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Technical and Economic Aspects of Solar Space Heating in Palestine

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Abstract: A computer analysis of solar heating has been performed for Palestine. Results are presented for a prototype building using either fuel oil or gas under different heating loads in three climatic regions (Jordan valley, coastal, and hilly). Cumulative cost flows are compared for the life-cycle present value technique. Optimum design magnitudes are determined for maximum life-cycle savings. The payback period for capital invested in a solar system, and total savings are found for the optimum conditions. Variations of system performance are estimated. The effects of collector slope, proportionate storage tank volume, heat-exchanger parameters, and the design load on system performance are studied. Finally the economics of solar heating in Palestine are discussed and recommendations are made for increased utilization of solar energy.

Key words: Solar energy heating systems, technical-economic analysis, optimization, F-chart, optimum collector area, solar heating fraction, total savings.

Nomenclature

A	Collector area, m^2
CI	Conventional installation
DD	Monthly degree-days, ℃-day
F	Fuel-oil
F_R	Collector heat-removal factor
G	Gas
H	Monthly mean solar radiation on a horizontal plane, GJ/m^2
$\dot{m}$	Mass flow rate of primary and secondary fluids, lt/m$^2\cdot$h
N	Number of heating hours per day, h
OCA	Optimum collector area, m^2
PBP	Payback period, year
Q	Monthly heating load, GJ/month
R1	First climatic region
R2	Second climatic region
R3	Third climatic region
SI	Solar installation
SHF	Annual solar heating fraction
T_a	Monthly mean ambient temperature, ℃
TS	Total life-cycle savings using the solar installation, NIS
U_L	Collector heat-loss coefficient, kJ/m$^2\cdot$h$\cdot$℃
V	Storage tank volume per square meter of collector area, lt/ m^2

Subscript

o	Optimum and/or maximum value of a parameter

Greek Letters

β	Collector tilt angle (degrees)
ε	Heat-exchanger effectiveness
$\tau\alpha$	Transmittance-absorptance product

1. Introduction

In addition to global warming or global climate change that encouraged the use of renewable energy worldwide, today's sky-rocketing of the fuel price makes the study of energy savings necessary and worth to search for and find any possibility of reducing the cost of energy, especially in the heating sector which constitutes a considerable portion of the national as well as the per-capita budget. Solar energy is considered as the most clean and friendly to the environment.

Fortunately, the sun is available in Palestine in a better manner compared to other countries, which increases

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and encourages the feasibility of such a study.

This paper focuses on the economics of solar heating systems under Palestine conditions. In order to emphasize the fundamental relationship between technical and economic aspects of solar heating-system design, the paper also discusses some technical aspects of the f-chart model and the effects of various fundamental parameters. No attempt has been made to predict the future prospects of solar heating in Palestine since these depend on future pricing of conventional fuels.

The results are presented for a wide range of economic parameters, and the correct future panorama would most probably be one of the expected cases presented in this analysis. Despite the fact that, prediction of the future success or failure of the solar heating in Palestine would require knowledge of the future price fluctuations of conventional fuels, all the worldwide seen and given indications or panoramas emphasize that (at least for the next coming future), the situations of fuel price would not be better than today's situations.

Computer simulation programs are extremely useful tools in the design and technical-economic analysis of solar heating systems. With the aid of a valid computer simulation model, the effects of various design parameter changes on the performance of a given system can be easily determined, as well as the economic feasibility of the solar system in comparison with a conventional alternative. Economic optimization procedure in a particular solar heating design is based on the estimation of the size of a solar system that will yield the highest economic benefit on behalf of the solar system. This is usually made by comparing the cost flows recurring throughout the lifetime of the solar and conventional alternative system. One of the major tasks in such analysis is the estimation of the best set of values for design parameters that will maximize the criterion function in a solar heating system.

A previously developed computer program [1] is modified to serve for the needs of this analysis [2, 3]. The program first calculates the annual solar heating fraction (SHF) for the specified design parameters that comply with f-chart model [4-9]. Next, using the life-cycle present worth technique, the yearly cost comparisons of the solar energy system and a conventional alternative for the given economic data are estimated. Finally, the program is used to optimize the solar collector area (A) and to maximize lifetime savings for the solar installation (SI) [10].

2. Selection of the Prototype Building

The computer analysis may be extended to any region or prototypical building if the design and climatic parameters are specified. Here, the representative results for three locations and one prototype building using either gas (G) or fuel oil (F) are presented. In these comparisons, it is assumed that the auxiliary part of the SI and the conventional installation (CI) use the same fuel. The selected locations are Jericho (R1), Gaza (R2), and Hebron (R3), which represent the principal climatic regions of Palestine (Jordan valley, coastal and hilly regions, respectively). Some relevant monthly climatic data are presented in Table 1 [11].

The prototype building considered is a single-storey house of about 120 m^2. The overall heat-loss coefficient area products (UA) were calculated and are presented in Table 2. The solar systems under discussion also supply domestic hot water, and the main water-supply temperatures are taken as a correlation of the number of day in the year modified to suit the Palestine climatic conditions [12].

3. Cost Selection

The purchase costs of both CI and SI were determined from a market study. The purchasing costs of CI are given in Table 3. The purchasing cost of a SI includes the fixed solar system costs (pumps, additional tubing, heat exchangers, etc.) and the cost of solar collectors and a storage unit. Fixed SI costs were determined to be 10500 NIS (1 US$ = 3.9 NIS, January

Table 1 Monthly average climatic data for three climatic regions: ambient temperature (T_a); total radiation on a horizontal plane (H); degree days (DD).

Month	Jericho (R1)			Gaza (R2)			Hebron (R3)		
	T_a (℃)	H (MJ/m^2·d)	DD (℃-d)	T_a (℃)	H (MJ/m^2·d)	DD (℃-d)	T_a (℃)	H (MJ/m^2·d)	DD (℃-d)
January	13.2	9.72	148.8	13.4	9.46	142.6	7.1	10.17	337.9
February	14.6	11.41	95.2	13.7	10.75	120.4	8.1	11.94	277.2
March	17.4	17.45	0	15.6	16.98	74.4	10.5	18.26	232.5
April	21.7	18.36	0	18.7	17.30	0	14.7	19.21	99.0
May	25.6	25.47	0	20.7	24.78	0	18.4	26.65	0
June	28.5	26.12	0	23.3	25.42	0	20.8	27.33	0
July	29.9	26.38	0	25.4	25.68	0	22.7	27.61	0
August	30.0	23.34	0	25.8	22.71	0	22.1	24.42	0
September	28.6	19.12	0	24.3	18.61	0	20.9	20.01	0
October	25.1	14.08	0	22.9	13.70	0	18.6	14.73	0
November	19.6	11.38	0	18.7	11.08	0	13.7	11.91	129.0
December	14.7	9.58	102.3	15.1	9.32	89.9	8.8	10.02	285.2
Yearly average	22.4	17.70	346.3	19.8	17.15	427.3	15.5	18.52	1360.8

Table 2 Overall heat loss-area product UA for the prototype building in three climatic regions.

Location	UA (kJ/h·℃)
Jericho (R1)	1800
Gaza (R2)	1600
Hebron (R3)	1400

Table 3 Initial investment for conventional installation in NIS (1 US \$ = 3.9 NIS).

Location	CI (NIS)	
	G	F
R1	17500	15600
R2	23000	21000
R3	25000	23000

2009 prices). Liquid-based flat-plate solar collectors cost 350 NIS/m^2 and the storage tank costs 460 NIS/m^2 of surface area. Based on December 2008 figures given by the Ministry of Energy and Natural Resources, unit fuel prices were taken as 109 NIS/GJ and 156 NIS/GJ for gas (G) and oil fuel (F) respectively [13].

First, the optimum collector area (A_o) is determined, which maximizes the total life-cycle savings (TS). A_o, $(SHF)_o$, $(TS)_o$, and the corresponding payback period $(PBP)_o$ are then calculated using either G or F for three climatic regions. Based on current economic conditions in Palestine, an average discount rate of 25% and a fuel-price increase of 30% have been assumed. The results are shown in Table 4.

Table 4 Optimum results for collector area A_o, solar heating fraction $(SHF)_o$, life-cycle savings $(TS)_o$, and payback period $(PBP)_o$.

Climatic region	Fuel	A_o (m^2)	$(SHF)_o$ (%)	$(TS)_o$ (NIS)	$(PBP)_o$ (yr)
R1	G	22.6	67.8	22168	9.8
	F	16.3	59.1	17447	6.3
R2	G	39.0	48.8	28121	11.6
	F	22.7	40.1	20732	7.9
R3	G	61.1	47.5	46390	11.5
	F	39.4	36.7	32021	9.9

A_o is higher for cold climates, whereas $(SHF)_o$ decreases from hot to cold regions. The $(TS)_o$ increases towards the coldest regions.

4. Analyses and Comparisons of Economic Results

The influences of the unit price of conventional fuels, fuel-price increase rate, discount rate, and collector and storage tank unit prices will now be assessed. The most important economic results compiled in this study are presented in graphical form.

4.1 Payback Period and Total Savings

Figs. 1-3 show the total discounted cash flows for three regions. These curves, based on cost comparisons of CI and SI, give the PBP and TS. The intersection point corresponds to the PBP, i.e., the year when the

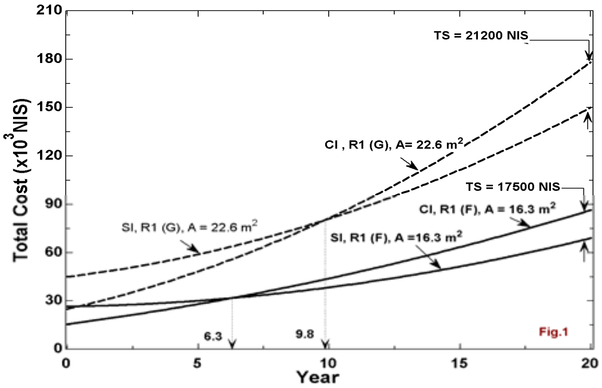

Fig. 1 **Total lifetime discounted cash flows for R1.**

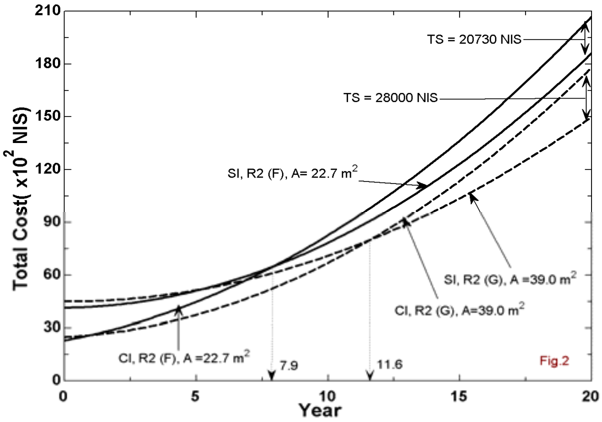

Fig. 2 Total lifetime discounted cash flows for R2.

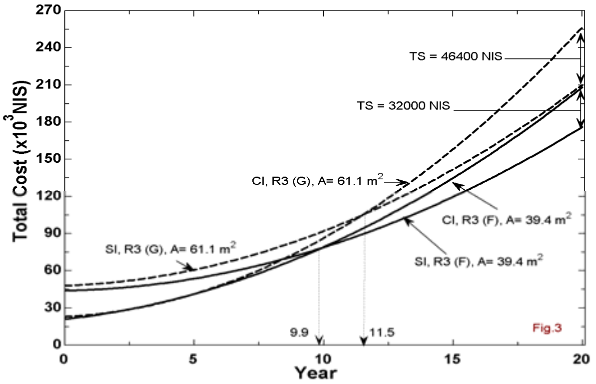

Fig. 3 Total lifetime discounted cash flows for R3.

costs of CI and SI become equal and TS is zero. From this year onwards, the SI begins to produce economic benefit. The TS produced during the lifetime is the difference of the total accumulated costs of the SI and CI at year 20.

For all climatic regions, the average PBPs for the SI under optimum conditions are about 11 and 8 yr, respectively, compared with G and F using CIs.

Payback periods are shorter in comparison with F using CIs, as the fuel cost per GJ is higher for F, and the auxiliary part of SI consumes the same fuel. However, an average increase of 18% and 57% in the PBP is observed from the warmest (R1) to the coldest (R3) climatic regions for G and F using SI systems respectively.

4.2 Optimum Collector Area and Solar Heating Fraction

The variations of SHF and TS with collector area are shown in Figs. 4-6. In these graphs, all design parameters are kept constant and the collector area is varied. A_o corresponds to $(TS)_o$ and is found to be very sensitive to the type of fuel consumed (unit energy cost) and the region (climatic conditions). Increasing the collector area above the optimum value results in a relatively small increase in the SHF and is therefore uneconomical. For a given prototypical building, A_o is greater for G systems in all comparisons. The TS are greater when the SI is compared with G using CI. Total life-cycle savings increase steeply from the warmest to the coldest climatic regions.

4.3 Unit Fuel Price

In Figs. 7-9, the changes in TS, A_o, and PBP are shown. The unit conventional price is found to be a dominant parameter. An increase in the unit fuel price leads to exponentially increasing TS and A_o, and also to an exponential decrease in the PBP, since installation of more collector area becomes economical. Doubling the unit fuel price leads to A_o and TS increases from a low of about two times in the warmest region to a high of about six times in the coldest region; the PBP may be dropping about 5 yr in almost all regions.

4.4 Collector and Storage Unit Price

The variations of A_o, TS and PBP with the collector and storage unit prices are shown in Figs. 10-15. The collector price per square meter is found to be a parameter as sensitive as the conventional fuel price, especially in determining A_o. From the economic point

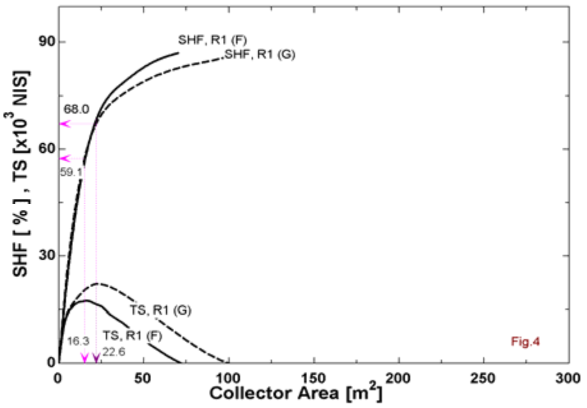

Fig. 4 Variation of SHF and TS with collector area in region R1.

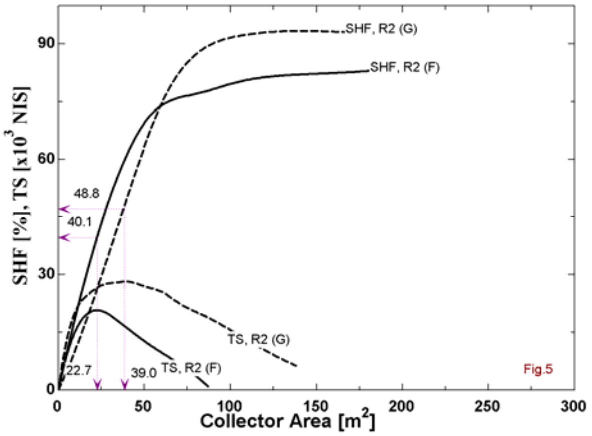

Fig. 5 Variations of SHF and TS with collector area in region R2.

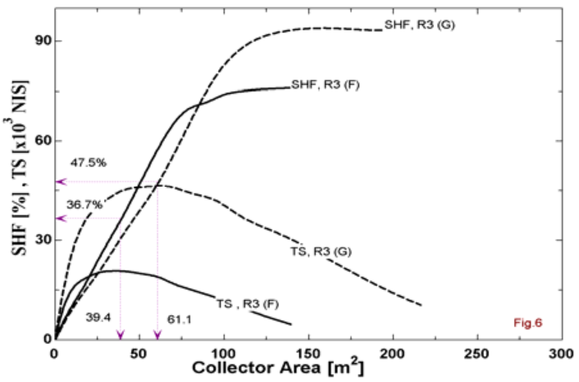

Fig. 6 Variations of SHF and TS with collector area in region R3.

of view, smaller collector area has to be used to compensate for the high unit storage tank price (Fig. 10). Very steep increments in the collector area are observed below the actual market costs (350 NIS/m²), cf. Fig. 11. Variations in PBP and TS are observed to

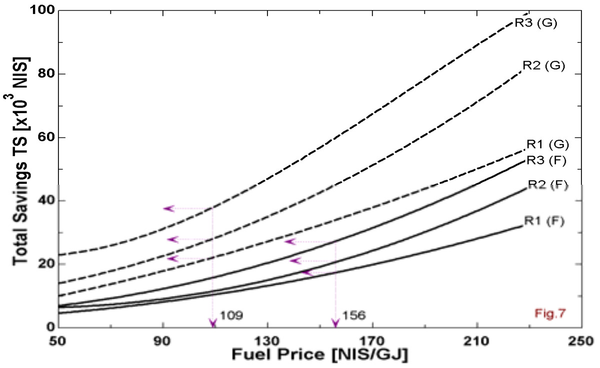

Fig. 7 Variations of TS with fuel price.

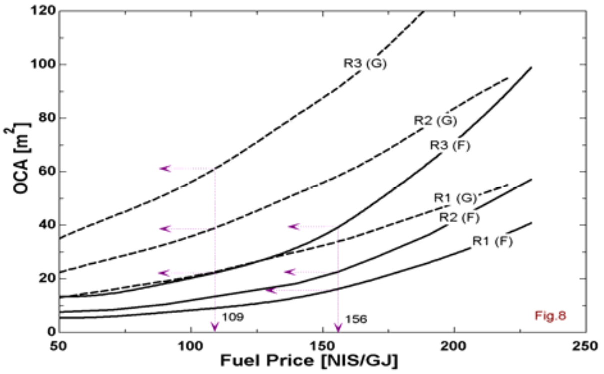

Fig. 8 Variations of OCA with fuel price.

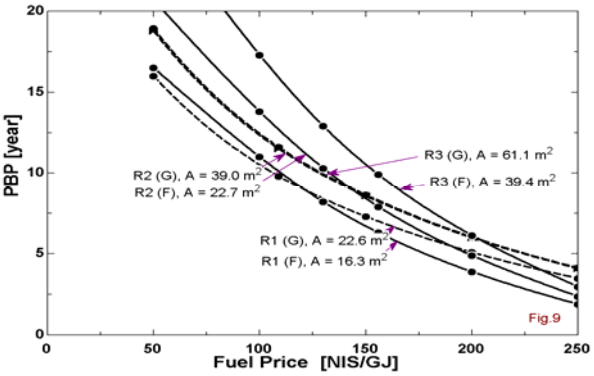

Fig. 9 Variations of PBP with fuel price.

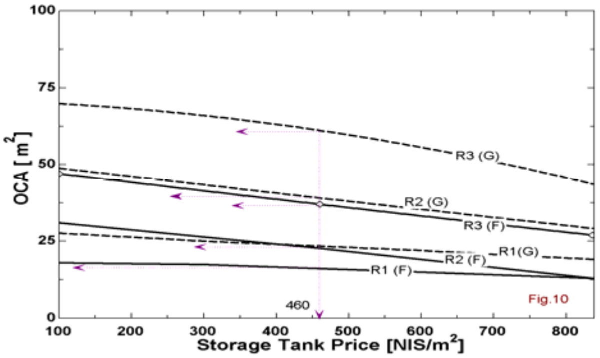

Fig. 10 Variations of OCA with storage tank price.

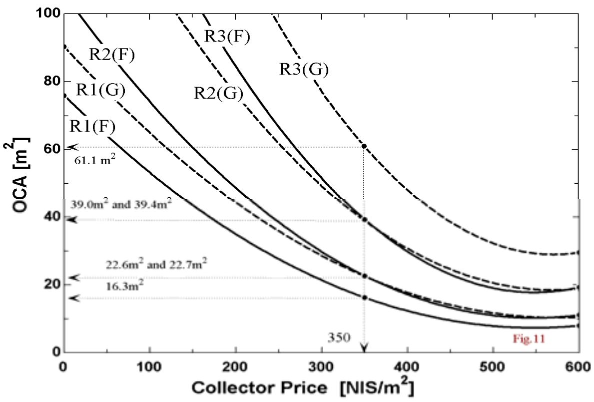

Fig. 11 Variations of OCA with collector price.

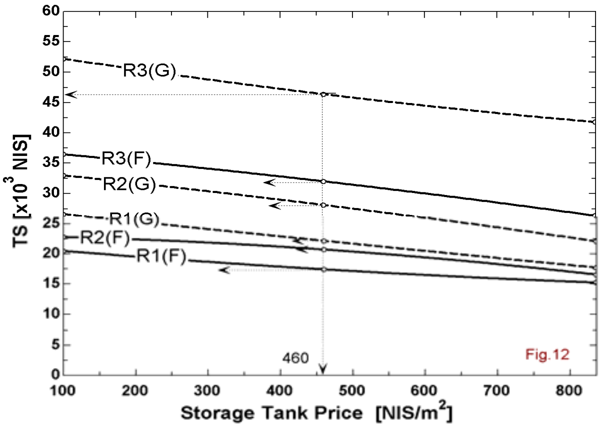

Fig. 12 Variations of TS with storage tank price.

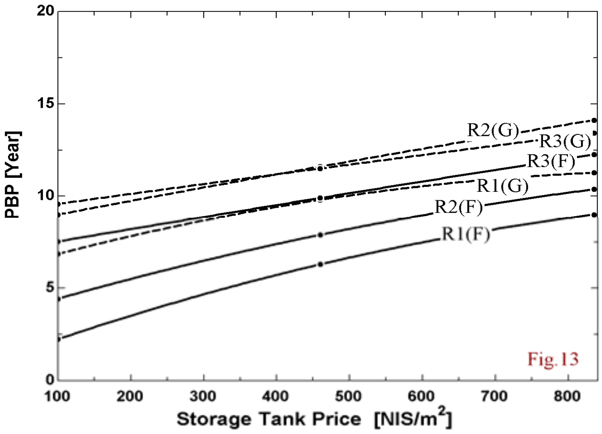

Fig. 13 Variations of PBP with storage tank price.

be almost linear. By increasing the unit price of the storage tank for a fixed A_o, the TS is decreased by an average of 10%, whereas the PBP increases by an average of 5 yr in almost all cases (Figs. 12 and 13). These variations are about 20% greater when the collector unit price is changed (Figs. 14 and 15).

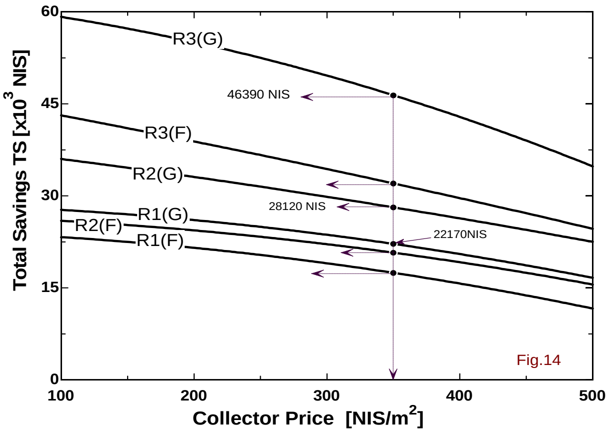

Fig. 14 Variations of TS with collector price.

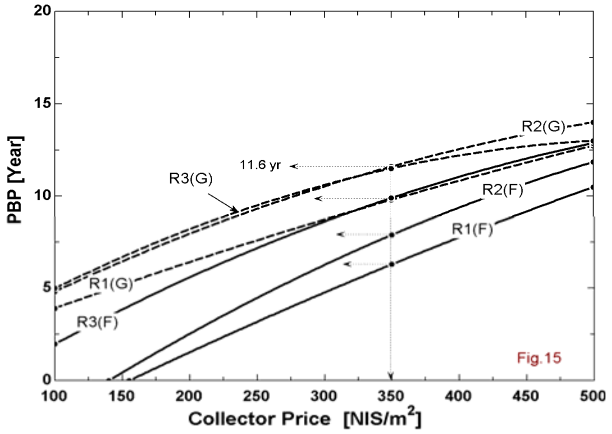

Fig. 15 Variations of PBP with collector price.

4.5 Fuel-Price Increase and Discount Rates

The rate of increase of conventional fuel prices and the discount rate are two important and uncertain economic parameters. Since both parameters influence the PBP and TS similarly, graphical results are presented only for G in one climatic region (Figs. 16 and 17). An increase in the discount rate slows down the increase of TS with the rate of fuel-price increase. Less steep decrements are observed in the PBP but these are slightly accelerated by an increase in discount rate.

4.6 Cost of Solar Energy

The solar energy cost is defined as the present value of the total costs for SI at the end of its lifetime (Tot. cost of SI) divided by the total heating load during the lifetime (ΣQ) multiplied by SHF as:

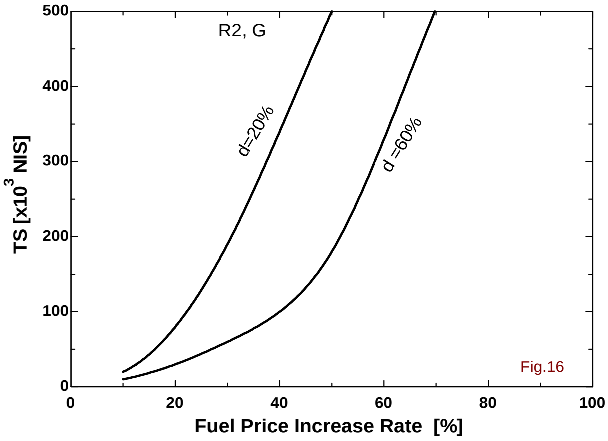

Fig. 16 Variations of TS with fuel-price increase rate for gas in R2, the discount rate (d) is a parameter.

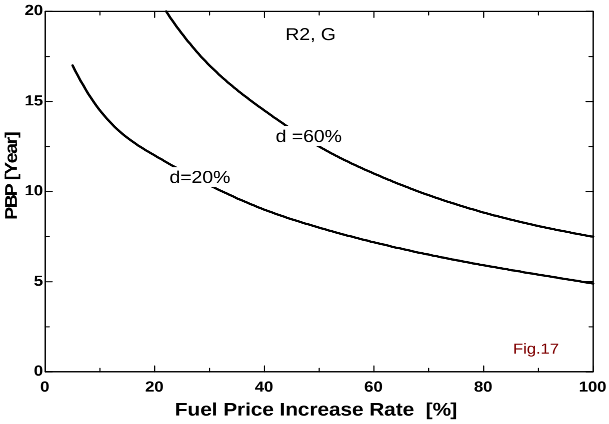

Fig. 17 Variations of PBP with fuel-price increase rate for gas in R2, the discount rate (d) is a parameter.

$$\text{Cost of Solar Energy} = \frac{Tot.\cos t\ of\ SI}{\sum Q \times SHF} \qquad (1)$$

Costs for SI include initial investment, maintenance and operations. A useful measure of solar energy cost is NIS per kWh. By averaging the results for the different cases studied, the solar energy cost for heating is found to be 0.342 NIS/kWh. This figure is found to be the lowest one compared with the fossil-fuels and electricity (Table 5).

5. Analyses and Effects of Design Parameters

In the preceding sections, the effects of economic parameters are described and optimum values are obtained for the fixed design parameters. These include the collector slope and characteristics [F_R ($\tau\alpha$) and (F_R U_L)], storage-tank volume, primary and secondary heat exchanger effectiveness, flow rate of primary and secondary fluids, and the number of heating hours per day. These parameters may also change within reasonable ranges according to the f-chart model (see Table 6). When parameters deviate from optimum values, their effects on performance and system economics must also be evaluated. The results are presented in Figs. 18-24. In each figure, the variations of TS, PBP, and SHF with the design parameter are shown. The left vertical axis represents both SHF (%) and TS (× 10^3 NIS), whereas the right axis shows the PBP in years. The observed variations are similar for the three climatic regions. For this reason, results are presented for G located in R1.

Table 5 Comparison of conventional fuel costs with solar-energy cost (NIS/kWh).

Gas	Fuel-oil	Electricity	Solar energy
0.393	0.562	0.583	0.342

1 kWh = 3.6 MJ; different electricity tariffs are averaged over Palestine on December 2008.

5.1 Collector Slope

The optimum slope of the collector is the angle at which the solar heating system provides the largest fraction of the annual heating load. This angle does not necessarily correspond to the tilt at which the annual solar radiation on the collector is a maximum. Considering the relative time distribution of the solar radiation and heating loads [14, 15], the optimum angles are estimated to be 50, 42, and 36° for R1, R2 and R3 regions, respectively.

Fig. 18 shows that the maximum SHF occurs for a collector tilt between φ+13 and φ+23 (for Jericho, φ the latitude angle ≈ 31.86°). According to my economic analysis, the maximum TS and the minimum PBP correspond to the same ranges of tilt angles. The graphs show that if the maximum TS, maximum SHF or minimum PBP is taken as criterion for finding the optimum slope, the same results will be obtained. Changing the slope from 10 to 90° causes changes of about 15% in SHF, 1.5 yr in PBP, and 6000 NIS in TS.

Table 6 Optimum values and parameter ranges for design: slope (β), collector characteristics [F_R (τα) and (F_RU_L)]: storage-tank volume per square meter of collector area (V), heat exchanger effectiveness (ε), primary and secondary fluid flow rates ($\dot{m}$), number of heating hours per day (N).

Parameter		Optimum value	Studied range
β [degrees]	R1	50	10-90
	R2	42	10-90
	R3	36	10-90
F_R (τα)		0.67	0.5-0.9
F_RU_L (kJ/m²·h·℃)		23.3	5-30
V (lt/m²)		87	50-300
ε		0.7	0.5-0.9
$\dot{m}$ (lt/m²·h)		54	20-80
N (hr)		14	8-24

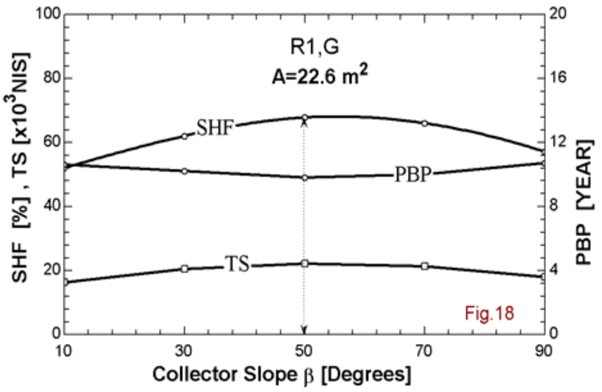

Fig. 18 Variations of SHF, TS and PBP with slope (β).

5.2 Collector Characteristics

The parameters F_R (τα) and F_R U_L measure the operating efficiency of a solar collector. In Fig. 19, the effects of F_R (τα) are shown on the variables. An increase in the transmittance-absorptance product will sharply increase SHF, since this factor represents the amount of energy absorbed by the collector. Changing F_R (τα) from 0.5 to 0.9 causes an increase of 25% in SHF. Within the same range, PBP decreases by about 2.5 yr. The value of F_R (τα) was fixed at 0.67, which is the average estimated value for collectors produced in Hebron [16] and tested in REERU laboratory at PPU.

The influence of F_RU_L is shown in Fig. 20. Since this parameter indicates energy losses from the collector, increasing its value decreases both the useful energy gain and the SHF. Consequently, TS will also decrease while PBP increases. As is evident from the graphs of Fig. 20, with F_RU_L ranging from 5 to 30 kJ/m²·h·℃, the decrease is about 20% for SHF and 10000 NIS for TS; there is an increase of about 2.5 yr in the PBP, which was taken to be 23.3 kJ/m²·h·℃ for the locally manufactured collectors.

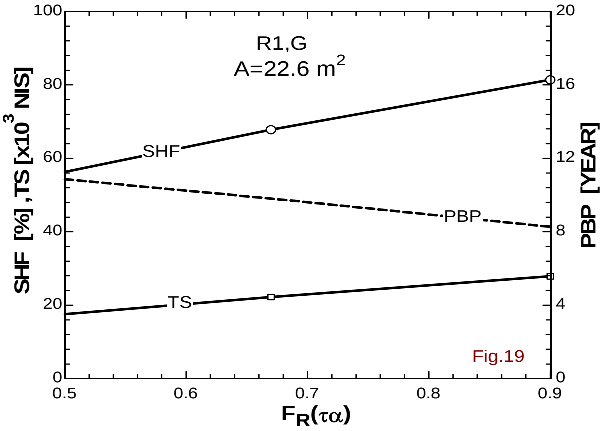

Fig. 19 Variations of SHF, TS and PBP with F_R (τα).

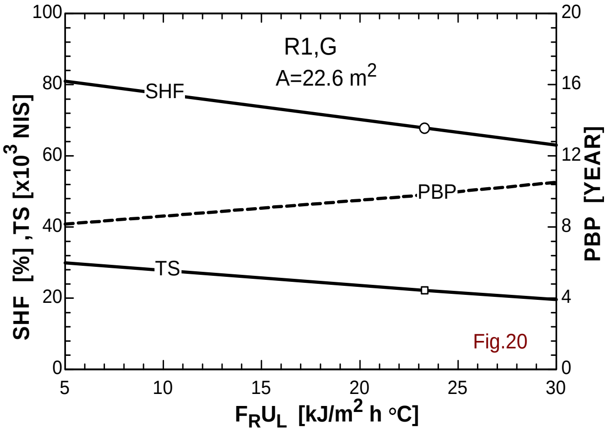

Fig. 20 Variations of SHF, TS and PBP with F_RU_L.

5.3 Storage-Tank Volume

Fig. 21 demonstrates the effects of storage tank volume in liters/m² of collector area. An increase in storage volume causes a slight increase in SHF, and a smaller decrease in TS. The increase in SHF will decrease the amount of auxiliary fuel consumed, which, in turn, will decrease the total cost of SI as compared with the total cost of CI. This change results in a decrease in TS. The increase in the PBP is about 5 years. Fig. 21 indicates that an increase in storage-tank volume will increase the cost of SI. The actual value taken was 87.0 lt/m² for the locally manufactured collectors.

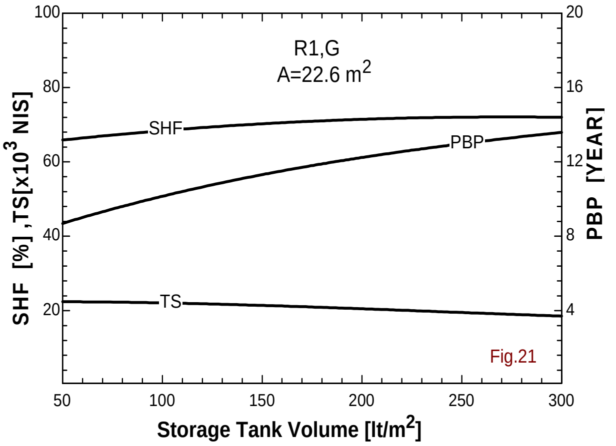

Fig. 21 Variations of SHF, TS and PBP with storage tank volume.

5.4 Heat Exchanger

A f-chart design for liquid-based collector heating systems usually presupposes two heat-exchangers. The one located between the collectors and the storage tank is referred to as the primary heat exchanger and has the greatest influence on system performance. This heat exchanger is characterized by its effectiveness and the fluid-flow rate.

Variations of the variables with the effectiveness of the primary heat exchanger and the flow rate are shown in Figs. 22 and 23. The effects of both are negligible as compared with those of the other design parameters studied. The actual values used in this study are 0.7 and 54 lt/m²·h for heat-exchanger effectiveness and flow rate, respectively.

5.5 Number of Heating Hours

The number of heating hours per day is an important input parameter. The effects of this parameter on the variables are shown in Fig. 24. The annual solar heating fraction is sharply affected by the number of heating hours. For 24 heating hours, the SHF is about 30% less than for a heating period of 8 h a day, as can be seen from Fig. 24. A value of 14 h/day is used as a normal value in this analysis.

An increase of heating hours will naturally increase the heating load for a building and the required energy supply from the collectors; it will reduce the SHF. Fig. 24

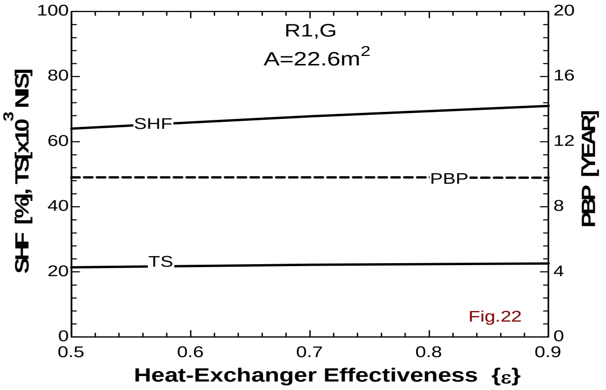

Fig. 22 Variations of SHF, TS and PBP with primary heat-exchanger effectiveness (ε).

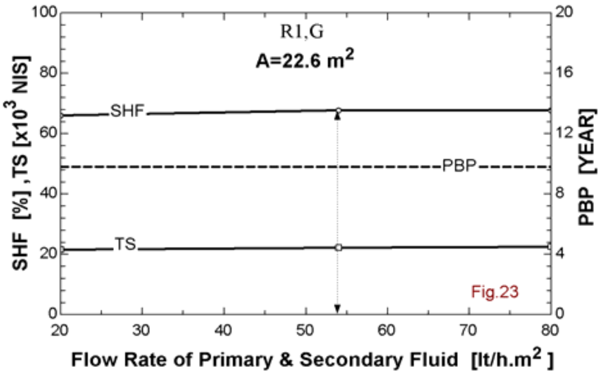

Fig. 23 Variations of SHF, TS and PBP with flow rates of primary and secondary fluids ($\dot{m}$).

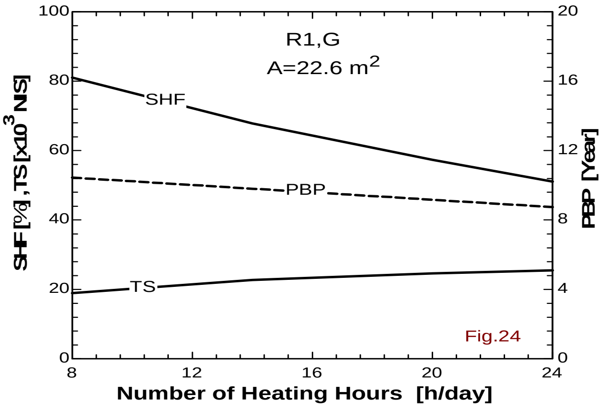

Fig. 24 Variations of SHF, TS and PBP with the number of heating hours per day (N).

shows that the TS increases with an increasing number of heating hours. This result is due to the increase in the building heating load, which makes the unit price of conventional fuel the dominant parameter. Thus, the increase in TS is directly related to an increase in the amount of conventional fuel consumed. Longer heating hours also require larger collector areas.

6. Discussion and Recommendations

The validity of a capital-investment calculation depends on accurate estimation of future cash flows. A commonly used standard procedure for evaluating a capital investment, which involves both costs and benefits over a number of years, is the present value life-cycle costing method. This method accounts for the time value of money by multiplying costs occurring in future years by a discount factor. These reduced annual costs are added to obtain a single number that is equal to the present value of future annual expenditures.

The uncertain and unstable factors involved in such a forecast are discount rate, inflation rate and the rate of increase of fuel price. Values of the economic parameters averaged over the last 10 yr and based on the year 2008 have been used. The important results are presented for a wide range of values of the economic parameters to present the user with several decision alternatives. The quality of the results will depend on the quality of these assumptions.

The maintenance and operating costs of solar installations are generally low, but the initial costs of purchasing and installing such a system are high compared to conventional systems. In Palestine, the initial investment in a solar heating system is at least twice the initial cost of a conventional alternative, which is beyond the purchasing power of many families, but can be recovered within 8-11 yr depending on the particular design conditions. Due to low consumption of conventional fuel in the auxiliary parts of the SI, the corresponding TS are observed to be between 1 and 3 times the initial investment made in the SI. Thus, a long payback period and high initial investment costs are the major drawbacks of solar energy heating systems in Palestine.

The government might offer financial incentives such as subsidies, loans, tax credits, etc. on the capital cost of solar system, especially, on solar collector and storage tank. For instance, if either the collector cost per square meter or the storage tank price dropped by 20% through governmental intervention, the PBP of the capital invested in a solar system would decrease by an average of 3 yr and the TS would increase by an average of 25% (see Figs. 12-15). Such conditions might encourage a building owner to install solar system. In addition to economic incentives, other institutional, environmental and managerial efforts might be used to enhance solar energy use in our country Palestine.

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