# Possibilities Study of Using Hybrid Solar Collectors in Northeastern Libya Residential Home

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**Abstract-** The majority of electricity generated in Libya comes from fossil fuels. More oil and gas will be consumed, resulting in higher $CO_2$ emissions, as energy demand is projected to grow sharply in the near future. A feasibility study of a climate photovoltaic solar thermal collector and its relation to solar photovoltaic and solar water heating systems is being conducted. Based on population consumption in northeastern Libya, the study aims to determine the daily and annual electrical load coverage of 10.5 and 3942 kWh/year, respectively. The Polysun software simulation was used to analyze the electrical and thermal efficiency environment of Almarj city as a case study. Three of 280 W monocrystalline crystal solar collectors were used to generate 1445 kWh/year. By the number of collectors from five to seven, 3420 kWh/year can be generated. Increasing the number of collectors to nine protected 10.5 kWh/day, resulting in 4733 kWh/year of electrical energy, and the average annual consumption of a house is about 10,529 kWh. If the Libyan network losses are ignored, the device will use 263,225 MWh over its 25-year lifespan, resulting in a fuel cost of $47,380. The estimated annual savings per house is 1895 dollars, and the reduction of carbon dioxide emissions for light oil, heavy oil, and gas is 252, 195, and 15447 kg, respectively. Based on the existing study, the hybrid system has a substantial economic viability system compared to other solar systems, depending on the demand for power, heat, or a combination of both. As a result, the Almarj residential on-grid electrical loads, fossil fuel demand, global warming, and pollution to the atmosphere will all be reduced.

**Keywords** Photovoltaic, Solar energy, Hybrid solar energy, Polysun software, Feasibility study.

## 1. Introduction

Global energy demand is expected to rise by 45% between 2006 and 2030, which will rise by 1.6% annually [1]. Renewable energy can be recovered and available in various forms like solar, wind, biomass, hydroelectric power, etc. [2]. Renewable energy plays a crucial role in contributing to global energy growth in the 21st century and beyond [3]. Fossil fuel energy production is not sustainable due to various adverse environmental impacts and limited fuel quantities [1]. Global warming and greenhouse gas emissions can significantly limit the use of renewable energy sources. In the last three decades, greenhouse gas emissions have risen at an annual rate of 1.6%, with carbon dioxide emissions from non-renewable energy supplies increasing at an annual rate of 1.9% [4]. According to the Intergovernmental Panel on Climate Change's fourth 2007 assessment report, sea-level rise correlates to global warming. The rise in sea level is caused by the melting of snow and ice in the Arctic Sea by global warming. Renewable energies, such as solar energy, wind energy, biofuels, hydropower, etc., are proposed to solve the global warming problem and meet the growing demand for energy [3]. The demand for fossil fuels will decrease when the demand for renewable energies increases. Solar energy is one of the most challenging energy sources as solar radiation reaches the Earth's surface at a rate of about 80,000 TW, which is 10,000 times the current use of energy on the planet [1]. Solar energy is a system that converts solar radiation into electricity using solar cells.

Moreover, PV research's main driver is creating low-cost solar cells and a cheap and effective PV system [5]. Hence, this study focused on the feasibility study of the PVT solar thermal water collector in the Almarj, Libya climate. Several studies have been conducted on photovoltaic collectors over the past years [6]. A hybrid photoelectric system PVT is a dual combination of solar thermal and photovoltaic systems. A hybrid/thermoelectric system is an integrated system that can produce heat and electricity. PVT system consists of a typical PV plate at the back, including a heat exchanger. A hybrid photoelectric/thermal system refers to a system that concentrates heat from the plate using heat transfer fluid, usually air or water, and sometimes both. Significant reasons are driving the improvement of the PVT system. One of the main reasons is that the PVT system can provide a higher thermal efficiency collector. When the efficiency increases, the system cost recovery time will be reduced due to increased power production. The study [7] explores the feasibility of a solar combi system for space heating. According to the findings of the economic study, the SCS saves approximately 48% of electric energy, and approximately 46% of gas/gas town kept back by the traditional scheme has gotten much coverage in recent years. The study selected 5,000 homes in Benghazi. During the twenty years of using solar heaters, the cost of solar water heaters was about 49,875,000 Libyan dinars. The cost of traditional electric water heaters is 214,050,000 dinars per liter, which is four times more. Additionally, solar water heaters save money on fuel and reduce carbon dioxide emissions [8].

Additionally, solar water heaters save money on fuel and reduce $CO_2$ emissions [8]. More oil and gas are consumed, resulting in increased $CO_2$ emissions. As a result, renewable energy must participate in the electricity market to ensure long-term growth. Because of Libya's unique position in the highest sunny belt, solar energy is one of the most reliable renewable energy sources. This study proposes a viable approach for improving the quality of life and proposes an effective solution for improving continuous power availability and reducing peak load demand in the Libyan electric grid by replacing electric heaters with domestic solar water heating (DSWH). Alternatives for water heating and electric power production are selected and compared considering technical, economic, and environmental aspects. Parameters used in the comparison are capital cost, maintenance cost, fuel cost, and $CO_2$ emissions in terms of cost. The study begins with an overview of the current energy situation in Libya. In the second section, Solar Potential Energy is being entered. Determining the potential of renewable energy in Libya in the third section. The fourth section describes the complex systems, and simulations and a feasibility study are presented in the fifth and sixth sections. Finally, the seventh, eighth, and ninth sections contained the economic cost, emissions, and conclusion.

## 2. Current Energy Situation

The General Electricity Company of Libya (GECOL) is a government company responsible for generating electricity from generation, transmission, and distribution. GECOL operates 71 power stations spread all over Libya in 12 main power stations; these stations can generate 8,347 GW, while the available capacity is 6,357 GW, as shown in Figure 1.

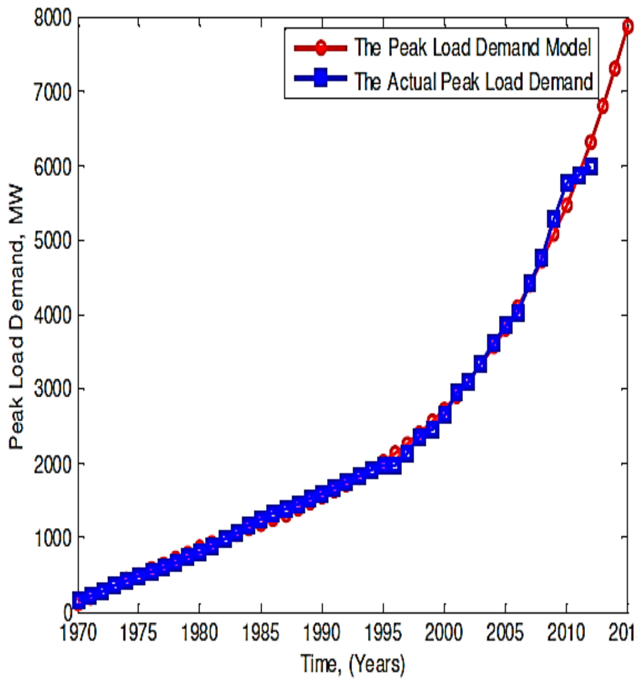


**Fig. 1.** The maximum demand load in Libya [8].

Increase reliance on natural gas from the GECOL policy to reduce $CO_2$ emissions. GECOL is experiencing difficulties in meeting the growing electricity demand. As shown in Figure 2, energy consumption is distributed among several types of loads. The residential load is the most dominant load, with 31% of the total energy consumed. Street lighting is about 19% of energy consumption while 50% distributed in commercial, agricultural, industrial, etc. Water heating is one of the main areas of household energy consumption by about 29.82%, which means that water heating consumes about 10% of all electricity. According to the GECOL report, the total electricity generation in 2012 was around 33,980 GWh [10]. Therefore, the annual electricity used to heat the domestic water was approximately 3,398 GWh. These areas help the Libyan government to reduce energy consumption. There is a need to use heat from solar energy technologies and replace electrical heating with a solar water heating system (SWHS) to reduce energy waste and reduce peak loads.

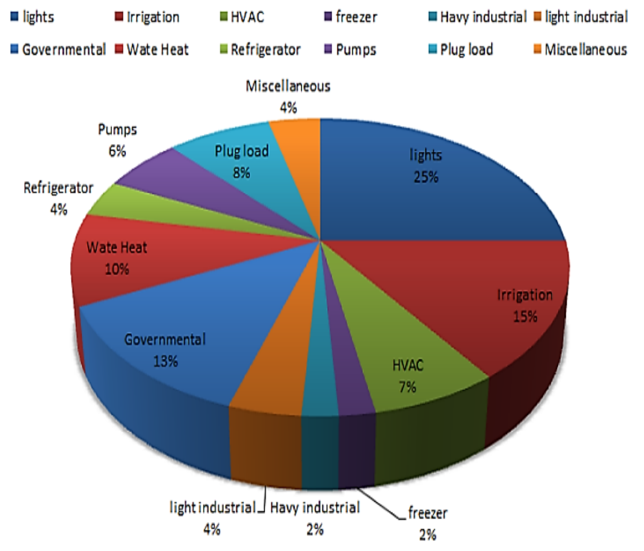


**Fig. 2**. The distribution of energy consumption among several load types [10].

## 3. Solar Photovoltaic Thermal Technology

Researchers explored the concept of PVT after banning OPEC oil in the 1970s, and in the same decade, Wolf [10] launched the first project of the PVT complex. Boer and Tamm [11] proposed the first work on the air type for PVT systems called a single solar home in 1973. The study enabled the sunlight to convert into heat and electricity for residential use. Several projects were implemented on building-integrated (BIPV) in Switzerland in the 1990s. Extensive studies have been conducted around the world to enhance PVT performance and reduce costs [12]. At present, PVT is promising in reducing the gap between conventional and renewable energy sources.

### *3.1. Photovoltaic thermal collector design*

The PVT design consists of conducting sheets or tubes connected to the back of the PV unit. Water circulated through the plate channels or coolants, and the heat absorbed from the PV units directed to the water through the attached plates and tubes. The hybrid complex PVT is a mixture of solar photovoltaic PV cells and a solar thermal complex that simultaneously produces electricity and heat. The PVT system design has certain things, such as the working fluid (water or air), electrical and thermal efficiency, temperature, and solar radiation [13]. In a conventional photoelectric system, the relationship between solar radiation falling on the PV panel and the plate's electrical output is proportional [14]. With the increase of solar irradiance, the electrical production from the photovoltaic plate increases with the solar cells' temperature as well. As a result, the efficiency of the plate decreases [9]. The PVT electrical conversion efficiency system depends on the type of solar cell at standard temperature and pressure. The conversion efficiency of solar cells is about 6-15%. As the temperature increases by 1 $^{o}$C, the PV efficiency decreases by 0.5%. A copper tube is attached behind the panel copper sheet, as shown in Figure 3.

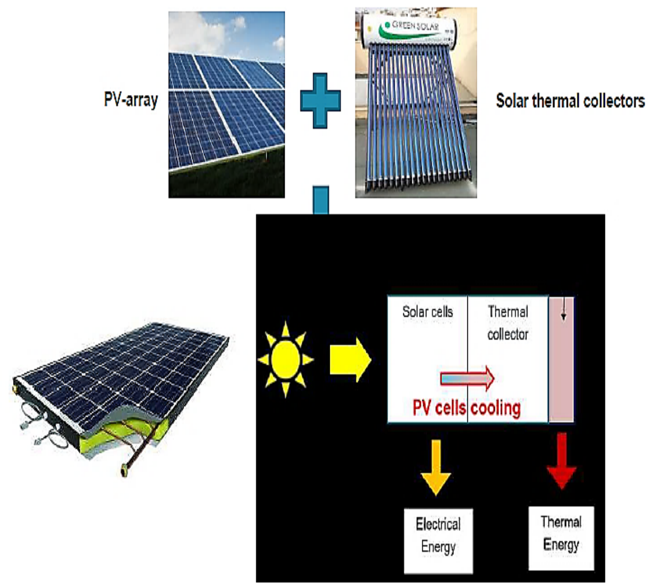


**Fig. 3.** Schematic diagram of a PVT Water Collector [15].

## 4. Electrical and Thermal Performance

The thermal and electrical efficiency mixture is called the performance of the PVT collector. The electrical and thermal efficiency conditions are the ratio of the collector's electrical and thermal gain to the solar radiation falling on the collector's surface during a specific period [1]. The total efficiency is the sum of electrical and thermal efficiency and is usually used to evaluate the PVT system. Three types of efficiencies are described as the PVT complex. The first is electrical efficiency dependent on the consumed load's resistance, the incident solar radiation, and the photocell temperature. The following equation determines the system's electrical conversion efficiency [16]:

$$\eta el = \frac{I_m \ X \ V_m}{I_r \ X \ A_p \ V_t} \qquad (1)$$

Where, $I_m$: Maximum current, $V_m$: Maximum voltage, $I_r$: Incident solar radiation, $A_{pvt}$: Area of the panel. The second type of efficiency is thermal efficiency, which is calculated as:

$$\eta th = \frac{(m \times Cp \times (Tout - Tin))}{Ir \times Apvt} \qquad (2)$$

Where, m: Mass flow rate (kg/s), Cp: Specific heat capacity of water (4186 J/kg°C), $T_{out}$: Water temperature out from collector (°C), Tin: Water temperature in of collector (°C), Ir: Incident solar radiation (W/m$^2$), $A_{pvt}$: Photovoltaic thermal collector area (m$^2$). The third type of efficiency is the sum of electrical efficiency and thermal efficiency, which is known as the total efficiency and calculated as:

$$\eta tot = \eta el + \eta th \qquad (3)$$

The simplified equation of current-voltage characteristics of the electrical circuit of the PV cell, as shown below:

$$I = Imax - Io \times exp^{[q \times (V - IRs) A \times K \times T]} \quad (4)$$

The electrical output power of solar PV is:

$$Pel = I \times V \quad (5)$$

The maximum output power from solar PV is calculated as:

$$Pmax = Vmax \times Imax \quad (6)$$

$$Pmax = Vop \times Isc \times FF \quad (7)$$

The fill factor of solar PV varies according to ambient temperature and solar radiation intensity, and it can be calculated as:

$$FFcell = \frac{Vmax \times Imax}{Vop \times Isc} \quad (8)$$

## 5. Modeling and Simulation Methodology

The Fur Solartechnik Institute released the first version of this program in 1992. Polysun is used to design, analyze, and calculate renewable energies' production and consumption, such as solar thermal and photovoltaic systems and installed systems. The program contains a library with a database of modules list of PV modules, solar thermal collectors, inverters, and refrigeration and heating units [17]. The user can design a new model or use one of the sample systems found in the program. Different scenarios for the solar system were considered, for example, PVT water collector, flat thermal solar panel complex, PV system, and flat-panel complex combined with the PV system. The program gives each configuration's pros and cons in terms of electrical and thermal energy, energy production, and system cost. The PVT collector simulation diagram is defined in Polysun, as shown in Figure 4.

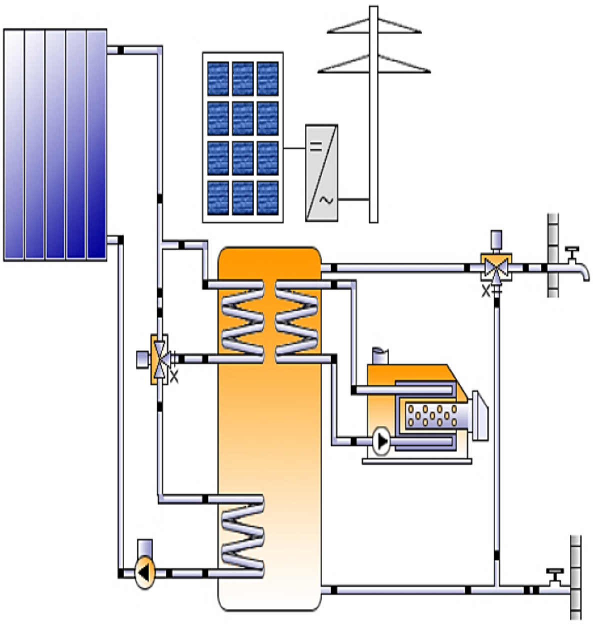

**Fig. 4**. Simulation of PVT Collector in Polysun.

The simulation design includes a reflector and a set of PVT collectors, tank, pump, boiler, mixing valve, cold water supply, and demand for hot water. Table 1 and Table 2 give the average daily hot water consumption and pregnancy for one family of four people living in Almarj.

**Table 1**. Hot water consumption for one family.

| No. People | No. Unit | Operation | Temp, °C | Volume, L |
|---|---|---|---|---|
| 4 | Hand wash | Daily | 45 | 3.5 |
| | Showering | Daily | 45 | 35.1 |
| | Bathing | Daily | 45 | 120.1 |
| | Hair Washing | Daily | - | 9.6 |
| | Cleaning | Daily | - | 3.1 |
| | Cooking | Daily | - | 2 |
| | Dishwashing | Twice a week | 50 | 20.1 |
| | Washing Machine | Twice a week | 50 | 30.1 |
| Hot water consumption | | | 15 L.person/week | |
| Daily average hot water consumption for a family | | | 255 | |

**Table 2**. Average one family daily electrical consumption for one.

| Equipment Description | Electrical Consumption, kWh |
|---|---|
| Light lamps | 0.975 |
| TV | 0.2 |
| Electrical Heater | 3 |
| Heater | 2.25 |
| Airflow | 0.07 |
| Washing & Dryer | 0.6 |
| Oven | 0.65 |
| Microwave | 0.03 |
| Wi-Fi | 0.04 |
| Toaster | 0.03 |
| Boiler | 0.084 |
| Cooker | 0.3 |
| Freeze | 2.3 |
| Total Daily Electrical Consumption | 10.529 |

Calculation of Average daily hot water consumption for a single-family:

VHW = number of people × daily hot water consumption/person = 4 × 60 + 15 = 255 L/day

Calculation of hot water heat requirement:

QHW = VHW × CW × ΔT = 2550 × 1.16 × (45-10) × 365 = 10.8 KWh/year

During simulations of the PVT system, the system must achieve a daily load of electricity and hot water required, as shown in Tables 1 and 2. The family living in a household consumes about 60 liters/day of water per person. The average daily electricity consumption for a home is about 10.5 kWh, and the average annual consumption is 3942. On average, the number of family members consists of four members in the house.

## 6. Simulation and Modelling Analysis

The Fur Solar Technik Institute released the first version of this program in 1992. Polysun is used to design, analyze, and calculate renewable energies' production and consumption, such as solar thermal and photovoltaic systems and installed systems. The program contains a library with a database of modules list of PV modules, solar thermal collectors, inverters, and refrigeration and heating units [17]. The user can design a new model or use one of the sample systems found in the program. Different scenarios for the solar system were considered, for example, PVT water collector, flat thermal solar panel complex, PV system, and flat-panel complex combined with the PV system. The program gives each configuration's pros and cons in terms of electrical and thermal energy, energy production, and system cost. The PVT collector simulation diagram is defined in Polysun, as shown in Figure 4.

### *6.1. PVT performance collector home use*

Radiation and weather data are the primary requirements for modeling and designing the solar thermal PV system. The main factors studied are the maximum and minimum temperature, solar radiation values, wind speed, and air humidity.

### *6.2. Climate*

Almarj is a Libyan city with latitude and longitude coordinates of 31 .91087º, 21.147787º, respectively [18-19]. The climate is moderate and usually makes it sunny all year round. Summer begins in June with an average high temperature of 27-30 °C during the day and continues through the end of September. The autumn season begins in October with an average high temperature of 16-20 °C throughout the day and continues through the end of December. Winter begins in January with an average high temperature of 17-21 °C during the day and continues through the end of March. Spring begins in March with an average high temperature of 22-24 °C during the day and continues until the end of May. Monthly and daily climate data by the Polysun Designer program is shown in Figures 5 and 6. The average daily solar irradiation in the summer is around 251 kWh/m$^2$, which is the highest value of the winter months with radiation of about 90 kWh/m$^2$, mainly due to the summer's extended sunlight [20].

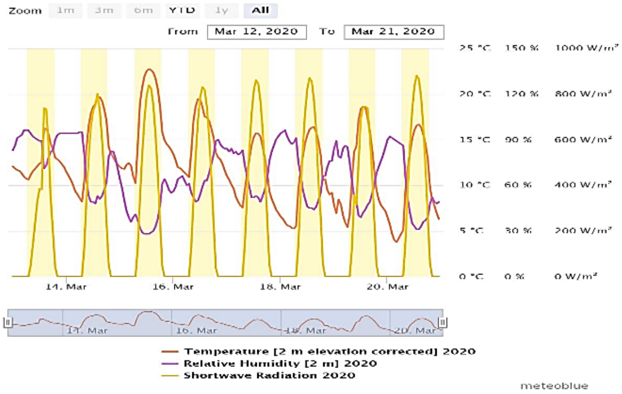


**Fig. 5**. Climate data for Almarj weather data according to Meteoblue [21].

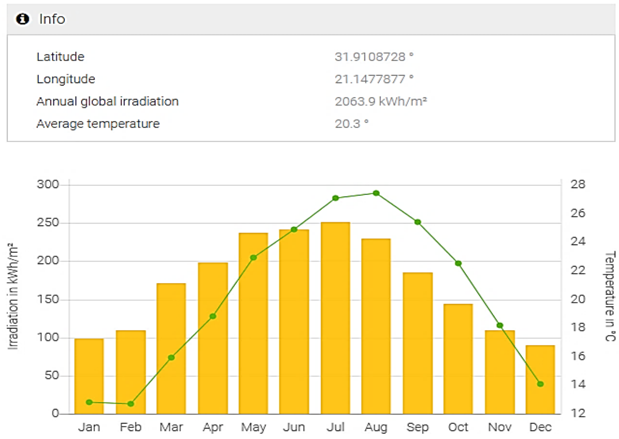


**Fig. 6**. Monthly Climate Data for Almarj by Polysun Weather Data [22].

### *6.3. Electrical power consumption daily for one house*

The average daily consumption of the population in the home is about 10.5 kWh. Usually, the average number of family members in one household in the home is four. The off-peak load for summer and winter from 8:00 AM to 03:00 PM and 8:00 AM to 4:00 PM, respectively. The daily consumption of the electric load for summer and winter is about 9 kWh/day and 15.7 kWh/day, respectively, as illustrated in Figure 7.

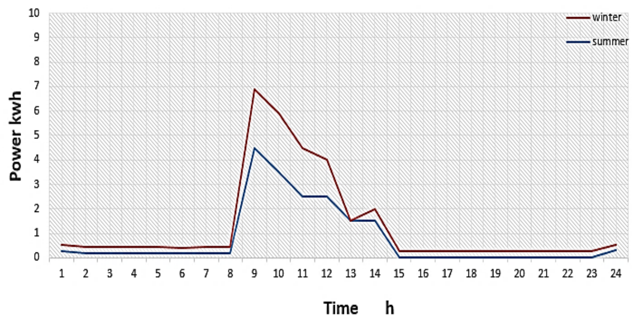


**Fig. 7**. Average daily load for one family.

The simulation's target is determined to cover the daily and annual electrical load of 10.5 kWh/day and 3942 kWh/year based on the daily consumption of the population, as shown in Figure 8. Using three solar collectors of 280 W with monocrystalline crystals produces 1445 kWh/year. By increasing the number of collectors from 5 to 7, it produces 3420 kWh/year. By increasing the collectors to 9, it is possible to cover 10.5 kWh/day that produces 4733 kWh/year of electrical energy.

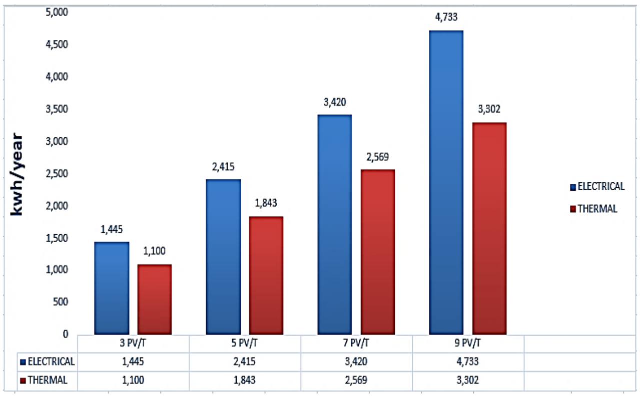


**Fig. 8**. Electrical and thermal production from the Polysun simulation program.

*6.4. Consumption of daily hot water*

House residents consumed about 60 liters/day of water per person, as mentioned prior in Table 1. The average number of single beds in the house is four people. The demand for hot water is 255 liters/day, and the annual energy required to heat this amount of water is about 3,940 kWh/year. The demand for hot water is set from 255 L/day in the simulation program. With nine solar collectors, it is possible to cover 75% of the demand for hot water. The volume of water storage is determined based on the daily demand for the consumption of hot water and the heat energy produced by PVT collectors. The 150-liter water tank will not provide enough storage for the hot water. By increasing the storage volume to 200 liters, the PVT system's heat output increases by 10%. Therefore, a 500-liter water tank is suitable for storing hot water for a daily load of 255 liters/day, as shown in Figure 9.

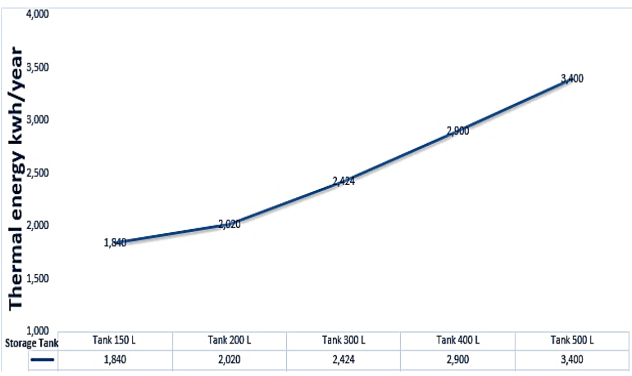


**Fig. 9**. Annual thermal energy of the PVT system with different storage tank sizes.

Verify the PVT systems' electrical and thermal output power at nine different inclination angles of the solar collector from 0° to 64°. It can be concluded that the 32° tilt angle gives the best results for thermal energy output throughout the year. Figure 10 shows energy production throughout the year.

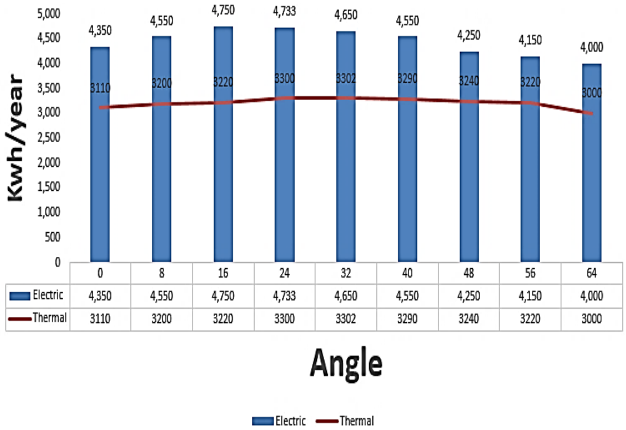


**Fig. 10**. Energy performance of PVT collectors with different tilt angles.

The results provided the highest energy performance of a PVT complex throughout the year at a tilt angle of 32°. This angle was chosen as the ideal tilt angle, and the system was designed based on this tilt angle. Figure 11 showed the electrical, thermal, and total power output of the PVT system for different months at a tilt angle of 32°.

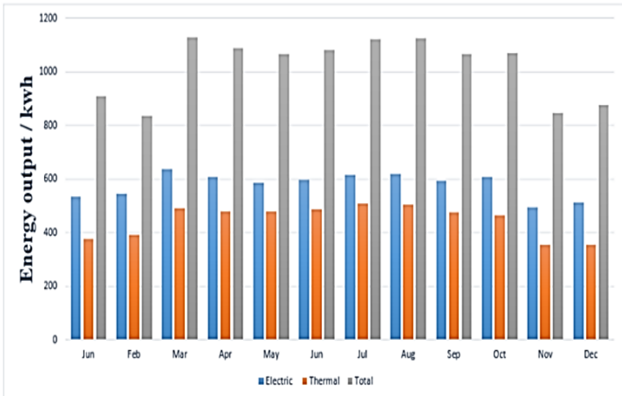


**Fig. 11**. Monthly electrical, thermal and total performance for the PVT system.

## 7. System Economics

The economic viability requirements of these different solar technologies were assessed, and the results of the case are outlined in Table 3. The PVT system cost is higher than for individual solar water heating systems and the single PV system. However, using the PV hot solar heating system separately will cost higher than the combined system. In addition, the recovery period for the PVT system is less than one, which separately uses solar PV and hot water. So, in Libya's climate, the PVT system tends to be economically profitable. The system that uses solar hot water heating and

PV needs more space than the PVT system. The cost of electricity in Libya is $ 0.18 kWh for residential units. The average, typical consumption of a house is around 10,529 kWh per year. Since the system has a life span of 25 years, it will consume 263,225 MWh, making the cost of fuel $ 47,380 if losses in the Libyan network are neglected. That is, the average annual saving is $ 1895 per house.

**Table 3**. Economic values of the PVT system.

| | PVT+ Gas Boiler | PVT+ Electrical Heater | PVT+ Gas Boiler+ Battery | PVT+ Electrical Heater+ Battery |
|---|---|---|---|---|
| No. of Collectors | 9 | 9 | 9 | 9 |
| Collector Area, $m^2$ | 14.8 | 14.8 | 14.8 | 14.8 |
| Gas Boiler, kW | 5 | - | 5 | - |
| Electrical Heater, kW | - | 5 | - | 5 |
| Battery Cap, kW/h | - | - | 5.56 | 5.56 |
| Tank Cap, liter | 500 | 500 | 500 | 500 |
| System total cost, $ | 11,208 | 10,908 | 17,258 | 16,958 |

## 8. Carbon Dioxide Emissions

Fossil fuels are a carbon dioxide emission factor for different sources, as presented below in Table 4.

**Table 4.** Carbon dioxide emissions for different fuels [23-24-25].

| Fuel type | Light oil | Heavy oil | Gas |
|---|---|---|---|
| Conversion ratio, Kg. $Co_2$/kWh | 20518 | 20764 | 0.185 |

A barrel of light fuel oil generates about 418 kWh, a barrel of heavy fuel oil generates about 500 kWh, and natural gas generates about 3.112 kWh generated from fossil fuels. If the house's electricity consumption during 25 years is 263,225 megawatts/hr of fossil fuels, then the need to burn 629.72 barrels of light oil, 526.45 barrels of heavy oil, or 83498 $m^3$ of natural gas. Carbon dioxide emissions per household consumption with different fuels and generation technology are given in Table 5[26-27-28-29].

**Table 5.** Carbon dioxide emissions from home using fossil fuels.

| Fuel type | Light oil | Heavy oil | Gas |
|---|---|---|---|
| Conversion ratio, Kg.$Co_2$/kWh | 20518 | 20764 | 0.185 |
| $CO_2$ emission, kg | 252 | 195 | 15447 |

## 9. Conclusion

The electrical and thermal performance under the climate of Almarj city was analyzed using the Polysun software simulation. In terms of heat output, the PVT system produces a heat output less than the same size as a solar water heating system. Three solar collectors of 280 W with monocrystalline crystals were used to produce 1445 kWh/year. The increasing number of collectors from five to seven will produce 3420 kWh/year. Meanwhile, at nine solar collectors, this leads to cover 10.5 kWh/day that generates 4733 kWh/year of electrical energy. The typical average consumption of a house around 10,529 kWh/year. The results showed that the PVT system's amount is more significant than a similar size for the PV system. Since the system has a life span of 25 years, it will consume 263,225 MWh, making a fuel cost $ 47,380 if the Libyan network losses are neglected. The annual average saved 1895 $/house. The saving of carbon dioxide emissions for light oil, heavy oil, and gas is 252 kg, 195 kg, and 15447 kg, respectively. The existing work has indicated that the hybrid system, compared to other solar systems, has a significant economic feasibility system depending on the demand for electricity, heat, or a combination of both. Thus, this study would reduce the Almarj residential on-grid electrical loads, fossil fuels demand, and global warming and emissions to the environment.

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