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Photovoltaic Systems in Existing Residential Building in Egypt

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Abstract - Recently, world has become more conscious about the environment, changes occurring in climate and in earth in general. It started to pay more attention to the impact of the technological and industrial revolution on the ecology and human health, which resulted in directing all the new researches towards renewable energy and recycling materials. In the development of energy sources in Egypt of the 21st century, it is necessary to view the use of solar energy in all applications as one of the most promising new and renewable energy sources. This paper presents a study and design of a complete photovoltaic system for providing the electrical loads in an existing family house according to their energy requirement. It is found that providing electricity to a family house in a rural zone using photovoltaic systems are very beneficial and competitive with the other types of conventional energy sources, especially considering the decreasing prices of these systems and their increasing efficiencies and reliability. They have also the advantage of maintaining a clean environment. These principals are applied in the case study (Renovation of the existing staff housing unit at Wardan railways training institute, 6 of October, Egypt) and calculated the life cycle cost of the proposed alternatives.

Keywords - Ecology, Life Cycle Cost, Photovoltaic, Renewable Energy

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1 INTRODUCTION

Attention to living sustainably requires us to actively be aware of the environmental, social and economic needs of our present generation. Solar energy is expected to play a very important role in meeting energy demands in the near future.

Since it is a clean type of energy with a diversity of applications, decentralized nature and availability, solar energy will represent a suitable solution for energy requirements especially in rural areas and new urban communities. It is important to state that the use of solar energy will protect these areas from pollution, since the use of solar home systems avoids large amounts of CO2 emissions [1]. In Egypt, there are many new projects such as those carried out in the new valley in the western desert of Egypt and those on the northern coast of Egypt, which will be accompanied by a new population who require energy for principle life requirements

List of Abbreviations

A	Initial cost	MTOE	Million Tons Oil Equivalent
BCC	The batteries charge controller	n	Number of years
d	The market discount rate	N C	Number of continuous cloudy days
DOD	The allowable depth of discharge for the batteries	P e	Electrical power (W)
EL	The average daily load energy (kWh / day)	PSI	Peak solar intensity at the earth surface (1000 W / m2)
g	9.81 m / s2	PV	Photovoltaic panels
G.S.	The Government Subsidization	PW	Present worth of total cost
H	Average solar energy input / day (kWh / m2 / day)	Q	Water discharge (m3 / h)
h	Total head (m)	TCF	Temperature correction factor
i	The annual inflation rate	P	Water density (kg / m3)

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2 AIM & OBJECTIVES

2.1 Aim

- This research aims at introducing the specific architectural design elements of the existing residential buildings according to the surrounding environmental elements.

2.2 Objectives

- Introduce a model for a family house that depends mainly on solar energy to run the electrical appliances.
- Encourage owners and operators of existing buildings to implement sustainable practices and reduce the environmental impacts of their buildings over their functional life cycles.

3 ENERGY CHALLENGES FACING EGYPT

1. The increase in population (1.3 million / year)
2. Over concentration of population on 5% of total area of Egypt
3. An extra infrastructure system for about 60 million (2035) peoples are needed concentrated most probably in the desert and this requires a big amount of embodied energy as well as operating energy and effort [2].
4. The limitation of conventional energy resources in Egypt
5. Conventional technology as well as the use of high intensive energy industrial construction for production of building material
6. The construction sector produced around 30% of solid waste generation and this is considered one of the biggest challenges facing the population cities

3.1 Energy Limitations

Energy is a critical resource needed for development. Apart from small quantities of coal in Sinai, fossil fuels in the form of oil and gas are known to exist around Gulf of Suez and the northern part of the western deserts. With the present increase in oil prices and its unsustainable production, as well as the international move against CO2 evolution caused by burning fossil oils, it is imperative that Egypt must devote more efforts to promoting the use of renewable energy (solar, wind, biogas, and biomass)

The changes in production and consumption of oil & gas are showed in table 1 over the period from 1991 to 2020. Although the balance shows an increase, it should be emphasized that Egypt in most cases has to pay 50% of the production to the foreign partner [3].

3.2 Concerning Primary Energy

In 2007, Egypt's primary energy total consumption was 63 MTOE. This is expected to reach 210 MTOE by 2030. In 2007, primary energy consumption was mainly in industry (34%) and residential and commercial buildings (23%). The later is expected to reach more than 35% by 2030. Different studies have shown that the primary energy supply will not meet demand starting from 2015; this gap is widening after 2020 [2].

3.2.1 Concerning Electricity

In 2007, current installed capacity was 22000 MW. This is expected to reach 74000 MW by 2030. This would require the addition of more than 50000 MW. The peak demand was 18500 MW. It is expected that this demand will reach 62000 MW by 2030 [2].

In 2010, electricity consumption in residential (39.9%), industry (32.7%), commercial (8.1%) and governmental (4.6%), buildings reached 58% of total electric energy demand in Egypt [4].

Table 1
Yearly energy production & consumption in Egypt

Year	1991 / 1992	1999 / 2000	2004 / 2005	2019 / 2020
Production	55.10	60.70	69.70	104.0
Consumption	31.90	38.70	43.70	70.00
Balance	23.00	22.00	26.00	34.00

(Unit = MOTE) Source Beshay, 2010

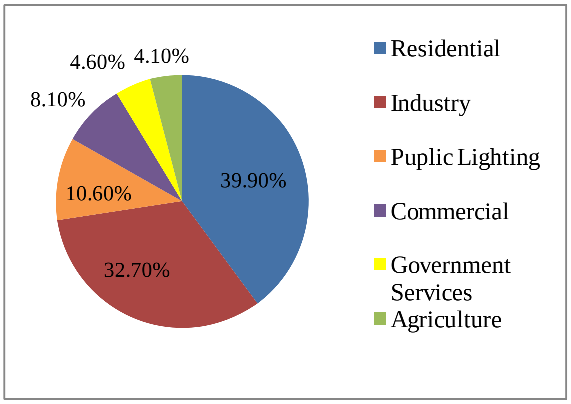

Fig. 1. Electricity consumption in Egypt (Ministry of Energy and Electricity, 2010

4 RENEWABLE ENERGY

Renewable energy represents an important option for the change in energy mix. In 2009, renewable energy, mainly hydropower, accounted for 12 per cent of Egypt's electricity generation. Egypt's hydropower potential is about 3,664 MW with an estimated energy of 15,300 GWh per annum. Renewable resources wind and solar energy offer significant potentials [5].

4.1 Wind Energy

Egypt is endowed with an abundance of wind energy resources especially in Suez Gulf area which considered one of the best sites in the world due to high and stable wind speeds. The west of Suez Gulf zone is the most promising sites to construct large wind farms due to high wind speeds which ranges between 8-10 meter/second in average, proximity to load centers and transmission infrastructure, and availability of large uninhabited desert area. There are also other promising sites having wind speed of 7-8 meters/second in the east and west of Nile River near Beni-Suef, Menia and El-Kharga Oasis in theNew Valley [5].

Fig. 2. Wind energy, Red Sea, Egypt

4.2 Solar Energy

Solar energy is also rather abundant. Due to its geographic location, Egypt enjoys sunshine all year, with direct solar radiation which reaches 6 KWh/m2/day [6].The present energy strategy (the resolution adopted by supreme council on energy in 2007) aims at increasing the share of renewable energy to 20 percent of the energy mix by 2020.

Fig. 3. Solar energy, El-Sadat City, Egypt

This target is expected to be met largely by scaling-up of wind power as solar is still very costly and the hydro potential is largely utilized. The share of wind power is expected to reach 12 percent, while the remaining 8 percent would come from hydro and solar.

This translates into a wind power capacity of about 7200 MW by 2020. The solar component is at this stage considered to start with 100MW of CSP and 1 MW of PV power [5].

4.2.1 Photovoltaic System

Photovoltaic cells convert sunlight directly into electrical energy. The electricity they produce is DC (direct current) and can either be used directly as DC power; converted to AC (alternating current) power; or stored for later use. The basic element of a photovoltaic system is the solar cell that is made of a semiconductor material, typically silicon.

Because sunlight is universally available, photovoltaic devices have many additional benefits that make them not only usable, but of great value, to people around the world. They are the future and by 2020, when the conventional oil supplies begin to really dry up, they will be everywhere [7].

As shown in fig. 4. The PV system can either depend on a PV array, charge controller, batteries and DC / AC inverter.

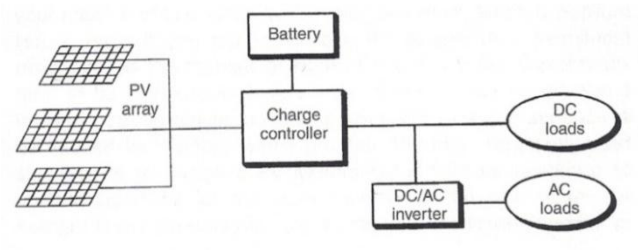

Fig. 4. Photovoltaic Systems (Roaf, 2001)

5 CASE STUDY

Renovation of Wardan staff housing unit, Wardan, 6 of October City, Egypt

Fig. 5. Wardan institute site (Google earth, 2010)

Location
Wardan Training Institute is located at kilo 58 Cairo / Alexandria desert road, 6 of October, Egypt.
It is located at latitude 30o 22'N, and longitude 30o 27'E, and it is 50 kilometres north-west Cairo. (Rural zone)
Design
Architect: Ezat, H. Abougad, Alexandria, 1964

Project Description
Institute Area is 150 acres and farm area is 20 acres.

Wardan Campus Contents:
Educational zone, residential zone, recreational zone and services zone

Fig. 6. Residential zone & Executive villas (a) (Abou-Gad, 2008)

5.1 Executive Villas

Executive villas Area consists of:
- 8 villas with 2 floors (total area 360 m2) villa (a)
- 3 villas with 2 floors (total area 600 m2) villa (b)

5.1.1 Staff Housing Unit "Villa (a)" Description

Orientation: All villas are with two stories and oriented to the north / south.

Ground Floor: Entrance hall, living area, dining room, office room, kitchen, house keeper room, toilet, and terraces

First Floor: Three bedrooms, bathrooms, toilet, upstairs sitting area, kitchen, and terraces

Fig. 7. West perspective Fig. 8. North perspective

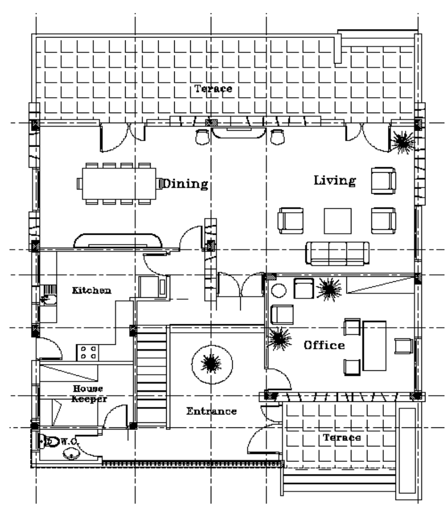

Fig. 9. Existing villa (a) ground floor plan

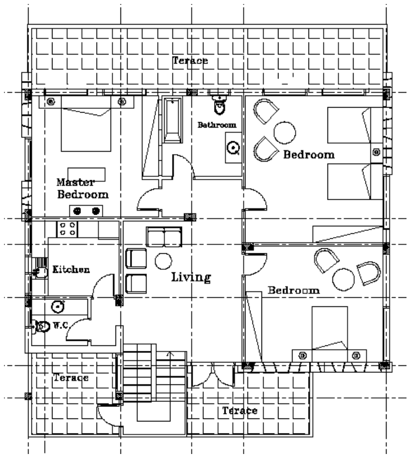

Fig. 10. Existing villa (a) first floor plan

5.2 Case Study Proposal

The Wardan residential unit was modified as follows:

Fig. 11. Proposed ground floor plan

Fig. 12. Proposed first floor plan

5.2.1 Solar Energy

Using photovoltaic panels to generate electricity & hot water

5.2.1.1 Photovoltaic System Design

The average solar input over the year, H (kWh/m2/day):

According to the fig. 12, the average solar input over the year at Cairo region and its environs is 19.11 MJ/m2/day [8]. To transfer the loads from MJ to kWh use the following equation:

Average H = 19.11 MJ/m2 ×0.2778 = 5.31 kWh/m2/day

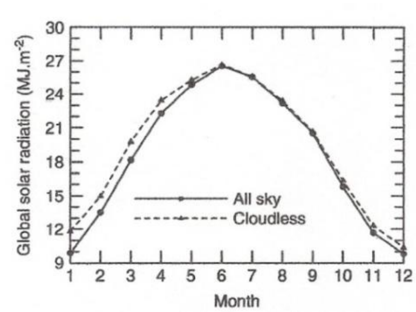

Fig. 13.The monthly average values of daily solar energy (MJ/m2/day) in the Cairo region

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Table 2

The monthly mean values of cloudiness in the Cairo region

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Clear Sky	22	21	26	28	29	30	31	31	30	29	26	25	27
Cloudy Sky	2	1	0	0	0	0	0	0	0	0	0	1	0
Partial cloud sky	7	6	5	2	2	0	0	0	0	2	4	5	3
Season	Winter			Spring			Sumer			Autumn			
Clear Sky	23			28			31			28			
Cloud Sky	1			0			0			0			
Partial cloud Sky	6			3			0			2			

Source: Robaa, 2006

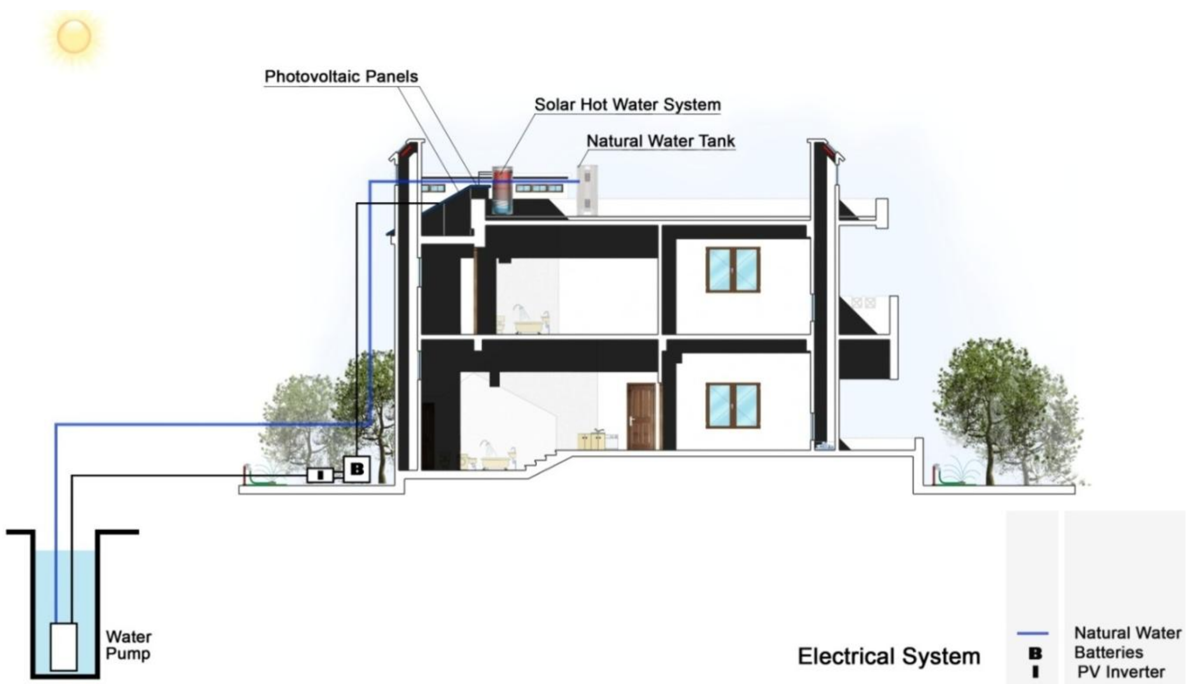

Fig. 14. Proposed photovoltaic and solar hot water system (water is taken from 25m underground) "Sec. A-A"

- Calculating the Average Daily Load Energy Requirements:

Water pumping is an important item in designing PV systems; the depth of the water level in Wardan campus is 25m under ground level. Water required in the villa = 2 m3/day

$$Pe = \frac{p\,gh\,Q}{\eta p \eta m} \quad (1)$$

Assuming that $\eta p = 0.45$ and $\eta m = 0.85$, Q=0.5 m3/h and h= 33.5 m

Pe(Electrical Power) = 120 W

Table 3
The daily load energy requirement for Wardan residential unit

Load	No. of units	Load power (W)	Winter operating periods/day	Spring operating periods/day	Summer operating periods/day	Autumn operating periods/day
DC lamps (light)	18	6×60 12× 40	From 17.00 to 22.00	From 19.00 to 23.00	From 20.00 to 24.00	From 19.00 to 23.00
Refrigerator AC	1	100	24 h / day	24 h / day	24 h / day	24 h / day
TV & Receiver DC	1	80	From 17.00 to 22.00	From 18.00 to 23.00	From 17.00 to 24.00	From 18.00 to 23.00
Computer & Printer DC	1	100	From 17.00 to 19.00	From 18.00 to 20.00	From 19.00 to 21.00	From 18.00 to 20.00
Washing machine AC	1	250	From 12.00 to 14.00	From 12.00 to 15.00	From 12.00 to 16.00	From 12.00 to 15.00
Electric Fan DC	8	45×8	_	From 12.00 to 17.00	From 11.00 to 19.00	From 12.00 to 17.00
Motor + Pump AC	1	120	From 12.00 to 14.00	From 11.00 to 14.00	From 10.00 to 14.00	From 11.00 to 14.00
Total Energy (W h/day)			7940	9020	10880	9020

(Calculated by the researcher)

From table 3 the average daily load energy of villa “A” = 9.215 kWh / day

- PV Array Sizing

PV (Area) = EL / H × η PV × TCF × η out (2)

If the cell temperature is assumed to reach 60 C˚, then the temperature correction factor (TCF) will be 0.8 [9].
Assuming η PV = 17%, η out = 0.85 × 0.9 = 0.765

PV (Area) = 9.215 / 5.31 × 0.17 × 0.8×0.765 = 16.6 m2 (3)

PV cost according to the market price = 9215 w / h × 1.1$= 10136$ (4)

- Design of the storage system:

Battery storage = NC EL / DOD × η out (5)

NC : Number of continuous cloudy days according to table (5.1) = 2days

Battery storage = 9.215×2 / 0.8×0.765 = 30114 W h

If a 24 V system is chosen the required amp. Hours of batteries = 30114 / 24= 1254 AH

If 2V blocks with 1254 AH each are chosen, 12 batteries (2V, 1254 AH) connected in a series are needed. This battery bank can drive the loads for continuous 2days without any sunshine.

The battery charge controller is chosen to maintain a longer lifetime for the batteries.

- DC/AC Inverter

The inverter has to be capable of handling the maximum expected power of AC loads. Thus, it can be chosen 20% higher than the rated power of the summation of AC loads.

Total power of AC loads = 100+250+120=
470 × 1.2 = 564 W (6)

The specifications of inverter will be 564W, 24 VDC, and 220 VAC.

Fig. 15. Proposed photovoltaic panels in the south elevation (before & after)

- The Life Cycle Cost of Photovoltaic System

From the economical viewpoint, photovoltaic energy systems differ from conventional energy systems in that they have high initial cost and low operating costs.

The price of the PV system and its installation are important factors in the economics of PV systems. These include the prices of PV modules, storage batteries, and the control unit, the inverter, and all other auxiliaries. The cost of installation must be taken into consideration.

For the present PV system, the life cycle cost will be estimated as follows. The lifecycle of the system components will be considered as 25 years except for the batteries, which will be considered to have a lifetime of 8 years. In addition, the annual inflation rate in batteries prices is considered 8.58% and the market discount rate as 8.5% [10].

The cost of the first group of batteries (A) =

No. of batteries × cost of battery = 12×250$ = 3000$

The present worth of the second group of batteries (after 8 years) $= \frac{A\,(1+i)^{n-1}}{(1+d)^{n}}$

$$= \frac{3000(1+0.0858)^{7}}{(1+0.085)^{8}} = 2763\$ \quad (7)$$

The present worth of the third group of batteries (after 16 years)

$$= \frac{3000(1+0.0858)^{15}}{(1+0.085)^{16}} = 2557\$ \quad (8)$$

The initial cost of PV system = PV array cost (according to the market price) + first group of batteries cost + BCC cost + inverter cost + auxiliaries cost

Substituting from (4),(5),(6) into (9):

A = 10136+3000+1000+600+250 = 14986$. (9)

The PV system installation cost can be estimated as 10% of the initial cost. Also, the annual maintenance and operation cost is about 1% of the initial cost.

Substituting from (7), (8), (9) into (10):

Life cycle cost = initial cost of PV system + installation cost + maintenance and operation cost = 14986 + (0.1× 14986) + (2763 + 2557) + (0.01×25×14986) = 25549$ (10)

The life cycle output energy = 9.215×365×25 = 84086 kWh (11)

The cost of 1 kWh from the PV generator = 25549 / 84086 = 0.30$

- The Life Cycle Cost of Diesel Generator System

If a diesel generator is used to feed the house in question with its energy requirements, then it is important to estimate its life cycle cost. This will give an indication of the difference in energy cost between PV systems and diesel generator systems.

To estimate the diesel generator life cycle cost, there are some assumptions:

1. Two diesel generators will be used, each with a power capacity of 5 kW.
2. The diesel generators need reviving every 4 years. The cost of reviving is about 20% of their initial price.
3. The cost of annual maintenance, operation and oil changing is about 5% of the initial price.
4. Fuel consumption is about 10 l / day.
5. The inflation rate in prices is about 8.58%, while the market discount rate is about 8.5 % [10].

The life cycle cost of diesel generator system = initial cost + (present worth of 20% from the initial cost x 6 times reviving) + (present worth of 5% from the initial cost for maintenance, operation and oil changing) + (present worth of fuel consumption for 25 years) (12)

Initial cost (according to the market price) = 2×2000$ / unit = 4000$ (13)

Present worth of reviving = $\frac{A\,(1+i)^{n-1}}{(1+d)^{n}}$ for

N= 4,8,12,16,20,24 where, in this equation,

A= 20% from the initial cost:

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Present worth of reviving = $(0.2 \times 4000)\left[\frac{(1+0.0858)^3}{(1+0.085)^4} +\right.$
1+0.085871+0.0858 + 1+0.0858111+0.08512 +
1+0.0858151+0.08516 + 1+0.0858191+0.08520
+ 1+0.0858231+0.08524 =4420$ (14)

Present worth of maintenance, operation and oil changing

$$= \sum_{n=1}^{n=25} \times \frac{A\,(1+i)^{n-1}}{(1+d)^n}$$

Where N from one to 25 years, and A = 5% from initial cost.

$$= \frac{(0.05 \times 4000)(1+0.085)^{n-1}}{(1+0.0858)^n} = 4425\$ \qquad (15)$$

Present worth of fuel consumption for 25 years:

where N from 1 to 25 years, and A = first year fuel cost = 10 L / day

A= 10× 365×0.24 = 876 $

Present worth of fuel consumption for 25 years =

$$\sum_{n=1}^{n=25} \times \frac{876\,(1+0.0858)^{n-1}}{(1+0.085)^n} = 19342\$$$

(16)

Substituting from (13), (14), (15) and (16) into (12):

The life cycle cost of diesel generator system = 4000+4420+4425+19342=32187$

The life cycle output energy=9.215×365×25= 84086.8 kWh

The cost of 1 kWh from the diesel generator = 32187 / 84086.8 = 0.39 $ / kWh

Table 4

Comparing between electricity cost (kWh) using PV panels & diesel generator

Items	Photovoltaic Panels	Diesel Generator
Electricity Cost (kWh)	0.30$	0.39$

- Life Cycle Cost of Unavailable Local Electricity without the Government Subsidization

To feed Wardan institute with the local electricity it will cost approximately 4$ million [11].

4$million / 100000 m2 (The total of Wardan campus built area) = 40$ / m2 [12].

Villa (a) Electricity cost = 360 m2 × 40$ = 14400$

Initial cost = 14400$ (17)

Yearly electricity Bill without G.S.= 9.125 × 365 × 0.17$ = 567$ (18)

Present worth of electricity consumption for 25 years

$$= \sum_{n=1}^{n=25} \times \frac{A\,(1+i)^{n-1}}{(1+d)^n}$$

$$P = \sum_{n=1}^{n=25} \times \frac{567(1+0.0858)^{n-1}}{(1+0.085)^n} = 12530\$$$

The life cycle cost of electricity without G.S. = 14400+12530=26930$ (19)

The life cycle output energy = 9.215×365×25 = 84086.8 kWh

The cost of 1 kWh from the electricity without government support = 26930 / 84086.8 = 0.32 $ / kWh

- Life Cycle Cost of Local Electricity with the Government Subsidization

Initial cost of local electricity = 2000$ [11].

Yearly electricity Bill with G.S. = 9.125 × 365 × 0.05$ = 167$ (20)

Present worth of electricity consumption for 25 years

$$P = \sum_{n=1}^{n=25} \times \frac{167(1+0.0858)^{n-1}}{(1+0.085)^n} = 3690\$$$

The life cycle cost of electricity with G.S. = 2000+3690=5690$

The cost of 1 kWh from the electricity with G.S. = 5690 / 84086.8 = 0.07 $ / kWh

Table 5

Comparing between electricity cost (kWh) using PV panels, diesel generator and unavailable local electricity supply versus in case the local electricity supply is valid (with / or without G.S. government subsidization)

Items	Photovoltaic Panels	Diesel Generator	Unavailable Local Electricity without G.S.	Local Electricity with G.S.
Electricity Cost (kWh)	0.30$	0.39$	0.32$	0.07$

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The life cycle cost of the photovoltaic system is less than that of the diesel generator system or local electricity supply (without the government subsidisation) for providing Wardan staff housing unit with the energy supply. On the other hand, diesel generators cause noise and pollution (it produces gases and smoke)

The life cycle cost of the available local electricity (when is valid) is less than photovoltaic system but this case in not permanent in the nearest future in Egypt.

Fig. 16 Proposed south elevation with PV panels

6 CONCLUSIONS

- Renewable energy is the actual solution to face the future challenges in the Egyptian energy demands. Specially, solar energy and wind energy.
- Photovoltaic systems are clean and renewable sources of energy; they do not cause pollution during their use.
- From an economical point of view using PV systems in feeding rural zones is very important, especially when their life cycle costs are competitive with the other types of conventional energy sources.
- Energy efficiency through a set of design principles for renewable energy resources
- Applying economical but ecological design factors and through selecting an economical system that uses local and natural building features.
- In order to achieve an ecological, economical house; life cycle cost should be apply throughout all the design and renovation processes

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