Design Of Active Solar Water Heating System Using F-Chart Method

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Abstract

Design of a solar system is complex because of the presence of both predictable and unpredictable parameters. Predictable parameters include performance characteristics of collectors and other components and the latter mainly concern weather data such as solar radiation, ambient temperature, wind speed and direction. This work analyzes the use of f-chart method in designing liquid solar heating systems due to its simplicity and ability to estimate the fraction of total heating load supplied by solar heating system. This method can be used for designing both active and passive solar heating systems, especially in selecting the sizes and type of solar collectors that provide the hot water and heating loads. Paper includes the design of a solar water heating system for a family of six members in CALICUT using f-chart method. Variation of fraction of total load supplied by solar energy is studied. Optimum collector area for the required load is found out

1. Introduction

Proper design of solar water heating system is important to assure maximum benefit to the user, especially for a large system. Designing a solar hot water system involves appropriate sizing of different components based on predicted solar insolation and hot water demand. A number of design methods are available for solar water heating systems. Design methods for solar thermal processes [1] can be put in 3 categories:

First category applies to system in which collector operating temperature is known or can be estimated and for which critical radiation levels can be find out.
Eg: utilizability method.

Second category includes those that are correlations of the result of a large number of detailed simulations.
Eg: f-chart method.

Third category involves Short cut simulation in which simulations are done using meterological data for representative days. Eg: solcost method

2. F – Chart method

Solar fraction or solar contribution

Fraction of the total heating load that can be supplied by the solar energy system called the solar contribution. For a solar thermal system, if the energy required is denoted by Q_L, auxiliary energy is Q_{AUX} , and the solar energy delivered is Q_S ,then :

$$Q_L = Q_{AUX} + Q_S$$

For a month i , the fractional reduction of energy when a solar energy system is used , called the solar fraction or solar contribution, f , is given by the ratio:

$$f = \frac{Q_{S,i}}{Q_{L,i}}$$

The f-chart method was originally developed by Klein and Beckman. The method is in fact a correlation of the output of hundreds of thermal performance simulations of solar heating systems. In the f-chart method, the primary design variable is the collector area. Secondary variables can be the storage capacity, collector type, thermal load, collector heat exchanger size and fluid flow rate.

The resulting correlations give the fraction of the monthly load supplied by solar energy, f, as a function of two dimensionless parameters, namely: The ratio of collector losses to heating load, and the ratio of absorbed solar radiation to heating load.

$$X = \frac{\text{(collector energy loss during a month)}}{\text{(total heating load during a month)}}$$

$$X = F_R U_L \frac{F'_R}{F_R} (T_{ref} - \overline{T_a}) \Delta t \frac{A_C}{Q_L}$$

$$Y = \frac{\text{(Total energy absorbed on the collector plate during a month)}}{\text{(total heating load during a month)}}$$

$$Y = F_R\,(\tau\alpha)_n \frac{F'_R}{F_R} \left[\frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n}\right] \overline{H_t} \frac{A_C}{Q_L}$$

f=1.029Y-0.065X-0.245Y2+0.0018X2+0.0215Y

$0 <= X <= 15; 0 <= Y <= 3$

Where,

A_C = Area of solar collector (m^2)

F'_R = Collector-heat exchanger efficiency factor (%)

F_R = Collector heat removal factor (%)

U_L = Collector overall energy loss coefficient (W/m^2-°C)

Δt = Total number of seconds or hours in the month

T_a = Monthly average ambient temperature (°C)

Q_L = Monthly total heating load (GJ)

H_t =Monthly averaged daily radiation incident on collector surface per unit area (MJ/m^2

N = Number of days in the month

$(\tau\alpha)$=Monthly average Transmittance-absorptance product (%)

$(\tau\alpha)_n$ = Normal transmittance-absorptance product (%)

T_{ref} = Reference temperature (100 °C).

3. System description

Figure shows a standard configuration of the solar heating system (for Water Heating Only) covered by the f-chart method. This system may use water or an antifreeze solution as the collector heat transfer fluid. If the collector heat-transfer fluid is not water, a heat exchanger is used between the collectors and the tank. In this system, energy from the collector loop is transferred from the collector fluid to the preheat storage tank directly or via an external heat exchange. Losses from the auxiliary tank were not considered in the correlation.

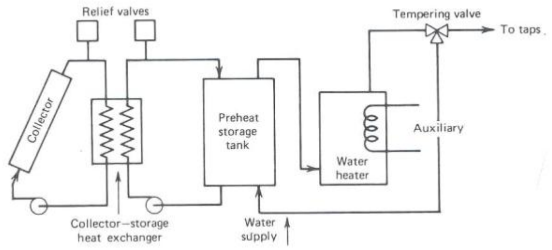


Fig.1 Standard Configuration for Water Heating Only

4. Design objective

A solar water heating system is to be designed for a family of six members in CALICUT (Latitude of 11.573°N, Longitude 76.051°E and altitude 471 m) with one cover collector facing south. Water heating collector characteristics for the available collectors are: F_RU_L= 4.00W/m^2, $F_R(\tau\alpha)n$ = 0.74 and $(\tau\alpha)/(\tau\alpha)n$ = 0.94 as determined from standard collector tests. Assume the collector-heat exchanger correction factor, F'_R / F_R is 0.97.

5. Design considerations

The f-Chart curves are numerically generated using fixed nominal values for storage capacity per unit collector area, collector liquid flow rate per unit collector area, and load heat exchanger size relative to space heating load. Thus it is very important to take into account the sensitivity of these design parameters in long-term performance of the system and to make corrections when necessary. The parameters to be considered are:

Storage Capacity

The annual performance of a liquid solar system is relatively insensitive to storage capacity as long as the capacity is more than 50 liters of water/square meter of collector. Only small improvements in annual performance can result from any added storage capacity. The f-Chart has been generated for a storage capacity of 75 liters of stored water per square meter of collector area. It can also be used to estimate the annual performance of systems with other storage capacities in the range of 37.5 to 300litre/m^2 by multiplying the dimensionless parameter X by a storage size correction factor X_c/X:

X_c/X = (Actual storage capacity/Standard Storage capacity)-0.25

For $0.5 \leq$ (Actual storage capacity/Standard storage capacity) ≤ 4.0.

Where the standard storage capacity is 75 liters of water per square meter of collector area.

Collector Liquid Flow Rate

The dependence of the system performance on the collector flow rate is asymptotic and only a small gain in energy collection rate is realized if the flow rate-specific heat product is increased beyond 50W/k per square meter of collector area . Having a longer flow rate can reduce energy collection rate significantly, particularly if the fluid boils and energy must be dumped through the pressure relief valve. The f- Chart has been generated using a collector fluid flow rate equivalent to 0.015 liters of antifreeze solution per square meter of collector area. Since an increase in collector flow rate beyond this nominal value only has a small effect on system performance, the correlations are applicable for all practical collector liquid flow rates.

Load Heat Exchanger Size

The size of load heat exchanger strongly affects the performance of the heating system. The size of heat exchanger is measured by the dimensionless parameter: $Z = (e_L.C_{min})/(U\,.\,A)$ .Practical values of Z are generally between 1 and 3 when the cost of heater exchanger is considered .The dependence of the system performance on the size of load heat exchanger is found to be asymptotic and only small improvement of the system performance can be achieved if the value of (e_L . Cmin)/(U.A) is increased beyond 2or 3. The f-chart for liquid system was developed with (e_L.Cmin)/(U.A) = 2. This chart can be used to estimate the annual performance of systems having other values of (e_L .Cmin)/(U.A) by multiplying Z with the following correction factor: Load heat exchanger correction factor

$$K_{l=} 0.39 + 0.65\left[e^{-\left(\frac{0.139*(UA)}{e_L C_{min}}\right)}\right]$$

$$For\ 0.5 \le \frac{e_L\, C_{min}}{(UA)} \le 50$$

where e_L = Heat exchanger's exploitation coefficient and C_{min} = minimum fluid capacitance rate (product of the fluid's mass flow rate and specific heat capacity) in the load heat exchanger .

Table .1 Ranges of design variables used in developing f -charts for liquid and air systems

Transmittance-absorptance product at normal incidence - $(\tau\alpha)_n$	0.6-0.9
Product of heat removal factor with heat exchanger and collector area - $F'_R A_c$	5-120 m^2
Collector heat loss coefficient - U_L	2.1-8.3 W/m^2-°C
Collector slope from horizontal – β	30-90°
Overall energy loss coefficient and area product for a building used in a degree day space heating load - $(UA)_h$	83.3-666.6 W/°C

6. Results and discussions

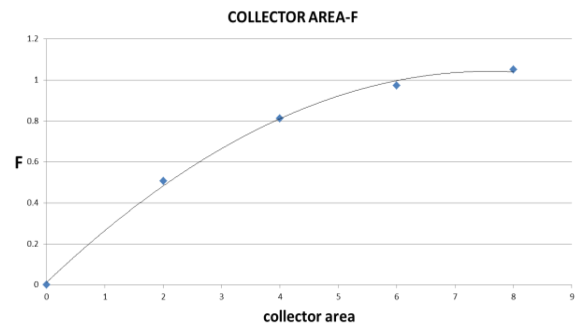
The required load and load provided by the solar thermal system with different collector areas(by applying the f-chartmethod) can be summarized as follows

Table 2. F- Values for different month

Month	Hotwater demand per month(GJ)	fL $2m^2$ (GJ)	fL $4m^2$ (GJ)	fL $6m^2$ (GJ)	fL $8m^2$ (GJ)
Jan.	0.954008	0.548	0.867	1.022	1.076
Feb.	0.800136	0.527	0.802	0.910	0.938
Mar.	0.749578	0.593	0.835	0.895	0.939
Apr.	0.857288	0.565	0.859	0.975	1.006
May.	0.954008	0.540	0.858	1.016	1.074
Jun.	1.187015	0.388	0.683	0.897	1.044
Jul.	1.226582	0.382	0.675	0.892	1.044
Aug.	1.158438	0.421	0.730	0.944	1.081
Sep.	0.989179	0.478	0.787	0.967	1.054
OCT.	0.885865	0.451	0.729	0.879	0.941
NOV.	0.791343	0.439	0.692	0.814	0.856
DEC.	0.954008	0.502	0.810	0.973	1.040
TOTAL	11.50745	5.839	9.335	11.18	12.10
F		0.507	0.811	**0.972**	1.051

From this it is clear that, a collector area of 6 m^2 provides a total load of 11.18944 GJ and our maximum annual demand is 11.50745 GJ.

The fraction of energy provided by the solar system with collector area 6 m^2 is **0.972365(≈1).**so,collector area which is capable to provide almost 100% required thermal energy is of $6m^2$ area.



6.1. Economic analysis

Cost of saved energy

(by taking cost of electricity as: Rs 3/unit)

If **d** is the discount rate and **n** is life of SWHS

$$\text{cost of saved energy} = \frac{\text{annualised capital cost}}{\text{annual energy saved}}$$

$$\text{annualised capital cost} = \text{capital cost} * \text{CRF}$$

$$\text{Capital Recovery factor(CRF)} = \frac{d * (1 + d)^n}{(1 + d)^n}$$

Cost of saved energy corresponding to each collector area is shown in the table and F value ,cost of saved energy corresponding to each collector is shown in the graph.

Table 3. Cost of saved energy

Collector area	**Cost of saved energy (Rs/kwh)**
2	0.830691
4	1.000216
6	1.19539
8	1.433122

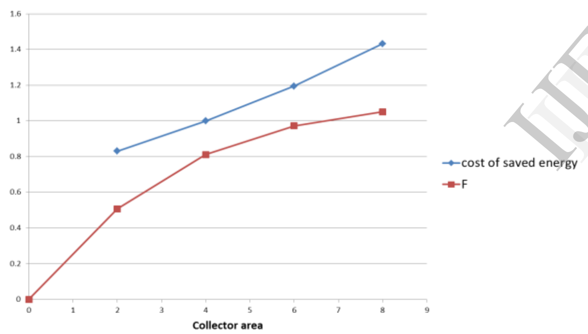


Fig.

7. Conclusion

Fraction of solar energy supplied by a system having solar collector area

2 sq.mtr = 0.5074
4 sq.mtr = 0.8112
6 sq.mtr = 0.9723
8 sq.mtr = 1.0515…..oversized

From techno-economic analysis,

Optimum solar collector area=**6sq.mtr.**

So, for the given load the system design parameters are

Collector area : 4 sq.mtr.
Collector type :FPC
Fluid in collector : water
Storage capacity required : 300 liters
Fluid flow rate : 0.06 ltr/sec
F : 0.81129
Expected payback period : 4.948655 years
Cost of saved energy : 1.000216 Rs/kwh

8. References

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