VOL. 12, NO. 21, NOVEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGNING A BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM (BIPV) FOR RESIDENTIAL FAÇADE: CASE STUDY IN EGYPT

Nermin Mokhtar Farrag[1] and Shaimaa Omran[2]
[1]Civil and Architectural Engineering Department, National Research Centre, Egypt
[2]Systems and Information Department, National Research Centre, Egypt
E-Mail: shmomran@gmail.com

ABSTRACT

Residential buildings consume more than 40% of the electricity in Egypt. Limited energy resources impact critically the energy usage in buildings. Moreover, there is an increasing demand for development of sustainable buildings. Incorporating solar photovoltaic (PV) systems into buildings which are referred to as building integrated photovoltaics (BIPV) systems is an attractive solution to alleviate the energy problem. It is considered a good alternative to centrally located utility and at the same time replaces conventional building elements. This paper investigates the implementation of a BIPV system for a residential villa in Egypt, highlighting the energy produced by such system and accordingly the reduction in emissions.

Keywords: building integrated photovoltaic, building façades, electrical loads, Egypt.

1. INTRODUCTION

According to the Egyptian Electricity Holding Company, the electric energy consumption in residential buildings is around 44% which is the maximum of all. An observed significant growth in residential loads in comparison with industry and other purposes was due to the expansion of residential compounds and new communities. Moreover, the increased use of household appliances specifically air conditioners in the summer increased the percentage of electricity usage by the residential sector in Egypt. This energy can be generated by non-conventional energy resources for the sake of energy conservation. Renewable energy resource from the sun has a great potential to meet that energy demand. Egypt is one of the countries lying in the solar belt region which makes ita promising area for solar energy application. The average solar radiation is 2000-32000 kWh/m2/year and the sun rises between 9 to 11 hours/day. Thus, this paper is an attempt to maximize the use of non-conventional solar energy in architectural buildings by using Building integrated photovoltaic (BIPV) system in a residential building façade in Egypt. The objective of the study is to evaluate implementation of a BIPV system fora villa, highlighting the energy produced by such system and the reduction in CO2 emissions. This will assist in evaluating the integration of PV systems into residential villas, and also estimating the contribution of this nonconventional energy solution when adopted on the national level of energy production in Egypt [1]-[3].

BIPV systems refer to systems in which the solar photovolatics are incorporated into buildings façades. BIPV is installing the solar photovoltaic panels on the surface of the maintenance structure of the building to provide electricity. The system depends on the amount of solar radiation produced rather than the warmth of the sun. The photovoltaic panels on the interface of a building convert sun rays into energy then the electricity produced is collected by cables and fed into the customer premises.
The BIPV technology integration was addressed in several literatures. [3] explored the potential of solar PV technologies by identifying the best ways of integrating these systems in the building envelope. [4] Discussed the design and evaluation of BIPV where the calculation of the tilt angle of the solar panels was presented to minimize the impacts of shading to maximize the output power. [5] Presented the advantages of frameless design of glass laminated, semi-transparent BIPV module and its application in Japan. [6] Defined two types of applications for the BlPV the first one is serving as an exterior skin to the building and the other is being mounted on the existing building exterior. [7] Introduced a computational tool that performs technical and economic analysis for BIPV. The authors concluded their work stating that without subsidies from the government or utilities, PV systems will not be financially competitive in the UAE market. [8] Proposed an improved methodology for evaluating the potential of BIPV systems in industrial buildings. [9] Focused on a technical and economic feasibility study of building integrated photovoltaic system (BIPVS). It studied the design of BIPV systems connected to the grid for the Central African Countries. [10] studied the performance of a domestic BIPV system; the study involved energy, environmental, and economic analysis. [11] Investigated improving the performance of BIPV for a single room with PV panel installed on the south side of the room by varying the air gap and the PV glazing type.

The next sections are organized as follows; section 2 shows a review of solar photovoltaic (PV) technology, then it introduces the pros and cons and comparison between different types of PV. It also introduces the BIPV system. Section 3introduces the case study and the design of the BIPV system for the villa façade. Section 4presents environmental impact of the designed BIPV system. The paper is then concluded in section 5.

2. SOLAR PHOTOVOLTAIC (PV) TECHNOLOGY

Solar power systems are divided into two main types; solar thermal systems that trap heat to warm up

ARPN Journal of Engineering and Applied Sciences

water, and solar PV systems that convert sunlight directly into electricity as shown in Figure-1.

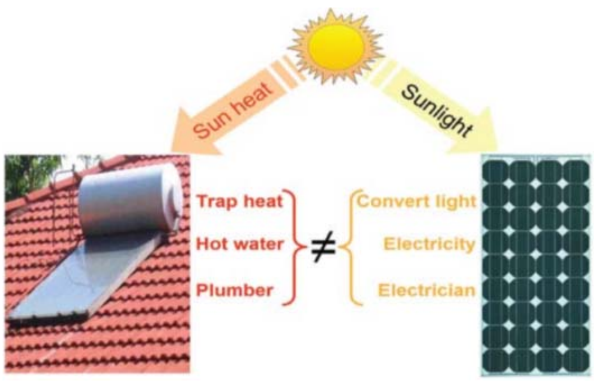


Figure-1. The difference between solar thermal and solar PV systems.

Direct current "DC" electricity is generated when the PV modules are directed to the sun. The DC electricity is then converted into alternating current "AC" electricity that is to be fed into a building's AC distribution boards without affecting the quality of power supplied.

Solar PV systems can begrid-connected (or grid-tied) or off-grid (or stand-alone) systems as illustrated in the configurations shown in Figure-2 and Figure-3 respectively.

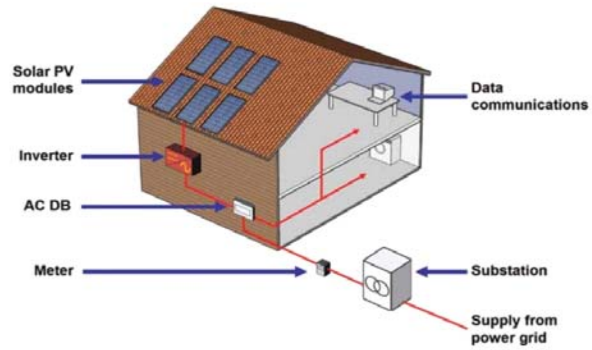


Figure-2. Grid-connected solar PV system configuration.

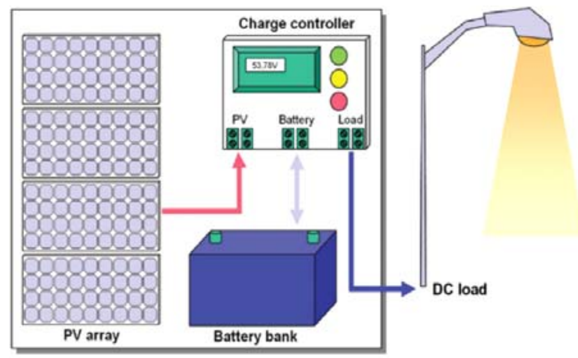


Figure-3. Off-grid solar PV system configuration.

PV technology has several advantages some of which are producing energy by using clean and endless sunlight energy, working over several years with minor problems after installation as they do not require continuous maintenance, and they are resistant to various weather conditions [12]. Moreover, PV is a module system thus it can be expanded and enlarged according to the increase in energy needs.

PV cells are made of sensitive semiconductor materials that use photons to free electrons to drive an electric current. Two main categories of PV technology are crystalline silicon (mono-crystalline silicon cells and polycrystalline silicon cell), and thin film, Figure-4 illustrates some of these technologies. Table-1 presents a comparison between various aspects of different PV technologies.

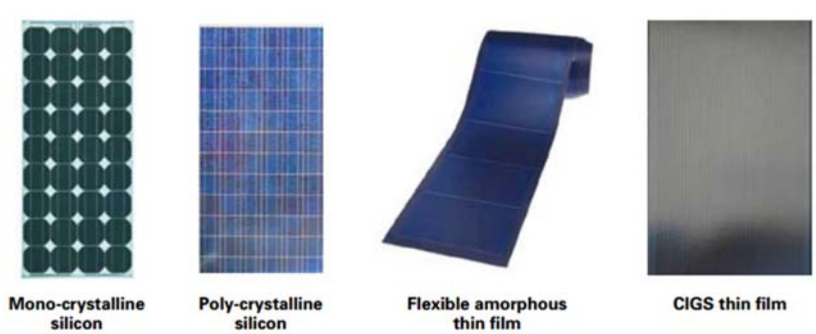


Figure-4. Common PV module technologies.

VOL. 12, NO. 21, NOVEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Table-1. Comparison of the PV cells [13].

Type of PV	Degree of module efficiency	Area requirement	Energy payback period	Cell color availability	Cell diameters	Cell thickness
Mono crystalline silicon cell	15-17%	7-9 m^2/kWp	≈ 5 years	Blue Black Violet Turquoise Dark and light grey Yellow	100 mm 125 mm 150 mm	between 0.2-0.4 mm
Poly crystalline silicon cell	13-15%	7-10 m^2/kWp	≈ 3 years	Blue Violet Brown Green Gold Silver	100 mm 125 mm 150 mm	
Thin film amorphous silicon cell	6-10%	14-20 m^2/kWp	≈ 2- 4 years	Black Brown	Variable	approx. 0.004 mm
Thin film CIS	8-12%	9-11 m^2/kWp	≈ 1-2 years	Black Grey	Variable	
Thin film CdTe	8-10%	12-17 m^2/kWp	≈ 1-3 years	Black Green	Variable	

2.1 Photovoltaic Modules Production

Crystalline solar cells are serially connected to each other. Afterwards, to increase the efficiency and durability of the solar PV cells, and to protect them from any external influences, and also to protect their surroundings from the electric current they produce; the PV cells are encapsulated (in other words laminated) and these are called solar modules. Figure-5 depicts different types of crystalline and thin film modules structure [14] [15].

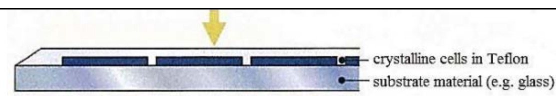


Figure-a. Teflon module

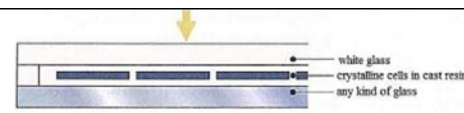


Figure-b. Resin (glass-glass) module.

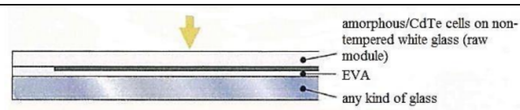


Figure-c. Glass-glass thin-film module (amorphous/CdTe cells in EVA).

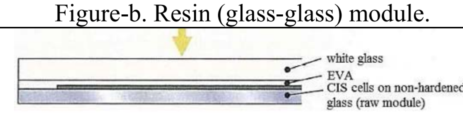


Figure-d. Glass-glass thin-film module (CIS cells in EVA).

Figure-5. Some types of crystalline and thin film modules structure [15].

2.2 Photovoltaic Modules Transparency

Modules can either be opaque or semi-transparent. When it is required to pass light inside the building semi-transparent modules can be used. Production of semi-transparent solar PV modules can be done via three methods. Figure-6 illustrates how glass-glass mono-crystalline semi-transparent PV modules are obtained by arranging crystalline cells opaque cells with 1 to 30 mm gaps between different cells so as to allow light to pass in [16]. Figure-7 depicts crystalline cells that are perforated mechanically such that they become 10% transparent [19]. Fig.8 shows how thin film cells which are already 20% transparent can be treated with laser to draw fine horizontal and vertical lines to provide more transparency that can reach up to 50%, or otherwise, cell spacing can be increased for strip as shown in Figure-9 [16]-[18].

Glass is used for front covering of the PV modules so that its high transparency allows maximum sunlight. Ultra-white low-iron glass is used as it has high transmission efficiency of about 92 % [16].

Different glass types provide additional construction features to PV modules such as, solar protection, heat insulation, and safety functions [15] this gives an additional value to the PV module making it multifunctional. Various types of glass include toughened (tempered) glass, laminated glass, insulating glass, body-tinted glass, screen printed glass, colored coated glass, solar protection glass.

ARPN Journal of Engineering and Applied Sciences

Figure-6. Mono-crystalline PV in a semitransparent module (glass on the back) [16].

Figure-7. Transparent module with transparent cells [19].

Figure-8. Transparent CIS thin-film modules [19].

Figure-9. Transparent a-Si modules [19].

2.3 Use of PV in Building Envelopes

Buildings give high potential with their large surface areas to provide energy by integration of PV systems. There are known as mentioned earlier Building Integrated PV systems they can be integrated into roof or façade, as a shading glazing element to control natural daylight, as atriums, balconies and skylights. PV module might be designed opaque, semi-transparent; also the base of module might be metal, plastic or glaze.

This BIPV system converts the electricity into alternating current; the typical electricity form used by electrical appliances in a building. The electricity generated is fed into the national electricity grid or used by the building's own electrical loads. A solar panel façade is convenient for both new and old buildings and can be installed on different base materials. A BIPV is ideal for modern energy-efficient buildings where more visibility is needed. BIPV façade materials give architects new opportunities to use glass in the façade. Some of the advantages that can be gained when using PV on facades are that module can protect the building from excessive solar radiation and they can also be an alternative to expensive cladding for prestigious buildings. PV modules might be installed on an inclined façade or modules might be installed inclined on the vertical facades to improve module output. Tables 2 and 3 depict various options for integration of the PV systems on the façade; these are illustrated using several figures (Figure-10 to Figure-25).

The BIPV system satisfies a multi-purpose function which is the renewable energy production and the architectural function. By using the BIPV system the façade of a building act as an external skin and a power producer at the same time. Energy saving and environment protection are the main aims that BIPV systems fulfill. When the sun shines at a very low angle of incidence, the output from a solar panel installed on a wall can be better than that of one on the roof; this is the case at northerly latitudes [20] [21].

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2. The options of PV integration into the facades [16].

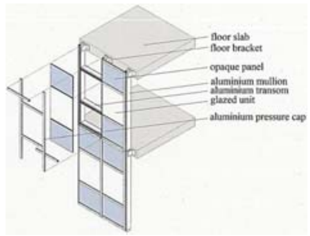
<table>
<tr><td rowspan="4">Use of Photovoltaic on Curtain Wall Systems</td><td colspan="6">Use of Photovoltaic on Stick System Curtain Wall</td></tr>
<tr><td colspan="2">

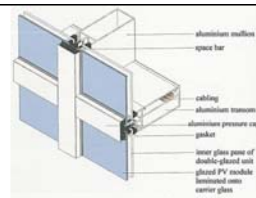
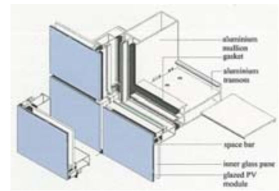
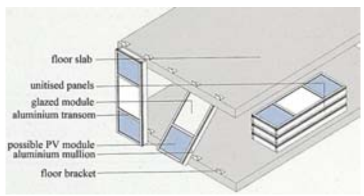
Figure-10. A stick-system curtain wall and erection process.</td><td colspan="2">
Figure-11. Detail of PV module and connections in a stick system curtain wall. The PV modules are laminatedonto a carrier glass.</td><td colspan="2">
Figure-12. Exploded view of a stick curtain wall with PV module fixed with structural silicone.</td></tr>
<tr><td colspan="6">Use of Photovoltaic on Unitized System Curtain Wall</td></tr>
<tr><td colspan="3">

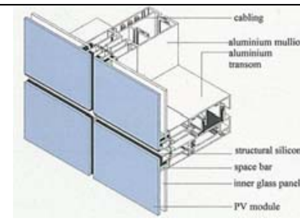
Figure-13. Unitized curtain-wall storage and the erection from inside</td><td colspan="3">

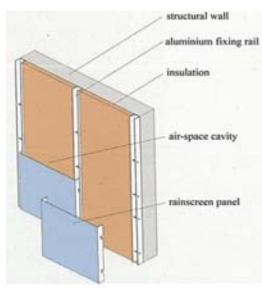
Figure-14. Detail of a unitized curtain wall system with PV modules in double-glazed panels. Cables are installed on the mullion.</td></tr>
<tr><td rowspan="2">Use of Photovoltaic on Rainscreen Cladding System</td><td colspan="3">

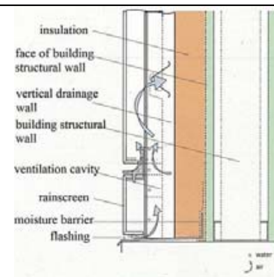
Figure-15. Detail of rainscreen cladding system.</td><td colspan="3">

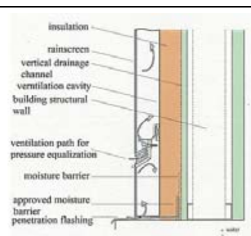
Figure-16. Vertical section through a typical horizontal joint detail in a drained and back-ventilated metal rainscreen.</td></tr>
<tr><td colspan="3">

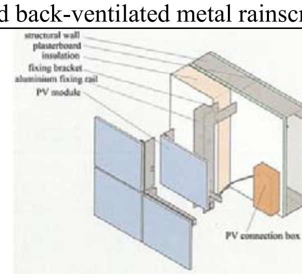
Figure-17. Vertical section through a typical horizontal joint detail in pressure-equalized rainscreen.</td><td colspan="3">

Figure-18. Detail of a rainscreen panel integrated with PV module showing electrical connections.</td></tr>
</table>

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

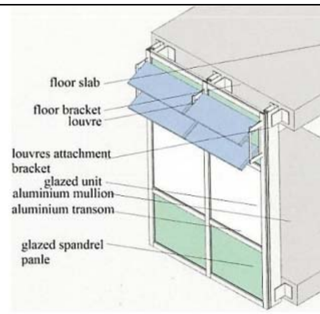
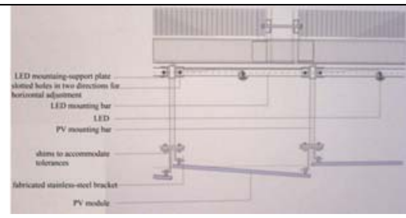
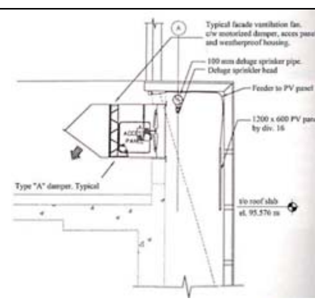
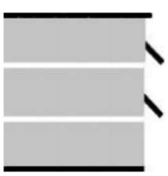
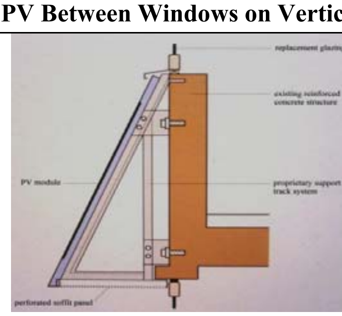
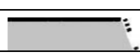
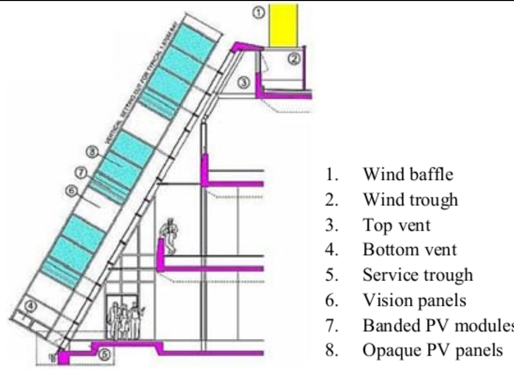
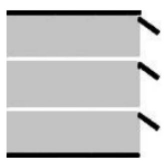
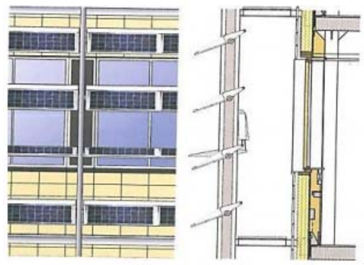
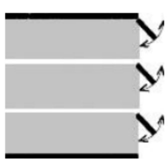
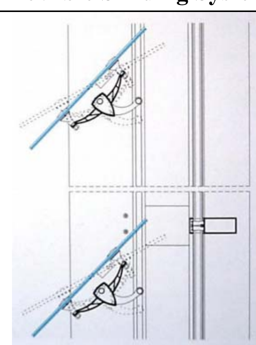
Use of Photovoltaic as Shading Systems	 Figure-19. General features of a curtain wall with louvers.

Table-3. Examples of PV Integration on Facades according to position of PVintegration.

PV on Vertical Surface	
	 Figure-20. Plan detail of PV modules on the façade [16].
	**PV Between Windows on Vertical Surface**  Figure-21. Architectural detail of fun / PV module layout [22].
	**Inclined PV Between Windows on Vertical Surface**  Figure-22. Vertical section through support inclined façade system [16].
	**PV Between Windows on Inclined Surface**

ARPN Journal of Engineering and Applied Sciences

	 Figure-23. Detailed section through solar façade and single bay in elevation [22].
	Fixed Shading System
	 Figure-24. Detail and section of PV shading system [22].
	Movable Shading System
	 Figure-25. Detail of the movable shading system[19].

3. Design of BIPV System for Villa Façade

The design of the BIPV system implemented in a 550 m^2 villa in Egypt is presented in this section. The villa architectural design used in this research work is in compliance with villa design standards implemented in 6th of October district in Giza, Egypt. Some parts of the villa have been redesigned slightly to become suitable for PV modules integration. Figure 26 and Figure-27 show the floor plans for the first and ground floors of the villa. The area of the ground floor is 290 m^2 and of the first floor is 260 m^2 which gives a total area of 550 m^2 for the villa.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

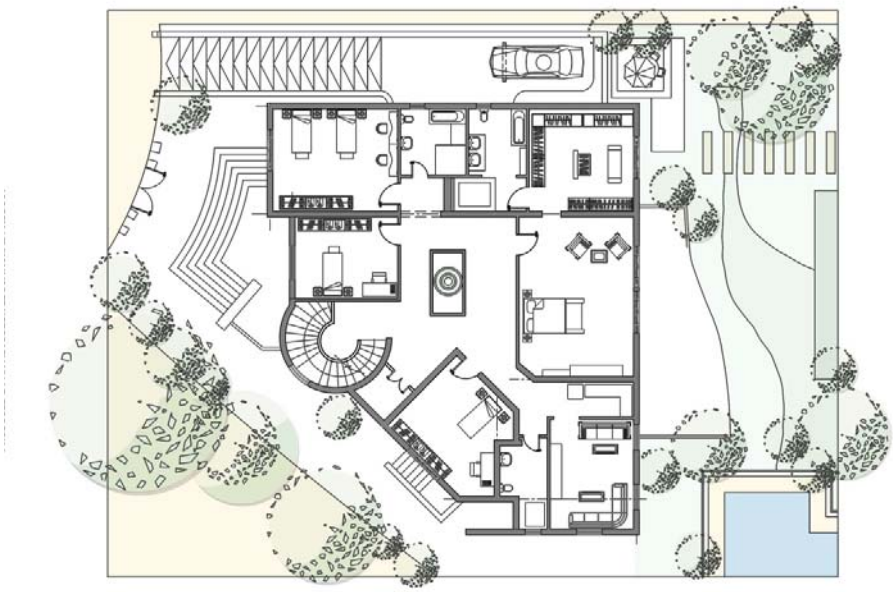


Figure-26. First floor planof the villa in 6th of October District in Giza.

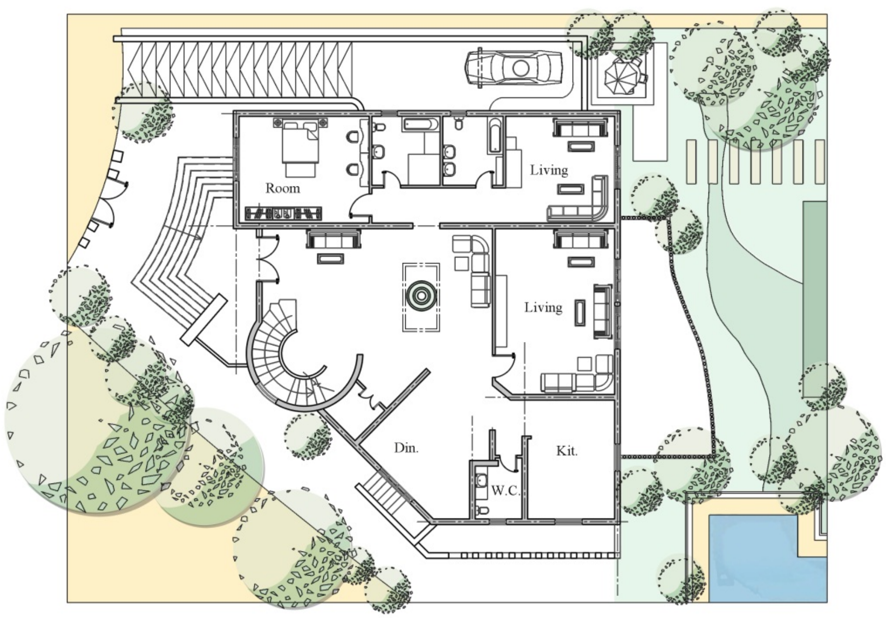


Figure-27. Ground floor plan of the villa in 6th of October District in Giza.

Designing the proposed BIPV system is performed in 3 steps:

a) Evaluating the electrical load and energy consumption of the villa.
b) Assigning the area of the PV modules to be integrated in the interface of the villa.
c) Performing the calculations to obtain the energy produced by the installed PV modules.

3.1 Electrical Load Evaluation

The first step to determine the Building Integrated PV (BIPV) system capacity required is to perform an assessment of the electric load consumption for the building under study. This is presented by a graph that is called load profile. The load profile shows the variation of electrical load with time. The load profile differs according to the type of the building whether it is residential, commercial or industrial and it also varies according to temperature and season of the year.

VOL. 12, NO. 21, NOVEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Figure-28 shows the load profile for the residential villa adopted in this study. The monthly winter and summer load profiles comply with the national average load profiles provided by the National Egyptian Electricity Holding Company [23] [24].

The maximum consumption of the villa as shown in Figure-28 is 4125 kWh during the summer month of August and the monthly average electrical consumption is 2039.5 kWh.

An estimation of the electrical demand of the villa represented by consumption of the electrical devices is shown and tabulated in Table A in Appendix A.

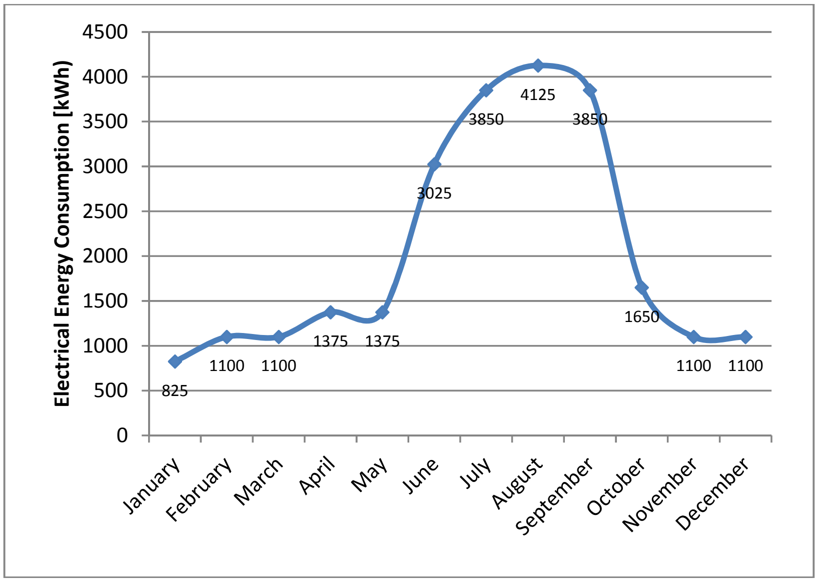


Figure-28. Load Profile for the Villa in 6th of October District in Giza.

3.2 BIPV Modules Area Assessment

The second step in designing the BIPV system is to determine the total area of the PV modules that can be integrated in the façade of the villa. The interface of the villa in 6th of October district in Giza, Egypt under study is redesigned such that glass façades will be used in the new design. The PV modules will replace the glass in the façade designed for the BIPV system. For optimum power production PV modules are integrated in the south-facing wall [21, 25]. The designs for the south-facing façade of the villa are depicted in Figures 29 and 30.

PV modules are placed on this south-facing façade in different orientation. Group of the modules are to be integrated vertically in the flat areas shown in blue in Figure-30. Other modules are to be integrated with an inclination angle; these ones will be placed in the windows shutters areas and in the roof south-facing wall. The curved wall with grey color in Figure-30 representing the interior stairs will be covered with conventional glass only with no PV modules.

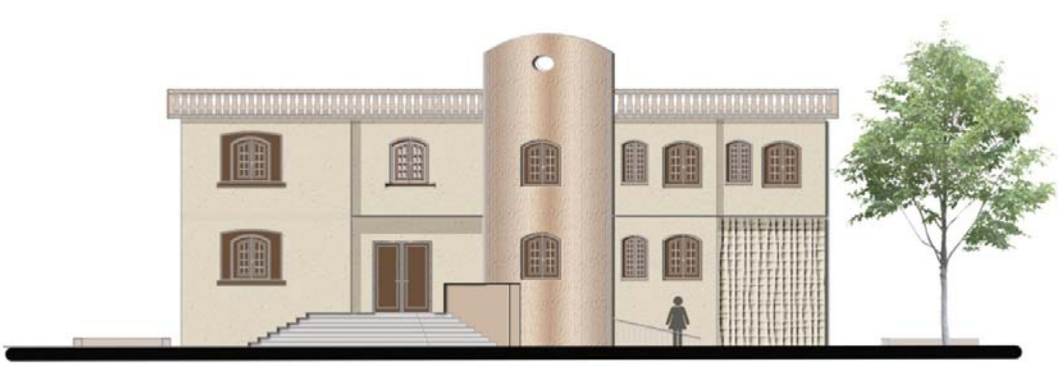


Figure-29. South-facing façade of the villa before redesigning (original interface with brick wall design).

Figure-30. South-facing façade of the villa after redesigning (new interface with glass wall design).

The total area of the south façade is about170 m^2, the flat blue surface area is about 118m^2 excluding the roof wall area, the roof south-facing wall area is 17m^2, and the curved grey area is about35 m^2. The total area of the windows in the flat blue surface is (6 x (1.2x1) + 3x(0.75x1)) = 9.45 m^2 and the door area is (2 x 1.5) = 3m^2. Assigning the areas for PV modules integration can be represented as follows:

a) Vertically integrated PV modules with an area of about 106m^2, this is calculated by subtracting the windows and the door areas from the total flat blue surface area.
b) Inclined integrated PV modules with an area of about 26m^2,this is calculated by summing up the windows areas and the roof south-facing wall area.

This gives a total area of 132m^2 of integrated PV modules on the south façade of the villa.

3.3 BIPV System Energy Output Calculations

Designing the PV modules that are to be integrated within the interface of the villa and calculating its output energy will be performed based upon several considerations which are:

a) PV modules are integrated in a south-facing wall for optimum power production [21, 25]. The south-facing façade of the villa is depicted in Figures 29and 30.The solar PV panel modules use the thin-film PV technology.
b) The conversion efficiency of the thin-film PV modules used is 12.34% [26].
c) The annual output of the system varies depending on the geographic location and the solar irradiance in this location. The current location which is Giza has a latitude and longitude of 30°0'47" North, 31°12'31" East. The values of solar irradiation used for the calculations are presented in Appendix B. Appendix B shows monthly solar irradiation (denoted with the letter H) for Giza location at different inclined surfaces [27].
d) When the energy production from the BIPV system is not enough to cover the load demand, it will be supplied by the electrical power grid. On the other hand, if electrical power produced by the PV modules exceeds the demand, this excess power will be sold to the grid.

The formula used to calculate the output of the PV system that is to be implemented and integrated on the south-facing interface of the villa is [28]:
Output electrical energy (kWh/month) =
PV panel surface area (m^2) x conversion efficiency x Monthly solar radiation (kWh/m^2/day) (1)

This formula is to be used for the 2 different orientations (vertical and inclined) used for integrating the PV modules.

3.3.1 Vertically integrated PV output

The area of the PV modules vertically integrated in the flat surface of the south-facing façade is 106 m^{2}as calculated in section 3.2, the conversion efficiency of the thin-film PV modules used is 12.34%, and the PV modules are vertically integrated thus the monthly solar radiation values in Table Bin Appendix B at the 90^{o}angle of inclination will be used. These monthly solar radiation values are shown in the third column in Table-4.

Table-4 is constructed to evaluate the energy production per month from the 106m^2 vertically integrated PV modules. The energy will be calculated using the same formula mentioned in equation (1) and the solar irradiation will be multiplied by the number of days per month to obtain the total kWh produced for each month from the proposed vertically integrated PV modules, for example calculating the energy output for January in kWh is as follows:

Output electrical energy (kWh/month) = PV panel surface area (m^2) x conversion efficiency x Monthly solar radiation (kWh/m^2/day)

Output electrical energy (kWh/month) = 106 x (12.34/100) x ((4690/1000) x 31) = 1901.7 kWh

Table-4. Energy produced for each month in kWh from the 106m^2 vertically integrated PV modules.

Month	**Days/ month**	**Solar radiation (90^o) (Wh/m2/day)**	**Output for H(90^o) (kWh/month)**
January	31	4690	1901.8
February	28	4560	1670.1
March	31	4500	1824.7
April	30	3090	1212.6
May	31	2170	879.9
June	30	1650	647.5
July	31	1870	758.3
August	31	2710	1098.9
September	30	3930	1542.2
October	31	4870	1974.7
November	30	4920	1930.7
December	31	4730	1918
Total			17,359.4

The vertically integrated PV modules produce a total energy of 17,359.4 kWh/year.

3.3.2 Inclined integrated PV output:

For the current location which is Giza that has a latitude and longitude of 30°0'47" North, 31°12'31" East. The PV modules are said to be optimally inclined at an angle of 28^o, this means that at this angle of inclination the PV modules produce the maximum and optimum energy output.

The total area of the inclined PV modules is 26 m^{2}as calculated in section 3.2, the conversion efficiency of the thin-film PV modules used is 12.34%,and the PV modules are optimally inclined thus the monthly solar radiation values in Table Bin Appendix Bat the 28^o angle of inclination will be used for the calculations. These monthly solar radiation values are shown in the third column in Table-5.

Table-5 is constructed to evaluate the energy production per month from the 26 m^2 inclined PV modules. The energy will be calculated using the same formula mentioned in equation (1) and the solar irradiation will be multiplied by the number of days per month to obtain the total kWh produced for each month from the proposed inclined integrated PV modules.

Table-5. Energy produced for each month in kWh from the 26m^2 inclined PV modules.

Month	**Days/ month**	**Solar radiation (28^o) (Wh/m2/day)**	**Output for H(28^o) (kWh/month)**
January	31	5040	501.3
February	28	5700	512.1
March	31	7090	705.2
April	30	6890	663.2
May	31	7070	703.2
June	30	7260	698.8
July	31	7260	722.1
August	31	7280	724.1
September	30	7070	680.5
October	31	6590	655.4
November	30	5520	531.3
December	31	4890	486.4
Total			7,583.6

The inclined integrated PV modules produce a total energy of 7,583.6 kWh/year.
The total annual energy produced from both orientations, vertical and inclined PV systems is 7,359.4+7,583.6 = 24,943kWh/year.

The output energy values calculated monthly in Tables 4 and 5 for different solar irradiations are depicted in Figure-31. It is clear from the chart that the inclination angle of the plane significantly affects the value of the output energy. For vertical placement of the modules the irradiation drops a lot during the summer months. This happens due to solar radiation reflections that are induced because of the position of the sun during that time of the year. The position of the sun and the solar access angles for buildings are depicted in Figure-32. Thus the output power drops accordingly during this period; unfortunately, when energy is abundantly required. To overcome this drop the optimum inclination angles 28^{o}is used for the deployment of the solar modules where possible; at the roof wall and windows of the south-facing façade. At 28^{o} the irradiation values and the energy output increased during the summer months, causing a rise in the total energy output produced.

Based on the values of output energy produced for different inclinations, the solar BIPV system is designed taking into consideration these inclination angles as follows:

The calculations presented in this section show that despite the fact that the PV panels are exposed to more daylight hours in the summer months, more energy is produced in the late winter to early spring. This happens due to two factors; the first is that the heating that the PV panels experience during the summer affects the daily energy production rate negatively. Moreover, as mentioned earlier in this section solar radiation reflections are induced because of the position of the sun during summer rather than winter time, and the angle of the radiations falling on the vertical PV surface in summer is less ideal than in winter [29] [30].

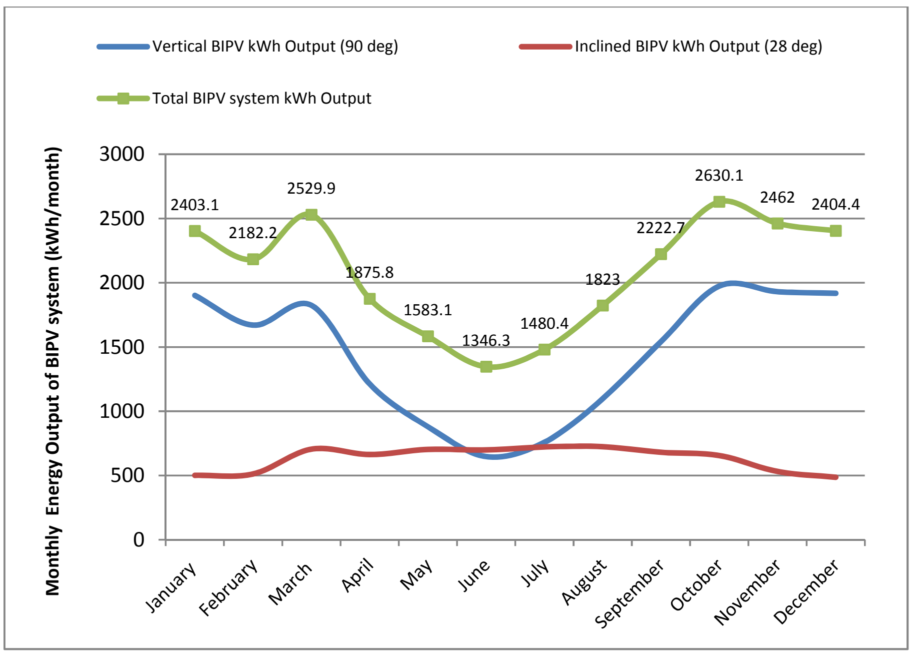


Figure-31. Monthly Energy Output from the 132 m^2 BIPV system on the south-facing façade of the villa.

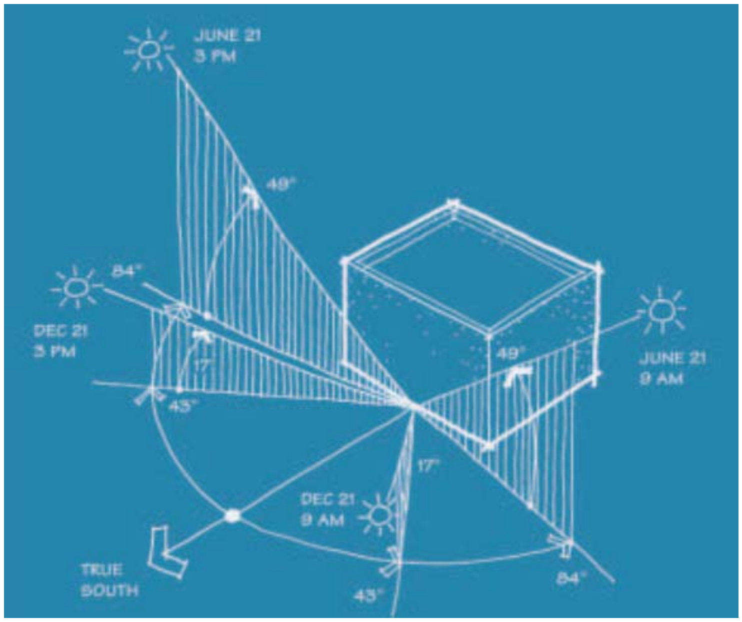


Figure-32. The solar access angles for building [31].

Comparison between the total kWh produced monthly from the designed BIPV system (green curve in Figure-31) and the monthly electrical demand of the villa (Figure-28) can be tabulated as follows:

Table-6. Energy imported/exported from/to the electrical grid.

Month	Designed BIPV system total kWh output	Monthly kWh electrical consumption of villa	Monthly imported/exported electricity from/to the grid in kWh
January	2403.1	825	1578.1
February	2182.2	1100	1082.2
March	2529.9	1100	1429.9
April	1875.8	1375	500.8
May	1583.1	1375	208.1
June	1346.3	3025	-1678.7
July	1480.4	3850	-2369.6
August	1823	4125	-2302
September	2222.7	3850	-1627.3
October	2630.1	1650	980.1
November	2462	1100	1362
December	2404.4	1100	1304.4

The last column in table 6 deploys the amount of electrical energy exported to (positive values) the grid and the amount of energy imported from (negative values) the grid. It is shown that during the summer months specifically from June to September the villa will be importing electricity from the grid, as the energy produced from the BIPV system is not sufficient to cover the demand of the villa loads at this time of the year. The increase in demand in this duration is due to the excess use of household appliances specifically air conditioners in the summer. This means that the designed BIPV system is capable of meeting the electrical needs of the villa and at the same time supplying 8,445.6 kWh of clean energy to the grid during 8 months of the year.

4. Environmental Impact

The impact of the BIPV system implemented on the environment is studied in this section. Greenhouse gas emissions for conventional and renewable energy resources are presented in Figure 33[4]. From Figure33it can be observed that natural gas plants emit 443 gm of CO_2/kWh and oil plants emit 778 gm of CO_2/kWh. These types of power plants are those of interest in this research as mostly the electric power generation in Egypt is obtained from these 2 resources [1]. Thus these values will be used for comparison with the BIPV proposed system Co_2 emissions. The cost of removing CO_2 after it has been emitted may reach$3,500 per ton [4].

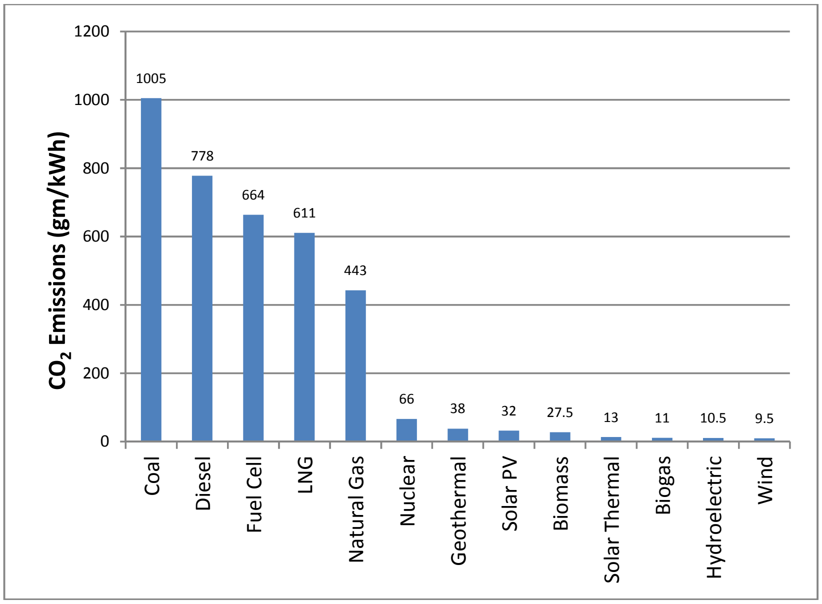


Figure-33. Lifecycle greenhouse gas emissions from conventional and renewable resources [4].

For the designed BIPV system, the annual electricity generation is 24,943 kWh, thus during its lifetime, assuming a lifetime of 30 years and an annual generation degradation rate of 1% for the system this system will produce 649,265 kWh during its lifetime. Figure-34 depicts the annual energy output of the designed system for the 30 years life time.

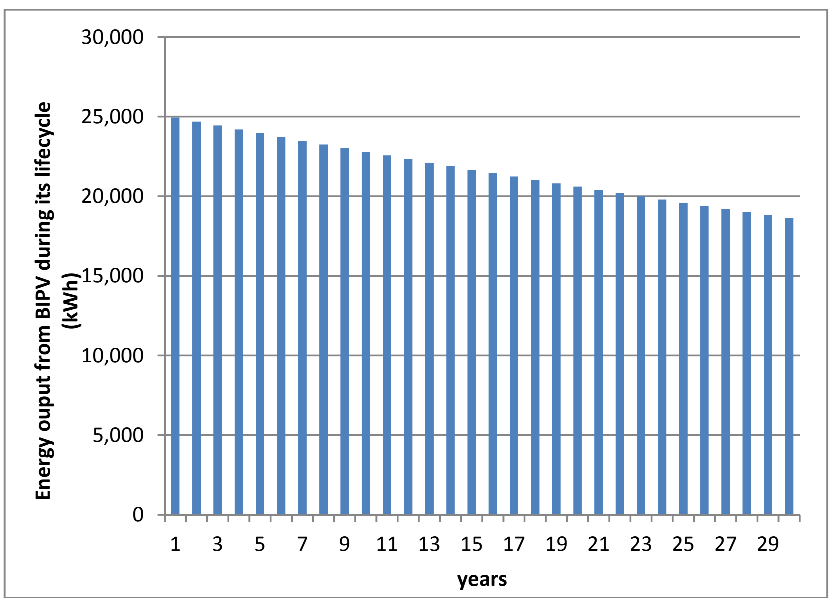


Figure-34. Energy output of the designed BIPV system during its 30 years lifetime.

Comparing the CO_2 emissions from this system and the conventional resources commonly used for electricity generation in Egypt the emissions can be tabulated as in Table-7. The cost for removing the CO_2

ARPN Journal of Engineering and Applied Sciences

emissions is calculated by multiplying the tons of emissions produced by $3,500; which is the cost of removing CO_2per ton.

Table-7. CO_2 emissions and their costs for different energy resources.

Fuel type	CO_2 emissions	Cost for removing CO_2emissions
Natural Gas	443 gm x 649,265 = 287,624.6kg = 317.1 tons	US$ 1,109,850
Oil	778 gm x 649,265 = 505,128.4 kg = 556.8 tons	US$ 1,948,800
BIPV proposed system	32 gm x 649,265 = 20,776.5 kg = 22.9 tons	US$ 80,150

Table-6 proves that the incorporation of the designed BIPV system reduces CO_2 emissions by about 294.2 tons and thus saves more than 1.1 million US dollars when compared to Natural Gasfor removing CO_2 emissions. It also reduces CO_2 emissions by about 533.9 tons; thus saving more than 1.8 million US dollars when compared to Oilfor removing CO_2 emissions.

Other than the CO_2 emissions there are other types of pollutants that are to be considered when assessing the environmental impact of any electrical generation resource. These pollutants are sulfur dioxides (SO_2), nitrogen oxides (NOx), and mercury (Hg). The rate of emission of these pollutants from conventional power plants is3.79 gm/kWh, 1.66 gm/kWh, and 0.0023 gm/kWh respectively[reference2]. Deployment of the BIPV system designed will reduce the emissions of these pollutants by 2,460.7 kg, 1,077.8 kg, and 1.5 kg respectively.

The environmental analysis presented here concludes that the implementation of the designed BIPV system is worthwhile.

5. CONCLUSIONS

This paper investigated the implementation of a BIPV system for a residential villa in 6^{th} of October district in Giza, Egypt, highlighting the energy produced by such system and accordingly the reduction in emissions. The motive for this study was that residential buildings consume more than 40% of the electricity in Egypt, and limited energy resources impact critically the energy usage in buildings.

The paper proposed a design for a BIPV system that was capable of meeting the electrical needs of the villa and at the same time supplying 8,445.6 kWh of surplus clean energy to the grid during 8 months of the year.

Assuming a lifetime of 30 years and an annual generation degradation rate of 1% for the system, the system would produce 649, 265 kWh during its lifetime. The incorporation of the designed BIPV system reduced CO_2 emissions by about 294.2 tons and thus saves more than 1.1 million US dollars for removing CO_2 emissions when compared to Natural Gas. It also reduces CO_2 emissions by about 533.9 tons; thus saving more than 1.8 million US dollars for removing CO_2 emissions when compared to Oil. Also the deployment of the proposed BIPV system designed will reduce the emissions of these pollutants sulfur dioxides (SO_2), nitrogen oxides (NOx), and mercury (Hg) by 2,460.7 kg, 1,077.8 kg, and 1.5 kg respectively.

REFERENCES

[1] Ministry of Electricity and Renewable Energy. 2017. Egyptian Electricity Holding Company Annual Report 2014/2015. Available: http://www.moee.gov.eg/english_new/EEHC_Rep/2014-2015en.pdf. Retrieved: March.

[2] Pranjale Pranita and Deepali K. Hejiib. 2013. Non Conventional Sources of Energy-Applications of Solar Energy in Architectural Buildings. International Journal of Computer Applications (0975 - 8887).

[3] Kinab Elias, Talal Salem and Ghimar Merhy. 2014. BIPV building integrated photovoltaic systems in mediterranean climate. In Renewable Energies for Developing Countries (REDEC), 2014 International Conference on, pp. 180-185.IEEE.

[4] Zeng Qiang, Jingpeng Chen, Jianmo Ni, Qian Ai, Zhaoyu Wang, Ruicong Zhai, Ping Xu, Chengzhi Ma and Pengmin Wang. 2015. A research on design and evaluation of BIPV. In Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 2015 5th International Conference on, pp. 1838-1843. IEEE.

[5] Takehara Tetsuo and Hidenori Hayashi. 2003. Building integrated photovoltaics (BIPV) module design & experience in Japan. In Photovoltaic Energy Conversion, 2003. Proceedings of 3rd World Conference on, 2: 2007-2010. IEEE.

[6] Frantzis Lisa, Sarah Hill Peter Teagan and David Friedman. 1994. Building-integrated PV-analysis and US market potential. In Photovoltaic Energy Conversion, 1994, Conference Record of the Twenty Fourth. IEEE Photovoltaic Specialists Conference-

ARPN Journal of Engineering and Applied Sciences

1994, 1994 IEEE First World Conference on. 1: 1204-1207. IEEE.

[7] Assi Ali, Khaled Al Kathairi and Mohammed Jama. 2009. Building integrated photovoltaic (BIPV) in the United Arab Emirates-Tool and case study. In GCC Conference & Exhibition, 2009 5th IEEE, pp. 1-5. IEEE.

[8] Klironomos Panagiotis G., Georgios A. Vokas and John K. Kaldellis. 2012. Potential of building integrated photovoltaic systems (BIPV): Study on the OinofytaViotias industrial buildings zone. (2012): 80-80.

[9] Tidjani Fadoul Souleyman, Ambrish Chandra and Pragasen Pillay. 2014. Design of building integrated photovoltaic system to the grid with power quality improvement features for Central African countries. In Industrial Electronics Society, IECON 2014-40th Annual Conference of the IEEE, pp. 2023-2029. IEEE.

[10] Hammond Geoffrey P., Hassan A. Harajli, Craig I. Jones and Adrian B. Winnett. 2009. Integrated appraisal of a building integrated photovoltaic (BIPV) system. In Sustainable Power Generation and Supply, 2009. SUPERGEN'09. International Conference on, pp. 1-9. IEEE.

[11] Irshad Kashif, Khairul Habib and M. W. Kareem. 2016. Effect of air gap on performance enhancement of building assisted with photo voltaic systems. In ARPN Journal of Engineering and Applied Sciences. 2(20).

[12] Tonuk S. and Ozdogan H. P. 2006. Bina Kabuğunda Kullanılan Fotovoltaik Panellerin Tasarım Bağlamında İncelenmesi. Tesisat Dergisi. (13): 130-136.

[13] Vahibe Kazek. Evaluation of Integrated Photovoltaic Systems on Facades, MSc in Architecture, Institute of Graduate Studies and Research, Eastern Mediterranean University January, 2012.http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.980.4702&rep=rep1&type=pdf.

[14] Erban C. 2009. Crystalline cells. In Lüling C. (Ed.), Energizing Architecture Design and Photovoltaics. Jovis Verlag GmbH, Berlin.

[15] Planning and Installing Photovoltaic Systems - A Guide for Installers, Architects and Engineers (2nd ed.). 2008. Earthscan, London.

[16] Robert S. and Guariento N. 2009. Building Integrated Photovoltailcs: A Handbook. Birkhauser Verlag AG. Basel, Switzerland.

[17] Eisenschmidt I. 2009. Thin-film Modules. In Lüling C. (Ed.), Energizing Architecture Design and Photovoltaics. Jovis Verlag GmbH, Berlin.

[18] Hegger, M., Fuchs, M., Stark, T. and Zeumer, M. (2009). Energy Manual: Sustainable Architecture. Birkhauser Verlag AG., Basel, Switzerland.

[19] Lüling C. 2009. Energizing Architecture Design and Photovoltaics. Jovis Verlag GmbH, Berlin.

[20] Ma Ding and Yi-bing Xue. 2013. Solar Energy and Residential Building Integration Technology and Application. International Journal of Clean Coal and Energy. 2(02): 8.

[21] Rukki. 2017. Façade generates electricity" Available: https://www.yumpu.com/en/document/view/19742138/white-paper-facade-generates-electricity-ruukki/2. Retrieved: March.

[22] Prasad D. and Mark S. 2005. Designing with Solar Power: A Source Book for Building Integrated Photovoltaic (BIPV). Images publishing, Australia.

[23] Attia S., Evrard A. and Gratia E. 2012. Development of benchmark models for the Egyptian residential buildings sector. Applied Energy. 94, pp. 270-284.

[24] Elharidi A.M.A.H., Tuohy P.G. and Teamah M. 2013, June. Facing the growing problem of the electric power consumption in Egyptian residential building using building performance simulation program. In Building Simulation Cairo 2013 Conference.

[25] Samir H. and Ali, N.A. 2017. Applying Building-Integrated Photovoltaics (BIPV) in Existing Buildings, Opportunities and Constrains in Egypt. International Conference - Green Urbanism, GU 2016.

[26] Cashmore J. S., M. Apolloni, A. Braga, O. Caglar, V. Cervetto, Y. Fenner, S. Goldbach-Aschemann et al. 2016. Improved conversion efficiencies of thin-film silicon tandem (MICROMORPH™) photovoltaic modules. Solar Energy Materials and Solar Cells. 144: 84-95.

[27] Photovoltaic Geographical Information System - Interactive Maps, Available: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=africa, Retrieved: March, 2017.

[28] How to Calculate the Output of a Solar Photovoltaic System - A Detailed Guide, Available: http://thegrid.rexel.com/en-us/energy_efficiency/w/solar_renewable_and_energy_efficiency/72/how-to-calculate-the-output-of-a-solar-photovoltaic-system---a-detailed-guide, Retrieved: March, 2017.

[29] Dirks E., A. M. Gole and T. S. Molinski. 2006. Performance evaluation of a building integrated photovoltaic array using an internet based monitoring system. In Power Engineering Society General Meeting, 2006.IEEE, pp. 5-pp. IEEE.

[30] Renewable Energy Focus. 2010. Masdar PV thin-film panels in solar building façade. September. Available: http://www.renewableenergyfocus.com/view/12126/masdar-pv-thin-film-panels-in-solar-building-fa-ade/, Retrieved: March 2017.

[31] LANL Sustainable Design Guide, December 2002, Available: http://www.lanl.gov/orgs/eng/engstandards/esm/architectural/Sustainable.pdf Retrieved: April 2017.

[32] Electrical Appliance Typical Energy Consumption, Available: http://www.chabotspace.org/assets/BillsClimateLab/Electrical%20Appliance%20Typical%20Energy%20Consumption%20Table.pdf Retrieved: April 2017.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Appendix A:

In this estimate calculations for the consumption of electrical devices in the villa all lights used are compact fluorescent 60 watts incandescent equivalent which has consumption of 16 watts.

Bedside and table lamps used are compact fluorescent 40 watts incandescent equivalent which has consumption of 11 watts [32].

Table-A. Estimation of the consumption of electrical devices in the villa under study.

Rooms & Appliances	Consumption (Watt)	Consumption (Hours per day)		Energy Consumption (Wh per day)		Energy Consumption (kWh per month)	
		Summer	Winter	Summer	Winter	Summer	Winter
Ground floor:							
Store							
Lights (2 lamps)	16 x 2	3	3	96	96	2.88	2.88
Vacuum Cleaner	1600	2	2	3200	3200	96	96
Dining room							
Chandelier (5-6 lamps)	16 x 6	5	5	480	480	14.4	14.4
TV (LCD)	213	3	3	639	639	19.17	19.17
AC	1000	5		5000		150	0
Bathroom							
1 main lamp	16	4	4	64	64	1.92	1.92
1 mirror lamp	16	4	4	64	64	1.92	1.92
Hair dryer	1000	0.5	0.5	500	500	15	15
Water heater	480	2	4	960	1920	28.8	57.6
Ventilation fan (shafat)	200	4	4	800	800	24	24
Kitchen							
2 lamps	16 x 2	6	6	192	192	5.76	5.76
Refrigerator	1200Wh/day			1200	1200	36	36
Deep freezer	1230Wh/day			1230	1230	36.9	36.9
Water heater	480	2	2	960	960	28.8	28.8
Fan (for gas stove, window)	200	6	6	1200	1200	36	36
Fan (furnace)	500	3	3	1500	1500	45	45
Kettle	1200	2	2	2400	2400	72	72
FoodBlender	300	0.5	0.5	150	150	4.5	4.5
FoodMixer	127	0.5	0.5	63.5	63.5	1.905	1.905
Microwave	1450	1	1	1450	1450	43.5	43.5
Coffee maker	800	0.5	0.5	400	400	12	12
Dishwasher	1200	1	1	1200	1200	36	36
Toaster	1150	0.5	0.5	575	575	17.25	17.25
Salon							
Chandelier (5-6 lamps)	16 x 6	3	3	288	288	8.64	8.64
AC	1000	3		3000		90	0
2 table lamps	11 x 2	1	1	22	22	0.66	0.66

ARPN Journal of Engineering and Applied Sciences

TV (LCD)	213	1	1	213	213	6.39	6.39
Terrace						0	0
3-4 lamps	16 x 4	3	3	192	192	5.76	5.76
Small living							
Small chandelier (4 lamps)	16 x 4	4	4	256	256	7.68	7.68
TV (LCD)	213	2	2	426	426	12.78	12.78
AC	1000	4		2000		60	0
Desktop Computer	100	1	1	100	100	3	3
Bathroom1							
2 main lamps	16 x 2	2	2	64	64	1.92	1.92
2 mirror lamps	16 x 2	2	2	64	64	1.92	1.92
Hair dryer	1000	0.5	0.5	500	500	15	15
Water heater	480	1	2	480	960	14.4	28.8
Ventilation fan (shafat)	200	2	2	400	400	12	12
Bathroom2							
2 main lamps	16 x 2	2	2	64	64	1.92	1.92
2 mirror lamps	16 x 2	2	2	64	64	1.92	1.92
Hair dryer	1000	0.5	0.5	500	500	15	15
Water heater	480	1	2	480	960	14.4	28.8
Washing machine	500	2	2	1000	1000	30	30
Ventilation fan	200	2	2	400	400	12	12
Bedroom(1)							
Chandelier (5 lamps)	16 x 5	5	5	400	400	12	12
TV (LCD)	213	4	4	852	852	25.56	25.56
AC	1000	5		5000		150	0
2 bedside lamps	11 x 2	1	1	22	22	0.66	0.66
Reception:							
Corner1+2							
2 chandeliers (10-12 lamps)	16 x 12	5	5	960	960	28.8	28.8
2 ACs	1000 x 2	5		10000		300	0
Fountain							
Lights (10 lamps)	16 x 10	5	5	800	800	24	24
Motor for water pumping	480	12	12	5760	5760	172.8	172.8
Rounded stairs							
Lights (4 lamps)	16 x 4	24	24	1536	1536	46.08	46.08
First Floor:							
Store							
2 small lamps	16 x 2	3	3	96	96	2.88	2.88
Vacuum Cleaner	1600	2	2	3200	3200	96	96
Bedroom (1)							

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Spot lights (4 lamps)	16 x 4	5	5	320	320	9.6	9.6
TV (LCD)	213	4	4	852	852	25.56	25.56
AC	1000	5		5000		150	0
2 bedside lamps	11 x 2	1	1	22	22	0.66	0.66
Laptop	50	12	12	600	600	18	18
Bathroom							
2 main lamps	16 x 2	2	2	64	64	1.92	1.92
2 mirror lamps	16 x 2	2	2	64	64	1.92	1.92
Hair dryer	1000	0.5	0.5	500	500	15	15
Water heater	480	1	2	480	960	14.4	28.8
Ventilation fan	200	2	2	400	400	12	12
Small living							
Small chandelier (4 lamps)	16 x 4	4	4	256	256	7.68	7.68
TV (LCD)	213	2	2	426	426	12.78	12.78
AC	1000	4		4000		120	0
Small kitchen							
Kettle	1200	2	2	2400	2400	72	72
Microwave	1450	1	1	1450	1450	43.5	43.5
Coffee maker	800	1	1	800	800	24	24
2 lamps	16 x 2	5	5	160	160	4.8	4.8
Bedroom (master)							
Chandelier (5 lamps)	16 x 5	5	5	400	400	12	12
2 bedside lamps	11 x 2	1	1	22	22	0.66	0.66
TV (LCD)	213	2	2	426	426	12.78	12.78
AC	1000	5		5000		150	0
Laptop	50	10	10	500	500	15	15
Dressing							
4 lamps	16 x 4	3	3	192	192	5.76	5.76
Iron	1000	1	1	1000	1000	30	30
AC	1000	3		3000		90	0
Bathroom1							
4 main lamps	16 x 4	2	2	128	128	3.84	3.84
4 mirror lamps	16 x 4	2	2	128	128	3.84	3.84
Hair dryer	1000	0.5	0.5	500	500	15	15
Water heater	480	1	2	480	960	14.4	28.8
Jacuzzi (pump)	1300	1	1	1300	1300	39	39
Ventilation fan	200	2	2	400	400	12	12
Bathroom2							
2 main lamps	16 x 2	2	2	64	64	1.92	1.92
2 mirror lamps	16 x 2	2	2	64	64	1.92	1.92
Hair dryer	1000	0.5	0.5	500	500	15	15

VOL. 12, NO. 21, NOVEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Water heater	480	1	2	480	960	14.4	28.8
Washing machine	500	2	2	1000	1000	30	30
Ventilation fan	200	2	2	400	400	12	12
Bedroom(2)							
Spot lights (6 lamps)	16 x 6	5	5	480	480	14.4	14.4
TV (LCD)	213	3	3	639	639	19.17	19.17
AC	1000	5		5000		150	0
2 bedside lamps	11 x 2	1	1	22	22	0.66	0.66
2 laptops	50 x 2	10	10	1000	1000	30	30
Bedroom(1)							
Spot lights (4 lamps)	16 x 4	5	5	320	320	9.6	9.6
TV (LCD)	213	3	3	639	639	19.17	19.17
AC	1000	5		5000		150	0
2 bedside lamps	11 x 2	1	1	22	22	0.66	0.66
laptop	50	10	10	500	500	15	15
Entrance:							
Main stairs							
Lights (6 lamps)	16 x 6	12	12	1152	1152	34.56	34.56
Gate							
4 lamps (2 on both sides)	16 x 4	12	12	768	768	23.04	23.04
Garden							
Lights (10 lamps)	16 x 10	12	12	1920	1920	57.6	57.6
Motor pumps (water for gardening)	480	2	2	960	960	28.8	28.8
Garage							
Lights (4 lamps)	16 x 4	12	12	768	768	23.04	23.04
Backyard							
Lights (10 lamps)	16 x 10	12	12	1920	1920	57.6	57.6
Motor pumps (water for gardening)	480	2	2	960	960	28.8	28.8
						3579.315	2120.115

VOL. 12, NO. 21, NOVEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Appendix B:

Table-B. Monthly solar irradiation for Giza location at different inclined surfaces [27].

Month	Solar irradiation (horizontal) (Wh/m2/day)	Solar irradiation (90º) (Wh/m2/day)	Solar irradiation (45º) (Wh/m2/day)	Solar irradiation (28º) (Wh/m2/day)
January	3530	4690	5500	5040
February	4400	4560	5960	5700
March	6160	4500	7020	7090
April	6710	3090	6380	6890
May	7520	2170	6180	7070
June	8130	1650	6110	7260
July	7920	1870	6210	7260
August	7340	2710	6570	7280
September	6390	3930	6830	7070
October	5280	4870	6780	6590
November	3970	4920	5960	5520
December	3330	4730	5400	4890