LIFE CYCLE ANALYSIS AND CARBON CREDIT EARNED BY SOLAR WATER HEATING SYSTEM

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ABSTRACT

Energetics of a 100 litre per day (lpd) solar water heating system, being used to meet the day-to-day hot water requirement of a typical Indian family, has been studied to estimate the primary energy required in manufacturing process and in maintaining it over an average useful life of the system viz. 10, 15 and 25 years. Energy input values have been calculated for Cu-Cu, Cu-steel, Cu-Al and polypropylene solar flat plate collector type system. The energy payback period and energy yield ratio (EYR) have been calculated. It is observed that Cu-Cu and Cu-steel collector type systems have relatively low embodied energy as compared to Cu-Al collector The EYR increases if the average life of solar water heating system increased as energy required to maintain the system even in most pessimistic case is not much compared to energy saved. Life cycle cost analysis has been carried out to evaluate annualized uniform cost (Rs/kWh) of the system. If this type of project is installed only at 20% of the Indian rural areas then the carbon credit earned by the system is Indian Rs. 2196 crores annually.

Keywords: *Cost analysis, energy production factor, energy payback time, carbon credit.*

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1. INTRODUCTION

Solar water heater is a simple and efficient device, which can be used to heat water without putting any extra burden on precious energy resources. Use of solar water heater as an energy conservation device helps in peak load management in the power plant [1]. In India, the use of solar water heating systems is getting popularity both in domestic and industrial sectors. Collector area of 10, 00,000 m^2 had reportedly been installed till the year 2004 [2]. A good manufacturing base has evolved in the country during last two decades for manufacturing solar water heating systems. It is anticipated that by the year 2012, an additional 1 million m^2 collector area would be introduced for water heating purposes [3]. Manufacturing of solar water heating systems is expected to require substantial energy inputs. Thus, large-scale dissemination of solar water heating systems may have implications for conventional energy supply systems. Energy analysis of solar water heating systems can provide useful insight towards estimation of energy demand in manufacturing solar water heating system and also their energy payback period. There are a number of studies available about economic viability of the solar water heating systems [4]. No significant work has, however, been reported in the area of energetics of the solar water heating systems in India. This chapter presents the results of the energetic evaluation exercise undertaken on a domestic solar water heating system of 100 litre per day (lpd) capacity. Energy embodied in such systems has been estimated for four most prominent combinations of materials (Cu-Cu,Cu-steel,Cu-Al and polypropylene) used in manufacturing the flat plate absorber of the flat plate solar collector, the main component of the solar water heating system. The life cycle energy outputs of the domestic solar water heating systems had been estimated using RET screen support software [5]. An economic analysis of linear concentrator based and plastic solar water heater was carried out to reduce the initial investment [6-7].

2. COMPONENTS OF A SOLAR WATER HEATING SYSTEM

The main components of the hot water system are flat plate collector and storage tank fixed on the roof of a house with the help of a stand. In India, the Bureau of Indian Standards (BIS) has specified the standards for flat plate collector for a typical output of 100 lpd at 60°C [8]. The flat plate collector used in the system has an absorber plate made up of a material having good thermal conductivity (usually copper, aluminium or steel). The process involved is to make grooves on the absorber plate to place the header-riser structure made up of copper. The grooves on the absorber plate are made to have maximum heat transfer to riser tube due to more area in contact to each other and avoid losses during heat transfer due to poor contact.

The risers are of 0.56 mm copper tubes of 12.7 ± 0.5 mm inner diameter and 1.80 m length. In one collector of $2m^2$, normally 10 risers are used. These risers are placed on the grooves of the absorber plate (normally made up of copper, aluminium or steel sheet). This assembly of absorber plate, headers and risers is coated with either black board paint or with selective coating having high absorptivity and low emittance. The collected heat is transferred to a fluid (normally water) flowing through risers. These risers are connected to headers on both the sides, which are made up of 0.71 mm thick copper tube with 1.10 m length and 25.4 ± 0.5 mm outer diameter having equidistant holes of 12.7 ± 0.5 mm diameter for riser connection using gas welding. The risers are fixed with the absorber plate through soldering to have better mechanical contact with the absorber plate and, thus, having better heat transfer. The absorber plate is generally corrugated to have more surface area for heat collection. This structure is tested for leakage under 5 kg/cm^2 pressure. Once the structure passes the pressure test, copper flange of 62 ± 3 mm diameter is connected at all the four sides of headers so that it could be connected with other collector in series or parallel or with GI pipe. The absorber plate is again black painted at the soldered/welded places. This structure is placed in a pre-fabricated box, which is separately made generally using aluminium sheet and has glass wool insulation at the bottom and sides to avoid conductive losses. After the collector plate is fixed in the box, it is covered with a toughened glass on the top and fixed at the installation site with the help of an iron stand grouted firmly on the ground/roof. The flat plate collector, thus, installed is connected with an insulated tank of adequate capacity.

3. LIFE CYCLE ANALYSIS

The negative environmental impact of solar energy systems includes land displacement, and possible air and water pollution resulting from manufacturing, normal maintenance operations and demolition of the systems. However, land use is not a problem when collectors are mounted on the roof of a building, maintenance requirement is minimal and pollution caused by demolition is not greater than the pollution caused from demolishing a conventional system of the same capacity. Another advantage of the system is that, when it reaches the end of its life, almost all materials used in the construction of the system can be recycled which minimizes the pollution of the environment. The pollution created for the manufacture of the solar collectors is estimated by calculating the embodied energy invested in the manufacture and assembly of the collectors and estimating the pollution produced by this energy. The analysis is based on the primary and intermediate embodied energy of the components and materials [9] as illustrated in Fig. 1. In the present analysis no allowance is made for the unit packing, transportation and maintenance as these have insignificant contribution compared to the total.

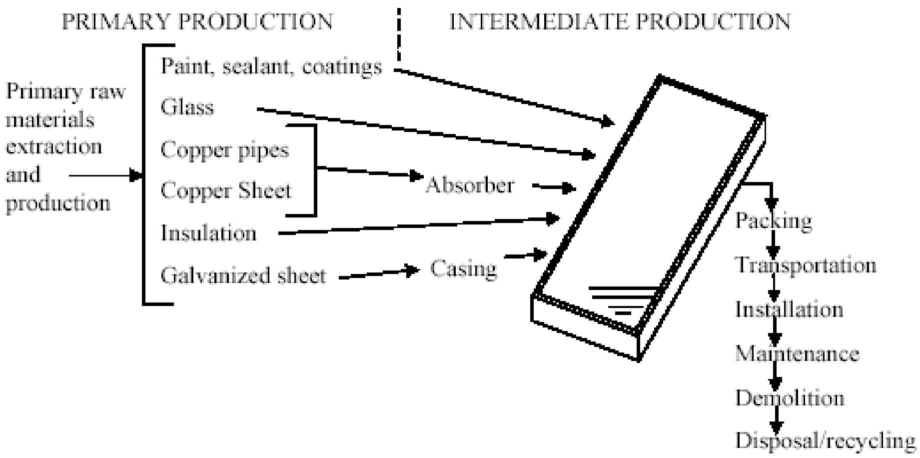


Figure 1: **Factors considered in the calculation of embodied energy of a flat-plate collector**

The total embodied energy required to produce a complete flat-plate collector is calculated using primary and intermediate production stages. The primary stage is established from an assessment of the various materials used and their corresponding mass. Using the embodied energy index (MJ/kg) defined by Alcorn [10] the material embodied energy content within the unit is determined.

4. METHODOLOGY

Among the three commonly used energetic evaluation methods i.e. energy intensity method, process analysis and input/output based energy accounting method [11], the process analysis method has also been adopted in this study. In this process, individual energy inputs are taken into account by estimating the direct and indirect energy embodied in the system during the entire process of manufacturing the finished good and in maintenance over its useful lifetime. Energy payback period and energy yield ratio are determined to judge the energetic viability of the system. Energy production factor (EPF) is also evaluated on annual basis for eight Indian locations having different weather conditions. Both the input and output energy are taken in equivalent to primary energy terms to facilitate a proper comparison and evaluation. Life cycle cost analysis has been carried out to evaluate annualized uniform cost (Rs/kWh) of the system [12].

4.1 Assumptions

The following simplifying assumptions have been made in the analysis presented in this chapter.

1. Manual labour has not been taken into account in estimating energy input because manual labour does not have impact on primary source of energy during manufacturing the device. Moreover, conversion of manhours into equivalent primary energy may have considerable errors and ambiguities.
2. The parameters charaeterising the thermal performance of the flat plate solar collector (F_RY_0, F_RU_L) used for estimation of the energy output have been taken from the literature provided with the device, though verified experimentally through standard tests at Solar Energy Centre, the apex test centre for testing solar energy devices in India.
3. Process analysis has been undertaken upto second level of regression only.

4.2 Energy Embodied

The estimation of energy embodied using process analysis comprises of the following steps:

(a) Identifying the components of the device and the quantity of primary material used in them.

(b) Estimation of the energy embodied in each component.

(c) Estimation of the useful life of the device and each component to determine the energy input during useful life of the device for each of the components.

(d) Estimation of the lifecycle embodied energy of the system.

Energy embodied in the material used in a domestic solar water heating system EE_{mat} can be expressed as:

$$EE_{mat} = \sum_{i=1}^{n} \xi_i m_i \qquad (1)$$

where m_i represents the mass/volume of the i^{th} component of the solar water heating system, ξ_i the energy intensity (in MJ per unit mass or MJ per unit volume as applicable) of the material of the i^{th} component and n the total number of components in the system. The numerical values for n and m_i's were finalised on the basis of several visits of a manufacturer of domestic solar water heating systems. The corresponding values of ξ_i have been obtained from the literature as shown in Table 1-2.

Table 1 presents the material required in manufacturing a 100 litre per day solar water heating system, and the corresponding embodied energy values for four different types of collectors whereas Table 2 presents the material being used and energy embodied in balance of system of a domestic solar water heater of 100 lpd capacity.

Table 1: Embodied energy in manufacturing of a flat plate collector

Flat plate collector components with headers and risers of copper	Materials	Quantity	Unit	Energy Intensity (MJ/unit)	Embodied energy (MJ)
Section frame (100mm × 25mm)	Aluminium	4.25	kg	254	1080
Sheet for back of the box (24 swg)	Aluminium	4.50	kg	254	1143
Angle for box (1" × 1" × 16 swg)	Aluminium	1.50	kg	254	381
Foil for heat reflection (0.5 mm)	Aluminium	1.50	kg	254	381
Neelpop rivets (60 nos.)	Aluminium	0.03	kg	254	8
Steel tapping screw	Aluminium	0.5	kg	50	25
Insulation	Glass wool	0.12	m^3	114	14
Glazing (4 mm thick)	Toughened glass	35.0	kg	30	1050
0.5" diameter riser tube (24 swg 10 nos.)	Copper	4.0	kg	133	532
1" diameter header tube (22 swg 2 nos.)	Copper	2.25	kg	133	299
Flanges (4 nos. 80 mm outer diameter)	Brass	0.8	kg	133	106
Beading for glass sealing	Rubber	1.50	kg	130	195
Continued Table 1					
Flat plate collector components with headers and risers of copper	Materials	Quantity	Unit	Energy Intensity (MJ/unit)	Embodied energy (MJ)
Black paint		0.5	kg	72	36
Absorber plate (0.71mm thick)	Aluminium	4.46	kg	254	1132
Absorber plate (34 swg)	Copper	4.25	kg	133	565
Absorber plate (0.71mm thick)	Steel	13	kg	50	650
Total embodied energy for aluminium plate collector (a)					6381
Total embodied energy for copper plate collector (b)					5814
Total embodied energy for steel plate collector (c)					5899
Polypropylene collector with header and risers also of polypropylene		17	kg	150	2550

Table 2: Embodied energy in manufacturing balance of a 100 lpd solar water heating system

System components	Material	Quantity	Unit	Energy intensity (MJ/unit)	Embodied energy (MJ)
(a) Storage tank					
1. Tank	Stainless steel	1.25	kg	50	625
2. Insulation	Glass wool	0.55	m^3	114	63
3. Cladding	Aluminium	1.5	kg	254	381
Total (a)					1069
(b) Stand					
1. Angle	Steel	12	kg	50	600
2. Paint		0.5	kg	72	36
Total (b)					636
(c) Pipeline 20'	GI	20	kg	50	1000
1. Insulation	Glass wool	0.14	m^3	114	16
2. Cladding	Aluminium	0.80	kg	254	203
Total (c)					1219
Grand total (a)+(b)+(c)					2924

The direct energy input E_{direct} in the manufacturing of the domestic solar water heating system is the direct energy consumed during manufacturing process of the system, such as welding, drilling, cutting, rolling etc.

Energy embodied in periodic replacement and maintenance of a domestic solar water heating system EE_{main} can be estimated as:

$$EE_{main} = \sum_{i=1}^{n} \left[\frac{UL_{dswh}}{FR_i} - 1 \right]^{+} (\xi_i m_i) \qquad (2)$$

where UL_{dswh} represents the expected useful life of the domestic solar water heating system and FR_i , the frequency of replacement of the i^{th} component. The **'+'** sign indicates that for the quantity inside the square bracket, the next higher whole number is taken.

The life cycle embodied energy E_{lc} in the domestic solar water heating system can, therefore, be expressed as

$$E_{lc} = E_{direct} + \sum_{i=1}^{n} \xi_i m_i + \sum_{i=1}^{n} \left[\frac{UL_{dswh}}{FR_i} - 1 \right]^{+} [\xi_i m_i] \qquad (3)$$

Table 3 presents the life cycle energy embodied in a domestic solar water heater for three collector types and for three different scenarios based on frequency of replacement of the components of the system for 20 years useful life.

Table 3: Life cycle embodied energy in 100 lpd solar water heating system (useful life = 20 years)

Material replacement	Qty	Energy Intensity (MJ/unit)	Optimistic scenario		Most probable scenario		Pessimistic scenario	
			Frequency of replacement (years)	Additional energy input for replacement during lifetime (MJ)	Frequency of replacement (years)	Additional energy input for replacement during lifetime (MJ)	Frequency of replacement (years)	Additional energy input for replacement during lifetime (MJ)
Glass	35 kg	30	10	1050	7	2100	5	3150
Rubber	1.5 kg	130	10	195	7	390	5	585
Paint	1.0 ltr	72	7	144	5	216	3	432
Insulation	0.81m^3	114	10	92	7	184	5	276
Total				1481		2890		4443
Annual energy requirement in maintenance				74		145		222
Life cycle embodied energy	For Cu-Cu collector system			10219		11628		13181
	For Al-Cu collector system			10786		12195		13748
	For steel-Cu collector system			10304		11713		13266

4.3 Energy Output

The annual useful energy output of a domestic solar water heating system $E_{o,u}$ would depend upon a variety of design and operational parameters. These include the thermal performance of the solar flat plat collector and storage tank, solar radiation availability, the operating temperature, the capacity utilisation of the system, inlet water temperature, and ambient conditions. The equivalent primary energy derived/saved by the domestic solar water heating system would also depend upon the characteristics of the energy resource technology combination substituted by the solar water heater. If the fuel substituted has calorific value CV_f and its efficiency of utilisation in the corresponding heating device is η_f then the equivalent primary energy saved by the use of domestic solar water heating system $E_{o,pa}$ can be estimated [5] as

$$E_{o,pa} = \left(\frac{E_{o,u}}{\eta_f}\right)(1+\alpha_1) \qquad (4)$$

where α_1 is the fraction of the process energy required to make the fuel available to the user.

4.4 Measures of Energetic Performance

In this study, two measures of energetic performance: (i) energy yield ratio (EYR) and (ii) energy payback period (EPBT) have been considered for evaluating the energy feasibility of domestic solar water heating system. Energy yield ratio (EYR_{dswh}) is defined as the ratio of the life cycle primary energy output of the domestic solar water heating system to the lifecycle embodied energy, i.e.

$$EYR_{dswh} = \frac{\left[\left(\frac{E_{o,u}}{\eta_f}\right)(1+\alpha_1)\right]UL_{dswh}}{E_{lc}} \qquad (5)$$

where UL_{dswh} is the useful life of the domestic solar water heater system. Similarly, the energy payback period, $EPBT_{dswh}$, which is defined as the time required to recover the initial primary energy embodied in the domestic solar water heating system by the net annual primary energy savings due to the use of the solar water heating system, can be expressed

$$EPBT_{dswh} = \frac{\left(E_{direct} + EE_{mat}\right)}{\left[\left(\frac{E_{o,u}}{\eta_f}\right)(1+\alpha_1)\right] - \left(\frac{EE_{main}}{UL_{dswh}}\right)} \qquad (6)$$

While writing the above equation, the life cycle requirement of energy for operation and maintenance of the system has been distributed uniformly over the entire lifetime of the system.

4.5 Energy and Economics Analysis:

4.5.1 Energy Production Factor (EPF):

It is used to predict the overall performance of the system. This is defined as the ratio of output energy and the input energy which predicts the overall performance of the system. It is defined on annual basis [13] as

$$EPF = \frac{E_{out}}{E_{in}} \quad (7)$$

or, $EPF = \dfrac{1}{EPBT}$

If $EPF \rightarrow 1$, for $EPBT = 1$ the system is worthwhile it is not worth from energy point of view.

4.5.2 Annualized Uniform Cost (Uncost)

Annualised uniform cost is defined as a product of present value of the system and capital recovery factor (CRF) [9].

$$Unacost = Net\ present\ value \times CRF \quad (8)$$

where $CRF = \dfrac{i(1+i)^n}{(1+i)^n - 1}$

and Annual salvage value of the system is calculated as

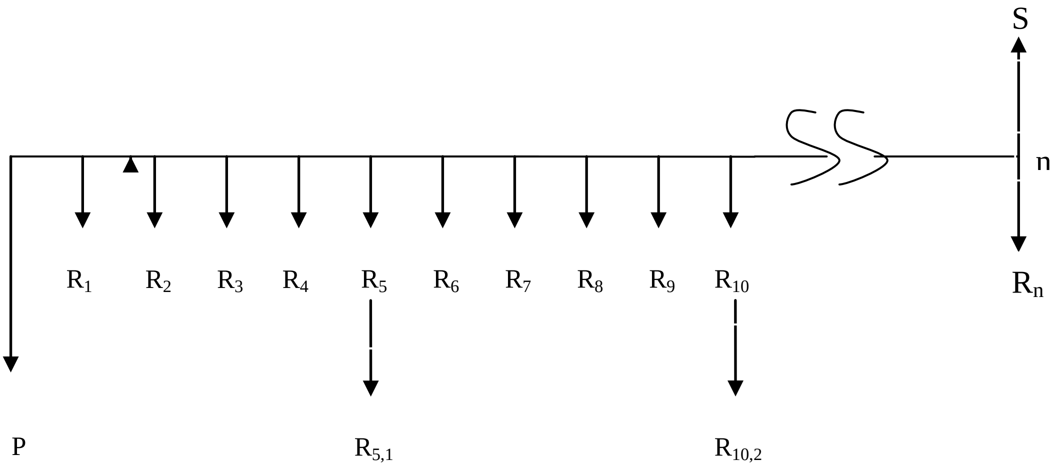
Annual salvage value=Salvage value $\times$ sinking fund factor (SFF) (9)

where $SFF = \dfrac{i}{(1+i)^n - 1}$

n = no. of years

and i = interest rate per year

Let P is present value and R1, R2…Rn is operational and maintenance per year and R5, 1, R10, 2…Rn, n is black painting, cleaning and glass replacement cost in every five year. Then the net present value is evaluated as,



Net Present value =

$$P + R_1 \times \left[\frac{(1+i)^n - 1}{i(1+i)^n} \right]_{i,n} + R_{5,1} \times \left[\frac{1}{(1+i)^n} \right]_{i,5} + R_{10,2} \times \left[\frac{1}{(1+i)^n} \right]_{i,10} + \ldots\ldots\ldots\ldots - S \times \left[\frac{1}{(1+i)^n} \right]_{i,n1} \quad (10)$$

4.6 Results and Discussion

From Table 1 it may be seen that the polypropylene collector is least energy-embodied system followed by steel-Cu, Cu-Cu and Al-Cu in the order of energy embodied. As all the components of the polypropylene collector are made up of polypropylene only, the energy embodied in polypropylene is only taken into account for this type of system. In a solar water heating system usually the absorber plate, outer box, storage tank and stand have long life of 20-25 years, therefore, the life cycle energy embodied have been calculated for three values of the useful life (15, 20 and 25 years). In this useful lifetime, components like glazing, material like insulation, paint may require replacement and, therefore, three different scenarios (optimistic, most probable and pessimistic) have been considered for their replacement and the energy embodied has been calculated for the overall system taking into account this replacement. In the optimistic scenario, the frequency of replacement is the least while in pessimistic scenario, it is quite large. Table 2 gives the embodied energy of domestic solar water heating system 100 lpd capacity.

Figure 2 presents the pie chart of energy embodied in a complete system for different collector type. It may be seen that the energy embodied in polypropylene collector based solar water heating system has the lowest value among all the four systems considered in this study. This is mainly because the collector is not glazed and only polypropylene is used in the collector unlike other collectors where glazing and Al cladding is used. As polypropylene collector type system is yet in the developmental stage and its performance details are yet not available, the lifetime energy analysis of this collector has not available, the lifetime energy analysis of this collector has not been undertaken.

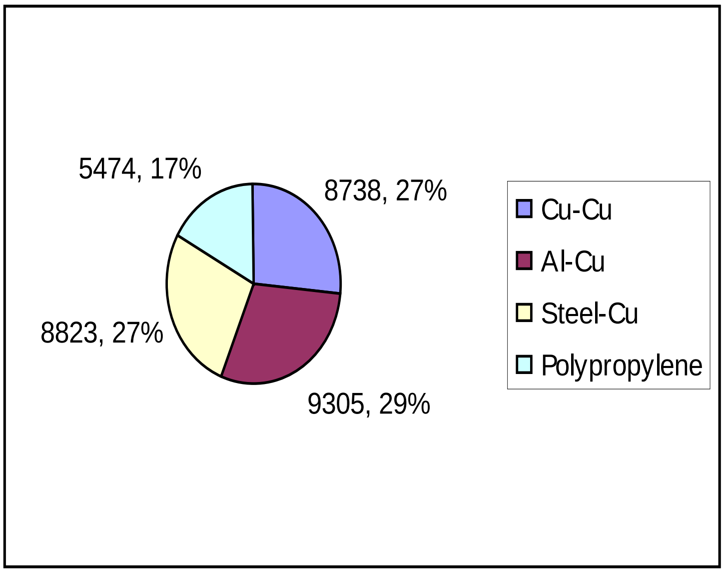


Figure 2: Embodied energy in 100 litre per day solar water heater system with different collector type (MJ)

From Table 3, it is observed that glazing has significant impact on energy embodied. It may be seen that about 25% energy input is there in maintaining the system in the most probable case for a 20-year lifetime of the system. Table 4 presents the EYR for three locations i.e. Delhi, Bangalore and Srinagar having different weather conditions [5].

Table 4: Energy yield ratio (EYR) of 100 lpd solar water heating system

Station	Scenario	Useful life 15 years			Useful life 20 years			Useful life 25 years		
		E_{out} (MJ)	E_{lc} (MJ)	EYR	E_{out} (MJ)	E_{lc} (MJ)	EYR	E_{out} (MJ)	E_{lc} (MJ)	EYR
Delhi	Optimistic	28800	10219	2.84	38400	10219	3.76	48000	11628	4.14
	Most probable	28800	11556	2.49	38400	11628	3.30	48000	13037	3.68
	Pessimistic	28800	13181	2.19	38400	13181	2.91	48000	14662	3.27
Bangalore	Optimistic	70020	10219	6.90	93600	10219	9.15	117000	11628	10.06
	Most probable	70020	11556	6.05	93600	11628	8.05	117000	13037	8.97
	Pessimistic	70020	13181	5.31	93600	13181	7.10	117000	14662	7.98
Srinagar	Optimistic	53650	10219	5.28	78200	10219	7.70	97750	11628	9.62
	Most probable	53650	11556	4.64	78200	11628	6.76	97750	13037	8.45
	Pessimistic	53650	13181	4.07	78200	13181	5.93	97750	14662	7.41

As the weather condition in Delhi is such that hot water requirement is limited to winter season only, the energy output value has been calculated for the period from October 1st to March 15th, while for Bangalore and Srinagar it has been taken for the entire year. The lower value of energy output in Srinagar as compared to Bangalore is due to relatively poor weather conditions there. The EYR has been calculated for 15, 20 and 25 years of lifetime and for three scenarios i.e. optimistic, most probable and pessimistic case as far as maintenance is concerned. It may be seen that EYR is the best for Bangalore, where hot water is used throughout the year and weather conditions are also almost uniform all over the year. In Srinagar also the EYR is better, as hot water requirement is uniform throughout the year, but due to varying weather condition it is less than Bangalore. Table 5 presents the energy payback period for eight locations in India for two scenarios i.e. (i) for use period from October 1st to March 15 and (ii) use period of 12 months.

Table 5: Energy payback period for 100 lpd solar water heating system

Station	Per year use of SWH (months)	Energy output per annum (MJ)	*Net annual energy output per annum (MJ)	Energy payback period for different collector types solar Water heater for 20 year lifetime(years)								
				Optimistic			Most probable			Pessimistic		
				Cu-Cu	Cu-Al	Cu-Steel	Cu-Cu	Cu-Al	Cu-Steel	Cu-Cu	Cu-Al	Cu-Steel
Delhi	5.3	1920	1804	4.6	5.1	4.9	4.8	5.1	4.9	5.2	5.5	5.2
	12	4050	3934	2.1	2.4	2.2	2.2	2.4	2.2	2.4	2.5	2.4
Bangalore	5.3	2440	2324	3.5	4.0	3.8	3.7	4.0	3.8	4.0	4.3	4.0
	12	4680	4564	1.8	2.0	1.9	1.9	2.0	1.9	2.0	2.2	2.1
Mumbai	5.3	2000	1884	4.4	4.9	4.7	4.6	4.9	4.7	4.9	5.2	5.0
	12	3940	3824	2.2	2.4	2.3	2.3	2.4	2.3	2.4	2.6	2.5
Kolkata	5.3	2230	2114	3.9	4.4	4.2	4.1	4.4	4.2	4.4	4.7	4.4
	12	4560	4444	1.9	2.1	2.0	2.0	2.1	2.0	2.1	2.2	2.1
Chennai	5.3	2380	2264	3.6	4.1	3.9	3.8	4.1	3.9	4.1	4.4	4.1
	12	5000	4884	1.7	1.9	1.8	1.8	1.9	1.8	1.9	2.0	1.9
Allahabad	5.3	2670	2554	3.2	3.6	3.4	3.4	3.6	3.4	3.6	3.9	3.7
	12	5460	5344	1.5	1.7	1.6	1.6	1.7	1.6	1.7	1.8	1.8
Srinagar	5.3	1360	1244	6.6	7.5	7.1	7.0	7.5	7.1	7.5	7.9	7.6
	12	3910	3794	2.2	2.4	2.3	2.3	2.4	2.3	2.5	2.6	2.5
Shilong	5.3	2060	1944	4.2	4.8	4.5	4.5	4.8	4.5	4.8	5.1	4.8
	12	3650	3534	2.3	2.6	2.5	2.5	2.6	2.5	2.6	2.8	2.7

* Net energy after deducting the annual energy requirement for maintenance

The payback period has been calculated for three types of collectors for optimistic, most probable and pessimistic cases. It may be seen that the energy payback period for is 3.2 years for Allahabad if solar water heater is used in winters only taking the optimistic case as regards to maintenance and 7.9 years for Srinagar in 12 months use is as low as 1.5 years in Allahabad for the optimistic case to 2.7 years for Shillong in most pessimistic case. Energy payback period most pessimistic case. Energy payback period is 3.2 years for Allahabad if we use solar water heater in winters only taking the optimistic case as regards to maintenance and 7.9 years for Srinagar in most pessimistic case. Fig 3 presents bar chart of energy production factor (EPF) on annual basis for eight Indian locations having different weather conditions. Figure shows that energy production factor is highest for Allahabad, i.e. 0.46.

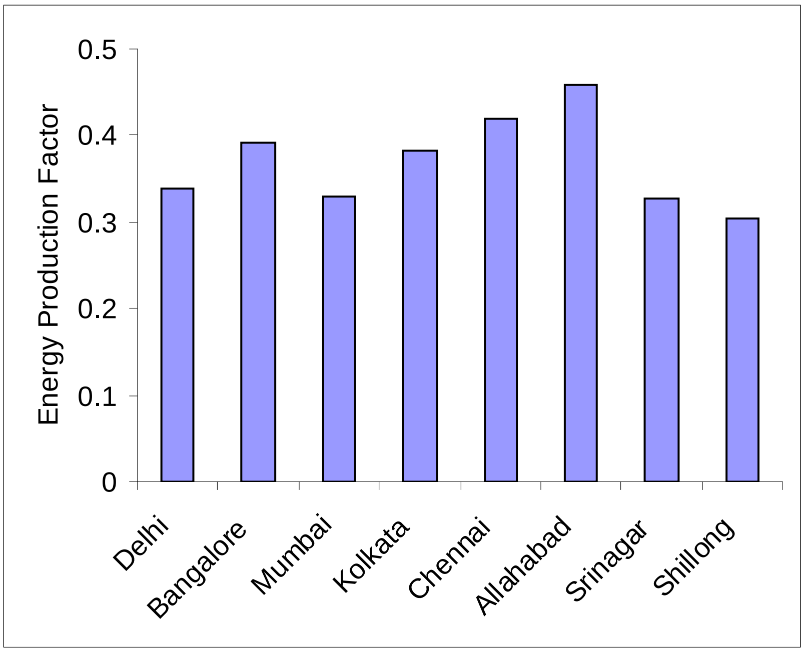


Figure 3: Energy production factor in 100 litre per day solar water heater system for different stations.

Equation. (8-10) have been used for evaluating the annualized uniform cost of the system. The capital cost (P) and Salvage value(S) of solar water heater are shown in Table 6 [13].

Table 6: Capital cost, salvage value and maintenance cost of 100 litre per day solar water heater

Components of Domestic Solar Water Heater	Qty	Present cost (Rs.)	Salvage value of different components(Ss) at the inflation rate of 4% (Present values of scrap for : Iron @Rs. 15/kg,Aluminium@Rs.80/kg and Copper @Rs.250/kg)		
			After 15 yrs (Scrap value)	After 20 yrs (Scrap value)	After 25 yrs (Scrap value)
			Iron @Rs. 27/kg Aluminium@Rs144/kg Copper @ Rs. 450/kg	Iron @ Rs 33/kg Aluminium@Rs175/kg Copper @ Rs 548/kg	Iron @Rs. 40/kg Aluminium @Rs. 214/kg Copper @Rs. 667/kg
Storage tank @ Rs. 90/kg	1.25 kg	113	203	247	300
Glass wool @ Rs. 60/m^2	0.55 m^3	7260	…..	…..	…..
Al Cladding	1.5 kg	250	…..	……	…...
Steel Stand	12 kg	600	264	396	588
Copper riser @ Rs. 380/kg	4 kg	1520	1800	2192	2668
Copper header @ Rs. 380/kg	2.25 kg	855	1013	1233	1500
Al sheet @ Rs. 165/kg	4.5 kg	743	648	788	963
Al angle	1.5 kg	270	216	263	321
Toughened glass 4mm	35 kg	2315	…..	…..	……
Glass wool @ Rs. 60/m^2	0.12 m^3	1584	….	…..	…..

Continued Table 6

Components of Domestic Solar Water Heater	Qty	Present cost (Rs.)	Salvage value of different components(Ss) at the inflation rate of 4% (Present values of scrap for : Iron @Rs. 15/kg,Aluminium@Rs.80/kg and Copper @Rs.250/kg)		
			After 15 yrs (Scrap value)	After 20 yrs (Scrap value)	After 25 yrs (Scrap value)
			Iron @Rs. 27/kg Aluminium@Rs144/kg Copper @ Rs. 450/kg	Iron @ Rs 33/kg Aluminium@Rs175/kg Copper @ Rs 548/kg	Iron @Rs. 40/kg Aluminium @Rs. 214/kg Copper @Rs. 667/kg
Al absorber Plate (0.71mm) @ Rs. 165/kg	4.46 kg	736	642	780	955
Cu absorber plate @ Rs 380/kg	4.25 kg	1615	1913	2329	2835
Glass wool for piping @ Rs.60/m^2	0.14 m^3	1848	…..	…..	…..
Frame, foil, rivets plate etc.	5.78 kg	954	833	1012	1237
Polypropylene	17 kg	1000	….	….	….
GI Pipeline	20 kg	1080	443	663	985
Black paint	1 litre	125	….	….	….
Capital cost(Rs)	**22868**	**7975**	**9903**	**12352**	**12352**

Operation, maintenance, black painting and glass replacement cost=Rs 1000/- per year

Annualised uniform cost (Rs./kWh) of the system are evaluated by considering the life time (n) of the system as 15, 20 and 25 years and money worth is 10% per year. Results shows that the annualized uniform cost in Rs. /kWh decreases with increases in life time of the system. Detailed results are shown in Table 7.

Table 7: Annualised uniform cost on life time basis for n =15, 20 and 25 years.

Station	Useful life15 years		Useful life 20 years		Useful life 25years	
	Use per year (months)		Use per year (months)		Use per year (months)	
	5.3	12	5.3	12	5.3	12
	Annualised uniform cost (Rs./kWh)		Annualised uniform cost (Rs./kWh)		Annualised uniform cost (Rs./kWh)	
Delhi	7.06	3.35	6.59	3.12	6.36	3.02
Bangalore	5.55	2.90	5.18	2.70	5.01	2.61
Mumbai	6.77	3.44	6.32	3.21	6.11	3.10
Kolkata	6.08	2.97	5.67	2.77	5.48	2.68
Chennai	5.69	2.71	5.31	2.53	5.13	2.44
Allahabad	5.07	2.48	4.74	2.32	4.58	2.24
Srinagar	9.96	3.47	9.31	3.24	8.98	3.12
Shillong	6.58	3.71	6.14	3.47	5.93	3.35

4.6.1 Carbon Credit:

Carbon Credit Trading (Emission Trading) is an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. Carbon credits are a tradable permit scheme. A credit gives the owner the right to emit one ton of carbon dioxide. International treaties such as the Kyoto Protocol set quotas on the amount of greenhouse gases countries can produce. Countries, in turn, set quotas on the emissions of businesses. Businesses that are over their quotas must buy carbon credits for their excess emissions, while businesses that are below their quotas can sell their remaining credits. By allowing credits to be bought and sold, a business for which reducing its emissions would be expensive or prohibitive can pay another business to make the reduction for it. This minimizes the quota's impact on the business, while still reaching the quota. Credits can be exchanged between businesses or bought and sold in international markets at the prevailing market price. There are currently two exchanges for carbon credits: (i) the Chicago Climate Exchange and (ii) the European Climate Exchange. In the year 2005, 375 million tons of carbon dioxide equivalents (tCO_2e) were transacted at a value of € 3.31 billion with an average price of € 10.56 per ton. In the first three months of 2006, the average reported price of carbon dioxide equivalent was € 16.72 per ton. European and Japanese Companies were the major buyers and China was the major seller of the carbon credits in 2005-06. Demand of carbon credits continued to soar in 2006-07, resulting in an increase in the treaded rate of carbon credits. The present market rate is fluctuating at € 20-22 in the European Climate Exchange (www.europeanclimateexchange.com) [14].

4.6.2 Population in Rural Areas

There are 602 districts and 127800 villages in India based on 2005 statistics and as per 2001 census. Each village has more than 1000 population. Most population of India lives in rural areas. Therefore total population of rural areas was 127.8 million in the year 2001.

Present population is given by the equation [15],

$$P_n = P_0 \times (1+i)^n \qquad (11)$$

where P_n is population in the nth year, P_0 population in the 0th year (the year 2001; P_{2001} =127.8 million) and i is the annual growth rate in the population, which equals to 2%.

The rural population in the current year will be as

$$P_{2010} = P_{2001} \times (1+0.02)^9 = P_{2001} \times 1.1951$$

$$= 127.8 \text{ million} \times 1.19151$$

$$= 152.733 \text{ million}$$

Then total number of families in rural areas $= \frac{1}{5} \times 152.733$ million

$= 30.55$ million. (12)

4.6.3 Carbon Credit Earned by Solar Water Heater:

Total power produced per annum =1224.2 kWh =1.224 MWh

If the unit cost of electricity at present is 5.5, then,

The cost of energy produced for a single household=1224.2×5.5 = Rs. 6733 per annum.

The average CO_2 equivalent intensity for electric generation from coal is approximately 0.982 kg of CO_2 per kWh at source [16, 17]. However, 40% is transmission and distribution losses and 20% loss is due to the inefficient electric equipment used. Then the total figure comes to be 2.04 kg of CO_2 / kWh.

The CO_2 (carbon) emission reduction by solar water heater comes to = 1224.2×2.04 = 2497.37 kg = 2.5 tons.

If carbon dioxide emission reduction is at present being traded @ € 21/ tons CO_2 , then carbon credit earned by the solar water heating system comes to = USD (2.5×30.55 million$\times 21 \times 1.29202$) = USD 2072 million per annum (where, 1€ = 1.29202 US dollar as on Jan 2012). Carbon credit earned with variation of household in rural areas is mentioned in figure 4. If this type of project is installed only at 20% of the Indian rural areas then the carbon credit earned by the system is USD 414 million (Indian Rs. 2196 crores) annually.

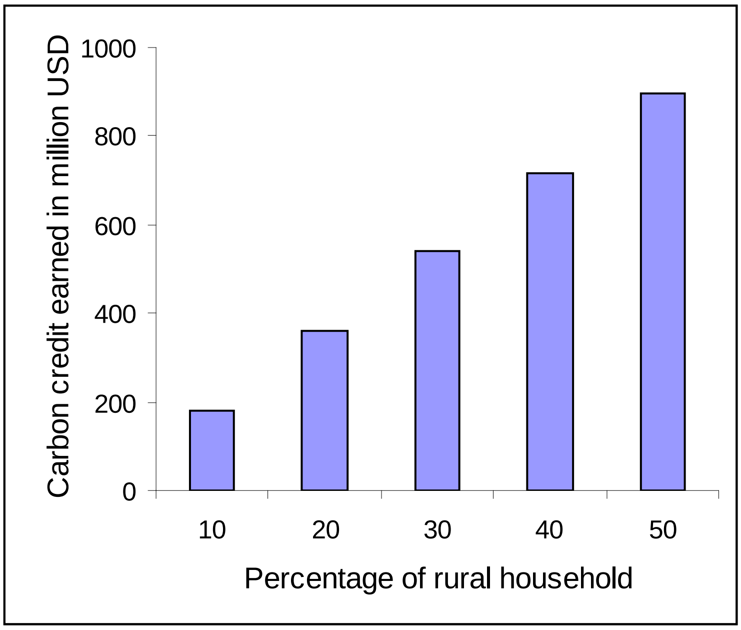


Figure 4: Carbon credit earned with variation of rural household

4.7 CONCLUSIONS:

The following conclusions have been drawn from the above analysis:

1. The polypropylene collector is least energy-embodied system followed by steel-Cu, Cu-Cu and Al-Cu in the order of energy embodied.
2. The EYR is the best for Bangalore, where hot water is used throughout the year due to weather conditions are also almost uniform all over the year.
3. The energy payback period is 3.2 years for Allahabad if solar water heater is used in winters only taking the optimistic case.
4. The energy production factor is least for Shillong i.e. 0.31.

5. The annualized uniform cost in Rs. / kWh decreases with increases in life time of the system.
6. The electricity saved by solar water heating system is Indian Rs. 6733 per annum.
7. The carbon credit earned by solar water heating system is Indian Rs. 2196 crores annually, if the project is installed only at 20% of Indian rural areas.

NOMENCLATURE:

EE_{mat}	Energy embodied in the material used in a domestic solar water heater
ξ_i	Energy intensity of the material of the i^{th} component (MJ/mass or MJ/volume)
n	The total number of components in the system
m_i	Mass/volume of the i^{th} component of the solar water heating system(kg/m^3)
EE_{main}	Energy embodied in periodic replacement and maintenance of a domestic solar water heating system (MJ)
UL_{dswh}	Useful life of the domestic solar water heating system (yrs)
FR_i	Frequency of replacement of the i^{th} component (yrs)
E_{lc}	Life cycle embodied energy (MJ)
E_{direct}	Direct energy input in the manufacturing of the domestic solar water heater (MJ)
$E_{o,u}$	Annual useful energy output (MJ)
$E_{o,pa}$	Equivalent primary energy saved by the use of domestic solar water heating system (MJ)
α_1	Fraction of the process energy required to make the fuel available
EYR_{dswh}	Energy yield ratio of domestic solar water heater
$EPBT_{dswh}$	Energy payback period of domestic solar water heater (years)
EPF	Energy Production Factor
E_{out}	Energy output (MJ)
E_{in}	Energy input (MJ)
Unacost	Annualised uniform cost (Rs.)
CRF	Capital recovery factor
i	Interest rate per year
SFF	Sinking fund factor
n	No. of years
P	Present value (Rs.)

$R_1, R_2 \ldots R_n$ Operational and maintenance per year

$R_{5,1}, R_{10,2} \ldots R_{n,n}$ Maintenance and glass replacement cost in every five year

S Salvage value (Rs.)

REFERENCES

1. Bouchelle and Parker, *www.fsec. ucf. edu*
2. Annual Report, Ministry of Non-conventional Energy Sources, Government of India,New Delhi, India, 2005-06
3. Annual Report, Ministry of Non-conventional Energy Sources, Government of India, New Delhi, India, 2002-03.
4. Kandpal, T.C. and Garg, H.P., 2003, Financial Analysis of Renewable Energy Technology, McMillan India Pvt. Ltd., New Delhi.
5. Pant P. C., Mishra A. K. and Kandpal T.C. Energetics of Solar Water Heating System. Proceeding of 3rd International Conference on Solar Radiation and Day Lighting (SOLARIS 2007) organized by Centre for Energy Studies, Indian Institute of Technology, Delhi, New Delhi - 110 016, India, 2007, p 509-516.
6. Pannal Lal Singh, Sarviya R. M. and Bhagoria J.L. Prospect of linear concentrator based solar water heating system in the silk reeling units. Proceeding of 1st International Conference on Advances in Energy Research (ICAER2007) organized by Department of Energy Science and Engineering, Indian Institute of Technology, Bombay, 2007, p 198-203.
7. Reddy S.V.K., Ashpak Sheikh, Nilesh P., Rohit J., Swapnil C., Shashank T. and Parijat B. Plastic solar water heater, Proceeding of 1st International Conference on Advances in Energy Research (ICAER2007) organized by Department of Energy Science and Engineering, Indian Institute of Technology, Bombay, 2007, p 191-197.
8. BIS 12933 (Part 5), Indian Standard-Solar Flat Plate Collector-Specification, Bureau of Indian Standards, New Delhi, 1992.
9. Soteris Kalogirou.Thermal Performance, economic and environment life cycle analysis of thermosiphon solar water heaters. Int. J. of Solar Energy available online www.sciencedirect.com, 2008
10. Alcorn J. Embodied energy coefficients of building materials. Centre for building performance Research, Victoria, University of Wellington, New Zealand, 1995.
11. Boustead I. and Hankok G.F. Handbook of Industrial Energy Analysis, Ellis Horwood Limited, Market Cross House, Chichester West Sussex, England, 1979.

12. Tiwari G. N. Solar Energy: Fundamentals, Design, Modeling and Applications. Narosa Publishing House, New Delhi, 2002, p 452-480.
13. Swapnil Dubey and Tiwari G. N. Life cycle cost analysis and carbon credit earned by hybrid PV/T solar water heater for Delhi climatic conditions. The Open Environmental Journal, 2008, 2, p 15-25.
14. European Climate Exchange. www.europeanclimateexchange.com (accessed July 03, 2008).
15. Tiwari G.N. Solar Energy. CRC Press, New York, 2002.
16. Watt M, Johnson A, Ellis M, Outhred H. Life-cycle air emission from PVpowersystems. Progress in Photovoltaics Research Applications, 1998; 6: 127.
17. Nawaz I, Tiwari G N. Embodied energy analysis of photovoltaic (PV) system based on macro and micro level. Energy Policy, 2006 34: 3144.