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Economic Analysis of Domestic Automated Forced Circulation Solar Water Heater

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Abstract:
Countries are currently facing the urgent need to tackle the climate crisis, reduce pollution, and protect our planet's biodiversity and other natural resources, while simultaneously ensuring that a transition to a low-carbon greener economy delivers benefits to all. To meet environmental goals and be in line with Agenda 2030, policy- and decision-makers need to consider links between environmental policy responses and other goals. In this direction, economic analysis is carried out based on previous experimental data obtained for both conventional energy savings: electrical and oil fuel with MENA region. The results of energy savings and overall efficiencies of domestic automated forced circulation water heating. The analytical results obtained lead to several conclusions; the importance is: The combined solar and oil-fuel water heaters become economics after a period of usage (14 years) with a collector area of 10 m^2 i.e. becomes commercial and the percentage of energy saving under continuous constant load varies between 14% during the winter season and 75% during the spring season. The yearly economic analysis is based on 9 months omitting summer months as the collector efficiency will be higher than 100%. The correlation coefficient between this study's results and other previous studies either with saved energies or payback periods approaches is clear that: correct data analysis, the precision of gathering experimental data and the assumptions were done.

Keywords: solar water heater, auxiliary heater, solar heat exchanger, electric heater, oil-fuel heater

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1. Introduction

Global power sector CO2 emissions (from both electricity and heat production) increased by close to 700 Mt CO2 in 2021, reaching an all-time high of more than 14 Gt. This was driven mostly by a strong increase in coal-fired electricity generation compared to the year before [1]. A fully decarbonised electricity sector is the essential foundation of a net zero energy system. Electricity is at the heart of modern economies, with its share of final energy consumption over 50% by 2050 as electricity demand increases rapidly. Unabated fossil fuels currently account for over 60% of total global electricity generation. To be consistent with the Net Zero Emissions by 2050 Scenario, that share needs to drop to 26% by 2030. The pace of deployment of low- and zero-emission sources has to pick up significantly to meet this milestone [1,2].

Solar energy plants are becoming more widespread even in northern countries because solar energy is not subject to crisis and is delivered free. The potential saving in oil and electricity is considerable. Whichever way you look at them, solar energy plants are an investment, since solar energy, especially useful in heating the water for domestic purposes, is also advisable for heating the water circulating in a central heating system as well as in desalination plants. Solar energy panels transform solar energy into hot water throughout the winter even during days with diffused radiation (overcast sky) [3]. Of course, the use of solar plants offers energy autonomy, consumption of clean energy (healthy environment) and saving of other energies if it is combined with them [3]**.** Solar collectors mainly classified into two main types:

(A) Non-concentrating collectors (Low temperature <100 ºC).
(B) Concentrating collectors (High temperature >100 ºC).

The existing solar system used in this study is classified as a non-concentrating collector. In this study energy saving amounts are obtained from the combination of both automated forced circulation flat plate collector solar water heater systems with the electric water heater or oil fuel heater under MENA region weather conditions [5].

2. Historical background

One of the most economical uses of solar energy today is domestic hot water heating. This is so because the installed equipment works at nearly full capacity throughout the year to satisfy a relatively constant domestic demand for hot tap water. Economics plays a major role in the future adoption of alternative energy technologies. Proper employment of economic tools should provide much useful information on impending research, marketing, and policy decisions. A comparison of the energy cost for solar water heating with the energy costs of various selected fuel-fired alternatives [6], noted that an installed solar system is noninflationary concerning energy costs because it is a one-nine investment outlay, while fuel prices will rise at a predicted rate of 7% per year plus the general inflationary trend, thus the payout periods was in the range 4.2 and 10.8 years for electric and natural gas respectively. In the simplest terms, a solar energy system will be less expensive than a non-solar system if the fuel savings are greater than the mortgage payments required to buy solar equipment [7].

A problem with this comparison is that it is difficult to take into account rising fuel costs. And, there may be other items affecting the economics of solar heating which should be taken into account, such as property taxes, income taxes, insurance and maintenance. Although solar energy is essentially free, there is a definite cost associated with its utilization. The technological cost does not rest on raw material, but rather on the processes necessary to transform it into a usable form. The purpose of economic optimization is to maximize the savings resulting from the use of solar energy. The major economic of solar heating studied, a thermal model devised for a solar heating system to compute annual thermal performance (based on one-year meteorological data) also used an amortization period of 20 years [8,9].

Their results are: (a) the optimum tilt has little effect on the cost; (b) two glass covers produce less expensive energy. In the cost analysis comparison of electric water heaters and solar water heaters in1977 (6), he found that the present worth of the solar water heater is ($ 196.2) and is lower than that of the electric water heater ($ 281.1) i.e. the domestic solar water heater is more economical than their corresponding electric devices. Economic analysis of solar district heating in studied [10], and found that 25% of the district heating demand (including hot tap water) is supplied by solar energy. It is predicted that this percentage may be doubled by the year 2000. Their calculations showed that solar heating should become competitive with oil within about a decade. A study to determine the feasibility of hot water and space heating by solar systems in Belgium was conducted (8), and a comparison was made between the solar system and an oil-fired conventional system. From the results of that study, it is concluded that solar systems for house heating and hot water production can be economically justified, depending on the system size. Oil price in Belgium increases by at least 8% per year and collector prices should be less than ($ 68/m2) for solar systems to be economical. The payback period of the economic systems is between 10-15 years. The % savings increase as the collector area is increased.

Measured and predicted the annual performance of solar domestic water heaters in South Ontario studied [11], four systems being used, the calculated annual solar fraction per square meter of the four systems (they have approximately the same collector area) varied between 7-10.3%, also it is concluded that solar hot water can reduce the electrical consumption by 35 to 55%.

The performance of a central solar domestic hot water system and the economic analysis studied (10), they used two sets of ten collectors (each 1.78 m2) and a storage tank of 2 m3. For their prototype unit, the total thermal energy collected was 69817 KJ/m2. They conclude that the use of modular collectors of 1.8 m2 each, as available commercially, is more economical than building one large solar panel, also they found that solar-assisted central daily hot water systems are usable, economical and competitive.

An economic analysis utilizing data from eighteen cities representing the variety of different weather conditions throughout the country (USA) was performed [12]. For each city, a cost comparison over twenty years is made. The analysis indicates that, in cities, where the cost of electricity is quite high, solar energy can be used efficiently for both space and/or domestic water heating. On the other hand, in cities, where electric power is much less expensive, the cost of installing a solar energy system does not make solar a viable companion to the conventional. The component cost of the different solar energy systems studied [13], they found that the installed cost of solar collectors for large projects is less than one-half the cost of the solar energy system unit. Optimal configuration of a combi-system in terms of life cycle energy and cost given the Canadian climate equipment, and energy costs presented [14]. Additionally, the paper presented the effectiveness of certain optimization techniques when they were applied to solar combi-systems. The transient simulation software TRNSYS was used with a model of an energy-efficient house in Montreal that was equipped with a solar combi-system. A hybrid practical swarm and Hooke-Jeeves optimization algorithm were used to determine the optimal configuration of the solar combi-system [15]. Two separate objective functions were used to find two separate optimal configurations in terms of life cycle cost and life cycle energy. The hybrid particle swarm optimization and Hooke-Jeeves algorithm were effective at reducing the value of the objective function regardless of which objective function was considered. The LCC of the combi-system was reduced by 16-19% and the LCE was reduced by 34% compared to the base case combi-system which was designed based on design recommendations to meet the needs of the house. Finally, a combi-system that performed well in terms of life cycle cost would perform poorly in terms of life cycle energy. A procedure for assessing and developing the economic viability of a solar heating system in terms of the life cycle savings of a solar heating system over a conventional heating system [16]. The life cycle savings were expressed in a generalized form by introducing two economic parameters, p1 and p2, which relate all life cycle cost considerations to the first-year fuel cost or the initial solar system investment cost. Using the generalized life cycle savings equation, a method was developed for calculating the solar heating system design which maximizes the life cycle savings. A similar method was developed for determining the set of economic conditions at which the optimal solar heating system design was just competitive with the conventional heating system [17]. The results of these optimization methods could be presented in tabular or graphical form. The sensitivity of the economic evaluation and optimization calculations to uncertainties in constituent thermal and economic variables was also investigated [19].

3. System layout

The system was manufactured by Merloni Company – Italy. It consists of two identical flat-plate solar collectors (3.4 m2 total) connected with a storage tank and solar control units equipped with a thermostat and pump. The storage tank capacity (200 litres) contains an immersion electric heater (1.2 KW capacity) and a solar heat exchanger [20]. Collectors were tilted to a 36˚ latitude angle within the MENA region – Middle East and North Africa. The collectors can be connected in parallel or series through the supply headers, each panel consists of ten evenly spaced parallel pipes (risers) bonded to the plate employing mechanical compression in semi-circular grooves formed in the flat plate [21]. The collector tubes and heat exchanger coil in this system are filled with a water solution of antifreeze and corrosion-proofing [22].

4. Performance of solar heating systems:

Energy balance of the storage tank with auxiliary heater. The performance of the solar heating system is given in terms of the following efficiencies [22].

Storage efficiency (η_{stor})

Is defined as the ratio of stored energy by the water inside the tank to the solar energy supplied by the solar heat exchanger.

$$\eta_{stor} = \frac{\Delta E_{tank}}{E_{solar}} x100 \quad (1)$$

Net system efficiency (η_s)

The net system efficiency is one of the most important parameters of any heating system. This value indicates how much of the energy put into the system is delivered as useful output (in this case, hot water).
The equation is written as follows [23]:

$$\eta_s = \frac{E_{H2O}}{E_{solar}} x100 \quad (2)$$

Loss factor (F_{loss} % loss)

Is defined as the ratio of energy loss from the storage tank to the solar energy supplied from the solar collectors:

$$F_{loss} = \frac{E_{loss}}{E_{solar}} x100 \quad (3)$$

Overall efficiency (η_o):

Is defined as the ratio of the total sum of the stored and useful energy gained by water to the solar energy supplied by the solar coil heat exchanger [24].

$$\eta_o = \frac{\Delta E_{tank} + E_{H2O}}{E_{solar}} x100 \quad (4)$$

Similarly, for an auxiliary water heater or the combined solar and auxiliary water heaters, except the relative contributions in case of both heaters working together being introduced, they are:

$$\%\, Load\ by\ solar\ (\%\, saving) = \frac{E_{solar}}{E_{solar}+E_{aux}} x100 \quad (5)$$

$$\%\, Load\ by\ aux.(\%\, saving) = \frac{E_{aux.}}{E_{solar}+E_{aux}} x100 \quad (6)$$

$$E_{solar} + E_{aux} = E_{H2O} + \Delta E_{tank} + E_{loss} \quad (7)$$

Where:

ΔE_{tank}: Change in the thermal mass of the storage tank and its content, (Watt);

E_{solar}: Energy supplied from solar collectors to the solar heat exchanger, (Watt);

E_{H2O}: Energy supplied, as hot water from the storage tank to the user, Watt);

F_{loss}: Energy loss from the tank to the surrounding, (Watt);

E_{aux}: Energy supplied by the auxiliary heater, (Watt);

E_{KWH}: Energy supplied by the immersed electric heater, (Watt);

(A) The thermal efficiency (overall system efficiency) of the solar water heater (η_{os})

Defined as: the ratio of heat gained in the storage tank during a period to the amount of incident solar radiation during the same period and can be calculated using this equation [25]:

$$\eta_{os} = \frac{\Delta E_{tank} + E_{H2O}}{A_c . I_T} x100 \quad (8)$$

For a period equal to one day, daily overall system efficiency can be calculated using the following formula:

$$(\eta_{os})_{daily} = \frac{\sum \Delta E_{tank} + \sum E_{H2O}}{A_c . \sum I_T} x100 \quad (9)$$

While the oil-fuel and the electric heater thermal efficiencies are calculated as follows:

$$(\eta_{os})_{oil-fuel} = \frac{\Delta E_{tank} + E_{H2O}}{m_f\ x\ C.V} x100 \quad (10)$$

$$(\eta_o)_{electric} = \frac{\Delta E_{tank} + E_{H2O}}{E_{KWH}} x100 \quad (11)$$

$$\Delta T_{sm} = (T_{sm})_2 - (T_{sm})_1 \quad (12)$$

$$\Delta E_{tank} = M.C_p.\frac{\Delta T_{sm}}{\Delta\tau} \quad (13)$$

$$T_{sm} = \left[\frac{\sum_1^n T_{n\,tank}}{n}\right]_{equally\ spaced\ thermocouples} \quad (14)$$

$$T_{sm} = \left[\frac{Area\ under\ curve}{Height\ of\ storage\ tank}\right]_{unequally\ spaced\ thermocouples} \quad (15)$$

The area under the curve is obtained by plotting the temperature of thermocouples against the storage tank height to calculate the storage tank mean temperature (T_{sm}).

$$E_{solar} = \dot{m}_c\,.\,C_p\,.\,(T_1 - T_2) \quad (16)$$

$$E_{H2O} = \dot{m}_L\,.\,C_p\,.\,(T_{Lo} - T_{Li}) \quad (17)$$

$$E_{loss} = U.A_s\,.\,(T_{sm} - T_a) \quad (18)$$

Where:

ΔT_{sm}: Mean storage tank water temperature change in a period of $\Delta\tau$ (sec), ºC; $(T_{sm})_1$, $(T_{sm})_2$: Mean storage tank water temperature at the beginning and end period of heating respectively. ºC; T_{sm}: Mean storage tank water temperature. ºC; T_{Li}, T_{Lo}: Inlet storage tank (supply) water temperature and outlet storage tank (load) water temperature respectively. ºC; T_1, T_2: Water temperature at inlet and outlet of the solar heat exchanger respectively, ºC; T_a: Ambient air temperature, ºC; C_p: Fluid specific heat, J/Kg. ºK; C.V: Fuel calorific value, J/Kg; A_c: Collector absorber surface area, m^2; A_s: Storage tank outer surface area, m^2; $\dot{m}_c$: Mass flow rate through the collector, Kg/sec; $\dot{m}_L$: Drained water mass flow rate (Load), Kg/sec; m_f: Fuel consumption mass flow rate, Kg/sec; M: Storage tank water capacity, Kg; $\dot{M}$: Total sum of storage tank capacity &drained water ($\dot{M} = \dot{m}_L + M$), Kg; n: Number of thermocouples; U: Heat transfer coefficient of the storage tank, W/m^2. ºC; I_T: Total solar insolation on collector plane, W/m^2;

5. Electrical energy and oil-fuel savings

The solar water heater acts as the major source of heat which is supported by electric or oil-fuel energy as auxiliaries. The electrical energy and oil-fuel saving calculations are divided into two types [20, 21]:

(A). Saving when both water heaters (solar and the auxiliary) work separately

This saving is again divided into two types:

A-1 saving under no load condition

The energy supplied by the solar collectors (which is the amount of energy saved) will be stored by the water inside the storage tank, which is calculated from the following equation:

$$E_{solar} = M.C_p.\frac{\Delta T_{sm}}{\Delta\tau} \quad (19)$$

Assuming the required mean storage tank water temperature is (T_r). The energy required to be supplied by the auxiliary heater to meet this required temperature after the combination is calculated from the following equation:

$$(E_{aux.})_{combined} = \frac{\frac{MC_p}{\Delta\tau}\left[T_r - \frac{(T_{sm})_1 + (T_{sm})_2}{2}\right]}{(\eta_O)_{aux.at\ no\ load}} \quad (20)$$

Thus the energy supplied by the auxiliary heater alone to meet the same required temperature (T_r), at no load condition is calculated from the following equation:

$$(E_{aux.})_{alone} = E_{solar} + (E_{aux.})_{combined} \quad (21)$$

A-2 Saving under load condition

The energy supplied by the solar collectors (which is the amount of energy saved) will be neglected by the water inside the accumulator; this is calculated from the following equation:

$$E_{solar} = E_{H2O} + \Delta E_{tank} \quad (22)$$

$$E_{solar} = \dot{m}_L C_p (T_{Lo} - T_{Li}) + M.C_p.\frac{\Delta T_{sm}}{\Delta \tau} \quad (23)$$

The energy required to be supplied by the auxiliary heater to meet the required temperature (T_r) after the combination is:

$$(E_{aux.})_{combined} = \frac{\frac{MC_p}{\Delta \tau}\left[T_r - \frac{(T_{sm})_1 + (T_{sm})_2}{2}\right] + \dot{m}_L C_p \left[T_{Lo} - \frac{(T_{sm})_1 + (T_{sm})_2}{2}\right]}{(\eta o)_{aux.at\ load}} \quad (24)$$

If it is assumed that (T_{Lo}) is the same as the required storage tank water temperature (T_r)

$$(E_{aux.})_{combined} = \frac{\frac{\dot{M}C_p}{\Delta \tau}\left[T_r - \frac{(T_{sm})_1 + (T_{sm})_2}{2}\right]}{(\eta o)_{aux.at\ load}} \quad (25)$$

Also, the energy supplied by the auxiliary heater alone to meet the same required temperature (T_r) at load condition is calculated from equation 21**.**

A. Saving when both water heaters (solar and auxiliary) work together

This will give the actual saving which is calculated from equation (21) either for load or no load conditions to meet the required temperature.

6. Size of the auxiliary heater

Consider that a system of a similar type operating under optimum conditions is required for heating purposes with a load of say Q *KW* (or Q/(C_p .ΔT) Liters of water to be heated by ΔT = 30 ºC). From the experimental work, the overall efficiency of the system can be obtained (e.g. overall system efficiency during the winter season under optimum conditions is on average equal to 42%, daily total solar insolation over 5 hours being 15038 KJ/m^2). Observation of the average solar insulation tested using a pyrometer varied from (400-850 W/m^2) during winter time and (400-1000 W/m^2) during springtime. The average ambient temperature varies from (5-15˚C) during winter time and (10-25˚C) during springtime. Then the necessary area of the collector can be calculated from the:

Net heat gained (Required load) = A_c. η_o. $\sum I_T$ (26)

Most designers choose a storage tank size giving a storage/collector area of 60 Lit/m^2, (for the present system this value will lead to a temperature rise of 25 °C).

Thus storage tank size = A_c x 60 (27)

The auxiliary heater required for this system can be estimated for the worst conditions (no solar energy at all). Therefore, the electric heater size should be Q KW (=1.2 KW in this case).

7. Auxiliary energy-saving calculations

7.1 Sample of calculation

a. For both water heaters (solar and auxiliary) working separately under no load condition:

Applying the experimental data from the test run. For the local time between 9 a.m. - 10 a.m. (i.e. Δτ= 3600 sec).

$(T_{sm})_1$ = 11 °C, $(T_{sm})_2$ = 18 °C calling equation 19

$$E_{solar} = M.C_p.\frac{\Delta T_{sm}}{\Delta \tau} \rightarrow E_{solar} = 200x4.186x\frac{(18-11)}{3600} = 1.62\ KW$$

Assuming the temperature required (T_r) is 30 °C, and assuming the auxiliary water heater is electric and it is efficient at no load = 100%

Calling equation 20 $\rightarrow (E_{aux.})_{combined} = \frac{\frac{MC_p}{\Delta \tau}\left[T_r - \frac{(T_{sm})_1 + (T_{sm})_2}{2}\right]}{(\eta o)_{aux.at\ no\ load}}$

$$(E_{aux.})_{combined} = \frac{200x4.186\left[30 - \frac{11+18}{2}\right]}{3600x1} = 3.6\ KW$$

Calling equation 21 $\rightarrow (E_{aux.})_{alone} = E_{solar} + (E_{aux.})_{combined}$

$(E_{aux.})_{alone}$ = 1.62 + 3.6 = 5.22 Kw

Not that the auxiliary immersion heater fitted to the storage tank is of a capacity of 1.2 KW.

b. For both water heaters (solar and auxiliary) working separately under load conditions:

Experimental data from the test run. For local time 9 a.m. - 10 a.m. (i.e. $\Delta\tau$= 3600 sec) $(T_{sm})_1$ = 7.5 °C, $(T_{sm})_2$ = 9°C $\dot{m}_L$= 60 Lit/hr , $(T_{Lo})_{aver}$ = 8.75 °C, $(T_{Li})_{aver}$ = 5 °C

Calling equation 23 $\rightarrow E_{solar} = \dot{m}_L C_p (T_{Lo} - T_{Li}) + M.C_p.\frac{\Delta T_{sm}}{\Delta\tau}$

$E_{solar} = \frac{60}{3600} x4.186x(8.75 - 5) + \frac{200}{3600} x4.186(9 - 7.5) = 0.61\ KW$

Assuming the temperature required (T_r) is 30 °C, and assuming the auxiliary water heater is electric and it is efficiency at no load = 100% Calling equation (25)

$$(E_{aux.})_{combined} = \frac{\frac{\dot{M}C_p}{\Delta\tau}\left[T_r - \frac{(T_{sm})_1 + (T_{sm})_2}{2}\right]}{(\eta_O)_{aux.at\ load}}$$

$$(E_{aux.})_{combined} = \frac{260x4.186\left[30 - \frac{7.5+9}{2}\right]}{3600x1} = 6.57\ KW$$

Calling equation 21 $\rightarrow (E_{aux.})_{alone} = E_{solar} + (E_{aux.})_{combined}$

$(E_{aux.})_{alone}$ = 0.61 + 6.57 = 7.18 KW.

7.2 Payback period calculations

According to the definition of the payback period represented by [17] which is:

$$Payback\ period\ (Year) = \frac{Initial\ cost}{Annual\ saving\ cost} \qquad (28)$$

Payback time also can be defined by [18] as the time needed for the cumulative fuel savings to equal the total initial investment in the system. Taking the cheapest system (oil-fuel) saving as the basis for payback calculations and back to data calculated.

The payback period for the combined solar and oil-fuel heaters = $\frac{500\ \$}{(41.8-28.9)\ \$/Year} = 38.7\ Years \approx 39\ Years$

This high payback period for the combined solar and oil-fuel heater is due to its high initial cost and the low cost of the fuel. While the combined solar and electric heater is not applicable because its operating cost seems higher than the oil-fuel heater. However, by considering a more practical collector area for the heating requirement; assumed (say three times the present one, i.e. approximately 10 m^2 panel which will raise the initial cost to about 600 $) [22]. Applying the data obtained from the actual tests on a series of automated forced circulation solar water heaters in which the temperature rises in the first collector–inlet water supplied was less than the second collector–outlet water leaves by 12%. Therefore, connecting these panels in series (each pair in parallel) should raise the storage tank water temperature by about 2.5 times the present value, and the yearly percentage saving will be nearly 2.5 times the present saving [23-26]. The total cost of the oil-fuel heater becomes greater than the total cost of the combined solar and oil-fuel heater after 14 years of operation i.e. nearly half the period of the previous case (with a collector's area of 3.4 m^2).

To estimate the rise in the cost of fuel that will make solar systems economical (assuming an oil-fuel heater is already available in an atypical house), the initial cost of the solar water heater then is 600$.

Assuring a payback period of 10 years

Yearly savings should be 60 $/year with such a panel (three times the present panel i.e. 10 m^2).

Yearly saving = 2.5 x (present fuel saving with 3.4 m^2 panel.

Yearly saving = 2.5 x (1552.8-1076.63) =1190.4 kg of kerosene.

As kerosene density is ≈ 0.8 kg/Lit.

Yearly saving = 1488 Liter kerosene/year

$The\ fuel\ price = \frac{60\ \$/year}{1488\ Lit/year} = 0.04\frac{\$}{Lit} = 4\ ¢/Lit$

Thus the oil prices should exceed one and a half folds ($1\frac{1}{2}$) the present prices to pay back an initial cost of 600 $ for 10 m^2 solar collector areas within 10 years.

Note that the above calculation is based on the following information:

- Monthly electrical. energy cost is calculated according to the local following tariff:

First	360 KWh …..…….	at price	10 ¢/KWh
Second	540 KWh … ……..	at price	20 ¢/KWh
Third	900 KWh……….....	at price	30 ¢/KWh

- The oil-fuel cost is calculated according to the official price of 25 ¢/Liter
- Long-term (quarter century) average wind velocity, ambient temperature and solar insulation are taken from reference [19].

8. Discussion

To evaluate the gains to be made by utilizing solar energy for domestic water heating, it is important to consider the combined effect of a solar water heater with an auxiliary water heater and to compare the cost of these systems. Most domestic purposes (bathing and cleaning) need warm water within the range of (30-50 °C), thus if this range is considered for operation in actual with 360 Liters of water consumed per day (i.e. 60 Lit/person in a family of 6 persons) as a basis of calculations. The required electrical energy of oil fuel in combination with a solar water heater can be estimated and hence finding the percentage of load supplied by an auxiliary, as well as the energies required when these auxiliaries work alone.

The test was accomplished with the solar system of the limited area of 3.4 m2 for both panels, first under no load conditions and then under load conditions during various months (Dec-May). the solar storage tank water temperature needs to be raised by the auxiliary heater. This means some savings will be achieved in the electrical energy or oil-fuel compared to the usual requirement for heating the tap water directly. In the MENA area region, water heating is necessary for at least nine months of the year, leaving out June, July and August. Power consumption by the solar pump is negligible in all calculations of saving because its consumption represents a small percentage (5.8%) compared with electrical heater consumption. Also, this consumed electrical energy by the pump is transferred to the working fluid and a maximum temperature rise across the pump of 1°C is found at the maximum flow rate. The days chosen for carrying out the experiments are near the middle of the month and clear skies, thus are taken to represent the mean of the month. Using the electrical energy and oil-fuel saving equations mentioned in section 5 and assuming the overall efficiency for an oil-fuel heater under load condition 28% and no load condition 36.6% and that for an electric heater under load and no load is 100%. Calculations on an hourly basis and using data from (19) which gives the average number of clear sky days for a quarter century time. Thus the use of solar energy per month can be obtained by multiplying solar energy per day by the number of clear days per month.

These results are shown the % saving obtained. The % savings are obtained for a mean water tank temperature of 30 °C and also for a mean water tank temperature of 50 °C, the yearly percentage saving ranges between 12.7 - 43.3%, it is observed that December is the month with minimum savings. For an average family of 6 persons which may consume 360 Liters of hot water per day, the yearly percentage saving is estimated to be 31% on basis of 18.7 GJ of total heat requirement. In the case of the mean water tank temperature raised to 30 ºC, and considering the cheapest system (oil-fuel heater) as the basis for evaluating the saving, it is clear that 12.9 $ saved/per year for the combined solar and oil-fuel heater while the combined solar and electric seems to be uneconomic because of no saving. This is calculated from data showing that the operating cost (payback period) is determined after (20) years by assuming the fixed cost of fuel and electricity. It is observed that the total cost depending on the electric heater will exceed the total cost of combined solar & oil-fuel after 9 years & exceed the total cost of the combined solar and electric after 12 years. Also, the total cost of the combined solar and electric heaters will be more than the total cost of the combined solar and oil-fuel after 5 years which means that the latter one will become more economic i.e. less payback period.

9. Conclusions:

The results obtained from this study lead to several observations as follows:

I. Solar energy offers good potential for the conservation of energy in (the MENA region) more than (5.7 GJ annually) can be useful.

II. For the existent solar water heater of 3.4 m2 area and load of 360 Lit/day of hot water at 30 °C the percentage saving ranges between 14% (December – winter season) and 75% (May – spring season).

III. The combined solar and oil-fuel water heaters become economical after a period of usage (14 years) with a collector area of 10 m2 i.e. becomes commercial.

IV. Applying the same water heating system to geographical places lower than 36º latitude angle will double or maybe triple the percentage saving of such a system during the winter season while it can reach 100 % during the spring season.

V. The correlation coefficient between this study's results and other previous studies mentioned in the historical background either saving or payback period approach to 1, with any doubt the correct data analysis, the precision of gathering experimental data and the assumptions were done.

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