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Numerical Study & Feasibility Analysis of Kuwait Standard House Water Heating System Using Active Indirect Forced Circulation Flat Plate Solar Collector

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ABSTRACT:
This project is concerned with the most important renewable energy source, solar energy, as a heating source for domestic hot water demand in a residential property in Kuwait. This project aims to conduct a numerical study for a solar water heating system (SWHS) to provide the ability to develop and modify the conventional electricity-based water heating system. They were also concerning the key factors affecting the performance of the (SWHS). Additionally, demonstrate the energy balance of the flats plate solar collector applied in the system to obtain the parameters of the solar collector according to the surrounding annual conditions. Moreover, demonstrate the WAHM method of the storage tank, solar energy gain, and auxiliary energy. The (SWHS) electricity saving is approximately 11.5 MWh annually, about 57 % of the project hot water demand. Hence, the annual reduction of the CO_2 emissions are 57% which is an excellent advantage of the (SWHS) application. The system's payback period is about 11.7 years, with a projected vision of Kuwait and average GCC countries. Moreover, the system's financial benefit will double at the end of the system life.

Keywords: Solar energy; Renewable energy; Flat Plate Solar Collector; Water Heating System; Flat Plate Solar Collector; Kuwait; GCC countries; CO_2; Emission; Electricity saving; payback period; Financial benefit

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and storage tank. Furthermore, financial appraisal of the system includes the energy cost, saving, and payback period. Furthermore, environmental evaluation of the system CO_2 emission & saving. Likewise, to evaluate the economic feasibility laterally with the environmental interest in the state of Kuwait and its region. Evaluate the designed system and baseline of household concerning cost, and CO_2 emissions.

Applying the solar water heating system in a residential building is considered an attractive method for house owners to reduce the electricity cost and the environmental impact of fossil fuel emissions (Dharuman et al., 2006). Kuwait is one of the oil-producing countries, and it depends 100% of its electric power on heavy fuel oil burning to power the thermal power plant to produce electricity. Fossil fuel is a significant source of pollution and global warming, which we are begun to see and feel its catastrophic implications. To comply with the agenda of the International Energy Agency to reduce the energy demand of the residential building sector, where 75% of residential energy demand is for space cooling and domestic water heating. Jaffar et al. [15] stated that

I. INTRODUCTION

Fossil fuel is the leading global energy source, approximately 90% of the global energy. Moreover, the demand for such energy sources significantly increases as the consumption is 105 times faster than the quantity nature can produce, as reported by Jamar et al. Furthermore, scientists expect that the fossil fuel reserves will be declined by 2050 according to the high consumption of the fossil fuel. Additionally, the global energy demand will increase to 30 and 46 terawatts by 2050 and 2100, respectively, as predicted, affecting the environment.

Kuwait is characterized as a high potential location for solar application. AlBusairi. et al. [1] reported that the annual range of irradiance is 3.2 $\mathrm{kWh}/m^2/\mathrm{day}$ to 7.4 $\mathrm{kWh}/m^2/\mathrm{day}$. The specific outcomes of the project are to establish a numerical analysis to preview the economic and environmental feasibility of a solar water heating system supplying hot water for a typical household in Kuwait for an average domestic household occupied by eight persons. Moreover, a numerical analysis implementation on the water heating system's solar collector

II. METHODOLOGY AND SYSTEM SPECIFICATIONS

A numerical study was employed on the active indirect solar water heating system. Generally, water antifreeze solution circulated into the solar collector. At that point, the heat gained from the collectors is transferred to the heat exchanger [4]. Then, the water storage tank gains and stores heat to supply it to the household. The system includes five solar collectors with a gross area of 10.2 m^2 with a tilt angle β of 30°, also the system has a plates heat exchanger and two pumps to supply both sides of the heat exchanger. The solar collector transfers heat to the first side of the heat exchanger (collector side), and the second side of the heat exchanger transfers heat to the water storage tanks (tank side). Moreover, two water storage tanks are used as they are standard in all Kuwait's domestic households; the 300 $liters$ water storage tank is connected to the heat exchanger and the water circulation pump. Then, on the other side is connected to the 190 $liter$s water storage tank, which has the electrical backup heating elements. It is connected to the household to supply the hot water through the (temperature-activated mixing valve); figure (1) clearly illustrates the system components, specifications, and water flow.

the state of Kuwait's residential sector is one of the highest energy consumptions in the world. It consumes about 60% of the country's electrical energy, noticeably more than all other sectors. The significant increase of the energy demand in the residential sector clarifies the serious energy challenges related to the residential sector according to the rise of population growth and housing demand [15]. Moreover, the current capacity is (14 GWh), which is too close to the peak demand of (11 GWh) Gigawatt hours of electrical energy, pressuring the country's energy security and supply. Kuwait's vision for 2030 is to replace 15% of the total electrical energy production with renewable energy (RE) and practice an energy-efficient system (EES).

Heffron [18] reported that the annual electricity consumption in Kuwait was 13,142 kWh/person, and the water consumption was (464 l/d/person) in 2008, which is considered the highest rate per capita in the world. The (GCC) Gulf Cooperation Council committed to reducing (GHG) greenhouse gas emissions through short-term and long-term strategies by making a more significant share of its energy from renewable sources and municipal waste to power by 2030 and, on the other hand, gradually reforming the subsidies of petroleum products, electricity, and water.

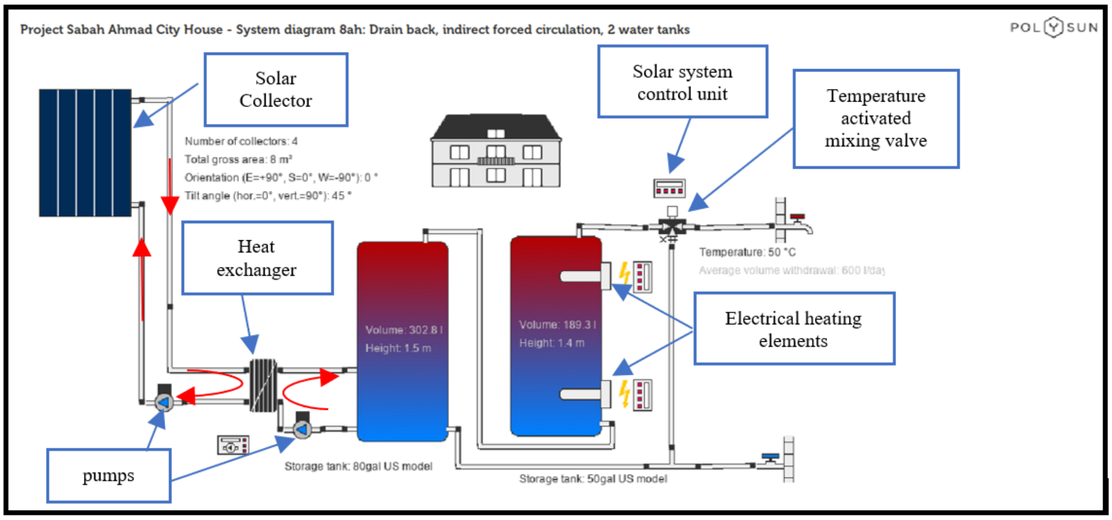

Figure 1. Solar water heating system components (Polysun Simulation Software)

2.1. Solar Collector Energy Balance & Governing Equation

The energy balance of the solar collector is divided into an external and internal energy balance of absorber as demonstrated by the governing equation of the system in equations (1). The external energy balancer of the absorber can be summarized by heat flow from the absorber surface to the ambient environment, the heat losses of the collector [8], and the quality of the solar collector envelope is illustrated in equations (2, 3, 4 and 5).

$$\frac{dQ}{dt} = \dot{Q}_s - \dot{Q}_{I,o} - \dot{Q}_{I,t} - \dot{Q}_u \text{ , Steady-state } \frac{dQ}{dt} = 0 \text{ , } \quad \dot{Q}_u = \dot{Q}_s - \dot{Q}_{I,o} - \dot{Q}_{I,t} \tag{1}$$

$$\dot{Q}_u = A_C\, F^{'}\left[(\tau\alpha) - U_L\left(\frac{T_m - T_a}{I}\right)\right] \quad (8)$$

Where, T_m the mean fluid temperature is $T_m = \frac{(T_{f,out} + T_{f,in})}{2}$ and the efficiency factor $F^{'}$ is illustrated in equation (9) which is related to absorber design. Moreover, the welded bond conductance C_b Equation (10) shows the geometry and quality of contacts between the absorber and the tube, as it influences heat transfer as a good metal to metal contact is essential [9].

$$F^{'} = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L[2a + (W - 2a)F]} + \frac{1}{C_b} + \frac{1}{h_{fi}\,\pi\, D_i}\right]} \quad (9)$$

$$C_b = \frac{\lambda_b\, a}{b} \quad (10)$$

Equation (11) represents the expression of the convection heat transfer inside the collector riser pipes at laminar flow condition, which showed in equation (9) as the convection part of the equation [9].

$$\frac{1}{h_{fi}\,\pi\, D_i} \quad (11)$$

The width of the absorber between two tubes is expressed by (W), equation (12) represents the term of heat conduction through the plate to the welded bond and then to the tube within its flowed fluid.

$$\frac{1}{U[2a + (W - 2a)F]} \quad (12)$$

The convective heat transfer coefficient of flowing fluid through the collector riser tube is given by equation (13).

$$h_{f,i} = \frac{N_u\, \lambda_f}{D_i} \quad (13)$$

Where $h_{f,i}$ is the flow convective heat transfer coefficient, D_i is the collector riser internal diameter, λ_f is the fluid thermal conductivity, N_u is the Nusselt number of the working fluid [9]. Nusselt number can be obtained by Gnielinski's correlation for smooth tubes as illustrated in equation (14), where f is the Darcy friction factor for smooth surface described in equation (15) [10].

The Useful heat removal from the solar collector illustrated in equations (2); demonstrates the solar energy obtained by a specific solar collector [9]. The right side of the equation parameters is A_C the collector area, F_R the solar collector heat removal factor, τ the glazing cover transmittance, α the absorptance of the absorber plate, I_T the solar radiation incident on the collector surface, U_L the collector overall heat loss coefficient, T_{amb} the ambient temperature, $T_{f,in}$ is the fluid inlet temperature. On the left side of the equation where, $\dot{m}$ is the mass flow rate, C_P is the specific heat, and $T_{f,out}$ is the fluid outlet temperature of the solar collector.

$$\dot{Q}_u = \dot{m}\, C_p\left(T_{f,out} - T_{f,in}\right) = A_C\, F_R\left[(\tau\alpha)I_T - U_L\left(T_{f,in} - T_{amb}\right)\right] \quad (2)$$

The internal energy balance of the absorber is the heat flow from the absorber surface into the heat transfer fluid and the ability to transfer heat and remove it from the collector, where the solar energy input is illustrated by equation (3).

$$\dot{Q}_s = A_C \,.\, I \quad (3)$$

The visual losses are demonstrated by equation (4).

$$\dot{Q}_{I,o} = \dot{Q}_s - \dot{Q}_s\,(\tau\alpha) \quad (4)$$

Then, equation (5) demonstrated the total thermal losses to the surrounding.

$$\dot{Q}_{I,t} = U.A_C\,(T_{abs} - T_{amb}) \quad (5)$$

Moreover, the collector heat removal factor can be obtained using equation (6), also the efficiency factor $F^{'}$ can be obtained using the dimensionless collector mass flow rate r illustrated in equation (7).

$$F_R = \frac{\dot{m}\, C_p\left(T_{f,out} - T_{f,in}\right)}{A_C\left[(\tau\alpha)I - U_L\left(T_{f,in} - T_{amb}\right)\right]} \quad (6)$$

$$r = \frac{\dot{m}\, C_p}{A_C\, U_L\, F^{'}} \quad (7)$$

The internal energy balance of the absorber is demonstrated by a useful heat gain equation which based on T_m fluid mean temperature as illustrated in equation (8). It also shows the effect of the absorptance property of the absorber plate and the glazing transmittance, which is presented with the Greek letters Tao τ and Alpha α, respectively [9].

2.4. Storage Tank (WHAM) Water Heater Analysis Model

The water heater analysis model (WHAM) is an energy equation that calculates the energy consumption of the water heater operating environments and storage tank characteristics. This method is based on assumptions of several parameters such as the recovery efficiency (η_R), heat loss coefficient (UA), rated power input (P_R), average daily hot water demand, water volume (V), inlet water temperature (T_{in}), setting temperature (T_{tank}), and the ambient temperature (T_{amb}). The advantage of the WHAM method is providing a precise estimation of energy consumption of the water heating storage tank [11]; also, it counts the standby losses of the storage tank over the day. For reasonable approximation, assumptions were considered as a constant value such as water density, ambient temperatures, water specific heat (C_P), recovery efficiency (η_R), heat loss coefficient (UA), and rated power input (P_R), WHAM method equation is illustrated in equation (21).

$$Q_{in} = \frac{V.\rho.C_p(T_{tank}-T_{in})}{\eta_{re}} . \left(1 - \frac{UA.(T_{tank}-T_{amb})}{P_{RT}}\right) + 24.UA.(T_{tank} - T_{amb}) \quad (21)$$

2.5. Carbon Dioxide Emission Analysis

Kuwait electricity generation emissions of carbon dioxide CO_2 , converted from energy consumption to CO_2 emissions using the 0.268 factor. This conversion factor depends on the fuel used in the power plant; for example, Kuwait electricity generation mainly depend on two fuel types, such as petrol and fuel oil which approximately has similar CO_2 emissions factor as reported by Carbon 2019 [21].

III. RESULTS & DISCUSSION

3.1. Results Accuracy

The accuracy of the metrological data, such as the solar irradiance, influences the entire results of the obtained numerical calculation methods. The sitting temperature of the water storage tanks is assumed to be 50℃, which affects the system's calculation; it is also considered the desired water temperature for domestic applications. The heat exchanger inlet temperature is assumed to be 80℃, approximately close to the solar plate temperature. Hence, it influences the accuracy of the system results.

3.2. Energy Delivered

3.2.1. Solar Water Heating System Analysis

The design stage is significant in predicting and evaluating the solar water heating system's performance with optimal energy gain and proper system

$$Nu_{D_i} = \frac{\left(f/_8\right)\left(Re_{D_i}-1000\right)P_r}{1+12.7\left(f/_8\right)^{1/2}\left(Pr^{2/3}-1\right)} \quad (14)$$

$$f = (0.790\ \ln Re_{D_i} - 1.64)^{-2} \quad (15)$$

Furthermore, the Reynolds and Prandtl number of the collector riser fluid to obtain the Nusselt number are illustrated in the equations (16 & 17) respectively [9].

$$Re = \frac{4\ \dot{m}_{riser}}{\pi\ D_i\ \mu} \quad (16)$$

$$\mathrm{Pr} = \frac{\mu\ c_p}{\lambda_f} \quad (17)$$

2.2. Solar Collector Efficiency Equation

The efficiency of the flat plate collector is an indication for the solar collector performance, where it is the fraction of the useful energy gain Q_u to the solar energy gained by the solar collector, as illustrated in equation (18). Where, $\dot{m}$ is the mass flow rate, C_P is the specific heat, and the Δt is the inlet and outlet temperature difference of the solar collector fluid. In addition, A_C is the solar collector area, and I_T is the solar irradiance [20]. For more clarification, Δt is the difference between $T_{f,in}$ is the fluid inlet temperature of the solar collector, and the $T_{f,out}$ is the fluid outlet temperature of the solar collector is illustrated on the left side of the solar collector useful heat removal equation (2).

$$\eta = \frac{\dot{m}\ C_p\ \Delta t}{A_C\ I_T} \quad (18)$$

The efficiency is obtained by several methods and equations based on the standards used to calculate the system energy. In this case, the US standards are based on the fluid's specific heat illustrated in the equation (19).

$$\eta = F_R\left[(\tau\alpha) - U\ \frac{(T_{f,in}-T_{amb})}{I_T}\right] \quad (19)$$

2.3. Water Storage Tank Energy Balance Equation

The energy balance of the water storage tank stated in general terms of the energy fraction (E_f), where it represents the ratio of the energy demand as (hot water drawn) divided by the energy input of the backup electrical heating element to heat and maintain the hot water stored to the sit temperature [11], is illustrated in equation (20).

$$E_f = \frac{m\ .\ C_p\ .(T_{tank} - T_{in})}{Q_{dm}} \quad (20)$$

shows the average energy gain for each month. The highest heat gain is in the winter season. It is reduced gradually until the mid-summer season according to irradiance reduction in the mid-summer because of dust storms influences. The range of the useful solar collector energy gain Q_{sol} are 1213.5 kWh to 1615.6 kWh a month, and the annual useful solar collector energy Q_{sol} is 17056.7 kWh/ year.

3.2.3. Hot Water Storage Analysis

The storage tank of the solar water heating system is a significant device, where the energy of the solar water heating systems is stored. In addition, the system heat exchanger is connected to the storage tank to supply the heat from the solar collector, where it is the median of heat transfer [4]. The market availability consideration of the hot water storage tank is the main factor during the design process; the system includes two tanks with different capacities, 302 litre (80 gallons) and 189 litre (50 gallons). The average annual energy consumption of the water heater is illustrated using the (WHAM) water heater analysis model for both storage tanks. The annual energy unit of hot water consumption ranges from 71.4 kW/day in the mid-summer period to 107 kW/day in the winter season as the highest in January for the total tank's capacity 491 liters (130 gallons). Also, the total annual hot water consumption of the tanks is around 16.6 $MW/year,$ as illustrated in table (1).

economic benefits. A numerical analysis was conducted on the solar water heating system to compare the long-term performance results of the numerical analysis [6]. The meteorological data and the energy demand of the specific household and location respectively are obtained from the (European Commission) for the particular location. The approximate hot water demand per person is $60\ liter/day$ as reported by Hobbi [7].

The meteorological data variables are hourly based on global solar radiation, diffused solar radiation, ambient temperatures, and water inlet temperatures to evaluate system performance. Those variables include the solar collector number and total area, storage tank volume, and total backup heater energy based on commercially available components. Hence, those variables significantly impact the solar water heating system performance. Therefore, all variables and parameters are numerically analyzed. Accordingly, it offers the opportunity to develop the performance of the solar water heating systems. Consequently, providing the optimum combination of the solar collector area and storage tank volume to obtain the greatest savings and shortest payback period of the solar water heating system [2].

3.2.2. Solar Collector Useful Energy Analysis

The method conducted provides a complete overview of the system operation. The useful annual heat gained by the solar collector illustrated in tables (2 & 3);

Table 1. Average annual energy consumption of water heater (WHAM) method

WHAM-Water Heater Analysis Model

Month	*302 liter storage tank* *kW/Day*	*189 liter storage tank* *kW/Day*	*Storage tanks total energy* *kW/Day*
JAN	64.6	42.4	107.0
FEB	64.4	42.0	106.5
MAR	62.8	40.7	103.5
APR	56.9	37.1	94.0
MAY	52.8	34.3	87.1
JUN	47.1	30.3	77.4
JUL	44.8	29.0	73.8
AUG	43.4	28.0	71.4
SEP	45.0	29.1	74.1
OCT	48.9	31.7	80.6
NOV	54.4	35.5	89.9
DEC	59.4	38.7	98.1
Total	**10109.4**	**6573.8**	**16683.2**

which is very low compared to other countries. The government is planning to mitigate the subsidy program according to World Bank 2014 report recommendation. This subsidy presently costs the Gulf Cooperation Council (GCC) governments approximately $160 billion annually from their incomes. The application of the solar water heating system will share the portion of energy consumption by a renewable source to save countries revenues [11]. The energy analysis of a single household solar water heating system in table (2) shows the average hot water demand per month and its cost in Kuwaiti Dinar (KD) and the US. Dollar. The annual average hot water demand is 26.6 MWh with a yearly cost of 133 KD and $ 438.6, respectively.

3.3. Financial Analysis

3.3.1. Fossil fuel Subsidies Influences on the Alternative Renewables

In the GCC region, subsidies are the major obstacle to the application of renewable energy; subsidies reduction is essential to encourage renewable energy application in the region [23]. Kuwait electricity and water minster (MEW) stated that " The Ministry consumes 350,000 barrels of oil a day to generate power, and this figure could hit two million barrels of oil a day in 2035 if excessive consumption continued ". The electricity tariffs in Kuwait are one of the lowest globally, with significant subsidies for consumers. The electrical energy rate in Kuwait for residential customers is KD 0.005/kWh,

Table 2. Energy Cost

Annual average hot water demand		Electricity tariff / kWh		Electricity cost for water heating / Month	
Month	**kWh/Month**	**KD**	**$**	**KD**	**$**
JANUARY	2797.8	0.005	0.01645	13.99	46.02
FEBRUARY	2527.0			12.64	41.57
MARCH	2734.2			13.67	44.98
APRIL	2338.3			11.69	38.47
MAY	2225.5			11.13	36.61
JUNE	1907.6			9.54	31.38
JULY	1844.0			9.22	30.33
AUGUST	1723.0			8.61	28.34
SEPTEMBER	1844.0			9.22	30.33
OCTOBER	1969.1			9.85	32.39
NOVEMBER	2289.1			11.45	37.66
DECEMBER	2461.4			12.31	40.49
Total	**26660.7**			**133.3**	**438.6**

by the solar collector. The total annual solar energy gain is 17.05 MWh/ year.

3.3.3. Auxiliary Energy Analysis

Electricity is the typical auxiliary energy source used in water heating systems when solar energy is deficient. The average monthly range of auxiliary energy Q_{aux} is 813.8 $kWh/month$ to 1787.7 $kWh/month$ as illustrated in the table (3). The total annual auxiliary energy of the solar water heating system is 15.121 $kWh/year$ which is 53% of the annual heat demand of the system. Where January and December are the highest auxiliary energy demand, and the lowest auxiliary energy is in June, July, and August.

3.3.2. Useful Solar Energy Gain & Energy Consumption Analysis

Table (3) illustrates the annual energy of solar collectors, and the annual energy consumption by hot water demand, in addition to the annual energy savings. The hot water consumption reaches the peak of 3317.5 kWh/Month in January, and it is reduced during the summer period to achieve the least of 2142.4 kWh/Month in August. Moreover, the total annual hot water consumption is 32.2 MWh/year. Solar collectors' annual useful energy gain ranges from 1.2 MWh/ Month to 1.6 MWh/ Month, as almost stable energy gain along the year. On the other hand, the high probability of sandstorms increases during the summer season, diffusing the solar irradiance, which negatively influences the energy gain

Table 3. Energy Analysis

	Useful energy gain by solar collector		Total energy consumption of water storage		Annual Auxiliary Energy	Annual Energy Saving
Month	kWh/Day	kWh/Month	kWh/Day	kWh/Month	kWh/Month	Percentages
JANUARY	49.2	1524.6	107.0	3317.5	1787.7	54%
FEBRUARY	52.7	1474.9	106.5	2981.5	1502.4	51%
MARCH	52.1	1615.6	103.5	3209.7	1589.4	50%
APRIL	50.4	1513.3	94.0	2820.4	1302.9	46%
MAY	50.4	1561.9	87.1	2699.9	1135.2	42%
JUNE	50.2	1505.9	77.4	2322.2	813.8	35%
JULY	46.5	1442.0	73.8	2287.6	842.7	37%
AUGUST	42.5	1273.8	71.4	2142.4	865.5	41%
SEPTEMBER	39.8	1234.8	74.1	2296.4	1057.8	46%
OCTOBER	40.4	1213.5	80.6	2418.2	1200.2	50%
NOVEMBER	44.3	1373.6	89.9	2787.5	1409.3	51%
DECEMBER	44.1	1322.7	98.1	2942.2	1614.4	55%
Total		**17056.7**		**32225.4**	**15121.2**	**47%**

3.3.4. Annual Energy Saving Cost Analysis

The energy-saving analysis of the project for a single household solar water heating system illustrated in the table (4) shows the annual average electricity saving of the solar water heating system, which cut approximately 57 % of the hot water demand by about 11.5 MWh a year. Hence, the energy cost reduction reaches 57.7 KD and $ 189.8 annually.

Table 4. Energy Saving analysis

Electricity savings by solar system / Month				
Month	kWh / Month	KD	$	Savings %
JANUARY	1010.1	5.05	16.62	64%
FEBRUARY	1024.6	5.12	16.85	59%
MARCH	1144.8	5.72	18.83	58%
APRIL	1035.4	5.18	17.03	56%
MAY	1090.3	5.45	17.94	51%
JUNE	1093.8	5.47	17.99	43%
JULY	1001.3	5.01	16.47	46%
AUGUST	857.5	4.29	14.11	50%
SEPTEMBER	786.1	3.93	12.93	57%
OCTOBER	768.9	3.84	12.65	61%
NOVEMBER	879.7	4.40	14.47	62%
DECEMBER	847.0	4.23	13.93	66%
Total	**11539.5**	**57.7**	**189.8**	**57%**

The payback period is crucial in specifying the project feasibility; in this case, the project will start to pay back its initial cost and (O&M) operation and maintenance in approximately 35.7 years. Consequently, Kuwait's current energy rate is characterized as a very high payback period with a 20 to 25 years operation life cycle. That is because of the significant subsidies and the effect of the low cost of electricity. However, this project in the nearest future will be cost-effective according to the mitigation of the subsidies as revealed by the government's future vision and plan, or by components cost reduction in the nearest future. Figure (2) illustrates the payback period for the projected solar water heating system at a typical household in Kuwait at the current energy rate.

3.3.5. Solar Water Heating System Cost

The solar water heating system's initial cost, operation, and maintenance (O&M) are around $ 6776.7, and it varies according to the quality of its components and performance. Additionally, the solar collector and water storage tank type and size. Furthermore, the control system and pumping units' facility and accessories are the second factors affecting the initial cost of the heating system. The operation and maintenance (O&M) costs of the solar water heating system are estimated at 1% of the initial cost annually within the usual range of (O&M) [25].

3.3.6. Payback Period at Current Energy Rate in Kuwait

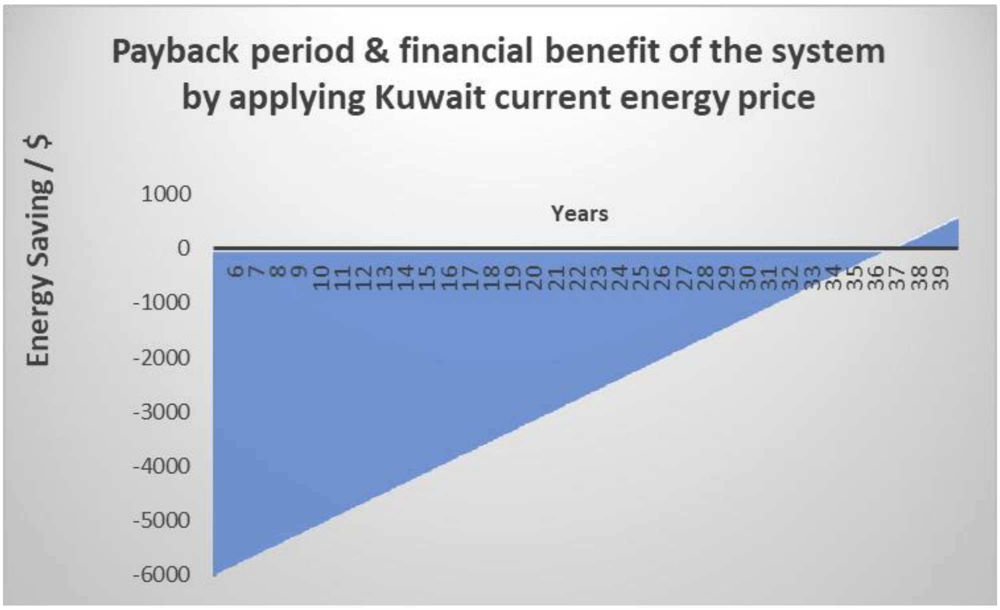

Figure 2. Payback period & financial benefit of the system by applying Kuwait current energy price

3.3.7. Payback Period at Projected Energy Rate Associated to GCC Countries

As stated previously, the major challenge of the system in Kuwait is low energy cost in recent time. However, the Kuwait government has a short and long strategy to draw the energy subsidies gradually. The projected payback period of the system with average GCC countries (Gulf Cooperation Council), for instance, Saudi Arabia energy price

about $ 0.05 / kWh, which represent approximately 300% of the current energy rate in Kuwait. Hence, it will reduce the payback period considerably from 35.7 years to 11.7 years when the energy subsidies are reduced to the Saudi Arabia energy rate. Consequently, it led to double the financial benefit of the system at the end of system life, which is approximately 25 years. Figure (3) illustrates the payback period and the financial benefit.

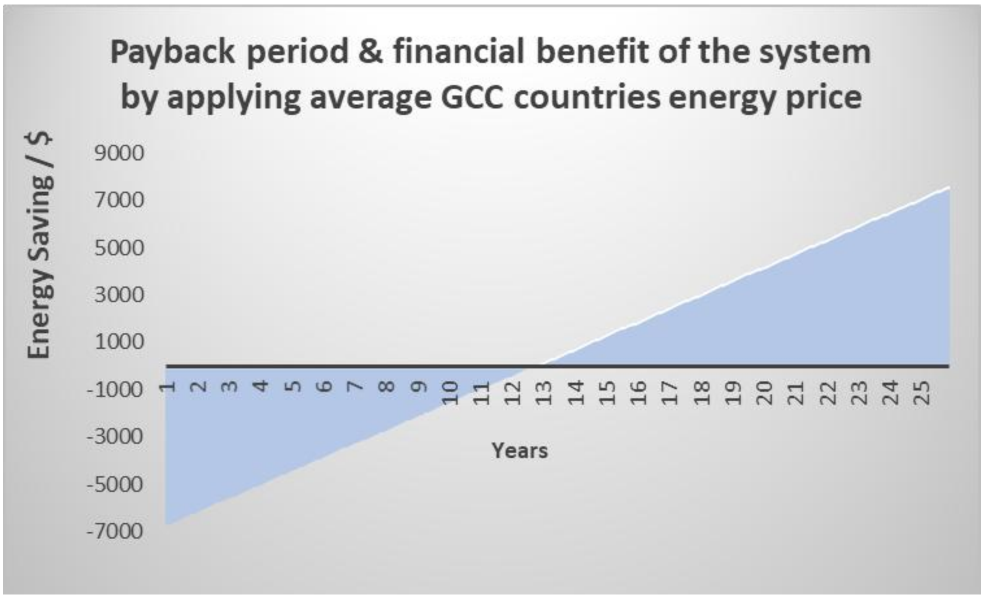

Figure 3. Payback period & financial benefit of the system by applying average GCC countries energy price

period significantly from 35.7 years to 4.2 years. Hence, it led to double the financial benefit of the system in 9 years. Figure (4) illustrates the payback period and the financial benefit of the world average energy price.

3.3.8. Payback Period at Predicted Energy Rate Compared to the World Average Energy Price

The world average energy price is about $ 0.14 / kWh; this rate is about 900% of the current energy rate in Kuwait, which decreases the payback

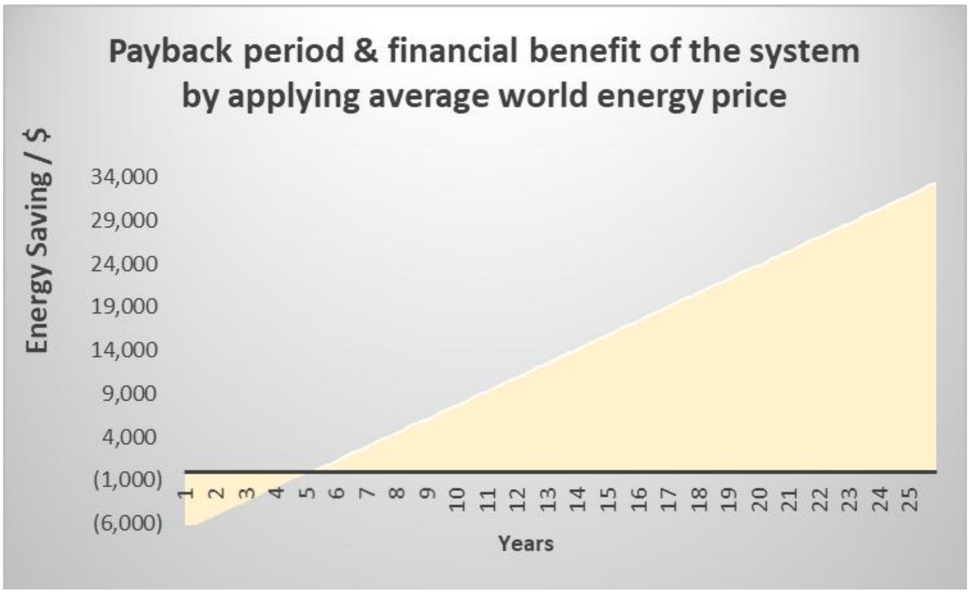

Figure 4. Payback period & financial benefit of the system by applying average world energy price

production is by fossil fuel burning, such as oil and natural gas. The domestic sector in Kuwait has a significant electricity consumption such as air conditioning, water heating, and lighting. Fossil fuel emission reduction is noticeable by applying energy efficiency systems and renewable energy technologies [3].

Kuwait is committed to the UN agreement on climate change and the Kyoto Protocol to reduce

3.4. Environmental Impact of Fossil Fuel Emission & Consumption

Fossil fuels burning to emit carbon dioxide CO_2 Moreover, other harmful air pollutants, which significantly affect public health and the world environmental concern such as the Greenhouse Gases (GHG), Global Warming Potential (GWP), acid rains, and smog at all levels such as national and international. Moreover, 99% of Kuwait's electricity global warming potential (GWP) consequences experienced recently increased heat waves devastating hurricanes. The significant environmental advantage of the solar water heating system is reducing the carbon dioxide CO_2 emission as illustrated in table (5), where the baseline emission of the hot water supply of the household without the solar water heating system is 7.2 $MtCO_2$ metric ton of CO_2 annual emission. In addition, the solar water heating system reduces the annual CO_2 emission to 3.1 $MtCO_2$ metric ton of CO_2 emission, which is about a 57 % reduction in CO_2 emission compared to the baseline emission of the hot water as energy unit of household.

greenhouse gas (GHG) emissions. Where Kuwait counted as one of the highest carbon dioxides CO_2 emitter which reaches 26.44 ($MtCO_2/capita$) metric tons per capita in 2002, representing even higher than the USA as fossil fuel is the primary source of energy according to EIA [26]. Consequently, Kuwait has an energy and environmental issue which challenges compliance with international laws. Applying renewable energy sources will reduce the average energy demand.

3.4.1 Carbon Dioxide CO_2 Emission Analysis & Reduction

Carbon dioxide CO_2 emission is the major environmental concern worldwide, and its association to the greenhouse gases GHG effects. The

Table 5. Carbon Dioxide CO_2 Emission & Saving

Annual Carbon Dioxide Emission & Saving

Month	Base line Emission	Emission Reduction	
	Kg CO2 / kWh	Kg CO2 / kWh	CO2 Reduction
JANUARY	763.0	275.5	64%
FEBRUARY	689.2	279.4	59%
MARCH	745.7	312.2	58%
APRIL	637.7	282.4	56%
MAY	607.0	297.4	51%
JUNE	520.2	298.3	43%
JULY	502.9	273.1	46%
AUGUST	469.9	233.9	50%
SEPTEMBER	502.9	214.4	57%
OCTOBER	537.0	209.7	61%
NOVEMBER	624.3	239.9	62%
DECEMBER	671.3	231.0	66%
Total	**7271.1**	**3147.1**	**57%**

sidies to the energy sector, the project's payback period is affected by the energy rate, which is too low compared to other countries. The global average energy rate is about 850% higher than Kuwait's energy rate. Hence, the project payback period with the average rate of GCC countries is 11.7 years. Consequently, start to profit and return the (SWHS) initial cost and the (O&M) cost of the entire system life at its end, which is about 25 years. The environmental implication of the solar water heating system makes the project more attractive by reducing the GHG emissions, for instance, the CO_2 emissions reduced to 3.1 $MtCO_2$ which is about 57 % reduction an-

IV. CONCLUSIONS

The purpose of this project is to evaluate the energy-saving, subsequently the economic and environmental benefits of a solar water heating system in a typical household in Kuwait. The evaluation conducted by numerical analysis demonstrates the influences of the solar collector major factors that present the system performance, such as solar energy gain and auxiliary energy. The numerical analysis depends on actual meteorological data of the more accurate location. The numerical analysis predicts a reduction of 53% in the total annual auxiliary energy, representing the household's economic and environmental influence. According to the intensive sub-

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nually, where the baseline emissions are about 7.2 $MtCO_2$ annually.

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Notation, and units

A_C	Collector area (m^2)
F_R	Solar collector heat removal factor
F'	The solar collector efficiency factor
τ	Glazing cover transmittance
α	Absorptance of the absorber plate
β	Solar collector tilt angle (°)
Q_{load}	Total energy removed (kW)
$Q_{auxiliary}$	Total auxiliary energy supplied (kW)
C_p	Specific heat of the fluid (kj/kg .°C)
T_{amb}	Ambient temperature (°C)
$T_{p,m}$	Mean absorber plate temperature (°C)
$T_{f,in}$	Inlet fluid temperature (°C)
$T_{f,out}$	Outlet fluid temperature (°C)
$T_{f,avg}$	Average bulk water temperature (°C)
$h_{f,i}$	Heat transfer coefficient between the pipe fluid (w/m^2.°C)
I_T	Solar radiation incident on the collector surface (w/m^2)
U_L	Collector overall heat loss coefficient (w/m^2.°C)
D_i	The internal diameter of the pipe (m)
λ_b	Welded bond thermal conductivity (w/m^2.°C)
λ_f	Fluid thermal conductivity (w/m^2.°C)
L	Pipe length (m)
$\dot{m}$	Mass flow rate (kg/s)
t	Thickness (m)
ν	Kinematic viscosity (m^2/s)
ρ_w	Water density (kg/m^2)
Q_{in}	Total energy consumption of water heater (k_j/day)
UA	Standby heat loss coefficient × area of tank (k_j/hr °C)
V	Volume of water drawn in 24 hours ($liter/day$)

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