Designing Solar Water Heating System For Anapatment in Tripoli -Libya

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Abstract:

In a step towards overcoming the increased energy demand of residential buildings in Libya, This study presents the design of solar water heating system for an apartment in Tripoli operating by thermo siphon, to provide the households by the required hot water for the domestic purpose.

In this study *f*-Chart method is used for this purpose, which is used by most researchers and professionals in the sector, due to its simplicity and ability to estimate the solar fraction (*f*), which is expressed as a percentage; is the contribution by the solar system to the average daily water heating requirements.

Once *f* is calculated, the amount of solar energy that displaces conventional energy for water heating can be determined. Solar fraction depends on several factors that include, among others, hot water consumption profile, system location, orientation and tilt angle of collector, and tank size. All data for this section are based on monthly daily averages of incident solar radiation, temperature, and atmospheric conditions.

Finally, this research shows the benefits that can be realized from this application, which includes the monthly and yearly amount of electrical savings and the quantities of harmful emission gases which can be avoided. Furthermore, some recommendations that support and spread the use of the solar water heating systems in Libya.

Introduction:

Problem Statement:

Hot water is required for many purposes and the sun can provide this heat. Using solar energy to generate hot water will

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prevent the use of the same amount of energyrequired by conventional source of energy for heating up the water. Using the sun's energy to heat water is not a new idea. More than one hundred years ago, black painted water tanks were used as simple solar water heaters in a number ofcountries [1]. Currently, heating water dominates the energy needs of households worldwide. In households in developing nations, heating water is often the most energy intensive process. In Libya, electric water heaters are the most dominant method of domestic water heating. Statistics published by the General Electric Company of Libya (GECOL) over the last few years, Figure (1) shows that 30% of the household electric consumption is for water heating [2].

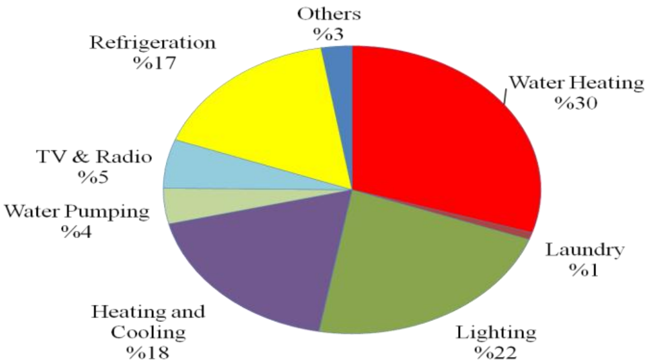

Figure (1): Classification of residential use of electric Energy in Libya (2006) [2].

To put this into perspective, it's worthwhile to mention that these GECOL report and other field studies [2] point out that the electrical energy consumption in the residential sector make up of 28 % of the overall national electric energyconsumption Figure (2).

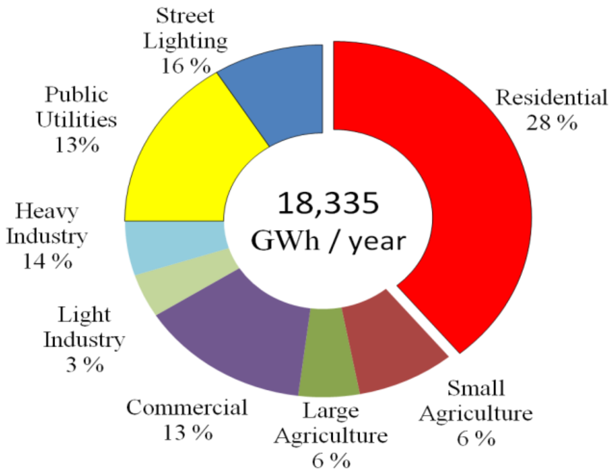

Figure (2): Classification of Electric Energy Consumption in Libya (2008) [2].

This clearly indicates that domestic water heating in Libya presents a huge burden on the national grid and on individual budget. Furthermore the government is focusing most of its attention and public sector work on residential provision [3]. This situation will surely lead to increase in demand for the hot water and subsequently will increase consumption of energy Figure (3).

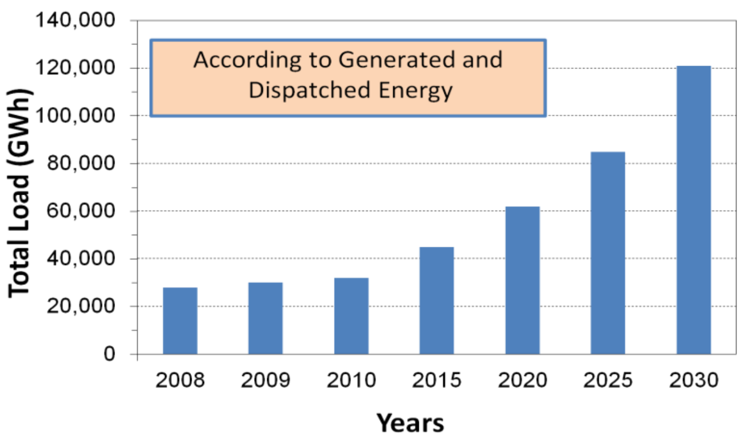

Figure (3): Annual increase of total electric energy demand in Libya [2].

Accordingly the use of solar water heating system will contribute in reduction of the energy consumption and greenhouse gases emission in the atmosphere.

Knowing that the solar radiation in Libya is suitable for this technology, where during the summer season, the monthly daily average of solar radiation on a horizontal plane is 7.1 kWh/ m^2. day in the coastal region, and 8.1 kWh/ m^2. day in the southern region, with average sun duration of more than 3500 hours per year [4]

Objectives:

In view of the problem stated above, it is felt essential to search for the ways and means of overcoming the increased hot water demand for residential use in Libya. This study aims to design a suitable solar water heating system for an apartment in Tripoli, to provide the household with the required hot water. The electric water heating will serve as a back-up for the solar water heating system.

Assump tions of the Study:

- Location: Tripoli, Libya (Latitude: 32.7°N, Longitude 13.2°E).
- Total number of persons in an apartment (5).
- The cold (mains) water temperature (assumed, Ta+5).
- The required hot water temperature (45°C).
- The required hot water per person (50 liters/day).

Methodology:

In order to determine the applicability of solar energy for heating water, it was decided that an *f*-Chart analysis would provide an adequate prediction of the heat that could be supplied by a solar water heating system. Before the analysis of the heating system could be undertaken, it was necessary to determine some meteorological characteristics. NASA website [5] provides basic data for the mean monthly air temperature and mean daily global radiation in Tripoli. In addition, the mean day for each month and declination on that day are also shown.

This data, however, cannot be directly applied in the *f*-Chart analysis. Firstly, it is necessary to calculate the sunset hour angle for each day. By knowing the sunset hour angle, it is possible to determine the integrated daily extraterrestrial radiation on a horizontal surface. The extraterrestrial radiation is the amount of radiation that would theoretically be received if there was no atmosphere. Subsequently, by taking the ratio of the mean daily extraterrestrial radiation to the measured daily mean global radiation, the mean daily clearness index was found. Then, by utilizing the Collares- Perreira and Rabl's correlation [6], the fraction of the diffuse radiation was calculated.

Finally, it is possible to determine the monthly mean daily radiation on the tilted surface. Having determined the radiation to which a tilted solar collector is exposed it is possible to determine the solar heating fraction that can be obtained from a solar energy system using the *f*-Chart method for a typical liquid heating system.

Results And Discussions:

Location And Site Conditions:

Solar radiation data were used from the NASA Surface meteorology and Solar Energy (SSE) website [5], at Latitude: $32.7°N$, Longitude $13.2°E$, for Tripoli, Libya. The website gives average monthly values for radiation incident on a horizontal surface. The monthly average air temperature was taken from reference [7]. Table (1) shows the monthly daily average solar radiation on horizontal surface and ambient air temperature.

Table (1): The monthly daily average of solar global radiation and air temperature in Tripoli.

Month	Ambient air temp.	Daily solar radiation horizontal
	°C	kWh/m^2.day
Jan	13.95	2.67
Feb	14.57	3.66
Mar	18.89	4.79
Apr	17.85	6.15
May	23.16	6.98
Jun	23.95	7.67
Jul	27.85	7.79
Aug	26.42	7.05
Sep	25.88	5.52
Oct	21.25	3.96
Nov	18.62	2.75
Dec	16.24	2.35
Annual	20.72	5.11

Determining Solar Radiation Values:

The monthly daily average radiation ($\bar{H}$) is obtained from Table (1), but the monthly daily average radiation on a tilted surface must be estimated based on the sun angles and the clearness index of the sky.

Declination (δ):

Declination (δ) is the angular position of the sun at solar noon with respect to the plane of the equator, north positive. $-23.45^{\circ} \leq \delta \leq 23.45^{\circ}$ [6]

Declination in degrees for any day of the year can be calculated by equation (1):

$$\delta = 23.45 * \sin\left(2\pi \frac{284+n}{365}\right) \quad (1)$$

Table (2) shows recommended average day for each month, and the corresponding value of n, and declination angle. Where {n: Number of the day of the year starting from the first of January (Dimensionless)[6].

Table (2): Monthly declination angle.

Month	***Date***	***n***	δ°
Jan	17	17	-20.917
Feb	16	47	-12.9546
Mar	16	75	-2.41773
Apr	15	105	9.414893
May	15	135	18.79192
Jun	11	162	23.08591
Jul	17	198	21.18369
Aug	16	228	13.45496
Sep	15	258	2.216887
Oct	15	288	-9.5994
Nov	14	318	-18.912
Dec	10	344	-23.0496

Sunset Hour Angle(ω_s):

The sunset hour angle ω_s is the solar hour angle corresponding to the time when the sun sets. Table (3) shows sunset hour angle for all months which is calculated by equation (2) (at the recommended day of each month):

$$\omega_s = cos^{-1}(-tan\,\emptyset\,tan\,\delta\,) \quad (2)$$

Where:

($\emptyset$)Latitude is the angular location north or south of the equator, north positive.

$$-90^{\circ} \leq \emptyset \leq 90^{\circ}.$$

Tilt Angle (β)

Tilt angle (β) is the angle between the plane surface and the horizontal position.

It's assumed that, the flat plate collectors facing south and tilted upward at the following angles:

- Case one $\beta = \emptyset - 15 = 17.7$ (deg) Fixed.
- Case two $\beta = \emptyset = 32.7$ (deg) Fixed.
- Case three $\beta = \emptyset + 15 = 47.7$ (deg) Fixed.

The Monthly Mean Radiation Tilt Factor($\bar{R}_b$):

By knowing the sunset hour angle (ω_s) for each day, and sunset hour angle on the tilted surface,(ω_s') by equation (3), it is possible to determine the monthly mean radiation tilt factor ($\bar{R}_b$)(it is equal to the ratio of the monthly average beam radiation on a tilt surface to that on a horizontal surface)by using equation (4), for a site in the northern hemisphere. Table (3) shows these values for different tilt angle.

$\omega_s' = \min \{\omega_s, \arccos [-\tan (\emptyset - \beta) \tan\delta]\}$ (3)

$$\bar{R}_b = \frac{\cos(\emptyset-\beta)\cos\delta\sin\omega_s' + (\pi/180)\omega_s' \sin(\emptyset-\beta)\sin\delta}{\cos\emptyset\cos\delta\sin\omega_s + (\pi/180)\omega_s \sin\emptyset\sin\delta} \quad (4)$$

Table (3):The monthly values of:ω_s°, ω_s'°, and $\bar{R}_b$ for different tilt angle.

		$\beta° = \emptyset° - 15$		$\beta° = \emptyset$		$\beta° = \emptyset° + 15$	
Month	ω_S	ω_s'	$\bar{R}_b$	ω_s'	$\bar{R}_b$	ω_s'	$\bar{R}_b$
Jan	75.796	75.796	1.484	75.796	1.786	75.796	1.966
Feb	81.508	81.508	1.328	81.508	1.509	81.508	1.586
Mar	88.447	88.447	1.177	88.447	1.240	88.447	1.219
Apr	96.111	92.547	1.048	90.000	1.013	87.454	0.911
May	102.618	95.231	0.963	90.000	0.869	84.769	0.723
Jun	105.881	96.558	0.928	90.000	0.810	83.442	0.647
Jul	104.407	95.960	0.943	90.000	0.836	84.039	0.680
Aug	98.835	93.675	1.010	90.000	0.948	86.324	0.826
Sep	91.424	90.594	1.123	90.000	1.143	89.406	1.086
Oct	83.767	83.767	1.275	83.767	1.414	83.767	1.457
Nov	77.294	77.294	1.440	77.294	1.707	77.294	1.859
Dec	74.147	74.147	1.536	74.147	1.878	74.147	2.092

Extraterrestrial Radiation ($\overline{\mathbf{H}}_{\mathbf{o}}$):

Solar radiation outside the earth's atmosphere is called extraterrestrial radiation. The monthly mean daily extraterrestrial radiation ($\overline{H}_o$)can be calculated with Equation (5) using n and δ for the mean day of the month from table (2),the depicted values are shown in table (4).

$$H_o = \frac{86400G_{sc}}{\pi}\left(1 + 0.033cos\left(2\pi\frac{n}{365}\right)\right)\left(cos\emptyset cos\delta sin\omega_s + \left(\frac{2\pi\omega_s}{360}\right)sin\emptyset sin\delta\right)(5)$$

Where:

G_{sc}:Is the solar constant equal to $1367W/m^2$, and all other variables have the same meaning as before.

Table (4): Monthly daily average Extraterrestrial radiation, $\overline{H}_o\ MJ/m^2$.

Month	n	$\delta°$	$\emptyset°$	$\omega_s°$	$\overline{H}_{\circ}$
Jan	17	-20.917	32.7	75.796	19.673
Feb	47	-12.9546	32.7	81.508	24.579
Mar	75	-2.41773	32.7	88.447	30.566
Apr	105	9.41489	32.7	96.111	36.339
May	135	18.7919	32.7	102.618	40.035
Jun	162	23.0859	32.7	105.881	41.401
Jul	198	21.1836	32.7	104.407	40.624
Aug	228	13.4549	32.7	98.835	37.669
Sep	258	2.21688	32.7	91.424	32.583
Oct	288	-9.5994	32.7	83.767	26.282
Nov	318	-18.912	32.7	77.294	20.793
Dec	344	-23.0496	32.7	74.147	18.274

Clearness Index, ($\overline{K}_T$):

Before reaching the surface of the earth, radiation from the sun is attenuated by the atmosphere and the clouds. The ratio of solar radiation at the surface of the earth to extraterrestrial radiation is called the clearness index. Thus the monthly average clearness index, $\overline{K}_T$, can be determined by equation (6).

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_0} \quad (6)$$

Where:

$\overline{H}$:the monthly average daily solar radiation on a horizontal surface.

$\overline{K}_T$: Values depend on the location and the time of year considered; they are usually.

between 0.3 (for very overcast climates) and 0.8 (for very sunny locations) [6].

Table (5): Monthlydaily average clearness index$\overline{K}_T$.

Month	$\overline{H}_0$ MJ/m^2	$\overline{H}$ MJ/m^2	$\overline{K}_T$
Jan	19.673	9.612	0.489
Feb	24.579	13.176	0.536
Mar	30.566	17.244	0.564
Apr	36.339	22.140	0.609
May	40.035	25.128	0.628
Jun	41.401	27.612	0.667
Jul	40.624	28.044	0.690
Aug	37.669	25.380	0.674
Sep	32.583	19.872	0.610
Oct	26.282	14.256	0.542
Nov	20.793	9.900	0.476
Dec	18.274	8.460	0.463

Average Insolation on Tilted Surfaces, ($\bar{H}_T$)

The monthly average radiation on the plane of the collector, ($\bar{H}_T$), can be calculated by using equations: (7), (8), (9), and (10). Figure (4).show the monthly values of ($\bar{H}_T$) for different tilt angles.

$$\bar{H}_T = \bar{H}_b\bar{R}_b + \bar{H}_d\left(\frac{1+cos\beta}{2}\right) + \bar{H}\rho_g(\frac{1-cos\beta}{2}) \quad (7)$$

Collares- Perreira and Rabl's correlation [6]:

- for values of the sunset hour angle ω_s: less than 81.4°:

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 \quad (8)$$

- for values of the sunset hour angle ω_s: greater than 81.4°:

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.82\bar{K}_T^3 \quad (9)$$

The monthly average daily beam radiation $\bar{H}_b$is simply computed from:

$$\bar{H}_b = \bar{H} - \bar{H}_d \quad (10)$$

Where:

ρ_g: Ground reflectivity.

$\bar{H}_b$:The monthly daily average beam radiation on a horizontal surface (MJ/m^2).

$\bar{H}_d$: The monthly daily average diffuse radiation on a horizontal surface (MJ/m^2).

$\bar{R}_b$: The monthly mean beam radiation tilt factor.

$\bar{H}_T$: The monthly daily average total solar radiation on a tilted surface(MJ/m^2)

The results are summarized in figure (4).

- Case one β = ϕ + 15 (maximum energy during winter).
- Case two β = ϕ (maximum energy on annual average).

- Case three β = ϕ − 15 (maximum energy during summer).

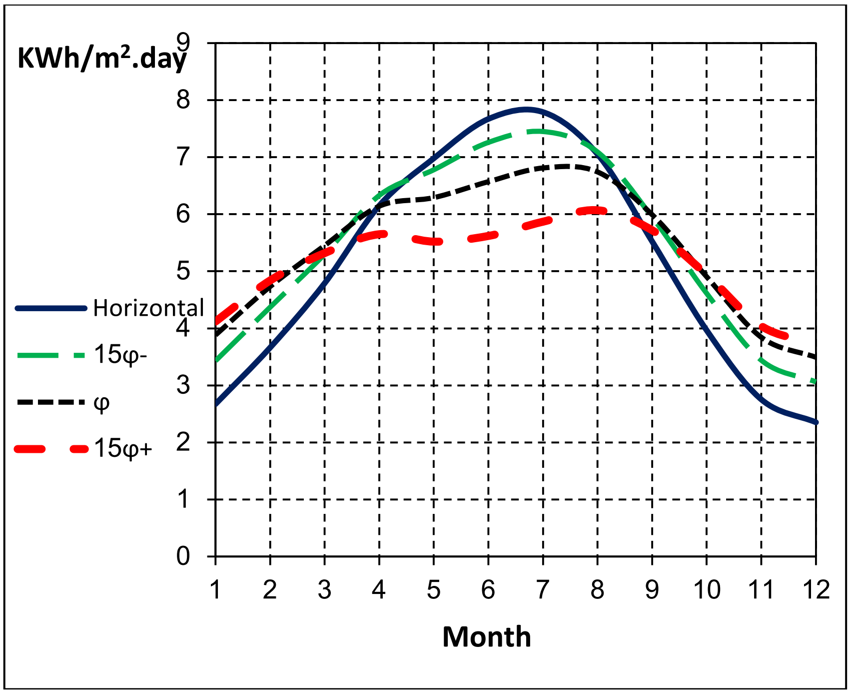

Figure (4): Monthly daily average insolation (kWh/m^2.day), at different tilt angles.

In this study, it was assumed that the stationary flat - plate collector, facing south and tilted up at latitude angle (i.e. 32.7 degrees).

The Selected Glazed Feat plate Collectors:

Typically, the performance of a glazed solar collector is modelled by the equation (11) [6].

$$\eta_c = \frac{Q_u}{A_c G} = F_R(\tau\alpha) - F_R U_L * \frac{(T_i - T_a)}{G} \tag{11}$$

Where:

η_c : Collector efficiency

Q_u:Useful energy output of a collector,(W)

A_c : Collector area, (m^2)

F_R: Collector heat removal factor

τ : The transmittance of the cover,

α : Absorptance

G : Global incident solar radiation on the collector (W/m^2).

U_L : Overall heat loss coefficient of the collector($W/m^2\ °C$)

$(T_i - T_a)$:The temperature differential between the working fluid entering the collector and the outdoors (°C).

$F_R(\tau\alpha)$:A parameter used to characterize the collector's optical efficiency (dimensionless).

F_RU_L : A parameter used to characterize the collector's thermal losses

($W/m^2\ °C$).

Parameters $F_R(\tau\alpha)$ and $F_RU_L$are determined from standard tests and are available for most collectors. The larger $F_R(\tau\alpha)$ is, the more efficient the collector is at capturing the energy from solar radiation. The smaller F_RU_L is, the better the collector is at retaining the captured energy instead of losing it through convection and conduction to the ambient air [8].

In this study, the selected glazed collector is ThermoDynamics collectors (S32-P,2013), where taken from RETScreen website [9] (Types of collectors available in this website) which provided with:

- $F_R(\tau\alpha)$ = 0.69
- F_RU_L= 4.81W/m^2. °C
- (Area 2.98m^2)

Losses Due to Dirt:

Dirt impact on the irradiance level is experienced by the collector. Therefore, $F_R(\tau\alpha)$is multiplied by $(1 - f_{dirty})$ where $(f_{dirty})$are the losses due to dirt expressed as a fraction of energy collected.

The value of this parameter depends on local climatic conditions, on the tilt angle of the collector, and on the presence of personnel on-site to clean the collector.

Solar water heating systemdepending on local conditions, use 2 to 5% for evacuated tube collectors rack-mounted on flat surfaces or well-maintained collectors, use 3 to 10% for other collectors [8].

In this study (f_{dirty}) assumed as average value (0.065).

$$F_R(\tau\alpha) = F_R(\tau\alpha) * (1 - f_{dirty}) \quad (12)$$

$$F_R(\tau\alpha) = 0.69 * (1 - 0.065) = 0.65 \quad (13)$$

Incidence Angle Modifier:

The average effect of angle of incidence upon the collector was estimated through simulations to be roughly 5%. Therefore, $F_R(\tau\alpha)$ is multiplied by a constant factor equal to 0.95 [10].

$F_R(\overline{\tau\alpha}) = F_R(\tau\alpha) * 0.95(14)$

$F_R(\overline{\tau\alpha}) = 0.65 * 0.95 = 0.62(15)$

After selecting the solar collector, sizing the rest of the system components depend on the operational characteristics and load pattern.

Estimated Load:

Load calculation is necessary for the service hot water (with or without storage) models. The actual load is calculated as the energy required to heat up mains water to the specified hot water temperature. If V_l is the required amount of water and T_h is the required hot water temperature, then the energy required $Q_{load}$is expressed as [10]:

$$Q_{load} = C_p \rho V_l (T_h - T_c) \quad (16)$$

Where:

- $C_p$is the specific heat of water (4.190 (kJ/kg.°C), ρ its density (1kg/L), and $T_c$is the cold (mains) water temperature(assumed, $T_a + 5$).
- Number of persons occupying anapartment$\cong$ 5 persons .
- The required hot water per person (50 L/day).
- The total hot water required (V_l) is 5*50=250 L/day.
- The required hot water temperature (T_h) (45 °C) .

Piping and Storage Tank Losses:

The water circulating in the pipes and the tank is hot, and since the pipes and the tank are imperfectly insulated, heat will be lost to the environment. Therefore, piping and storage tank losses are taken into account.

For systems with storage, to compensate the piping and tank losses, the load (Q_{load}) is increased to include piping and tank lossesas follow [10].

$$Q_{load,tot} = Q_{load}(1 + f_{los}) \quad (17)$$

Where:

$Q_{load,tot}$: Energy required including the tank and pipe losses(kJ).
In this study, assume the pipe losses 1.5 % and the tank losses 7.5 % (according to the RetScreen website [8].

$$Q_{load,tot} = Q_{load}(1 + 0.09)\ kJ/day$$

The required energy load to cover the hot water requirement is given in table (6).

Table (6): The monthly daily required loads.

Month	T_c °C	Q_{load} kJ/day	$Q_{load,tot}$ kJ/day	$Q_{load,tot}$ kWh/day
Jan	18.95	27287	29743	8.26
Feb	19.57	26638	29035	8.07
Mar	23.89	22113	24103	6.7
Apr	22.85	23202	25290	7.03
May	28.16	17640	19228	5.34
Jun	28.95	16812	18325	5.09
Jul	32.85	12727	13872	3.85
Aug	31.42	14225	15505	4.31
Sep	30.88	14791	16122	4.48
Oct	26.25	19641	21409	5.95
Nov	23.62	22396	24412	6.78
Dec	21.24	24889	27129	7.54
average	**25.72**	**20,197**	**22,014**	**6.12**

Storage Tank:

For domestic hot water applications, thermally insulated storage tank capacity is typically equal to the daily hot water use or a little less (Retscreen) [8] .Therefore, in this case, the storage capacity is 250 liter.

Estimating The Solar Area Required:

The thermal energy supplied by the solar system depends on the total collector area and the overall efficiency of the solar system. Where, the system efficiency is the ratio of "solar energy delivered" to "solar radiation incident on tilted surface".

It is common to adopt an estimate of the system efficiency, based on the designer's assumptions. They suggest the average system efficiency for a well-designed and well-installed SWH system is about 30% to 40% for flat-plate collectors, and about 40% to 45% for evacuated tube collectors [11].

Whereas, according to the RetScreen website [8], the SWH system efficiency is typically between 30 to 50 %, depending on climate, system size and water heating load. Generally, the greater the solar fraction, the lower the system efficiency (to obtain high solar fractions, the collector area is increased and the system operates more often at high temperature, with a lower efficiency).

The required collector surface area (A_C) can be estimated by the equation (18) [6], and the system efficiency assumed 35 %:

$$\text{Collector Area}(m^2) = \frac{\text{Daily heat requirement } at\ design\ time\ (kWh/day)}{\text{system efficiency} \times \text{Insolation}(\text{kWh/m}^2.\text{day})} \quad (18)$$

The design based on average annual condition:

- Daily heat requirement = 6.1 kWh/day ($Q_{load,total}$),
- Average system efficiency = 35 %, and Insolation = 5.40 kWh/m^2.day.
- Collector Area =

$$\frac{6.1\ \text{kWh/day}}{0.35 \text{ x } 5.40\text{kWh/m}^2.\text{day}} = 3.23\ \text{m}^2$$

- Since the area of the standard collector selected is 2.98m^2, then, therecommended area of the collectors will be; Ac = 2.98 m^2

The Performance of The System:

The performance of service hot water systems with storage is estimated with the *f*-Chart method. The purpose of the method is to calculate *f*, the fraction of the hot water load that is provided by the solar heating system (solar fraction). Once *f*is calculated, the amount of solar energy that displaces conventional energy for water heating can be determined [10].

Basic Equations of the *f*-Chart Method:

The mathematical model representing the *f*-Chart method was developed through the use of a dimensionless analysis by adopting two dimensionless parameters (X, Y). *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 [12].

Two dimensionless groups *X* and *Y* are defined as:

$$X = \frac{A_c F_R U_L (T_{ref} - \bar{T}_a)\Delta\tau}{L} \quad (19)$$

$$Y = \frac{A_c F_R (\overline{\tau\alpha}) \bar{H}_T N}{L} \quad (20)$$

Where:

T_{ref}= an empirical reference temperature equal to 100°C.

$\bar{T}_a$= monthly average ambient temperature(°C).

$\Delta\tau$ =total number of seconds in the month.

L = monthly total heating load(MJ).

$(\overline{\tau\alpha})$= monthly average transmittance-absorptance product.

$\bar{H}_T$= monthly daily average total solar radiation on a tilted surface(MJ/m^2).

N = number of days in the month.

(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 other storage capacities X has to be multiplied by a correction factor X_c/X defined by equation (21) [10]:

$$\frac{X_c}{X} = \left(\frac{\text{Actual storge capacity}}{\text{Standard storage capacity}}\right)^{-0.25} \quad (21)$$

This equation is valid for ratios of actual to standard storage capacities between 0.5 and 4. Finally, to account for the fluctuation of supply (mains) water temperature (T_m) and for the minimum acceptable hot water temperature (T_w) , both of which have an influence on the performance of the solar water heating system, X has to be multiplied by a correction factor X_{cc}/X defined equation (22) [10]:

$$\frac{X_{cc}}{X} = \frac{11.6+1.18T_w+3.86T_m-2.32\bar{T}_a}{100-\bar{T}_a} \quad (22)$$

The fraction f of the monthly total load supplied by the solar water heating system is given as a function of X and Y as:

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3 \quad (23)$$

There are some strict limitations on the range for which this formula is valid. 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 [10].

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 [6].

$$F = \frac{\sum_{i=1}^{12} f_i L_i}{\sum_{i=1}^{12} L_i} \quad (24)$$

Thus, the energy delivered from the solar heating system for each month can be calculated by $f_i\, L_i$ (i denotes the month), and the fraction of the annual heating load supplied by solar energy is determined by repeating the calculation of X, Y, and f for each month and summing the results as indicated by equation (24), and given in table (7) which shows monthly and annually performance of water heating system, and figure (5) shows the total required load , the useful energy obtained from the solar collector, and the shortage of energy thatis compensated electrically for each month.

Table (7): Monthly and Annual Performance of water heating system.

Month	$\bar{H}_T\ MJ/m^2$	Load,GJ	X	Y	f	f*L,GJ
Jan	13.97	0.92	4.28	0.87	0.48	0.44
Feb	17.02	0.81	4.91	1.09	0.58	0.47
Mar	19.62	0.75	5.63	1.5	0.76	0.57
Apr	22.11	0.76	5.48	1.61	0.81	0.62
May	22.65	0.6	7.44	2.16	0.91	0.55
Jun	23.66	0.55	8.2	2.38	0.94	0.52
Jul	24.50	0.43	11.01	3.26	1	0.43
Aug	24.28	0.48	9.71	2.9	0.99	0.48
Sep	21.58	0.48	9.64	2.49	0.92	0.44
Oct	17.64	0.66	6.6	1.53	0.73	0.48
Nov	13.83	0.73	5.76	1.05	0.52	0.38
Dec	12.55	0.84	4.84	0.86	0.44	0.37

Total		8.01				5.75

The annual fraction of the load supplied by solar energy is: F = 0.72

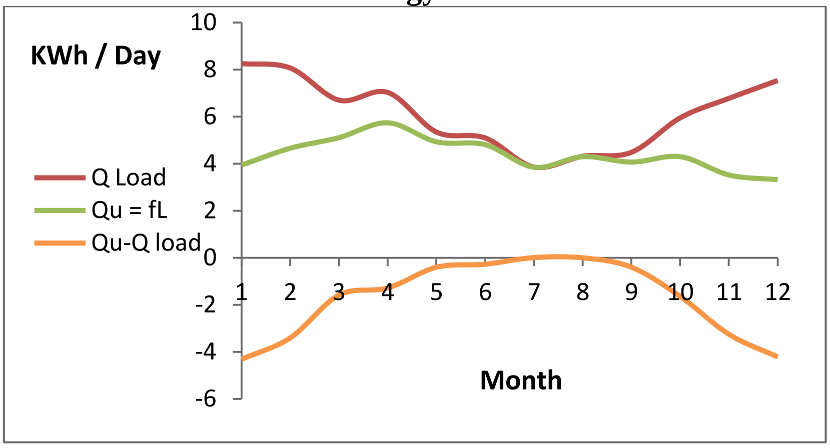

Figure (5): The totalrequired load, the useful energy obtained from the solar collector, and the shortage of the energy that is compensated electrically.

Energy Savings – Average Over full Year:

Over the year, the system will produce1,597kWh of energy. This will offset theenergy previously required from electric heater. Assuming the collectors offset energy previously required by an electric heater,taking an average cost of 0.05 L.D/kWh, this solar system can save 80L.D/ year in electricheating bills.

Layout:

Figure (6), shows the Schematic diagram of a thermosyphon solar water heater.

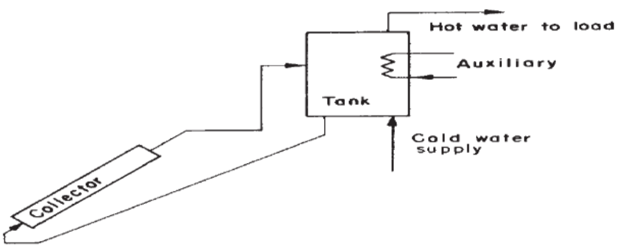

Figure (6): Athermosyphon solar water heater [6].

Environmental Benefits:

Utilizing renewable energy is not only economically beneficial but also environmentally sound. By using solar energy to heat the domestic water, less electricity is used, and generation of electricity decreases. Consequently, fewer fossil fuels are burned and the solar water heating system indirectly reduces greenhouse gas emissions.

Environmental benefits can be estimated through the estimate of the quantity of emissions to the environment associated with the generation of electrical energy from fossil fuels.Table (8) shows the rates of emission of gases and contaminants to the environment resulting from power generation [2].

Table (8): The rates of emission of gases and contaminants to the environment are resulting from power generation [2].

Pollutants	**The amount of pollutants (kg for 1 kWh/year)**	**Notices**
Carbon dioxide (CO2)	0.76	The leading cause of global warming.
Nitrogen oxides (NOx)	0.00057	Chemicals in the form of smoke Fogged and result in acid rain.
Sulfur dioxide (SO2)	4.50E-04	May cause permanent damage to the lungs.
(Ash)	1.13E-06	May cause allergic reactions and damage to the nose, throat, trachea and lungs.

Therefore, the estimated quantities of harmful gases to the environment can be avoided when the domestic water is heated by solar energy. As seen in Table (9), the most prominent pollutant is carbon dioxide which is the leading cause of the global warming. However, the use of solar collectors, lead to significant impacts on the environment by eliminating pollutants.

Table (9):The monthly and yearly amount of pollutants which can be avoided by using solar water heating system.

Month	Q_ukWh/month	CO_2 kg/month	No_x kg/month	SO_2 kg/month	Ash kg/month	Barrels oil
Jan	122.22	92.887	0.07	0.055	0.0001	0.22
Feb	130.56	99.226	0.074	0.059	0.0001	0.23
Mar	158.33	120.331	0.09	0.071	0.0002	0.28
Apr	172.22	130.887	0.098	0.077	0.0002	0.31
May	152.78	116.113	0.087	0.069	0.0002	0.27
Jun	144.44	109.774	0.082	0.065	0.0002	0.26
Jul	119.44	90.774	0.068	0.054	0.0001	0.21
Aug	133.33	101.331	0.076	0.06	0.0002	0.24
Sep	122.22	92.887	0.07	0.055	0.0001	0.22
Oct	133.33	101.331	0.076	0.06	0.0002	0.24
Nov	105.56	80.226	0.06	0.048	0.0001	0.19
Dec	102.78	78.113	0.059	0.046	0.0001	0.18
Annual	**1,597.21**	**1,213.88**	**0.91**	**0.72**	**0.002**	**2.85**

Conclusions:

Solar water heaters are a truly sustainable solution to water heating.

One square meter of solar collector produces 536kWh per year, approximately the equivalent of 1 barrel of oil, thus it is clear the amount of oil that can be annually saved when using the solar water heating system for a large number of houses.

Solar water heating system leads to reduce the peak load, and that would have a positive impact on the demand side management.

Environmental benefits: A meter square of solar collector can annually save407kg CO_2emissions, 0.31kgNO_x, 0.24kgSO_2, and 0.0007kg Ash.

The sizing of the solar water systems calculation showed that about 2.98 m2 of collector area with 250 liter of storage is fully capable of providing 1,597kWh/year whichis the equivalent of 72% of total annual demand for hot water.

Recommend at ions:

1. Prepare an educational and Propagandistic program, for the dissemination of scientific and technical awareness about the domestic solar water heating system.
2. Develop an action plan for the deployment of solar water heaters for domestic use in Libya, by replacing electric heaters in a phased manner with solar heaters.
3. Promote for a large-scale solar thermal systems for the buildings.
4. The need for the financial support for the benefit of the consumer to motivate him, and to make the solar system economically acceptable by the consumer.
5. The designs for new buildings need to be suitable for the installation of solar water heaters from the beginning.
6. Develop and adopt specifications and standards which are appropriate for the Libyan environment, to ensure the quality of application and consumer protection.
7. Apply solar water heating systems, in tourist facilities, health centers and others.

تصميم منظومة تسخين المياه المنزلية تعمل بالطاقة الشمسية لشقة بمدينة طرابلس– ليبيا

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المستخلص:

في خطوة نحو التَغَلُّب على المطلبِ المتزايدِ للماء الساخن في القطاع السكني في ليبيا، تقدم هذه الدراسة مقترحاً يتضمن تَصميم منظومة لتسخين المياه بالطاقة الشمسية لشقة في مدينة طرابلس تعمل بمبدأ التدفق الطبيعي (thermosiphon)، لتَزويد سكانها بالمياه الساخنة المطلوبة للأغراض المنزلية.

تم في هذه الدراسة استخدام طريقة مخططf (f-Chart method) لهذا الغرض، حيث أن هذه الطريقة تستخدم من قبل معظم الباحثين والمتخصصين في هذا المجال، وذلك لبساطتها ومقدرتها على تقدير الكسر الشمسي (f) الذي يعبر عنه كنسبة مئوية، حيث تمثل هذه النسبة مساهمة المنظومة الشمسية في الطاقة المطلوبة لتسخين المياه حسب متوسط الاحتياج اليومي. وبمعرفة هذه القيمة يمكن تحديد كمية الطاقة الشمسية التي تحلم الطاقةَ التقليدية َلتسخين المياه، ويعتمد هذا الكسر على العديد من العوامل، مثل سلوك استهلاك المياه الساخنة من قبل المستهلكين، والموقع الذي ستوضع فيه المنظومة، وتوجيه وزاوية ميل المجمعات الشمسية وحجم الخزان، وتمت الحسابات بناء على المتوسط اليومي الشهري للإشعاع الشمسي الساقط، ودرجة الحرارة، والظروف الجوية المحيطة.

وفي الختام يبين هذا البحث المنافع المتحصل عليها جراء استخدام هذه المنظومة الشمسية، التي تتضمن كمية وقيمة الطاقة الكهربائية التي تم توفيرها شهرياً وسنوياً وكذلك كميات الغازات المنبعثة الضارة التي تم تفاديها، إضافة إلى بعض التوصيات التي تدَعْم استخدام ونشر سخانات المياه الشمسية المنزلية في ليبيا.

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