CFLR mirror system might be in modules. There might be up to 15-20 modules in a collector area. Each of the module length and width of a commercial CFLR can be up to 100 m and 30 m respectively. And the width of a single mirror in a module can be 20 to 75 cm. In this study, three different size CFLRs are considered in the calculations. The number of the mirrors and the height of the receiver in the system are taken as 40 and 1m respectively. These can be assumed either a standalone CFLR system or a module in a larger system. Their technical specifications are given in the Table 3.

Table 3. The Technical Specifications of the CFLR Modules

Modul	Module length (m)	Mirror width (m)
M1	1	0.05
M2	4	0.20
M3	10	0.3

When the incoming daily average monthly total solar radiation is considered, the annual total solar energy collected by a tracking CFLR system in the aforementioned cities are calculated through all the equations given above and presented as in the Table 4.

Table 4. Monthly Average Annual Total Solar Energy

City	Collected solar energy (MWh)		
	M1	**M2**	**M3**
Istanbul	2,92	41,77	150,92
Izmir	3,47	49,95	180,73
Antalya	3,63	48,01	173,43
Konya	3,44	49,22	177,98
Gaziantep	3,60	52,89	191,39
Van	3,51	52,61	191,34

As it can be shown in the Table 4 that as the mirror size changes, the collected solar energy changes dramatically. Also, it can be noticed that although they are the cities in different locations from north to south and west to east, there are no big differences in collected energy in Turkey.

4. Conclusions

Turkey is due to take place in the Sunbelt, despite having high solar energy potential and sunshine hours; this resource is used only in low temperature applications. Concentrating solar energy systems are very promising on making use of this abundant energy. Among them, the relatively low cost and high efficient CFLR systems might offer a very huge advantageous in solar energy use.

In this study, optical performance of CLFR systems in different size is examined for different cities in Turkey. Results show that for residential and even for small size commercial use of CLFR systems could satisfy a very huge amount of solar energy. When the energy need in different processes like heating, cooling, drying is considered, it is easily said that the collected solar energy by a CLFR system would be enough for energy need in many processes. This kind of feasibility studies can help to those who want to make investment in solar energy sector as well as those who want to study further in the subject.

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