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Economic Analysis and Comparison of Two Solar Energy Systems with Domestic Water Heating Systems

R. KAYALI
Gaziantep University,
Department of Physics Engineering,
27310 Gaziantep - TURKEY

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Abstract

In this work, an economic analysis of different types of thermosiphons and geysers and flat plate collectors and solar ponds employeed in conventional solar energy systems used in houses is analized and the results obtained for these systems are compared with each other. These comparisons show that when the inflation rate is 50% or less solar energy systems are more economical than the other conventional systems, except for conventional systems in which solid fuels are used. If the calculations are done assuming that the consumer credit interest rate varies between 55-70%, it is seen that solar energy systems will only be more economical than thermosiphons operating with electrical energy and geysers using LPG. Thermosiphons operating with electrical energy will never be economical under any inflation.

1. Introduction

As technology develops, the energy needs of communities increases. This energy need is provided from different energy sources known as traditional energy sources, such as coal, fuel oils, geothermal energy, hydraulic energy, and nuclear energy. These energy sources have some disadvantages. The first three of these energy sources have limited life times. It is estimated that petroleum will run out in the middle of the 21st century and coal will run out 100 years later. Hydraulic energy is an insufficient energy source, and nuclear energy has some unsolved environmental and safety problems. Therefore, the researchers have condensed their studies on new alternative energy sources known as renewable energy sources. These are biomass, biogas, wind energy, wave energy, hydrogen energy, and solar energy. Solar energy among these energy sources is the most abundant and considerable research is being carried out in this area.

Studies done on solar energy can be arranged into three groups. These are, solar photovoltaic cells which are used to convert the solar energy directly into electrical energy, concentrated collectors which are used to heat liquids to high temperatures ($\approx 3000^\circ$ C), and solar energy systems which are used to obtain hot water at low temperatures (below 100° C).

Systems in the second and third groups do not require high technology and are also very low cost systems. The most well known are systems from the third group: flat-plate collectors and solar ponds. Today flat-plate collectors are very widely used and nearly all of their technological problems have been solved, however, solar ponds having lower cost than flat-plate collectors are not used as much as flat-plate collectors since they have still some problems to be solved [1]. Examples of systems in the second group are parabolic concentrated systems used for cooking.

The usage and the demand of these systems depend on whether they are economic or not. Therefore, different investigators have done many studies on the economic analysis of these systems. Bansal and Boettcher [2], Akdeniz [3], Ward [4] and Dang and Bansal [5] have studied the economic analysis of flat-plate collectors; Mills, Basset and Derrick [6] have carried out studies on concentrated collectors; and Kayalı [7] has analyzed the economics of an experimental solar pond.

In this work, the economic analysis of flat-plate collectors, solar ponds, and different types of thermosiphons and geysers operating using different energy sources for heating water have been performed for different economic boundary conditions. The results obtained from these analyses have been compared.

2. Economic Analysis of Systems

In most countries, systems used as an alternative to solar energy systems for heating water are electric geysers; and electric, LPG, coal and wood thermosiphons, to which solar systems can be economically compared.

Various criteria that can be used to perform an economic analysis are: pay back, the initial value of the system, utility-expense rate, equivalency of annual income, profitability and rate of interest. Another important point which must be taken into account during analysis, and is included in this study, is the dynamic character of the economy.

Method

The cost of a system in any economy in which the rate of interest is zero is generally calculated by using the equation:

$$\begin{aligned} TC_0 &= C_0 + C_1 + C_2 + \cdots + (C_n - S_n) \\ &= C_0 + \sum_{t=1}^{n} C_t - S_n, \end{aligned} \tag{1}$$

where TC_0 is the total cost of the system and S_n is the selling price of the system after it completes its life-time. All initial expenses of system are included in C_0. The annual running costs for the system is given by C_t. The running costs include fuel usage, maintanence and renewal of the system. Although the scrap value of the system is very small, it is included in the calculations.

Under economic conditions in which the rate of the interest is greater than zero, C_t and S values must be added to C_0 after their values are reduced to the real rate of interest. Hence, Eqn. (1) can be written as

$$TC = C_0 + \sum_{t=1}^{n} C_t/(1+i)^t - S_n/(1+i)^n \tag{2}$$

where, i is the annual rate of interest. If the values of $C_1, C_2, \ldots, C_n$ are equal to each other, the conversion of the annual payments is calculated by the equation:

$$C = C_0 \frac{(1+i)^n - 1}{(1+i)^n + 1}. \tag{3}$$

In this case, the equation which gives the total expense of the system can be written

$$TC = C_0 + C - S_n/(1+i)^n. \tag{4}$$

The following assumptions are taken into account to calculate the annual fuel oil expenses: that the average amount of water which will be used by a family every day at a temperature of 70° C is 160 litres, and that the temperature of the water is heated from 15° C to 70° C. The amount of the fuel needed is calculated by the equation

$$Y_j = \frac{E_0}{K_j} * \frac{1}{V_j} * 365, \tag{5}$$

where, E_0 is the amount of energy needed for one day, K_i is the energy equivalency values of one unit of various fuels in terms of calories and V_j is the efficiency of the system. Annual fuel expense is thus calculated by multiplying Y_i by the price of one unit of the fuel with the equation:

$$C_i = Y_i * P_j. \tag{6}$$

Similar calculations may be performed for the experimental solar pond as follows: First, it is assumed that the energy is extracted from the energy storage medium when the temperature is above 40° C. In this case, the amount of useful energy which will be extracted from the solar pond is given by

$$Q = mc(T_{storage} - 40), \tag{7}$$

where m is the mass of the water in the storage region of the solar pond, c is the specific heat of the water and $T_{storage}$ is the temperature of the storage region. The total energy which will be extracted from insulated and uninsulated solar ponds are found to be 2300 and 1040 MJ/m^2-year, respectively. Thus the area of a solar pond needed by a family for its yearly need is obtained by dividing the annual energy need for heating the water by the annual energy which can be extracted from one square meter of the solar pond. To harvest the same amount of energy from a flat-plate collector one needs a 6 and 10 m^2 insulated and non-insulated solar pond, respectively. Since the initial cost of a solar pond is approximately 2.5 times cheaper per square meter than flat-plate collectors it can be assumed that the initial costs of these two systems are the same.

3. Economic Analysis

Economic analyses of flat-plate collectors, solar ponds, and different types of alternative heaters have been performed. Values of some economic parameters on flat-plate collectors used in calculations are obtained from a study conducted by Özsabuncuoğlu et.al. [8]. Economical data for solar ponds is obtained from a study done by Kayalı [1] on an experimental solar pond built on the campus of Çukurova University. The initial costs of different heating systems are given in Table 1. As seen from this table, the ratio between the initial costs of flat-plate collectors and solar ponds and other alternative systems vary from 2 to 6. If this comparison is done between the solar pond and the flat-plate collector, it is seen that solar ponds are half the cost of flat-plate collectors. Among the alternative systems, electric geysers are the cheapest and LPG geysers are the most expensive.

Table 1. The initial costs of different water heating systems (1991 prices).

System	Price (TL)	Additional expenses (TL)	Total (TL)
Flat-plate collectors(*)	1 388 280	874 566	2 262 846
Solar ponds (insulated)	832 000	400 000	1 232 000
Electric geyser	280 000	125 000	405 000
LPG geyser	830 000	250 000	1 080 000
Electric thermosiphon	800 000	150 000	950 000
Kerosene geyser	500 000	75 000	575 000
Thermosiphon (**)	365 000	75 000	440 000

(*) naturally circulated systems (**) the systems using coal, lignite, or wood

The efficiency of various alternative water heating systems, the equivalent energy value of the energy source used in the system, the annual amount of the energy or fuel used in the system, the price per unit energy used in the system, and the annual fuel expense for the system are given in Table 2.

The annual maintenance and fuel expenses and the sum of these expenses (the running costs) for different systems are given in Table 3. As seen from this table, there is no need to pay any fuel expenses for flat-plate collectors and solar ponds. This is the great advantage of these two systems. If the total expenses of these systems are compared with each other, it is seen that the solar energy systems are the cheapest and the electric thermosiphons are the most expensive. According to these results the running costs for the domestic systems are 2-5 times greater than those for the solar energy systems.

Table 2. The total annual fuel expenses of various alternative water heating systems (1991 prices).

System	System efficiency (%)	Energy equivalent value	Annual fuel amount	Price	Total fuel expense (TL/Year)
Electric geyser	1.00	860 Kcal/Kwh	4 174.42 Kwh	240 TL/Kwh	977 861
LPG geyser	0.85	11 300 Kcal/Kg	364.81 Kg	2 480 TL/KG	904 729
Electric Thermosiphon	0.95	860 Kcal/Kwh	4 288.86 Kwh	240 TL/Kwh	1 204 526
Kerosene thermosiphon	0.70	10 450 Kcal/Lt	479.02 Lt	2 390 TL/Lt	1 145 288
Coal thermosiphon	0.50	6 100 Kcal/Kg	1 148.85 Kg	575 TL/Kg	660 589
Lignite thermosiphon	0.50	3 000 Kcal/Kg	2 336.00 Kg	375 TL/Kg	876 000
Wood thermosiphon	0.50	3 000 Kcal/Kg	2 336.00 Kg	400 TL/Kg	934 400

Reference: World Energy Council (1990).

Table 3. Annual maintenance and fuel expenses and the sum of these expenses for different water heating systems (1991 prices).

System	Maintenance (TL)*	Fuel (TL)	Total (TL)
Flat-plate collector	335 800	0	335 800
Solar pond (insulated)	200 000	0	200 000
Electric geyser	40 500	977 361	1 018 361
LPG geyser	108 000	904 729	1 012 729
Electric thermosiphon	95 000	1 204 526	1 299 526
Kerosene thermosiphon	57 500	1 145 288	1 202 788
Coal thermosiphon	57 500	660 589	718 089
Lignite thermosiphon	57 500	876 000	933 500
Wood thermosiphon	57 500	934 000	991 900

(*) 10% of the initial expense of the system is taken as the maintenance cost of the conventional systems.

The useful lifetime of the systems are approximately 10 years, with exception of electric thermosiphons which have an estimated lifetime of two years. The cash flow chart of each system for a 10 year period is given in Table 4.

Table 4. The cash flow of each system for a 10 year period for a zero interest rate.

System	Initial cost	Scrap value	End of the 0th year(*)	1-10 TL	Total TL
Flat-plate collector	2 262 846	212 709	2 050 137	335 800	5 408 137
Solar pond	1 232 000	100 000	1 132 000	300 000	4 132 000
Electric geyser	405 000	30 375	374 625	1 018 361	12 056 735
LPG geyser	1 080 000	81 000	999 000	1 012 729	11 126 290
Electric thermosiphon	950 000	71 250	878 750	1 299 526	13 874 010
Kerosene thermosiphon	575 000	43 125	531 875	1 202 788	12 559 755
Coal thermosiphon	440 000	33 000	407 000	718 089	7 587 890
Lignite thermosiphon	440 000	33 000	407 000	933 500	9 762 000
Thermosiphon (wood)	440 000	33 000	407 000	991 900	10 326 000

(*) The value of the system is obtained by subtracting the scrap value of the system from its the initial value. Annual expenses (1991 prices)

In economies in which the rate of interest is zero, comparisons of the systems are made by using the values obtained for the systems in the last column of Table 4. As seen from this table, solar energy systems are the cheapest. Comparing the two solar energy systems, it is seen that solar ponds are cheaper than flat-plate collectors. The most expensive systems are those systems using the electrical energy. Only thermosiphons using coal are comparable with solar energy systems, though they are about 40 % more expensive than the solar energy systems.

In economic analysis, comparisons must be done with the results obtained using the real rate of interests in the calculations. In these calculations, the consumer rate of interest, which is given by commercial banks, is taken as a reference rate of interest. The results obtained from the economic analysis of nine different water heating systems for nine different rates of interests are given in Table 5. As can be seen from this table, the proficiency rate of flat-plate collectors does not change until the rate of interest reaches 20%. Only coal systems become more advantageous when the rate of interest is greater than 20%, which results from the higher initial cost of solar systems. In economies in which very high rate of interests are applied the alternate systems become more advantageous. Now let us see under what equal conditions the flat-plate collectors will be economically equal to which systems. Flat-plate collectors can be comparable with coal thermosiphons, lignite thermosiphons, wood thermosiphons, electric geysers, kerosene thermosiphons, lignite thermosiphons, wood thermosiphons, electric geysers, kerosene thermosiphons, LPG geysers and electric geysers when the rate of interests are 20, 35, 40, 50, 56, 70 and 80%, respectively. If the same comparison is made for solar ponds, it is seen that solar ponds are comparable with the wood thermosiphon and lignite thermosiphon when the rate of interests are 30% and 50%, respectively, and are also comparable with electric geyser and kerosene thermosiphon when the rate of interest is 70% and 80%, respectively.

Table 5. Economic analysis of different water heating systems for different interest rates.

	The last value of the first investment and the expenses done for the system (× 1000 TL)(1991)								
	0%	10%	20%	30%	40%	50%	60%	70%	80%
	0.0	6.14	4.19	3.09	2.41	1.96	1.65	1.42	1.24
System									
Flat-plate collector	5 408	4 113	3 458	3 088	2 860	2 710	2 604	2 527	2 468
Solar pond	4 132	3 189	2 656	2 374	2 205	2 123	2 006	2 184	1 918
Electric geyser	12 056	7 583	5 297	3 399	3 196	2 664	2 291	2 017	1 809
LPG geyser	11 126	7 221	5 244	4 129	3 443	2 989	2 671	2 438	2 261
Electric thermosiphon	13 874	8 865	6 327	4 896	4 015	3 432	3 024	2 726	2 498
Kerosene thermosiphon	12 559	7 922	5 574	4 250	3 434	2 895	2 518	2 241	2 031
Coal thermosiphon	7 587	4 819	3 417	2 627	2 140	1 818	1 592	1 427	1 302
Lignite thermosiphon	9 762	6 143	4 320	3 292	2 660	2 241	1 948	1 734	1 570
Wood thermosiphon	10 326	6 501	4 565	3 473	2 801	2 356	2 045	1 817	1 643

4. Conclusion

As a conclusion, it can be said that when the rate of interest is equal or less than 50% solar energy systems are more economical than all the other alternative water heating systems, except systems using solid fuels. It is seen that electric thermosiphons are the most expensive systems for every rate of interest. If the consumer rate of interest is in the range 55-70% the solar energy systems are more economical than electric and LPG thermosiphons, but they are more expensive than all the other systems. As a result, solar energy systems will always have great advantages because all the alternative systems have some environmental problems associated with them.

Similar studies are planned for concentrated collector systems, which can be used for cooking and heating of asphalt used in the construction of roads.

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