Study and Simulation of Low Energy Solar Powered House in Libya

Nouri A. Alkishriwi[1] and Mustafa E. Elayeb[2]

[1] Engineering Faculty /University of Tripoli, Tripoli (Libya)

[2] Renewable Energy Centre/Misurata University, Misurata (Libya)

Abstract

This paper was prepared within the program of a national action plan for energy efficiency, where a building code will be prepared within this program in Libya. The goal of this work is to build a simulated environment that can accurately assess the energy consumption of a six-person, one-story family house. The simulation will consider the hot water heating system, the cooling and heating systems and the selection of building materials that help conserve energy. The TRNSYS model is built and programmed to evaluate system performance on an hourly basis throughout the year.

As a result of using an insulating material for the building envelope, the cooling load of the building loads were reduced by 55% compared to the original design of the project. In addition, a hot water solar heater is used to produce around 2546 kWh (with solar fraction of 96%) of hot water yearly. A 15-kW roof top PV system is designed for this house. The total electric energy produced from this system is 25424 kWh. This electrical energy generated by the solar PV system is sufficient to cover the loads of air conditioning, heating, and the auxiliary heating element in the solar water heater. The surplus of electricity generated by PV system can be exported to the public network in non-summer months.

Keywords: Low energy buildings, Solar cooling and heating, Rooftop PV, TRNSYS

1. Introduction

The continued rise in global demand for energy, especially in rapidly growing economies, has turned the issue of energy availability and security into an important geopolitical issue and a key component of all economies more than ever, especially with the Russo-Ukrainian war and the desire of European countries to search for new energy sources, especially from North African countries, instead of Russian oil and gas. Libya is facing a similar situation, as it depends entirely on fossil fuels as the main source of energy, in addition to the increasing consumption of energy against the background of large economic and population growth - all of which put pressure on the country. Also, due to the lack of renewable water resources, Libya depends partly on desalination, but it is expected that the share of desalination to provide water from desalination plants to the population will increase significantly in the near future, which will put additional pressure on the fossil fuels resources. In addition, the need for alternative and renewable energy is of strategic importance for the long-term prosperity and security of Libya's energy supply. In this context, this study was prepared to develop a sustainable sector for alternative and renewable energy in the Libyan state.

The Libyan electricity sector is going through a complex crisis due to aging infrastructure and the aftermath of recent political instability and associated conflict. The most visible and compelling aspect of the crisis is electricity blackouts and load shedding which are both increasing in severity every year. In simplistic terms, blackouts occur when the immediate demand for electricity exceeds the immediate supply. This triggers an unavoidable self-protection response from the generation and grid equipment, that rapidly shuts down the grid. Once offline, it can take hours to restart the grid. Load shedding is the practice of selecting parts of the grid to deliberately blackout, usually for several hours, to reduce the total load on the grid and thereby avoid a national blackout. The past response of the Libyan government to this crisis has been almost exclusively focused on trying to reduce blackouts, by maintaining and recovering the capacity to supply electricity. This translates into plans to overhaul existing power stations and build new stations which is a very expensive and slow process. However,

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the government of Libya is now considering other responses in the form of Demand Side Management (DSM), Energy Efficiency (EE) practices, and Renewable Energy (RE) development. Successful energy efficiency interventions will reduce the demand for electricity without reducing the benefits that electricity provides to the population of Libya and can be implemented quickly and cost-effectively. In this paper, we will simulate the use of air-conditioning units with Minimum Energy Performance Standard (MEPS), as well as the use of energy-saving LED lamps instead of the incandescent lamps currently used in buildings.

The built environment in the world accounts for over 55% of delivered energy consumption (Hamilton and Rapf, 2020). In Libya, the residential sector is responsible for almost 39% of final energy consumption (GECOL, 2010), Fig.1, where a huge proportion of electrical energy consumed in buildings is used to run air conditioning equipment. This is because Libya's climate is characterized by high ambient temperatures and high humidity, especially during summer periods. Therefore, there is significant potential to improve energy efficiency with savings in space cooling and water heating.

Libya's per capita electric consumption is consistently above world averages. The current demand for electricity in Libya is about 9000 MW, with a deficit of more than 2,000 MW. The main source of peak demand comes from air conditioning and heating load in summer and winter respectively. Based on monitoring of the energy situation in Libya, the United Nations estimates that air conditioners constitute between 40-70% of the peak electricity demand in the summer, while lighting constitutes about 10-15% of the total demand (UN Support Team in Libya, 2021). In addition, the increase in demand of air-conditioning has significantly increased and become the major of electricity consumption in residential buildings. Therefore, if quick measures are not taken to reduce the large increase in electricity loads, the General Electricity Company in Libya-GECOL, which is responsible for the generation, transmission, and distribution of electricity, will not be able to keep pace with the increasing loads on the one hand, which is now suffering from a generation deficit of more than 2000 megawatts on the other hand.

Energy efficiency involves using less energy to provide the same or an improved level of service to the energy consumer in an economically effective manner. Energy efficiency enhances energy security, stimulates the economy of countries, makes energy more affordable to families and businesses, creates jobs, provides economic benefits (increased productivity, lower costs, net job creation) and improves people's well-being and comfort. Achieving Libya's desired energy efficiency outcomes will require involvement of a broad range of actors. While there are many challenges to overcome in appropriately influencing all involved, consistent and appropriate energy efficiency policies are the foundational element for success.

This paper, directed to the Libyan government to draw its attention to the importance of focusing on initiating energy efficiency initiatives on the one hand and designed for architects and intended to be as direct and practical as possible, summarizes the knowledge needed to integrate energy efficiency principles of active solar technologies in buildings, while dealing with the same time with issues of architectural integration and energy production requirements.

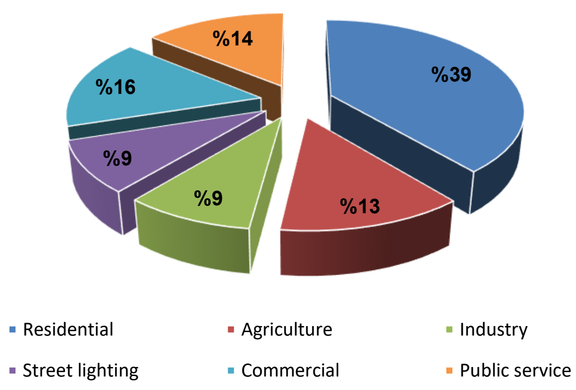

Fig. 1: Distribution of end energy consumption in Libya

2. Analysis Approach

The first step to design the low energy house is to reduce the energy consumption at minimal through passive design (insulation, orientation, natural ventilation, etc.). The next step is to use renewable energies to cover the optimized thermal loads; geothermal heat pumps, small wind turbines and solar energy are common methods to produce the required energy in the house. Flat plate collectors and PV panels offer a practical solution since they can be integrated on the design on the building. Also, a PVT collector system may be used for hot water production and electricity generation for the house. The technical specifications and the analysis of the PVT system is explained in detail by the authors in (Alkishriwi & Elayeb, 2017). The last step is to use conventional resources, e.g., extra energy from the grid as efficient as possible; it has a lot of importance in places where renewable energy resources are limited; however, the goal is to achieve energy neutrality without this last step. In this study, we seek to reduce the need for energy in the house under study as much as possible, while generating enough energy to meet the needs of the house and exporting the surplus to the public network to achieve the principle of a plus-energy building. When designing and constructing residential buildings, some auxiliary rules must be considered in the implementation of systems and specifications that lead to energy savings and reduce the operational cost of buildings to reach economic buildings in operation through the following:

- The use of thermal insulation materials for all external elements such as roofs, walls, bridges, and columns.
- Use double glazing for all external openings.
- Implementation of solar architecture standards to reduce heating and cooling loads.
- Use of solar energy technologies (every possible) to heat and cool the interior spaces of the building.
- Using solar energy to secure hot water for buildings when needed.
- Switch to the use of energy-saving lamps (LED lamps).
- Install photovoltaic cells to generate electricity as much as possible.

3. Building Description

The building is a typical residential building for a family located in Tripoli. The building is made of one-story building, Fig.2. It has a total volume of 594 m^3 and a treated floor area of 198 m^2 per house.

Fig. 2: The typical residential building under study

According to the construction files of building, walls are built as multi-layer to provide high quality of thermal insulation, high soundproofing with overall heat transfer U-Value (0.4-0.5 W/m^2. k). Likewise, the construction of the roof based on multi-layers to provide high quality of thermal insulation, high soundproofing with overall heat transfer U-Value (0.3-0.4 W/m^2. k). The overall U-value for the Floor is ranged between (0.4 to 0.5 W/m^2. k). The criteria to choose the technology is based on that insulation should be located outside. Table 1 shows the properties of selected insulation materials in both cases: Reference Case and Target (Low Energy) Case.

Tab. 1: The properties of selected insulation materials

	Reference Case	Target Case
External walls, W/m²K	2.8	0.5
Floor, W/m²K	0.6	0.5
Roof, W/m²K	2.2	0.4
Average uncontrolled infiltration, ACH	0.5	0.1
Glazing, W/m²K	2.1	1.4

4. The Operative Conditions

Libya is a country in the middle of North Africa, bordering the Mediterranean Sea to form a coast 1900 km long, 1,750,000 km^2 deep in the Sahara, Fig.3. It is exposed to a solar radiation reaches to 2300 kWh/m^2 /year, and sunshine duration is about 3500 h/year (Glaisa et al 2014).

Tripoli is located in the northwest of Libya with the GPS coordinates of 32° 53' 7.2708" N and 13° 10' 48.5796" E. Geographically located at the Mediterranean Sea on a plateau 17 meters above sea-level. Tripoli has relatively hot weather in summer with high humidity. Temperatures average around 33 °C in the mid of this season, although sometime reached 47 °C or above. In the evening the average temperature is around 28 °C due to cool breezes. Winter is a cold season. Rainfall usually starts from October to the end of April. The temperature drops to around 15 to 18°C. In Spring and Fall the weather becomes moderate, and usually there is no need to any cooling or heating system in this time of the year (Mashena and Alkishriwi 2016). The temperature set point is defined for this analysis in 24°C.

Fig. 3. Location of Tripoli, Libya (source: https://www.nationsonline.org/oneworld/map/libya-political-map.htm)

Building insulation was rare until recently in Libya. With the spread of air conditioning and the excessive consumption of electrical energy, interest in thermal insulation began to appear in some buildings in a limited way. This coincided with the authorities' interest in introducing energy efficiency standards and labels for appliances and equipment, where the energy efficiency specifications for air conditioners have been approved, with a minimum energy efficiency ratio (EER) not less than 11 BTU/h/W (Libyan national center of standardization and metrology, 2022). Domestic water heating is done using electricity in Libya so far, despite the favorable conditions for the use of the solar heater in the country. Figure 4 shows the hot water consumption pattern adopted in this study.

To run the simulation for a whole year, a weather data for Tripoli city was used. These are data for the typical meteorological year (TMY) for the period 1990-2005. This weather data is read by Type 109 TMY2 in TMY2 format which it uses to compute radiation on different surfaces defined by the user. Theses data is also compared with the data downloaded from (Photovoltaic Geographical Information System website). A good agreement was obtained by comparing the two weather data files together.

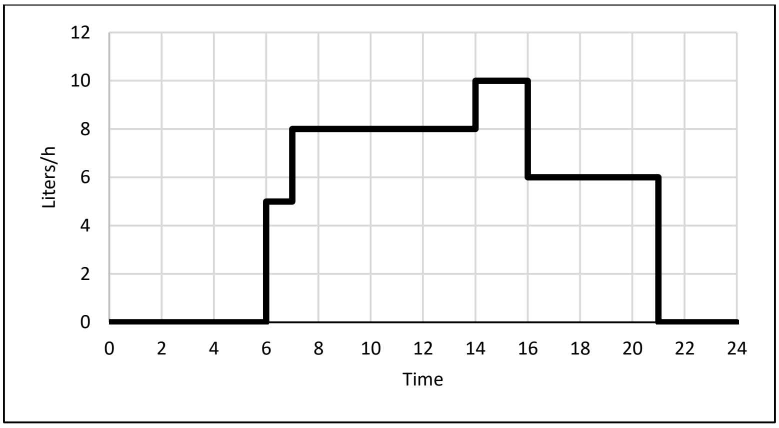

Fig. 4 shows the hot water consumption pattern

5. Model Approach

The dynamic simulation of multizone building, solar heaters, and solar photovoltaic system is carried out using the TRNSYS program (TRNSYS Simul. Platform, Sol., Univ. Wisconsin-Madison). The simulation was conducted for the selected systems over a year and at a time step of 15 minutes. The program chosen to model the residential building in terms of thermal loads (cooling and heating loads) as well as the power supply system of the solar building is TRNSYS. This transient systems simulation software was developed by the Solar Laboratory at the University of Wisconsin. This software supports detailed simulations of multi-zone buildings and their power supply equipment. TRNSYS equipment library includes advanced building models; many components of equipment commonly found in the construction of thermal power systems; Components that facilitate entry of weather data, equipment, and specific schedules; and components that support the output of simulation results.

The objective of this work is to build a simulation environment that can evaluate accurately the energy consumption of a 6 people, one story family house. The simulation will consider hot water heating system, PV system, and selection of construction materials helps in energy conservation. A TRNSYS model was constructed and programmed to evaluate the performance of the system on hourly basis throughout a complete year, Fig.5. The simulation of the residential building aims to calculate the effect of the shape of the building, external and internal walls, lighting, windows, internal loads for individuals, ventilation, roof and floor on thermal loads, in order to calculate the cooling and heating loads over a whole year. From the side of the energy supply to the building, the solar hot water system was simulated, and the building was supplied with electricity by installing a 15-kilowatt photovoltaic system.

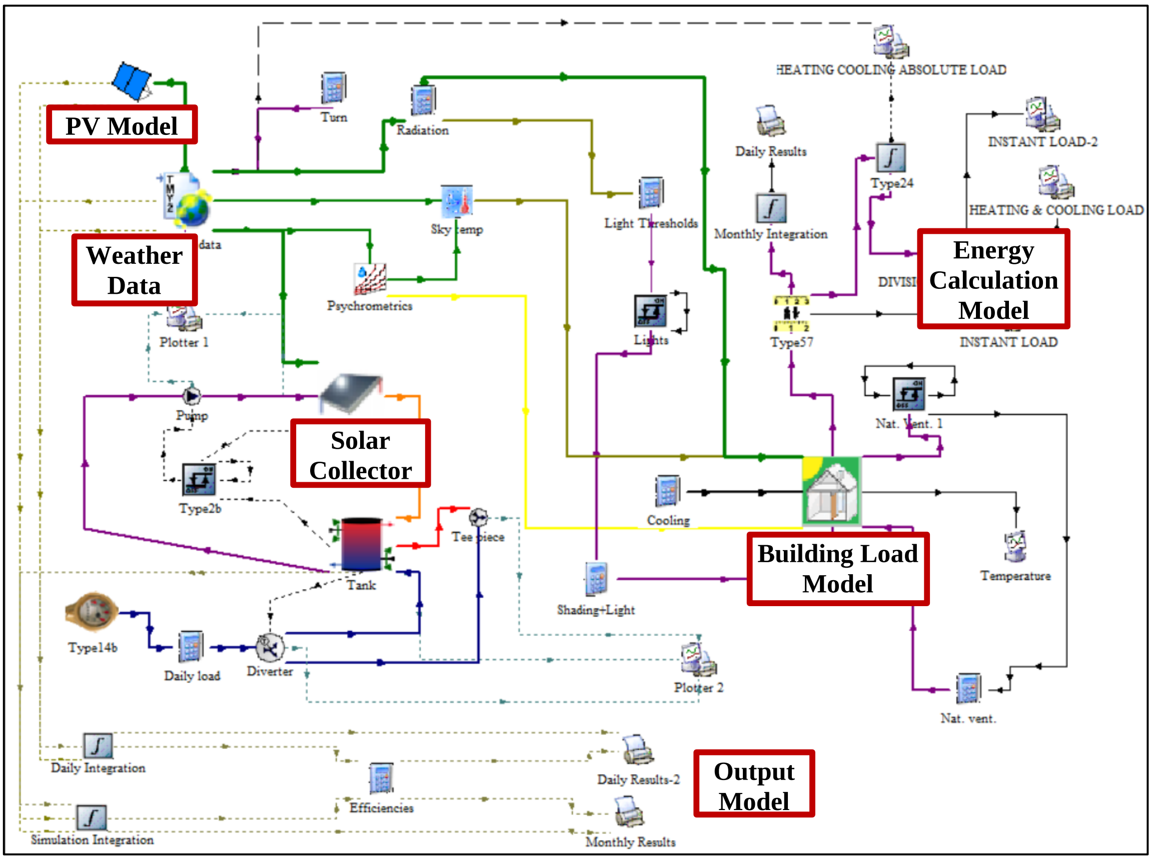

Figure 5. Performance prediction model.

6. The Results

The TRNSYS model is built for cooling, heating, water solar heater and PV system. The simulation was conducted to evaluate system performance on an hourly basis throughout the year. Here a sample of the results will be presented, discussed and some comparisons made.

Figures 6, 7 show the instantaneous cooling and heating loads throughout the year, while Figure 8 shows the accumulated energy required for cooling and heating in both cases: the reference case (business as usual- BAU) and the target case (sustainable-SUS). It is noticed that the cooling loads appear in March and increase steadily until October, when the weather begins to moderate before the heating loads appears in December. It is also noticed that the cooling loads are more important than the heating loads according to the weather of the Tripoli city. Similarly, the possibility of reducing the cooling loads seems more effective and illustrates the feasibility of energy efficiency in buildings in Libya, especially during summer, where the need for air conditioning is greater and the generation deficit in the electrical network increases.

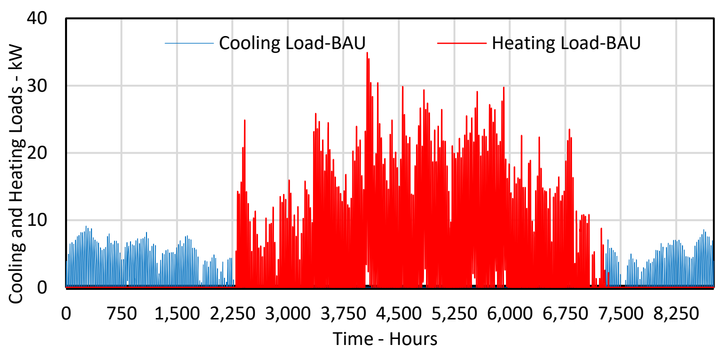

Fig. 6: Cooling and heating load in BAU case.

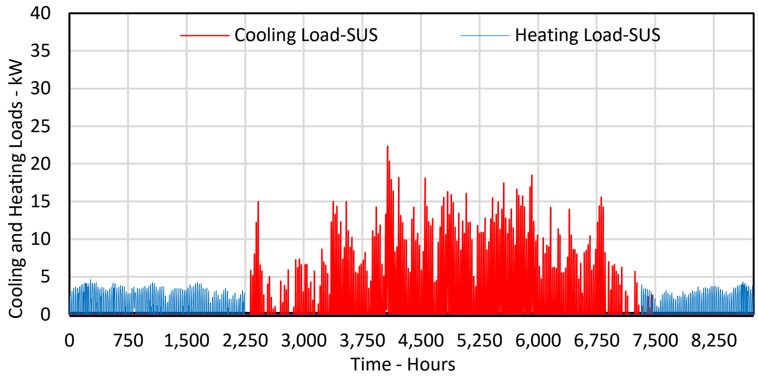

Fig. 7: Cooling and heating load in SUS case.

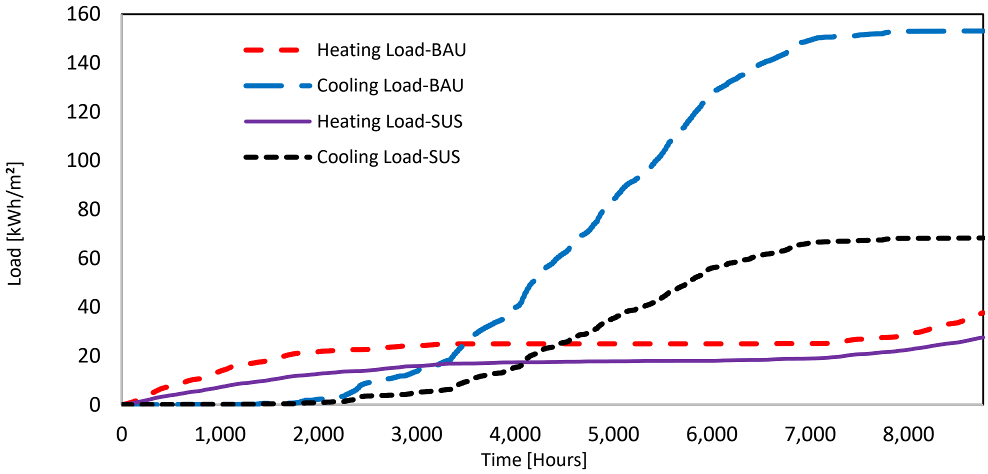

Fig. 8: Accumulated energy for cooling and heating load in BAU case and SUS case.

From the results obtained, it is clear that the annual cooling loads can be reduced from 151 kWh/m2 in the BAU case to 67 kWh/m2 in the SUS case. Figure 9 shows monthly cooling loads in both cases BAU and SUS. It can be seen that the significant impact of building insulation on saving energy wasted in building cooling.

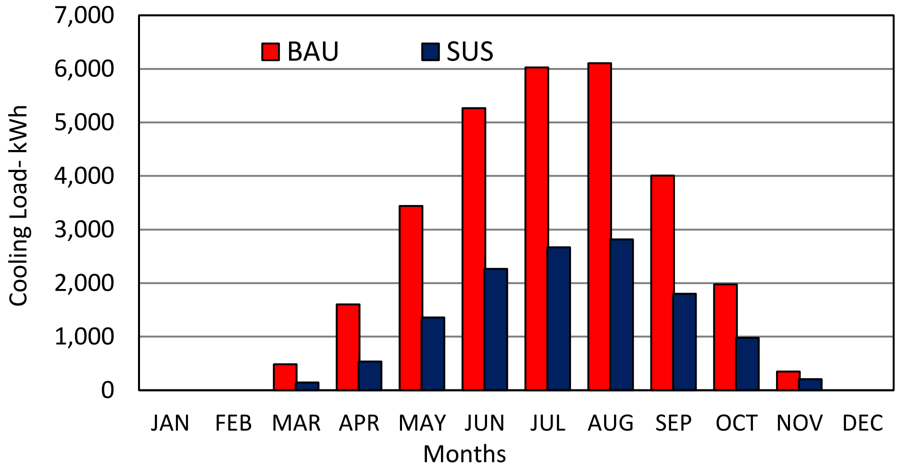

Fig. 9: Cooling load in the building in both cases

A 15-kWp roof top PV system is designed to supply the house with the necessary electrical energy. Figure 10 shows the daily monthly average of the solar irradiance incidence per unit area of the PV panels (the right vertical axis), as well as the monthly energy generated by the solar cells (DC output) and the electrical energy converted by the inverter (AC output) to feed the loads of the house. The total electric energy produced from this system is about 25424 kWh annually.

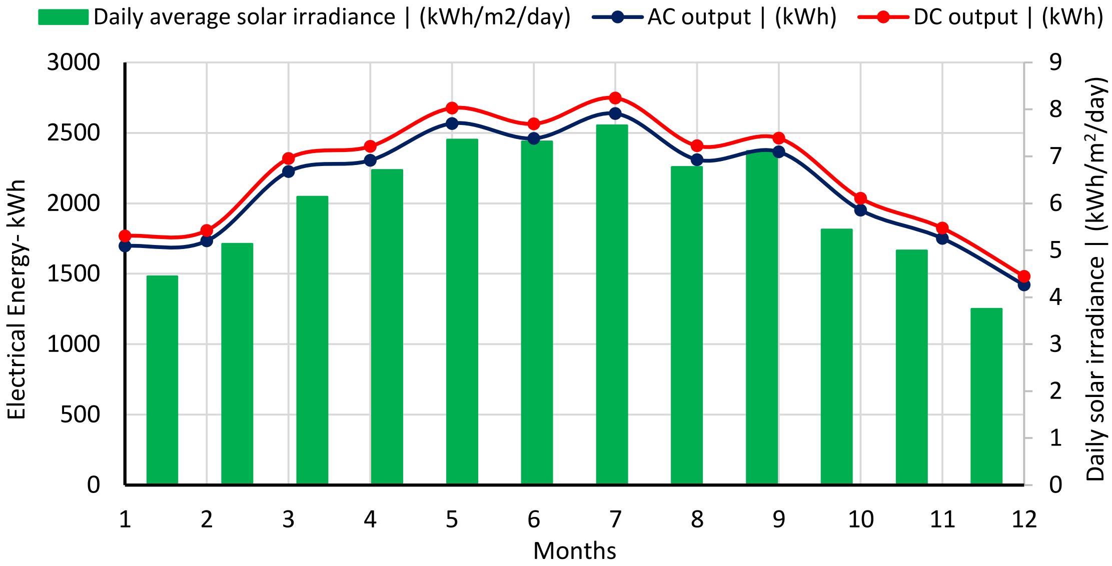

Fig. 10: PV electricity generation during the year on the roof of the house

This amount of energy is sufficient to operate an efficient heating and air conditioning system (4048 kWh when the minimum energy efficiency ratio, EER_{min}=11; according to the Libyan Energy Efficiency Standard for Air Conditioning and Heating Equipment 2022) and the energy consumed by the auxiliary heating unit (about 111 kWh annually), in addition to lighting and other household electrical supplies, Fig.11. The surplus generated energy can be exported to the public grid. In the same Figure, the monthly saving of electrical energy can be observed in the processes of air conditioning, heating and domestic water heating. As the total annual electrical energy savings in these processes is about 8294 kWh. Also, the figure shows the thermal energy used in solar water heating. The annual average of the solar fraction is equal to 96%. It is worth noting that the remaining 4% of water heating was made using solar electricity generated by PV system.

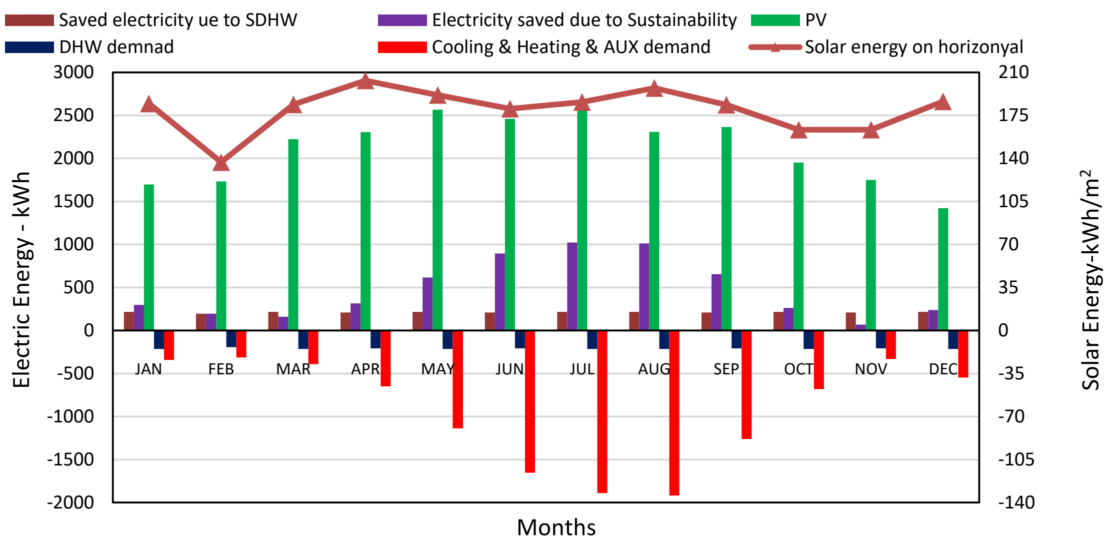

Fig. 11: Energy balance diagram

7. Conclusions

A proper passive design can reduce considerably the amount of energy that has to be consumed to cover the cooling or heating load. Our studies have shown that proper wall and roof insulation alone can save up to 55% of the energy used in MENA (Middle East and North Africa) region, especially in the residential sector. The prevailing climate in Libya, provides a suitable environment for zero-energy and plus-energy buildings. This would save huge amounts of fossil fuels burned daily to generate electricity in Libya, thus reduce the emission of tons of carbon oxides, in addition to contributing to solving the electricity generation deficit, which is a real problem at the present time in Libya. For Example, the average efficiency of the power plants currently operated in the Libyan utility grid in 2016 did not exceed 33.3%. This means that 66.7% of the fuel that was consumed in those stations was wasted, and this lost value represents about 2275 million dinars of the value of the fuel subsidy allocated to the GECOL in the same year, which resulted in the emission of about 23 million tons of carbon dioxide (Eshtaiwi, et al.2022). The authors recommend the local authorities in Libya pay attention to energy efficiency in buildings, and adopt the appropriate specifications for that, especially at this phase that has a shortage of electricity generation and the instability of the public network. Rooftop solar PV systems play an important role in the energy mix of sustainable cities. Currently, the installation of rooftop units can be an important option at this point for grid-connected solar deployment where utility scale PV systems are difficult to install on the ground due to instability in the country. Also, homeowners can reduce their electricity bills by consuming the energy produced by rooftop solar PV systems. In addition, these systems enable owners to export energy to the grid and make financial profits. Thus, this empowerment turns the owners of rooftop solar PV systems into the so-called producers and consumers, which is important now in the face of a significant increase in electricity prices.

8. Acknowledgments

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