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PERFORMANCE ANALYSIS AND DESIGN OF LIQUID BASED SOLAR HEATING SYSTEM

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ABSTRACT

Designing of a solar heating system involves appropriate sizing of different components based on predicted solar insolation and heating load demand. But, it is a complex problem due to unpredictable weather data components. A number of design methods are available for solar heating systems. In this paper, *f*-chart method has been used due to its simplified design procedure, analysis and low cost in selecting the sizes and type of solar collectors and in estimating the annual thermal performance of solar heating system. Using this method, the design of liquid solar heating system and the estimation of the fraction of total heating load (domestic water and space heating load) that will be supplied by solar energy for a family of six in Riyadh have been conducted. The study includes the effect of different collector areas and storage capacity per square meter of collector area and collector tilt angle on fraction of the load supplied by solar energy. It has been found that increasing the collector area results in an increasing of annual load fraction supplied by solar energy. It has also been seen that increasing the specific storage capacity results in small increase in solar load fraction and the effect is more visible during the summer than during the winter. The result of the study reveals that collector configurations with lower tilt angles are better during the summer and higher values of angles are better during the winter. The optimal annual collector configuration tilt angle which gives the maximum solar load fraction has been found to be 30^o.

1. INTRODUCTION

Energy generated by the sun is radiated outwards in all directions, and only two thousand-millionths of it is intercepted by the earth as light and infrared (heat) radiation. The intensity of the sun's radiation at the top of the earth's atmosphere at the mean distance of the earth from the sun is roughly constant (solar constant) with an observed value of 1353 W/m^2 [1].However, on average, only about half of this energy reaches the earth's surface .This is due to the fact that some of this solar radiation are reflected back into the space by clouds, absorbed by dust particles ,ozone and water vapor, while others are scattered by air molecules. It was found that Riyadh city in Saudi Arabia receives, on an annual average, 18.36MJ/m^2day of global solar radiation on horizontal surface [2]. However, effective utilization of solar energy in this country has not yet made reasonable progress mainly due to several barriers, some of which are listed as follows [3]: (i)the wide availability of oil, its superiority to solar energy as a source of energy and its relatively low cost, (ii) the dust effect, which in some parts can reduce solar energy by 10-20% and (iii) the availability of governmental subsidies for oil and electricity generation and non-availability of similar subsidies for solar energy programs.

Solar energy has wide range of applications such as heating of spaces, water desalination, production of hot water and steam for industries and in solar drying. It is also used in solar-powered thermal systems to generate electricity. Solar energy systems convert solar energy into either thermal or electrical energy. Solar heating, which is one of the solar energy conversion systems can be either passive or active systems. Passive solar heating is the capture, storage, and use of sun's energy for heating without the use of fans or pumps to aid in heat circulation (operates by using gravity, heat flow or evaporation), where as in active heating system, heat is produced in one place and moved to where it is needed by a fan or pump-propelled heat-transfer fluid such as air or water through ducts.

Designing of solar heating system which comprises of proper sizing of the components of a solar system is a complex problem as it involves unpredictable weather data conditions such as solar radiation and ambient temperature. It also includes predictable design condition: collector and components' performance characteristics. A number of design methods are available for solar heating systems. They can be put in 3 categories [1]: the first category applies to system in which collector operating temperature is known or can be estimated and for which critical radiation levels can be found out, e.g,utilizability method. Second category includes those that are correlations of the result of a large number of detailed simulations, e.g.: f-chart method. Third category involves short cut simulation in which simulations are done using meteorological data for representative days.

A number studies were undertaken in order to develop the design procedure for solar heating systems which provide a reasonably accurate result of monthly performance of the system with minimal effort.Palyvoset. al [4],for example, developed a standard design method for the purpose of quick-sizing of domestic hot water and space heating solar systems by driving a simple correlation so that long-term performance behavior is predicted.Another studywas the *f*-chart method developed by Klein et al. [5] which is applicable for many residential heating systems using liquid or air as the working fluid. It is widely used in designing both active and passive solar heating systems, especially in selecting the sizes and type of solar collectors that provide the hot water and space heating loads. Due to its simplified analysis, it has advantages of computational speed, low cost, rapid turnaround, which is especially important during iterative design phases, and easy to be used by persons with little technical experience [5].

In another different paper, Joudiet. al [6]made development of design charts for solar cooling systems by using computer simulation and developed a general design procedure for solar cooling systems and presented in a graphical form called the cooling *f*-charts which is similar to the f-chart method for solar heatingsystem. In another study, they compared the developed cooling f-chart predictions with the results of several experimental installations and verified the validity of design predictions by the new cooling f-chart [7].

One approach to the problem of determining economic solar heating system designs is to use computer simulations directly as a design tool. However, the use of computer simulations in the design of every solar heating application is not satisfactory for those architects and heating engineers concerned with the design of small buildings who do not have access to computing facilities. Simulation will remain an important design tool for large and nonstandard systems, but wide spread utilization of solar heating require a simplified design procedure for use by the heating industry, especially for standard types of systems where cost of detailed simulations cannot be justified[5].For these reasons, the *f*-chart has been developed.

The *f*-chart method is used to estimate the annual thermal performance of active building heating systems using a working fluid, which is either liquid or air, and where the minimum temperature of energy delivery is 20°C [1]. Using this method, the fraction of the total heating load that can be supplied by the solar energy system can be estimated. In the method, the primary design variable is the collector area, while the secondary variables are storage capacity, collector type, load and collector heat exchanger size, and fluid flow rate. The *f* -charts have been developed for three standard system configurations, liquid and air systems for space (and hot-water) heating and systems for service hot water only [1].

The solar heating system considered in this study is liquid based solar heating system and uses water as a working fluid. This is because water is in expensive, non-toxic and has high storage capacity based on both weight and volume. On other hand, since the system is thought to work for Riyadh weather condition, it is not subjected to extended freezing temperatures, i.e., freezing is not a problem. And thus, water-ethylene glycol which is used for freezing protection is not recommended here as it exposes to extra cost needed in operation and construction of such kinds of systems since the solution of glycol should be checked and changed every year[8].

In this paper, using f-chart method, the design of liquid solar heating system and the estimation of the fraction of total heating load (domestic water and space heating load) that will be supplied by solar energy for a family of six in Riyadh will be done. The study includes the effect of different collector areas and storage capacity per square meter of collector area and collector tilt angle on fraction of the load supplied by solar energy. The annual behavior of solar load fraction and the load variation with the months of the year will also be studied.

2. SYSTEM DESCRIPTION

The standard system configuration to be used under the study of this paper by the f-chart method is shown by schematic diagramof Figure 1.This system uses liquids (generally water or anti-freeze solution) as heat transfer fluid and water as storage medium [5].Flat-plate solar collectors are used to tranform incident solar radiation into thermal energy.This energy is stored in the form of sensible heat in a liquid storage tank and used as needed to supply the space and water heating loads.

The water-air heat exchanger, referred to as the load heat exchanger, must be used to transfer heat from storage tank to the building.An additional liquid-to liquid heat exchanger,shown in Fig.1, is used to transfer energy from the main storage tank to a domestic hot water system.A domestic hot water system consists of a pre-heat tank which supplies solar heated water to a conventional water heater.An auxiliary heater is provided to supply energy for the space heating load when the energy in the storage tank is depleted.

Controllers,relief valves,pumps and pipes make up the remaining equipment.The ranges of main design variables used in developing correlations for liquid based solar heating system are given in Table 1.

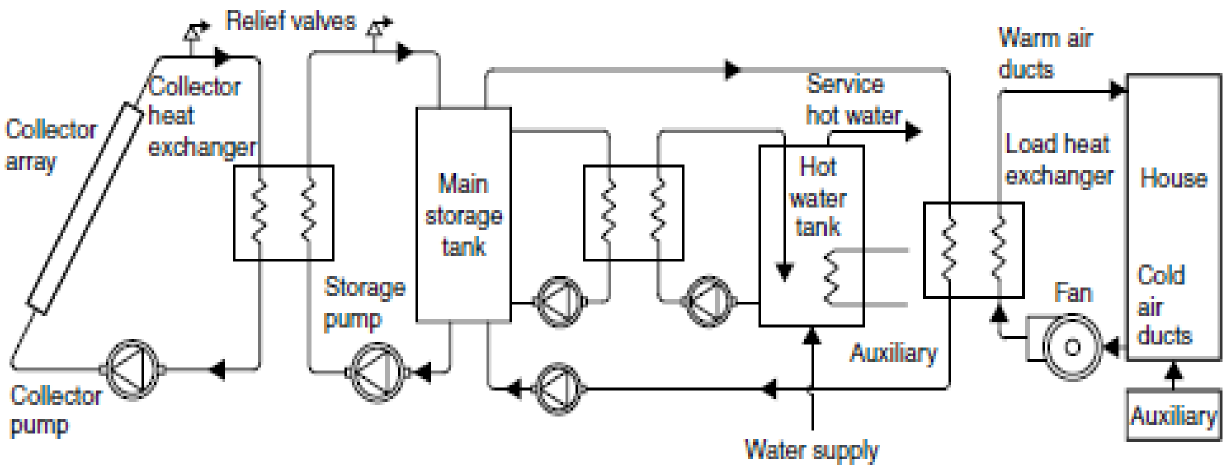

FIGURE 1. SCHEMATIC OF THE STANDARD SYSTEM CONFIGURATION OF LIQUID BASED SOLAR HEATING SYSTEM [8]

TABLE 1: RANGES OF DESIGN PARAMETERS USED IN DEVELOPING THE F-CHARTS FOR LIQUID SYSTEMS [5].

Parameter	Range
$(\tau\alpha)_n$	0.6-0.9
$F'_R A_c$	5-120m^2
U_L	2.1-8.3W/m^{2o}C
β (collector slop)	30-90^o
$(UA)_h$	83-667W/^{o}C

3. *f*-CHART METHOD

The *f*-chart method is based on correlations of the large number of simulations in terms of easily calculated dimensionless variables. The conditions of the simulations were varied over appropriate ranges of parameters of practical system designs. The resulting correlations give *f,* the fraction of the monthly heating load (in this case space heating and hot water) supplied by solar energy as a function of two dimensionless parameters. One is related to the ratio of collector losses to heating loads(X), and the other is related to the ratio of absorbed solar radiation to heating loads,Y.The result of simulations of systems for which f-chart is applied have been used to develop correlation between dimensionless variables and *f*,the monthly fraction of loads carried by solar energy.The dimensionless parameters X and Y are defined as follows [1], [5]:

$$X = \frac{Collector\ energy\ loss\ during\ a\ month}{Total\ heating\ load\ during\ a\ month}$$

(1)

$$Y = \frac{Absorbed\ solar\ radiation}{Total\ heating\ load\ during\ a\ month} \quad (2)$$

The parameters X and Y can be written as in equation 3 and 4 respectively.

$$X = \frac{A_c F'_R U_L (T_{ref} - \overline{T}_a)\Delta\tau}{L} \quad (3)$$

$$Y = \frac{A_c F'_R (\overline{\tau\alpha})\overline{H}_t N}{L} \quad (4)$$

where,
A_c= collector area (m^2)
F'_R= collector heat exchanger efficiency factor
U_L= collector overall loss coefficient (W/m^2◦C)
$\Delta\tau$ = total number of seconds in month
$\overline{T}_a$ = monthly average ambient temperature (◦C)
T_{ref}= empirically derived reference temperature (100˚C)
L= monthly total heating load for space heating and hot water (J)
$\overline{H}_T$ = monthly average daily radiation incident on collector surface per unit area(J/m2)

N = days in a month

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

For the purpose of ease of calculation, the values of dimensionless parameters X and Y in equation 3 and 4 are usually arranged as in equation 5 and 6 respectively. The reason for such an arrangement is that the value of factors $F_R U_L$ and $F_R(\tau\alpha)_n$ are obtained from the standard collector test results.The ratio F'_R/F_Rcorrects for various temperature drops between the collectorand the storage tank and is calculated by methods summarized in [1] and [5]. The ratio $(\tau\alpha)/(\tau\alpha)_n$is also estimated by the methods outlined in [1].

$$X = F_R U_L \frac{F'_R}{F_R}(T_{ref} - \bar{T}_a)\Delta\tau \frac{A_c}{L} \quad (5)$$

$$Y = F_R(\tau\alpha)_n \times \frac{F'_R}{F_R} \times \frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n} \times \bar{H}_T \times N \times \frac{A_c}{L} \quad (6)$$

where F_R is collector heat removal factor.

4. PERFORMANCE OF LIQUID BASED SOLAR HEATING SYSTEM

In this section thermal performance of the solar heating system shown in Fig.1 will be analyzed by using the f-chart method. Monthly solar fraction (solar energy contribution for each month), heating load and the solar energy contribution on annual basis are studied.

The fraction *f* of the monthly total load supplied by the solar space and water heating system (liquid system) is given as a function of *X* and *Y* in Figure 2. The relationship of *X*, *Y*, and *f* in equation form is [5]:

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3 \quad (7)$$

for 0<Y<3 and 0<X<18

Because of the nature of equation 7, it should not be used outside of the ranges shown by the curves of Figure 2.If a calculated point falls outside this range, the graph can be used for extrapolation with satisfactory results [1].

For the sake of ease, a simple degree-day method is used to calculate the monthly average space heating load needed by the system under this study. The degree-day method of estimating space heating load of a building is based up on the principle that the energy requirement for space heating is primarily dependent on the difference in temperatures between indoors and outdoors. The monthly space heating loads for a building maintained at 24°C is assumed to be proportional to the number of degree-days in a month, DD [1],

$$L_s = (UA)_h . DD \quad (8)$$

where L_s is space heating load and $(UA)_h$ is the loss –area product for the building. For this study a building with $(UA)_h$ of 467W/m²°C was taken from the design of the building. The number of degree days (DD) in a single day is the difference between 18.3°C and the mean daily ambient temperature (average of maximum and minimum daily ambient temperature).If the mean daily temperature is above 18.3°C the number of degree days is taken to be zero [5]. For Riyadh the number of *heating degree days*, monthly mean daily solar radiation and ambient temperature are shown in Table 2.

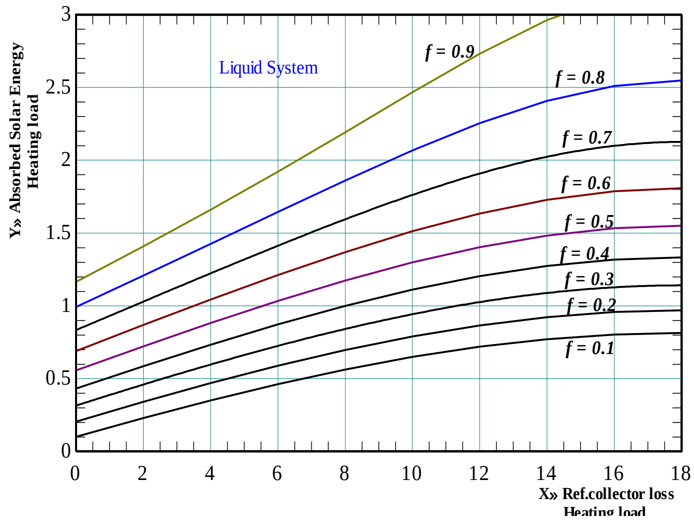

FIG. 2. THE *f*-CHART FOR SYSTEMS USING LIQUID HEAT TRANSFER AND STORAGE MEDIA [5].

The other load included in this study by the f-chart method is domestic water heating load (i.e, the amount energy required to heat water for domestic purposes).It is highly dependent on life style of the building occupants. On average for Riyadh, the estimated water demand and consumption is 300litre per person per day [11].

The monthly water heating load, L_w,is given by

$$L_w = N \times N_p \times V \times (T_w - T_m) \times \rho \times C_p \quad (9)$$

where

N = the number of days in a month

N_p = the number of persons in a family

T_w= the minimum acceptable temperature for hot water: It is $\approx$60°C [5].

V = daily water consumption per person in m³

T_m = main supply water temperature (°C)

ρ= density of water in kg/m³

C_p= Spacific heat of water (4190J/kg-°C).

The monthly total load (L) is the sum of space heating load (L_s)and domestic water heating load (L_w) given by [5].

$$L = L_s + L_w \quad (10)$$

The fraction of the monthly total load supplied by the solar space and water heating system shown in Figure 1 is given as a function of dimensionless parameters X and Y defined in equation 1, 2 and in Figure 2.To determine *f*,the fraction of heating load supplied by solar energy for a month, values of X and Y are calculated for the collector and heating load .The value of *f* is determined at the intersection point of X and Y on the chart of Figure 2.This is done for each month of the year. The solar energy contribution for the month is the product of *f* and the total heating load, L, for that month. The fraction of the annual heating load supplied solar energy, is then the sum of the monthly solar energy contributions divided by the annual load as in the following equation:

$$F = \frac{\sum f_i L_i}{\sum L_i} \quad (11)$$

TABLE 2. HEATING DEGREE-DAYS AND MONTHLY AVERAGE DAILY AMBIENT TEMPERATURE AND GLOBAL RADIATION FOR RIYADH [9], [10].

Month	Heating Degree-days	$\overline{T_a}$ (°C)	$\overline{H}$ (MJ/m²day)
January	133.3	14.2	12.6
February	43.9	16.5	16.5
March	0	20.8	18.36
April	0	26.4	19.8
May	0	31.7	20.16
June	0	33.9	21.96
July	0	35.2	21.96
August	0	35	21.24
September	0	32.3	20.52
October	0	27.4	19.08
November	0	21.6	16.56
December	95.43	16.4	12.96
Annual	**272.63**	**26**	**18.48**

5. INPUT DATA USED IN THE ANALYSIS

The performance analysis and the parametric study of the solar water and space heating system under consideration is done for a family of six members in RIYADH (latitude 24.72°N ,longitude 46.70°E and altitude 635m) using one cover collectors facing south with collector optimum tilt angle for Riyadh. The input data required to accomplish this study are:

I. The characteristics for the available collectors: F_RU_L=4.00W/m²°C,$F_R(\tau\alpha)_n$=0.74 and $(\tau\alpha)/(\tau\alpha)_n$= 0.96 as determined from the standard collector tests.
II. The water storage tank capacity is 150 liters per square meter of the collector.
III. The collector heat exchanger correction factor, F'_R/F_R,is 0.97.
IV. The building to be heated has loss-area product, $(UA)_h$, of 467W/m²°C.
V. The effectiveness of the water-air load heat exchanger, ε_L=0.70 and
VI. The minimum fluid capacitance rate ($C_{\min}$) has been taken to be 630W/°C.

6. DESIGN FOR LONG-TERM PERFORMANCE

Three design parameters are held at fixed values to generate the *f*-chart. These are: storage capacity per unit collector area, fluid flow rate per unit collector area and the size of the load heat exchanger relative to the size of space heating load. It is crucial to modify the *f*-chart standard calculation to estimate the changes in long-term performance due to changes in these parameters. This is done by modifying the values of X or Y as described in subsections 7.1 and 7.2.The calculated values of corrected parameters of X ,Y and total solar radiation are shown in Table 3.

6.1 STORAGE CAPACITY CORRECTION

It can be proven that the annual performance of liquid-basedsolar energy systems is insensitive to storage capacity as long as the capacity is more than 50 liters of water per square meter of collector area[1], [5].The *f* -chart shown in Figure 2 was developed by considering a standard storage capacity of 75 liters of stored water per square meter of collector area. It can also be used to estimate the performance of systems with storage capacities in the range of 37.5 to 300 liters/m²[5].This can be determined by multiplying the dimensionless group X by the storage size correction factor X_c/X shown by equation12 or from Figure 3 directly.

$$\frac{X_c}{X} = \left(\frac{Actual\,Storage\,Capacity}{Standard\;Storage\,Capacity} \right)^{0.25} \quad (12)$$

for $0.5 \le \left(\frac{Actual}{Standard} \right) \le 4.0$

where the standard storage capacity is 75liters of water per square meter of collector area [1].

6.2 LOAD HEAT EXCHANGER SIZE CORRECTION

The performance of the solar heating system is highly affected by the size of the load heat exchanger. This is due to the fact that the rate of heat transfer across the load heat exchanger directly affects the temperature storage tank which then affects the collector inlet temperature. A measure of the size of the heat exchanger needed for a specific building is provided by the dimensionless parameter, $\varepsilon_L C_{\min}/(UA)_h$, where $\varepsilon_L$is the effectiveness of the water-air load heat exchanger, $C_{\min}$ is the minimum fluid capacitance rate in the load heat exchanger and is generally that of the air, and $(UA)_h$is the overall energy loss coefficient–area product for the building used in the degree-day space-heating load model. Practical values of $\varepsilon_L C_{\min}/(UA)_h$are generally between 1 and 3 when the cost of the heat exchanger is considered[5].The *f* -chart for liquid systems was developed with $\varepsilon_L C_{\min}/(UA)_h$= 2. The performanceof systems having other values of $\varepsilon_L C_{\min}/(UA)_h$can be estimated from the *f* –chartby modifying Y by a load heat exchanger correction factor Y_c/Y, as indicated in Equation *13* or Figure 4[5].

$$\frac{Yc}{Y} = 0.39 + 0.65 e^{\left(-0.139\frac{(UA)_h}{\varepsilon_L C_{\min}}\right)} \quad (13)$$

$$\text{for } 0.5 < \left(\frac{\varepsilon_L C_{\min}}{(UA)_h}\right) < 50$$

6.3 COLLECTOR LIQUID FLOW RATE CORRECTION

The dependence of the system performance on the collector flow rate is asymptotic; only a small increase in collector heat removal factor,F_R (and thus only a small gain in energy collection) is possible if the collector fluid capacitance rate is increased beyond about 50W/^{o}C per square meter of collector area which corresponds to an antifreeze solution flow rate of about 0.015Lit/s-m^2 [5]. The correlations in the f-chart were obtained using collector fluid flow rate equivalent to 0.015Lit/s of antifreeze solution per square meter of collector area [5].However, since a change in the collector liquid flow rate generally has only small effect on system performance, the correlation developed in f-chart for liquid systems are applicable for all practical collector liquid flow rates.

7. RESULTS AND DISCUSSION

In this section, the result of heating load demanded, the fraction of the load supplied by the solarenergy system for different collector areas and the parametric studies are discussed. From figure 5 and table 3, we can clearly see that increasing collector area results in increasing of annual load fraction supplied by solar energy. But increasing of collector area is limited by the economics and information of this type is used in the study of economics of solar heating.

Figure 6 illustrates the variation of monthly load fraction for four different collector areas over the year. It can be noticed that the monthly load fraction rises with collector area. It also shows that the monthly fraction is higher for summer months in Riyadh (August being with the highest value) and lower for winter months (January being with lowest value).

The variation of total heating load, space heating load and domestic water heating load with the months of the year is depicted in Figure 7. It is observed that the lowest heating load is seen during the summer months of the year. Infact, this is the time during which the demand for the heating load is minimum. The figure also indicates that the space heating load is available only during three months namely, December, January and February. For the rest of the month, the space heating load is almost nil. This is a very interesting result due to the fact that the load matches the winter peak demand during which the space heating load is needed and this result also provides an important benefit from economic point view by reducing the total cost of fuel/electricity which would have otherwise been expended for the energy needed for heat supply required during winter time.

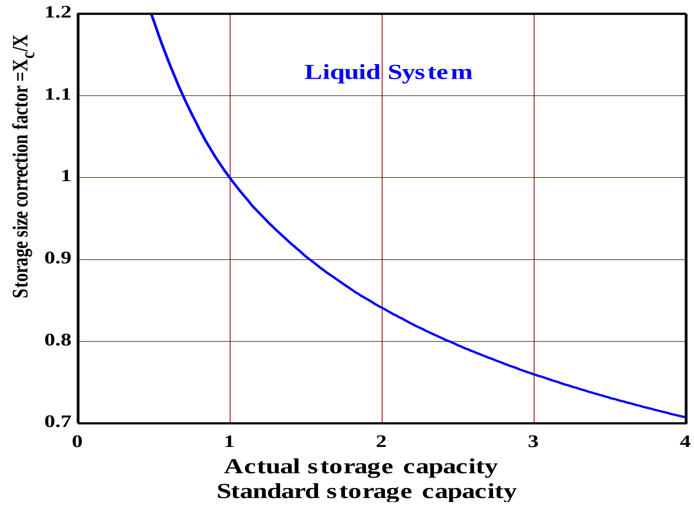

FIG 3. STORAGE SIZE CORRECTION FACTOR FOR LIQUID SYSTEMS [1]

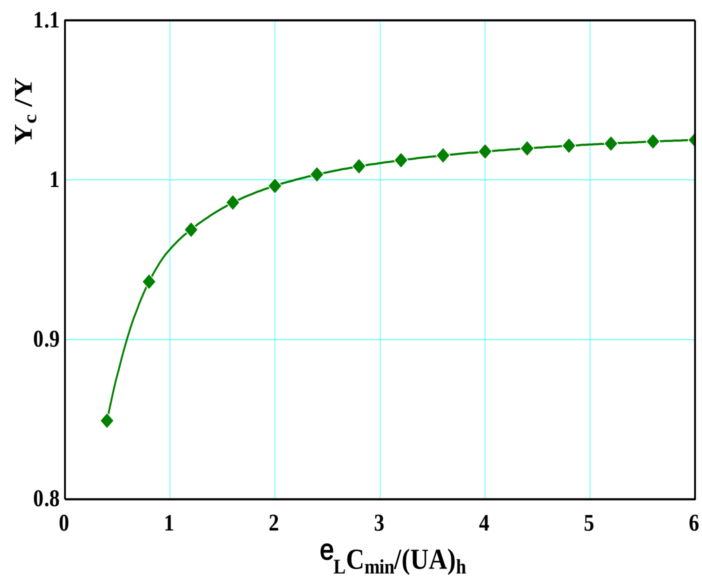

FIGURE 4. LOAD HEAT EXCHANGER SIZE CORRECTION FACTOR [1]

Figure 8 illustrates the effect of actual storage capacity in liters per m^2 of collector area on annual load fraction supplied by solar energy. It indicates that the annual load fraction increases by small amount and greater fraction is seen in larger collector area of 25m^2. Specifically, if storage capacity is greater than around 50 Liters of water per m^2 of collector area, only small increase (improvement) is seen in the annual load fraction supplied by solar energy.

Figure 9 describes the behavior of the solar fraction during the year for three different tilt angles of the solar collector: 20°, 30°, and 40°.This figure illustrates that the difference in percentage between the solar fraction due to decreasing of collector tilt angles from 40^o to 20^o, increases from minimum value of 1.2% in March till it reaches the peak value of 11% in July and then declines to take the next minimum value of 2.02% in October. It is also observed that configurations with lower angles are better during the summer and higher values of angles are better during the winter. This is due to the sun's apparent position during the year. But it has been found and shown in figure 10 that for Riyadh, the optimal annual collector configuration tilt angle which gives the maximum solar load fraction is found to be around 30^o.

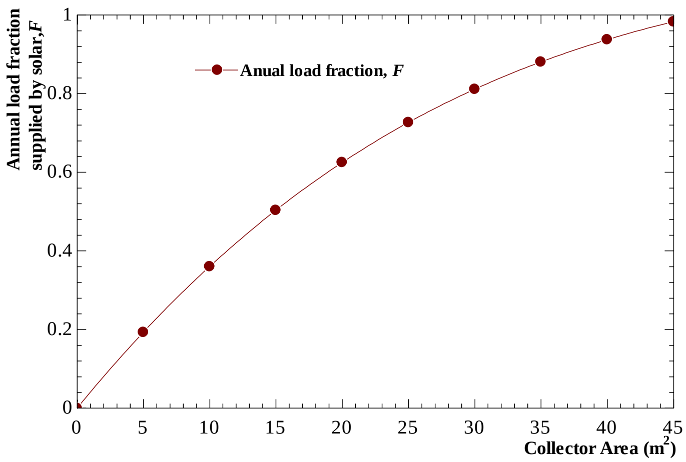

FIGURE 5. EFFECT OF COLLECTOR AREA ON ANNUAL LOAD FRACTION SUPPLIED BY SOLAR ENERGY

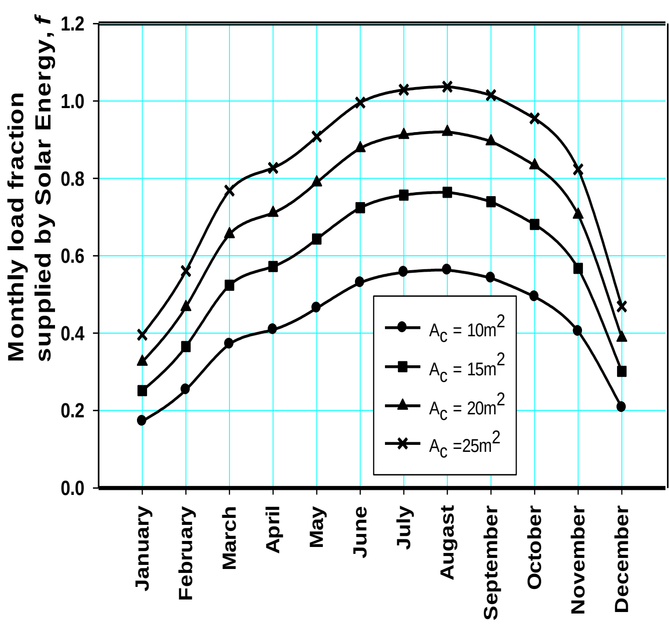

FIGURE 6. VARIATION OF MONTHLY LOAD FRACTION SUPPLIED BY SOLAR ENERGY FOR DIFFERENT COLLECTOR AREAS.

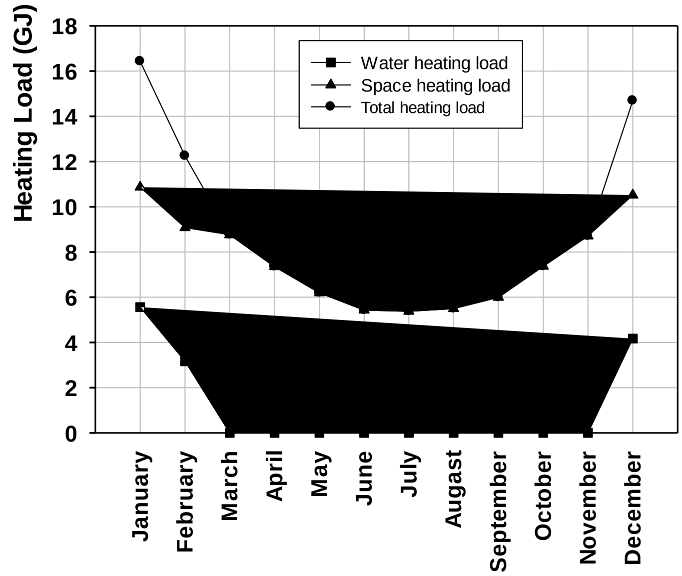

FIGURE 7. MONTHLY HEATING LOAD VARIATION

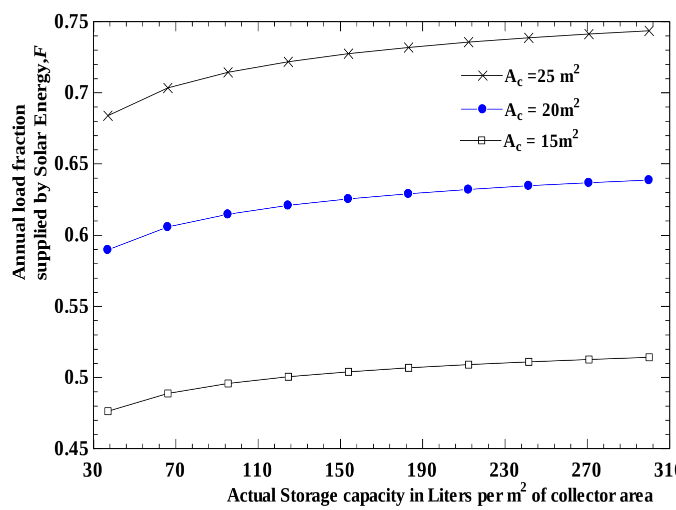

FIGURE 8. VARIATION OF ANNUAL LOAD FRACTION SUPPLIED BY SOLAR ENERGY WITH ACTUAL STORAGE CAPACITY IN LITERS PER m^2 OF COLLECTOR AREA.

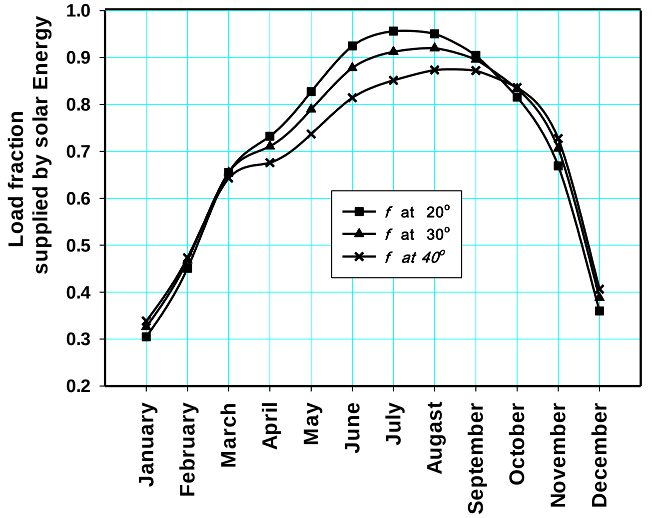

FIGURE 9. MONTHLY SOLAR FRACTION WITH THREE DIFFERENT TILT ANGLES OF SOLAR COLLECTOR

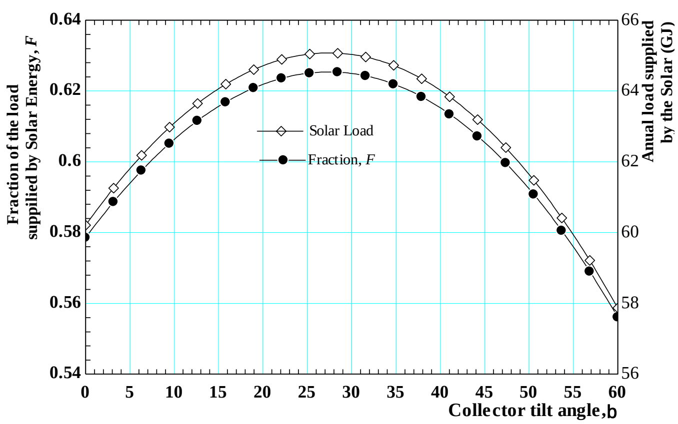

FIGURE 10. EFFECT OF COLLECTOR TILT ANGLE ON SOLAR LOAD AND ANNUAL LOAD FRACTION SUPPLIED BY SOLAR ENERGY

Figure 11 shows the behavior of the solar fraction during the year for three different specific storage capacities: 60Lit/m^2,160 Lit/m^2, 260 Lit/m^2. This variation is very simple, the more the mass, the more the fraction is.It is observed in the same figure that increasing the storage capacity from 60Lit/m^{2}to 260Lit/m^2 results in increasing of solar fraction from minimum value of 0.29 in January till it reaches the maximum value of 0.97 in July and then decreases attaining the next minimum value of 0.37 in December. In other words , because of the storage capacity change from 60 to 160Lit/m^2, theeffect of solar contribution percent is minimum in January with 2.18% and increases to peak value of 4.5% in July and then declines to 2.38% in December. This means that for the months of January, February, March, November and December the effect of storage capacity is negligible as compared to the remaining months. In conclusion, the effect due to the change of storage
capacity is more visible during the summer than during the winter time.

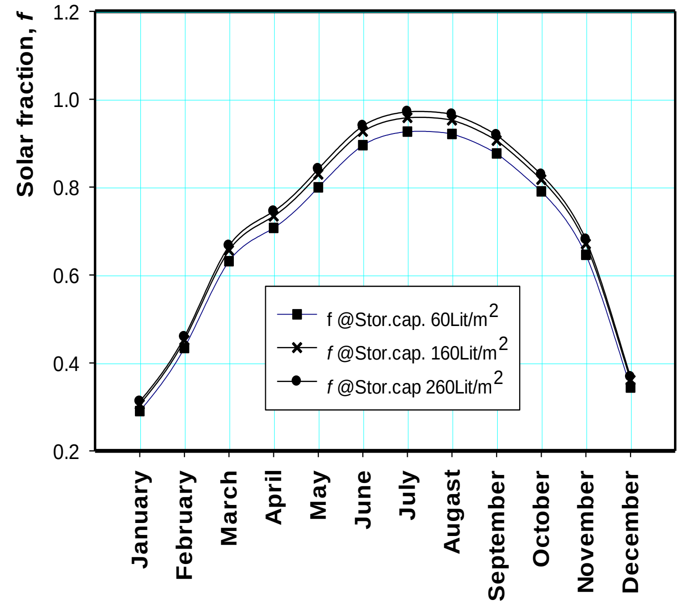

FIGURE 11. SOLAR FRACTION WITH DIFFERENT STORAGE CAPACITIES

8. CONCLUSION

In this paper, using f-chart method, the design of liquid solar heating system and the estimation of the fraction of total heating load (domestic water and space heating load) supplied by solar energy for a family of six in Riyadh has been conducted. The following can be concluded from this study:

- Increasing collector area results in increasing of annual load fraction supplied by solar energy.
- Monthly solar fraction contribution is higher for summer months (August being with the highest value) and lower for winter months (January being with lowest value).
- The peak value of heating load is during the month of January while the lowest heating load occurs during the summer months of the year. This indicates that heating load variation is in phase with the heating load demand.
- The difference of contribution of solar fraction due to the effect of collector tilt angles increases from minimum value in March and reaches the maxim value in July.
- It has been found that for Riyadh, the optimal annual collector configuration tilt angle which gives the maximum solar load fraction is found to be around 30^o.
- The effect due to storage capacity difference is more visible during the summer months than at the time of winter months.

TABLE 3. TOTAL SOLAR RADIATION AND CORRECTED PARAMETERS

Month	$\overline{H}_T$ (MJ/m^{2}day)	X/A_c	Y/A_c	[a]Corrected X/A_c(m^{-2})	[b]Corrected Y/A_c (m^{-2})
January	16.67	0.05471	0.02167	0.045956	0.020609
February	20.07	0.06361	0.03161	0.053432	0.030062
March	19.7	0.09186	0.048	0.077162	0.04565
April	18.97	0.09915	0.05333	0.083286	0.050719
May	17.9	0.1115	0.06173	0.09366	0.058707
June	18.78	0.1185	0.0715	0.09954	0.067999
July	19.05	0.1218	0.0757	0.102312	0.071993
August	19.65	0.1201	0.0764	0.100884	0.072659
September	21.09	0.1115	0.0727	0.09366	0.06914
October	22.42	0.1009	0.06503	0.084756	0.061846
November	21.99	0.09063	0.05219	0.076129	0.049634
December	17.9	0.06014	0.02603	0.050518	0.024755

[a]Storage size correction factor,X_c/X=0.840 , [b]*Load heat exchanger correctiofactor,Y_c/Y=0.951*

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NOMENCLATURE

$A_c$collector area (m^2)
C_{min} the minimum fluid capacitance rate
F'_Rcollector heat exchanger efficiency factor
$F_R$collector heat removal factor
f fraction of the monthly heating load supplied by solar energy
*F*fraction of the annual heating load supplied by solar energy
$\overline{H}_T$ monthly average daily total radiation incident on collector surface per unit area
Lmonthly total heating load for space heating and hot water (J)
$L_s$space heating load (J)
$L_w$domestic water heating loads(J).
N days in a month
$N_p$number of persons in a family
X ratio of collector losses to heating loads
Y ratio of absorbed solar radiation to heating loads
X_c/X storage size correction factor
Y_c/Yload heat exchanger correction factor
$U_L$collector overall loss coefficient (W/m^2◦C)
$(UA)_h$overall energy loss coefficient–area product for the building (W/◦C)

$\Delta\tau$ total number of seconds in a month
$\overline{T}_a$ monthly average ambient temperature (◦C)
T_{ref}reference temperature
$T_m$main supply water temperature
$T_w$the minimum acceptable temperature for hot water(^{o}C).
$\overline{\tau\alpha}$ monthly average transmittance-absorptance product
V daily water consumption per person in m^3
ρ density of water in Kg/m^3
$C_p$spacific heat of Water(J/Kg-^{o}C).
$\varepsilon_L$effectiveness of the water-air load heat exchanger

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