A COMPARISON OF FLAT PLATE AND EVACUATED TUBE SOLAR COLLECTORS WITH F-CHART METHOD

Abdulkadir KOCER[*], Ibrahim ATMACA[**] and Can ERTEKIN[***]
[*]Vocational School of Technical Sciences, Akdeniz University, TR - 07058, Antalya, Turkey, akocer@akdeniz.edu.tr
[**]Department of Mechanical Engineering, Faculty of Engineering, Akdeniz University, TR - 07058, Antalya, Turkey, atmaca@akdeniz.edu.tr
[***]Department of Farm Machinery, Faculty of Agriculture, Akdeniz University, TR - 07058, Antalya, Turkey, ertekin@akdeniz.edu.tr (Corresponding Author: Tel: +90 242 310 2481)

Abstract: Solar energy is used for variety of heating systems such as domestic hot water systems and industrial applications. The use of solar energy for domestic hot water and steam generation in industry is economical and environmentally friendly. "The F-chart" is a method that provides an easy way to determine the thermal performance of the solar heating and hot water systems. In this study, the solar systems are analyzed with the F-chart method in order to meet the hot water requirements of hotels. Annual fraction and heating loads for different solar collector areas and number of people is estimated. Flat plate and evacuated tube type collectors are compared and analysed.

Key words: solar energy, f-chart, flat plate collector, evacuated tube collector

DÜZLEMSEL VE VAKUM TÜPLÜ GÜNEŞ KOLEKTÖRLERİNİN F-CHART METODU İLE KARŞILAŞTIRILMASI

Özet: Güneş enerjisi, evsel sıcak su temini ve endüsriyel uygulamalar gibi çeşitli ısıtma sistemlerinde kullanılır. Evsel sıcak su ve endüstriyel buhar üretiminde güneş enerjisinin kullanımı hem ekonomik hem de çevre dostudur. F-Chart yöntemi; ısıtma ve evsel sıcak su temininde, ısıl performansın kolayca belirlenmesini sağlayan bir yöntemdir. Bu çalışmada otellerdeki sıcak su ihtiyacının karşılanması için güneş enerjisi sistemlerinin F-Chart methodu kullanılarak analizi yapılmıştır. Farklı kollektör alanları ve kişi sayılarına göre yıllık faydalanma oranı ve ısıl yükler hesaplanmıştır. Düzlemsel ve vakum tüplü kollektörler karşılaştırılmış ve incelenmiştir.

Anahtar Kelimeler : güneş enerjisi, f-chart, düzlemsel kollektör, vakum tüplü kollektör

NOMENCLATURE

A_c	Collector area (m²),
F_R	Collector heat exchanger efficiency factor,
G_{sc}	Solar constant
H_D	The monthly average daily diffuse radiation (MJ.m⁻².day⁻¹)
H_o	Average daily extraterrestrial radiation (MJ.m⁻².day⁻¹)
H_T	Monthly average daily radiation incident on the collector surface per unit area (J/m²),
H_T	Monthly average daily total solar radiation on tilted surface (MJ.m⁻².day⁻¹)
I	Solar radiation (W.m⁻²)
L	Monthly total heating load for space heating and hot water (GJ),
n	Number of days in the month,
P	Number of people,
T_a	Monthly average ambient temperature (⁰C),
T_f	Fluid temperature (⁰C)
T_m	The tap water temperature (⁰C),
T_{ref}	An empirically derived reference temperature (100 °C),
T_w	Required hot water temperature (⁰C),
U_L	Collector overall loss coefficient (W/m² ⁰C),
X	Collector Loss
Y	Collector Gain
η_{col}	Collector efficiency
β	Tilt angle (degrees)
Δt	Total number of seconds in the month,
ρ	Ground reflectance (≈0.2).
Φ	Latitude of the site (degrees)
ω'	Sunset hour angle (degrees)
F_R'/F_R	The collector heat exchanger correction factor (≈0.97)
γ	Azimuth angle (degrees)
δ	Solar declination (degrees)

ω	Solar hour angle (degrees)
$(\tau\alpha)$	Monthly average transmittance - absorptance product,
$(\tau\alpha)/(\tau\alpha)_n$	The ratio of the monthly average to normal incidence transmittance-absorptance product
f	monthly fraction of thermal load
F	annual fraction of thermal load

ABBREVIATIONS

ETC	Evacuated tube collector
FPC	Flat plate collector

INTRODUCTION

With the advancing technology and living standards, the demand for energy is increasing with each passing day. The strong coupling of gross domestic product and fossil fuel consumption points to the need for the development of renewable energy technologies, and conservation and efficient use of energy resources (Evrendilek and Ertekin, 2002). It is also possible to reduce fossil fuel consumption by using renewable energy sources (Yesilata and Pihtili, 1991) As a result of the environmental impacts and higher prices of fossil fuel based sources (oil, coal, natural gas), the trend towards renewable energies. The sun is one of the most important natural energy resources. It has several good qualifications such as being clean, plentiful and renewable. It is a sphere with intensively hot gaseous matter with a diameter of 1.39×10^{11} m away. The sun has an effective surface temperature of 5778 K. It has the enormous untapped potential to supply our energy needs. Solar energy technologies offer a clean, renewable and domestic energy source and are essential components of a sustainable energy future (Menges vd, 2006). Solar radiation is the principal energy source that drives physical, biological and chemical processes such as snow melt, photosynthesis, evapotranspiration and plant development as well as solar energy applications such as solar furnaces, solar collectors, photovoltaics, and interior illumination of buildings (Evrendilek and Ertekin, 2008).

Turkey lies in a sunny belt between 36° and 42°N latitudes and is geographically well situated with respect to solar energy potential. Turkey's yearly average total sunshine duration is 2640 h and the yearly average solar radiation is 1311 kWh.m^{-2} (3.6 kWh.m^{-2}.d^{-1}).The highest and lowest solar energy potential of Turkey is in the Southeast Anatolian region with an average solar radiation of 14.37 MJ.m^{-2}.d^{-1} and sunshine duration of 8.2 h.d^{-1} and in the Black Sea region with an average solar radiation of 11.02 MJ.m^{-2}.d^{-1} and sunshine duration of 5.4 h.d^{-1} (Gunerhan and Hepbasli, 2007). The solar energy potential unconstrained by technical, economical or environmental requirements of Turkey is estimated as 88 million tones oil equivalent (toe) per year, 40% of which is considered economically usable. Three-quarters (24.4 million toe per year) of the economically usable potential is considered suitable for

thermal use, with the reminder (8.8 million toe per year) for electricity production (Ertekin vd, 2008a).

Solar energy systems convert solar energy into either thermal or electrical energy and such systems can either be passive or active systems. While the passive systems do not require input of any form of energy apart from the solar radiation, the active systems require additional mechanisms such as circulation pumps or automatic systems etc (Okafor and Akubue, 2012). Solar energy is used for a variety of heating systems such as domestic hot water systems and industrial applications. The use of solar energy for domestic hot water and steam generation in industry is economical and environmentally friendly. The most common way of using solar energy is through hot water by solar water heaters (SWHs). Hot water is required for domestic and industrial uses such as houses, hotels, hospitals, and mass-production and service industries. SWHs provide hot water at an average temperature of 50-70 ^{o}C, which can be retained to 40-60 ^{o}C until used next day morning (Ertekin vd, 2008b). Flat plate solar collectors are the most widespread solar thermal application in Turkey, which are generally used for the production of commercial and domestic hot water, especially throughout the coastal regions. The main important feature of this method is capturing solar energy that can reduce energy consumption for water heating (Capik vd, 2012). In 2008, Turkey had 12 million m^{2} of collector surface area installed (Keles and Bilgen, 2012). If the amount of incident solar radiation increases, the share of solar energy usage in water heating could be improved (Konaklioglu, 1988). The coverage rate of energy requirements for water heating in household consumption over Turkey by selective, copper and galvanized absorber plate solar water heaters were ranged between 64-100%, 44-89% and 41-88%, respectively. In addition, the payback periods (PBPs) were calculated by considering savings equivalent in electricity and liquid petroleum gas (LPG). The PBPs ranged between 2.98 and 12.28 years for electricity and between 2.02 and 5.04 years for LPG (Ertekin vd, 2008b).

Antalya is the fastest growing city in Turkey and tourist from all around the World are discovering its fabulous mix of great beaches and traditional Turkish culture. The total number of five star hotels in Antalya is more than all in Turkey. Antalya is also one of the leaders about having five star hotels in all around the World. The number of all facilities in Antalya is 862 and has bed capacities of more than 400 thousand (Anonymous, 2011; Internet, 2014). They generally use fossil energy sources for water heating processes and also pay huge money to receive this service. So, it could be better to cover this requirement by sun as possible as they can.

"The F-chart" is a method that provides an easy way to determine the thermal performance of the solar heating and hot water systems. This method is widely used in designing both active and passive solar heating systems,

in particular providing for the selection of collector capacity.

In this study, the design for hot water needs of different sized touristic facilities in Antalya, Turkey is analyzed theoretically by using F-chart method. At first, total solar radiation on the solar collector surface with the tilt angle of $\theta=36.91^0$ (latitude of Antalya, Turkey) is calculated, then annual fraction and heating load for different SWH areas and number of people is computed. In addition, two different types of collectors including flat plate and evacuated tube were analyzed and compared.

SOLAR COLLECTORS

The manufacturing of SWHs began in the early 60s. The SWH industry is expanded very quickly, in many countries of the World. In many cases, typical SWH is the thermosyphon type and consist of two flat plate solar collectors (FPCs) having an absorber area between 3 and 4 m^2, a storage tank with capacity between 150 and 180 L and a cold water storage tank, all installed on a suitable frame. An auxiliary electric immersion heater and/or a heat exchanger, for central heating assisted hot water production, are used in winter during the periods of low solar insolation. Another important type of SWH is the forced circulation type. In this system, only the solar panels are visible on the roof, the hot water storage tank is located indoors in a plant room and the system is completed with piping, pump and a differential thermostat. Obviously, this latter type is more appealing mainly due to architectural and aesthetic reasons, but also more expensive especially for small-size installations (Breeze vd, 2009).

For example, for Australia's energy consumption, about 20% is used for heating fluids to low temperatures (<100 ^{o}C). Because of this, the manufacturing of SWH has become an established industry in several countries, especially Australia, Greece, Israel, USA, Japan and China. The great majority of SWHs are domestic properties, despite the large volumes of hot water being used for process heat in industry.

The main component of any solar system is the solar collector which absorbs the solar radiation and converts it into heat. There are different solar collector types such as flat-plate, evacuated and concentrated. Solar energy collectors are basically distinguished by their motion such as fixed, single axes and two axis. In general, fixed collectors are used due to economical factors.

Non-focusing collectors absorb both beam and diffuse radiation and therefore still function when beam radiation is cut off by cloud. This advantage, together with their ease of operation and favourable cost, means that non-focusing collectors are generally preferred for heating fluids to temperatures less than about 80°C (Twidell and Weir, 2006).
The principal features of flat plate collectors are;
- A high transmission on transparent cover,

- An absorber plate coated with a high absorptance (solar) and low emittance (infrared) layer,
- A high conductivity absorber plate with fins and tube construction or low conductivity plate with short heat conduction paths through the absorber,
- Heat removal fluid passageways in good thermal contact with the absorber plate,
- Weather proof casing with insulation behind the absorber plate (Gordon, 2001).

FPCs typically include the following components; enclosure, glazing, glazing frame, insulation, absorber and flow tubes. A typical FPC is shown in Fig. 1. The solar radiation passes through a transparent cover (generally single or double glazed) and absorbs on the blackened surface of high absorptivity, then transferred to fluid for use. Flat-plate collectors are usually fixed in position that oriented directly to south. The performance of the solar collector is highly dependent on its orientation, optical and geometric properties, macro and microclimatic conditions, geographical position and the period of use. Collector orientation affects the collector performance by influencing the amount of solar radiation incident on the collector surface and transmittance of the transparent covers and the absorptance of the collector plate (Beckman vd, 1977; Kalogirou, 2004).
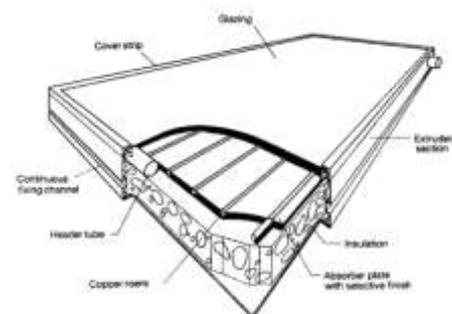
Fig. 1. Pictorial view of flate-plate solar collector.

The orientation of the solar collector is described by its azimuth (γ) and tilt angle relative to the horizontal and considered to be optimal when facing south ($\gamma= 0^{o}$) in the northern hemisphere. The optimum tilt angle depends on latitude (λ), solar declination or days of the year (Ertekin vd, 2008a). The optimum tilt angle is about the same to the latitude for domestic hot water (DHW) systems. Deviations from the optimum tilt angle as much as 15° have little effect on the annual performance of solar heating systems (Beckman vd, 1977).

The evacuated tube solar collectors (ETCs) consist of a heat pipe inside a vacuum-sealed tube, as shown in Fig. 2. ETCs have combination of a selective surface and an effective convection that resulting in high performance. ETCs work on the principle of using vacuum as an excellent insulating barrier, preventing heat loss primarily due to convection and conduction (Kalogirou, 2004).
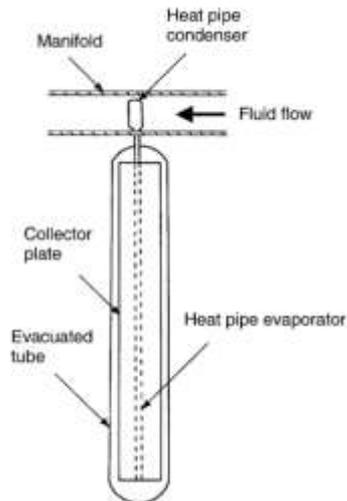
Fig. 2. Schematic diagram of an evacuated tube collector

Using a selective absorbing surface substantially reduces the radiative losses from a collector. To obtain larger temperature differences, it is necessary to reduce the convective losses as well. A method that gives better efficiency but is technically more difficult is to evacuate the space between the plate and its glass cover. This requires a very strong structural configuration to prevent the large air pressure forces breaking the glass cover; such a configuration is an outer tube of circular cross section. Within this evacuated tube is placed the absorbing tube.

Evacuated tube devices have been proposed as efficient solar energy collectors since the early twentieth century. In 1909, Emmett proposed several evacuated tube concepts for solar energy collection, two of which are being sold commercially today. With the recent advances in vacuum technology, evacuated tube collectors can be reliably mass produced (Goswami vd, 2000). From the 1990s, evacuated tube collectors have been mass produced in China mostly for domestic consumption and of a more sophisticated design using a central heat pipe within a central metal strip collector, in the UK. The manufacturing process, especially with automatic equipment, is sophisticated. The tubes should have a long lifetime, but are susceptible to damage from hailstones and vandalism.

ETCs are a relative newcomer on the solar hot water scene and are a serious departure from conventional flat plate collectors. These solar collectors consist of numerous (20 to 30) long, parallel glass or plastic tubes. Inside the each tube is a copper pipe as absorber tube coated with selective surface material. It runs down the center of an absorber plate, which increases the surface area for absorption. Air is pumped out of the glass or plastic tube, creating a vacuum, hence the name evacuated tube collectors (vacuums are poor conductors of heat and therefore great insulators).

Inside the each black copper pipe is a heat transfer fluid (typically methanol). It absorbs the heat created when

sunlight strikes the black selective surface of the absorber plate. Methanol flows upward naturally by convection to a heat exchanger at the top of the unit. Here, heat is transferred to another heat transfer fluid, typically high temperature non-toxic antifreeze (propylene glycol). It carries the heat to a solar water tank where it is transferred to water and stored for latter use. Cooled methanol returns to continioue the cycle.

There are several designs of vacuum solar collectors. The most widely used types of evacuated tube collectors are shown in Fig. 3. ETCs are much more sensitive than flat plate collectors in terms of optimal tilt angle. For solar domestic hot water systems where the required temperature of warm water, there is no clear advantage of evacuated solar collectors over the much cheaper flat plate collectors (Pluta, 2011). But it is important to use large plants and industrial applications. In addition, different design characteristics can be found from the literatures (Pihtili, 1980; Arinc, 1986; Beckman and Duffie, 1980)
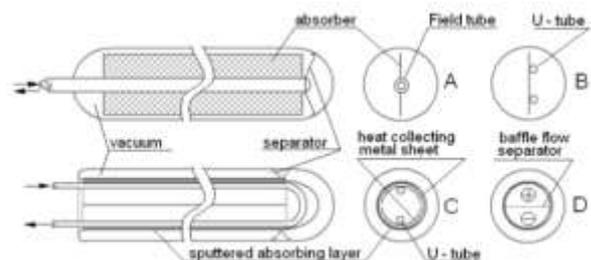
Fig.3. Two basic vacuum solar collectors design. A and B types are sometimes named as "Dornier-type" collectors, while C and D types are known as "Sydney type" or "all-glass vacuum tube" (Pluta, 2011).

F-CHART METHOD

The *F*-Chart method is an analysis that is useful for designing active and passive solar heating systems, especially for selecting the size and type of solar collectors supplying the SWH and heating loads. It was originally developed as part of the Dr. Sanford Klein's Ph.D. thesis, entitled "A Design Procedure for Solar Heating Systems" (1976), Klein et al. (1976a, 1977). The *F*-Chart method consists of result correlations of a large number of detailed simulations using TRNSYS, a transient systems simulation program by Klein et al. (1973) (Haberl, 2004; Stickney, 2010).

F-chart is the most popular solution method and is well-known, simple, user-friendly and precise. The purpose of the *F*-Chart method is to provide an estimate for the fraction of total heating load that will be supplied by solar energy for a given solar heating system (Pagnier, 1986).This method enables the calculation of the monthly or yearly amount of energy delivered by hot water systems with storage, given monthly values of incident solar radiation, ambient temperature and load (Anonymous, 2004). The performance predictions of *F*-Chart have been compared with calculations made by Transient System Simulation Program (TRNSYS) and

experimental results. The standard error between the TRNSYS simulation and the F-Chart results was about 2.5% and F-Chart predictions were found to be 1% to 5% lower than the experimental results (Okafor and Akubue, 2012; Redpath, 2012). Agreement between F-Chart simulations and measured results for most locations in the USA was regarded to be better than 3%, the worst agreement of 11% was found to be for locations such as Seattle where the climates had a higher diffuse component (Redpath, 2012).

The F-Chart method has provided a high standard in solar heating analysis in the USA for decades. Its capabilities go well beyond solar water heating and include the flexibility to handle passive solar collectors, pool heating, rock bins and thermal mass in buildings (Stickney, 2010).

The F-Chart method is a correlation of the results of many hundreds of thermal performance simulations of solar heating systems. The resulting simulations give f, the fraction of the monthly heating load (for space heating and hot water) supplied by solar energy as a function of two dimensionless parameters, X (Collector Loss) and Y (Collector Gain). X is related to the ratio of collector losses to heating loads, and Y is related to the ratio of absorbed solar radiation to the heating loads (Haberl, 2004). The ranges for major design parameters used in developing the correlations are given in Table 1.

Table 1. Ranges of design parameters used in developing the f-Charts for liquid systems.

$0.6 < (\tau\alpha)_n < 0.9$
$5 < F_R' A_C < 120 \ m^2$
$2.1 < U_L < 8.3 \ W.m^{-2}.C^{-1}$
$30 < \beta < 90^o$
$83 < (UA)_h < 667 \ W.C^{-1}$

The loss variable (X) is given by equation below;

$$X = F_R U_L \times (\frac{F_R'}{F_R}) \times (T_{ref} - T_a) \times \Delta t \times \frac{A_c}{L} \quad (1)$$

where F_R is collector heat exchanger efficiency factor, U_L is collector overall loss coefficient (W/m^2.°C), Δt is total number of seconds in the month, T_a is monthly average ambient temperature (°C), T_{ref} is an empirically derived reference temperature (100 °C), F_R'/F_R is the collector heat exchanger correction factor (0.97), A_c is collector area (m^2) and L is monthly total heating load for space heating and hot water (J).

X has to be corrected for both storage size and cold water temperature. The F-Chart method was developed with a standard storage capacity of 75 liters of stored water per square meter of collector area. For different sized storage tanks X has to be multiplied by a correction factor defined as (Anonymous, 2004);

$$\frac{X_c}{X} = \frac{(11.6 + 1.18T_w + 3.86T_m - 2.32T_a)}{(100 - T_a)}$$

$$(2)$$

where T_w is required hot water temperature (°C) and T_m is tap water temperature (°C).

The incident solar variable (Y) is given by;

$$Y = F_R(\tau\alpha)_n \times \frac{F_R'}{F_R} \times \frac{(\tau\alpha)}{(\tau\alpha)_n} \times H_T \times N \times \frac{A_c}{L} \quad (3)$$

where $(\tau\alpha)_n$ is monthly average transmittance-absorptance product, $(\tau\alpha)/(\tau\alpha)_n$ is the ratio of the monthly average to normal incidence transmittance-absorptance product (0.96), N is number of days in the month, H_T is monthly average daily radiation incident on the collector surface per unit area (J/m^2).

The monthly total heating load for hot water (L) can be calculated as;

$$L = p \times 75 \times c_p \times (T_w - T_m) \times N \quad (4)$$

where p is the number of people. The heating load increased by 10% for heat losses of the storage tank.

Once X and Y have been calculated, the monthly fraction of the load met by solar energy can be calculated as (Polagye and Malte, 2003);

$$f = 1.029Y - 0.065X_c - 0.245Y^2 + 0.0018X_c^2 + 0.0215Y^3 \quad (5)$$

The fraction f of the annual heating load supplied by solar energy is the sum of the monthly solar energy contributions divided by the annual load;

$$F = \frac{\sum_{i=1}^{12} f_i L_i}{\sum_{i=1}^{12} L_i} \quad (6)$$

If the formula predicts a value of F less than 0, a value of 0 is used, if F is greater than 1, a value of 1 is used.

The f-Chart method requires two values to describe a solar collector: the solar collector thermal performance curve slope ($F_R U_L$, W.m^{-2}.°C^{-1}) and intercept ($F_R(\tau\alpha)_n$, %) from standard collector tests (Fig. 4). These parameters include the F_R (Collector Efficiency Factor), U_L (Collector Overall Energy Loss Coefficient) and $\tau\alpha$ (Transmittance-Absorptance Product) (Haberl, 2004) (Table 2).

Table 2. Collector characteristics (Atmaca and Kocak, 2013).

Collector description	$F_R(\tau\alpha)_n$	$F_R U_L$
Flat-plate single glazed	0.6675	5.5
Evacuated, selective surface	0.7000	3.3
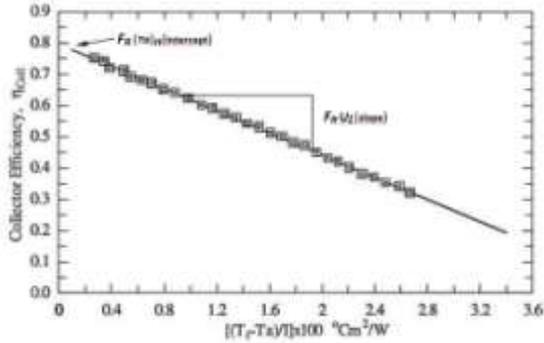
Fig. 4. Thermal performance of a typical solar collector.

In order to determine the monthly average daily total solar radiation on tilted surface (H_T) in equation (3) may be expressed as follows (Liu and Jordan, 1960);

$$H_T = (H - H_D)R_b + H_D\left(\frac{1+\cos\beta}{2}\right) + H\rho\left(\frac{1-\cos\beta}{2}\right) \tag{7}$$

where H is the monthly average daily global radiation on the horizontal surface, H_D is the monthly average daily diffuse radiation, R_b is the ratio of extraterrestrial radiation on the tilted surface to that on a horizontal surface for each month, β is the tilt angle of the heater and ρ is ground reflectance (≈ 0.2). This ratio can be estimated as for a surface facing directly towards the equator (Liu and Jordan, 1960);

$$R_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega' + (\pi/180)\omega'\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega + (\pi/180)\omega\sin\phi\sin\delta} \tag{8}$$

where ϕ is the latitude of the site, δ is the solar declination, ω is solar hour angle and ω' is the sunset hour angle for the tilted surface and given by;

$$\delta = 23.45\sin\left(360\frac{284+n}{365}\right) \tag{9}$$

$$\omega = \cos^{-1}(-\tan\phi\tan\delta) \tag{10}$$

$$\omega' = \min\left[\begin{array}{l}\omega = \cos^{-1}(-\tan\phi\tan\delta)\\\cos^{-1}(-\tan(\phi-\beta)\tan\delta)\end{array}\right] \tag{11}$$

where n is the day of the year and "*min*" means the smaller of the two items in the bracket (Beckman and Duffie, 1980);

To find out the value of the monthly average daily diffuse radiation (H_D), the below equation can be used (Aras vd, 2006);

$$\frac{H_D}{H} = 1.6932 - 8.2262\frac{H}{H_o} + 25.5532\left(\frac{H}{H_o}\right)^2 - 37.807\left(\frac{H}{H_o}\right)^3 + 19.8178\left(\frac{H}{H_o}\right)^4 \tag{12}$$

The average daily extraterrestrial radiation (H_o) can be calculated as follows;

$$H_o = \frac{24}{\pi}G_{sc}\left[1+0.033\cos\left(\frac{360n}{365}\right)\right] \times \left[\cos\varphi\cos\delta\sin\omega + \frac{\pi\omega}{180}\sin\varphi\sin\delta\right] \tag{13}$$

where G_{sc} is the solar constant (1367 W.m^{-2}).

RESULTS AND DISCUSSION

The main objective of this study is to compare and analyze the use of *F*-Chart method in the design for hot water needs of touristic hotels in Antalya, Turkey, which is located in the southern part of Turkey and is the seventh biggest city in the country by population and a main touristic attraction point by the south coast facing the Mediterranean.

The fraction of the annual load (*F*) to be supplied by solar energy with the number of collector is determined using Eq. 5. Monthly total heating load for hot water is calculated with Eq. 4 and increased by 10% for heat exchanger loss. The *f*-Chart has been produced for a storage capacity of 75 liters of stored water per square meter of collector area (Okafor and Akubue, 2012). In calculations, the ambient and tap water temperature was taken from the meteorological data and monthly average total solar radiation at the inclined surface was calculated according to the above mentioned method (Table 3). The fraction value is calculated for 50 collectors (each collector area was considered as 1.82 m^2) and 100 people at different required hot water temperatures of 40 °C, 50 °C and 60 °C, respectively (Fig. 5-7).

Table 3. Monthly average solar radiation (MJ/m^2), ambient temperature (°C) and tap water temperature (°C) for 50 °C required hot water in Antalya, Turkey.

Months	H_T (MJ/m^2)	T_m (°C)	T_a (°C)	L (GJ)	Flat plate collector			Evacuated tube collector		
					X	Y	f	X	Y	f
January	11.01	12.8	9.7	39.86	3.18	0.48	0.25	1.91	0.51	0.34
February	11.55	12.0	10.2	36.78	2.98	0.50	0.28	1.79	0.52	0.36
March	18.21	13.1	12.6	39.54	3.02	0.81	0.50	1.81	0.85	0.60
April	19.72	16.0	16.0	35.26	3.40	0.95	0.57	2.04	1.00	0.68
May	20.67	19.9	20.4	32.25	4.03	1.12	0.64	2.42	1.18	0.76
June	21.43	24.4	25.4	26.55	5.02	1.37	0.72	3.01	1.44	0.86
July	21.03	28.2	28.4	23.36	6.32	1.58	0.76	3.79	1.66	0.91
August	21.22	29.7	28.1	21.75	7.18	1.71	0.78	4.31	1.79	0.94
September	20.59	28.6	24.7	22.19	7.01	1.57	0.73	4.21	1.65	0.89
October	18.61	25.1	19.8	26.68	5.92	1.22	0.61	3.55	1.28	0.75
November	13.04	19.9	14.5	31.21	4.59	0.71	0.35	2.75	0.74	0.47
December	10.34	15.4	11.0	37.08	3.67	0.49	0.23	2.20	0.51	0.33
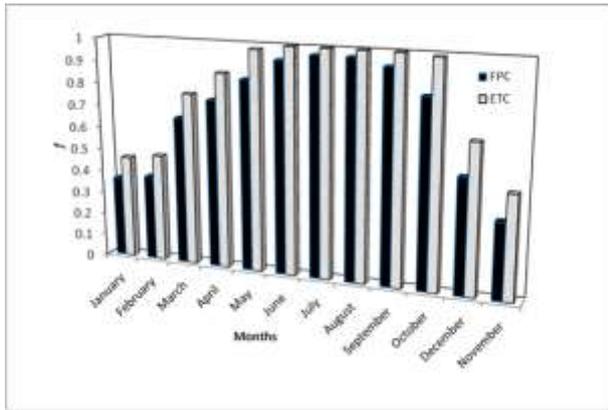
Fig.5. Solar fraction changes at the hot water temperature of 40 °C.
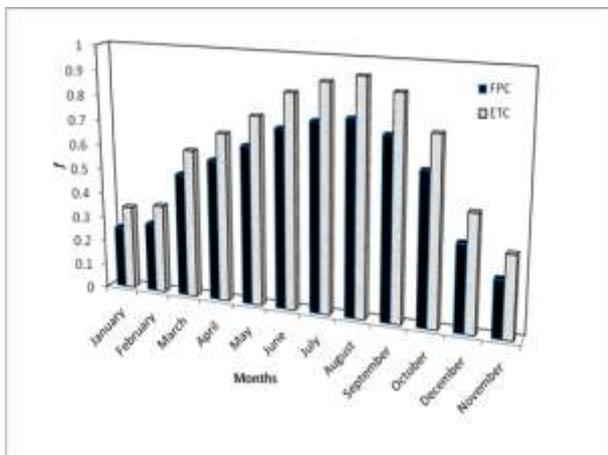
Fig. 6. Solar fraction changes at the hot water temperature of 50 °C.
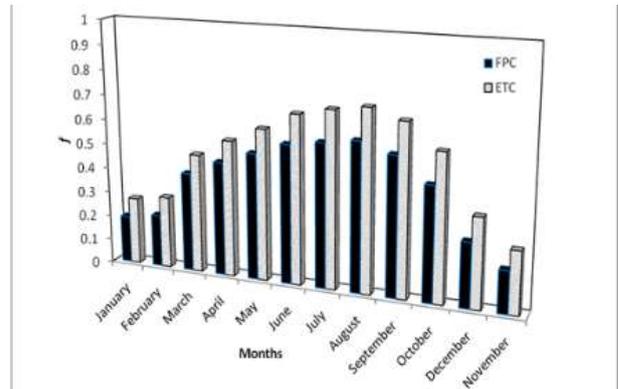
Fig. 7. Solar fraction changes at the hot water temperature of 60 °C.

As seen in the figures, the solar fraction is decreased by increasing required hot water temperature. In addition, at all required hot water temperatures, evacuated tube collectors covered much more requirement than flat plate collectors. While the solar fraction was ranged between 34% and 97%, 23% and 78%, 17% and 60% for flat plate collectors at hot water temperatures of 40, 50 and 60 °C, it was changed between 46% and 100%, 33% and 94%, 25% and 73% at the same conditions for evacuated tube collectors. In addition, the solar fraction values were higher in summer under all conditions. The annual system performance is obtained by summing the energy quantities for all months as given in Eq. 6 for two types of collectors. The annual fraction of the load supplied by solar energy is given in Table 4, where can be seen that the evacuated tube collector covers more energy requirement for water heating than flat plate collectors.

The solar fraction is increased by increasing number of collectors for different hot water temperatures (Fig. 8-9). While fewer collectors are required at lower hot water temperature of 40 °C, more collectors are needed

to reach the same solar fraction value at hot water temperature of 60 ^{o}C. When the different collector types were compared, the required number of ETC was lower than FPCs under all working conditions. While the number of collectors was ranged between 109 and 260 for FPCs, it was changed between 89 and 212 for ETCs to reach solar fraction of 100% (Fig. 10).

Table 4. The annual fraction of the load supplied for two type collectors (*F*) (50 collectors and 100 people)

T_w (^oC)	Flat plate collector F (%)	Evacuated tube collector F (%)
40	64	77
50	50	62
60	39	50
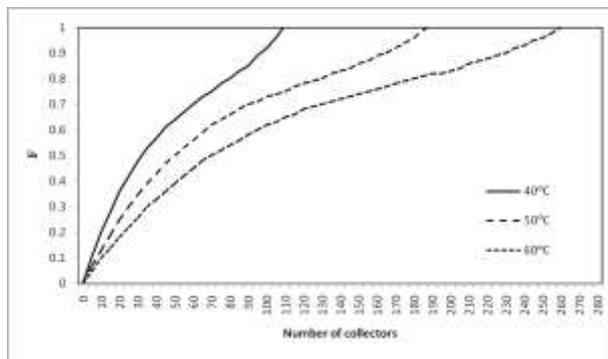
Fig. 8. Solar fraction for different collector numbers at different hot water temperatures for flat plate collectors.
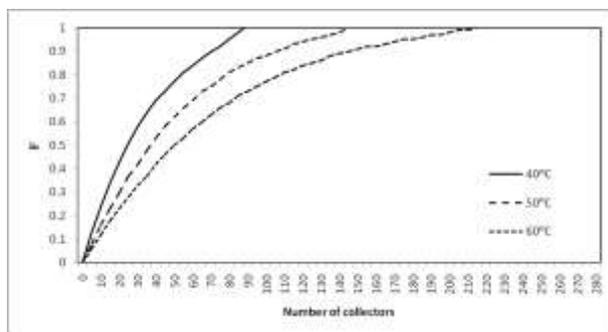
Fig. 9. Solar fraction for different collector numbers at different hot water temperatures for evacuated tube collectors.
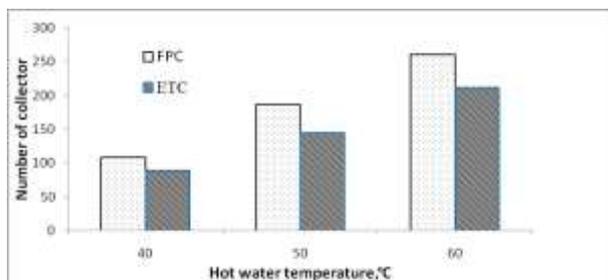
Fig. 10. Number of different collectors at different hot water temperatures for solar fraction of 100%.
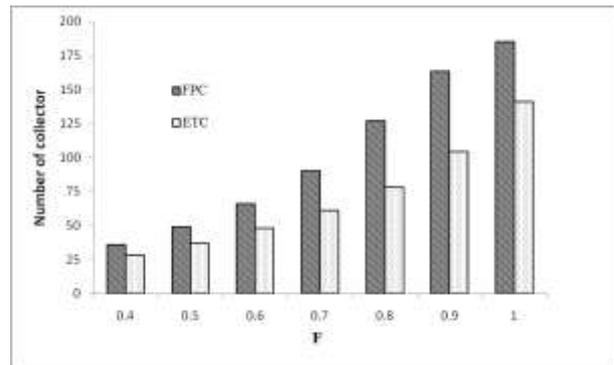
Fig. 11. Variety of solar fraction versus number of collector for 100 people at hot water temperature of 50 ^{o}C.

It is possible to decide how much required energy can be covered by solar collectors for hot water. In Fig. 11, it can be seen that, the amount of solar collectors needed is increased by increasing solar friction. While 28 ETCs are enough to reach solar friction of 40%, 36 FPC is needed for the same conditions. It was reached to 141 and 185 for ETCs and FPCs, respectively, for solar fraction of 100%. The required number of collectors was decreased around 22.22% and 38.58% by using ETCs.

CONCLUSIONS

It is possible to predict how much required energy can be covered by solar collectors for different types by f-chart method. According to this method, the f-value is calculated monthly and annually by two dimensionless variables as X and Y. In calculations, the meteorological data as average solar radiation, ambient temperature and tap water temperature changing between 10.34 and 21.43 MJ.m^{-2}, 12.0 and 29.7 ^{0}C, 9.7 and 28.4 ^{0}C is used respectively. According to the results, while the f-value ranged between 36% and 95% for FPCs, it was between 46% and 100% for evacuated tube collectors at required hot water temperature of 40 ^{0}C. This f-value is decreased by increasing required hot water temperature and it was higher for ETCs for 50 collectors and 100 people. The annual F-value ranged between 39% and 64% for FPCs, 50% and 77% for ETCs for required hot water temperature of 60 and 40 ^{0}C, respectively. In order to cover hot water requirement by solar collectors, the amount of collectors needed ranged between 109 and 260 for FPCs, between 89 and 212 for ETCs. In general, the number of collectors was decreased by using ETCs.

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Abdulkadir KOCER was born in Bolvadin, Afyonkarahisar in 1981. He graduated from the Mechanical Education Department of Gazi University Technical Education Faculty in 2002. In 2005, he obtained his MSc degree from the Mechanical Education Department of Gazi University in Ankara, Turkey. He is currently a PhD candidate in the Farm Machinery Department of Akdeniz University. He is also a lecturer in Vocational School of Technical Sciences of Akdeniz University since 2005. His main research fields are solar energy, computer programming and biomass energy.

Ibrahim ATMACA received his BSc in Mechanical Engineering from Uludag University, Turkey in 1999, and received his MSc and PhD in the Department of Mechanical Engineering from Uludag University in 2002 and 2006, respectively. He currently works as an Associate Professor in Akdeniz University, Turkey. His research interests are solar absorption cooling systems, thermal comfort, solar heat pump technologies, energy and exergy analyses.

Can ERTEKİN was born in Karsiyaka in 1970. He graduated Ege University, Faculty of Agriculture, Department of Farm Machinery in 1991. He received his PhD degree in 2001 at Akdeniz University. He currently works in Akdeniz University Faculty of Agriculture Department of Farm Machinery as a Professor and head of department. He is interested in solar applications in agriculture, drying technology and energy usage in agriculture.