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ARCHITECTURAL SOLUTION BY SAVING ENERGY USING PHOTOVOLTAIC PANELS AS AN ENVIRONMENTALLY FRIENDLY SOLUTION: EXISTING EGYPTIAN GOVERNMENT BUILDINGS

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ABSTRACT

Conventional electric power generation methods require excessive burning of fossil fuel, which leads to global warming, excessive carbon dioxide emissions, and resulting in global climate change. Nowadays, the world's main concern is using green electrical power generation methods. Government office buildings currently use excessive electrical power, mostly during the morning. Solar electric power generation through its envelopes is one of its electrical energy-saving methods. The research goal is to illustrate an applicable methodology that can be applied to convert existing office-building envelopes into solar electrical power-generating ones with the minimum effect on their architectural aesthetics. To accomplish the research goal, it began by choosing one of the existing governmental office buildings with a south-oriented façade. Using a 3-dimensional terrestrial laser scanner, a building facade survey was done to distinguish its existing situation. Three architectural adaptation alternatives for merging photovoltaic panel types available in the Egyptian market on the south building façade were done, followed by evaluating the solar amount of electrical power generated by each alternative and the annual savings in electricity costs that could be accomplished. The research concluded that getting an appropriate architectural photovoltaic panel (PVP) façade merging solution will affect the amount of solar electric power generated.

Keywords: photovoltaic systems, 3D terrestrial laser scanners, architectural aesthetics, environmentally friendly.

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1. INTRODUCTION

Recently, energy saving in government buildings has been an important research topic, especially in a developing country like Egypt. Retrofitting existing building envelopes to be energy saving is done passively by conserving the energy needed for its internal spaces heating and cooling by adding thermal insulation layers to its external envelope and its internal partitions, also by preventing heat loss or gain from its openings [1]. Building envelopes can be positively retrofitted by producing green energy through utilizing solar energy. Solar energy, as one of the renewable energy sources, can be utilized efficiently for buildings' thermal and electrical applications [2]. Electrical energy can be generated via solar energy through the photovoltaic effect, which can convert solar radiation directly into electricity by the use of photovoltaic panels [3]. Installing solar electrical-generating elements, such as photovoltaic panels (PVP) mainly on a building’s flat roofs has a minor effect on the architectural aesthetics, while PV panels installed on building facades affect its architectural aesthetics. The PVP installation process mainly considers its operational requirements rather than its impact on the aesthetic manifestation of the building [4, 5, and 6]. Existing building architectural styles vary according to either its construction period or its architect's design. A lot of existing Egyptian governmental buildings that were built during the 60th share modern architectural style, common style features are horizontal straight window lintels and sill lines, vertical window sides. Some governmental buildings from the 60th have windows with projections on their sides for shading purposes, while others do not. Rdadhi, (2010) [7], explored the variation of total energy of building integrated photovoltaic systems (BIPV) as wall cladding systems applied in the United Arab Emirates commercial sector, the research showed that the ratio between PV output and saving in energy due to PV panels is within the range of 1:3-1:4. Kim *et al*, (2019) [8], introduced a new Building Cladding System Using Independent Tilted BIPV Panels with Battery Storage Capability, through the research individual cladding unit has been designed at tilts of 45° and 60°. The degree of building energy resiliency provided through multiple BPPLs was examined. The research concluded that the system would be able to provide adequate power for office appliances. Attoye *et al*, (2017) [9], conducted a Review on Building Integrated Photovoltaic Façade Customization Potentials to overcome the conflict between architectural design objectives the energy performance. The research identified customization parameters such as customization

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category, level, strategies, and related architectural potential. The paper concluded that a wide range of BIPV adoption barriers such as aesthetics, architectural integration, and performance can be overcome by appropriate BIPV customization. Hwang *et al*, (2012), [10], conducted a study on building integrated photovoltaic systems in office buildings in Korea that Focused on its orientation, inclined angle, and installed area, then analysed the maximum electric energy production according to the inclination and direction of photovoltaic (PV) installations and noted that proper combinations installation factors such as inclination angle, module type, installation distance to module length ratio, and direction can produce electric energy that can cover approximately 1-5% of the electric energy consumption of a typical office building. Prieto *et al*, (2017), [11], discussed perceived barriers to widespread façade integration of solar technologies results of a survey addressed to professionals with practical experience in the development of façade systems for office buildings. The definition of main perceived barriers to façade integration of solar technologies are product performance, aesthetics, technical complexity, durability, and availability Appearance customization through a variety of components for façade design was encouraged to appeal to architects and clients, while modularity and the use of standardized elements and connections were advised to minimize construction and operation problems [12]. As Photovoltaic panels generate heat that affects their power-generating efficiency and adds extra surface heat to the faces they are installed on due to their black surface colour, Ventilated building facades is done by projecting the PVP installation layer on the solid façade parts to help in reducing the photovoltaic panels generated heat. The PVP installation layer is opened from its lower and upper ends to conduct an air current that helps cool the PV panels and drop shadows on the solid façade parts [13, 14, 15]. On the other hand, architecture facade surveys are carried out for various reasons such as validation, maintenance or facility management, alterations and additions, restoration and simply recording building architecture details. Building facades are usually presented through elevation drawings. So, if a laser scanner is used for facade recordings, 3D drawings can be produced with a higher degree of detail with less effort [16, 17, 18, and 19]. The advantage of the laser scanner technique compared to traditional surveying techniques is the higher degree of detail (3D Model) with less effort. Nap (2022) [20] stated that terrestrial laser scanner solutions have become increasingly popular in the process of three-dimensional (3D) modeling. This is because they can operate in difficult-to-access or hazardous areas, guaranteeing the safety of users and researchers, especially for hugo buildings. Furthermore, Marzouk and El-Bendary (2022) [21] employ 3D laser scanning to operate gas turbine power facilities. However, Pavelka (2022) affirms the potential of utilizing diverse technology, such as laser scanning, to document damaged monuments or buildings. In addition, Moyano *et al*. (2022) [22] employed a terrestrial laser scanner to generate highly precise 3D models of expansive structures. Arjmand *et al.* (2023) [23] contend that incorporating 3D laser scanners into different software platforms enables precise assessment of construction quality by acquiring point cloud data. This, in turn, promotes sustainability in the building industry. So, the present study will concentrate on the practicability of using the laser scanner technique in 3D survey and documentation of governmental architecture facades to be the backbone of designing the installation of the solar electrical generating elements.

Adding new energy-producing elements to existing buildings' envelopes, especially those that have unique architectural styles requires a careful choice of the shape of the energy-producing element and it's merging architectural treatments [24, 25]. As a result, photovoltaic panel producers face problems concerning its shape limitation, which imitates the architect's design flexibility [9]. During the architect's early design phase, new concerns for integrating photovoltaic panels are its solar radiance needs to generate the maximum electrical power amount, its physical dimensions, and its mounting systems. Adding PVP to existing buildings without affecting their aesthetics is another architect's concern. As a result, a variety of customized shapes of photovoltaic panels can be produced to enhance its integration with existing building envelopes as:

- Flexible silicon panels
- Rigid Panel shapes
- Glass embedded photovoltaic cells
- Photovoltaic
- Panel roof shingles

Photovoltaic systems can be classified as off-grid or on-grid systems. Off-grid systems are used to generate electrical energy directly from solar radiation and use the generated energy to supply isolated loads such as houses, street lighting, boats, satellites, and water pumping systems. Off-grid systems usually consist of solar panels for generating electricity, storage batteries, charge controllers, and power inverters [26]. Figure-1 shows a schematic diagram of a typical off-grid PV system. The on-grid PV systems, as shown in Figure-2, convert solar radiation into electrical energy and feed the generated energy directly to the public electric grid. These systems mainly consist of PV panels and grid inverters with the required control, safety, and switching facilities [27, 28, and 29].

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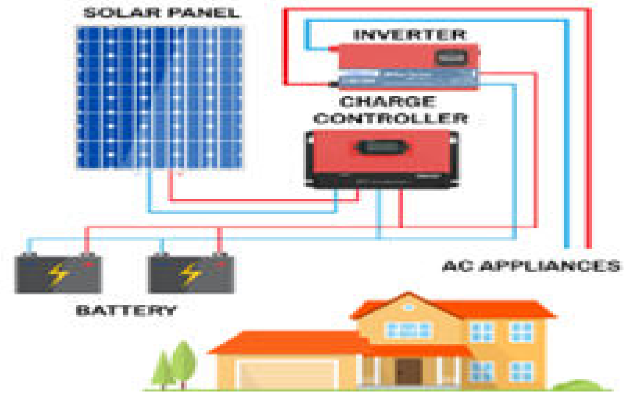

Figure-1. Off-grid PV system.

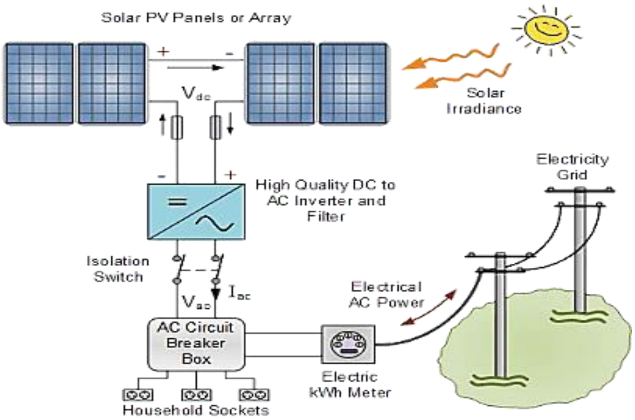

Figure-2. On-grid PV system.

2. METHODOLOGY OF INVESTIGATION

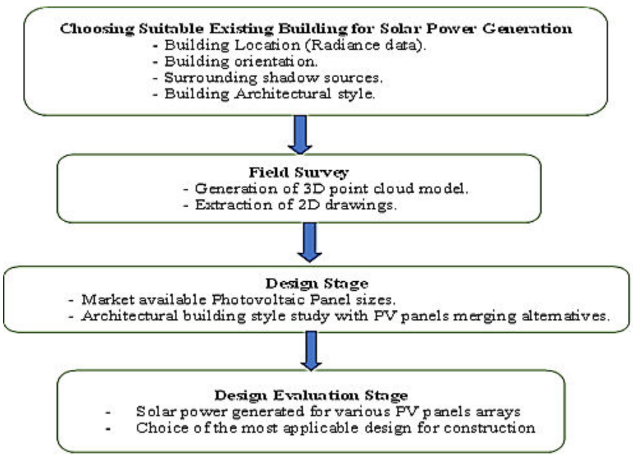

Figure-3. Methodology Flow-chart.

3. STUDY SITE

3.1 Selection of the Study Site

One of the existing buildings at the National Research Centre in Giza, Egypt. The building of the Engineering Research Institute and Renewable Energy as shown in Figure-4 was chosen as a model that simulates the existing government buildings to conduct surveying experiments using a laser scanner. These buildings represent existing governmental buildings that were built in the late 50th and early 60th. The building is currently in use, it consists of a double-height research area on the ground floor, part of the ground floor area has a mezzanine floor used for offices and the rest of the building has three upper floors used for offices and laboratories.

Figure-4. Engineering Research Institute of New and Renewable Energy building, Egypt.

The building is currently surrounded at various distances by other research buildings and on its East side with a side street as shown in Figure-5 [18, 30].

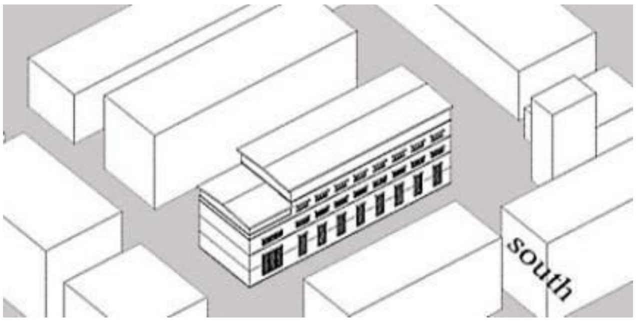

Figure-5. The Relation between the selected study building and its surroundings.

3.2 3D Surveying of the Site

Using the laser scanner in surveying and producing a 3D point cloud model for the building validating that the 3D point cloud model measurements match the building's real ones using the Trimble TX8 Laser Scanner [31], as shown in Figure-6.

Figure-6. The 3D Laser Scanner Survey 3D Point Cloud Model Studying Building.

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The 3D laser scanner surveys the 3D POINT CLOUD MODEL product of the Engineering Research Institute and Renewable Energy building; then, the 3D point cloud model is converted into a 3D model by the use of AutoCAD (Computer Aided Design) software as a preliminary step for its exporting to simulation programs with an accuracy of 1 cm [32, 33]. Figures (7) through (10) represent the North, South, East, and West facades of the Engineering Research Institute and Renewable Energy building after converting them to the AutoCAD software environment.

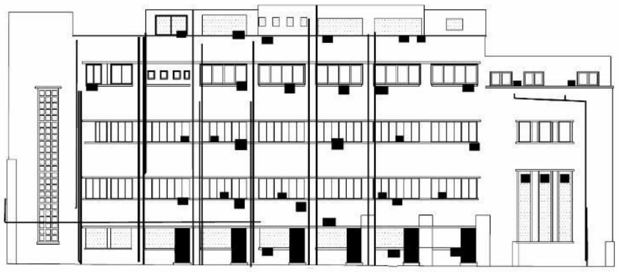

Figure-7. The north façade.

Figure-8. The South façade.

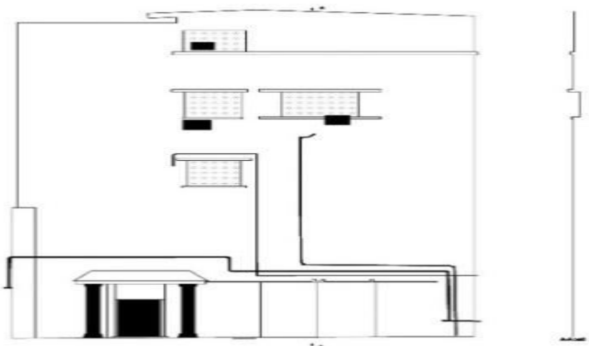

Figure-9. The East façade.

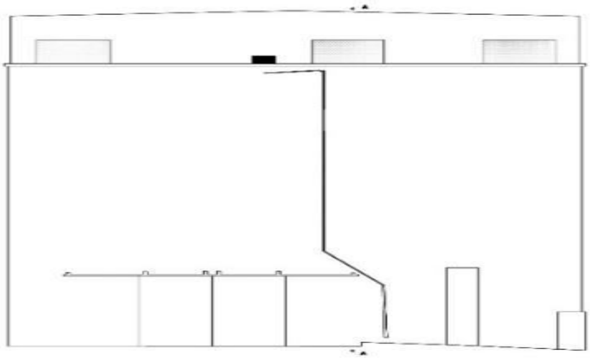

Figure-10. The West façade.

4. SOLAR RADIATION

For any solar system either electrical or thermal, the output from the system is mainly affected by the amount of solar radiation received by the system. The solar radiation incident on an arbitrary solar system consists of three components; direct normal, diffuse, and ground reflected radiation. Both diffuse and reflected components are only about 15-20 % of the total radiation, while the direct normal radiation is more than 80 %. The direct normal radiation is mainly affected by the incident angle between the direct radiation from the sun and the normal to the solar system surface, which is affected by the system orientation. Also, the orientation, season, and geographic location of the system can all have an impact on the amount of solar radiation as well as the energy produced by any given solar system. Cairo is the capital of Egypt, located in the northern hemisphere, and lies at a longitude of 31.24° East and a latitude of 30.04° North of the Equator. Accordingly, for optimum operation, the PV systems in Egypt should be installed facing south and can be tilted horizontally to receive the maximum available solar energy. According to the system's location and orientation, the amount of solar energy incident on any arbitrary system can be changed. Figure-11 shows the total monthly incident solar radiation in kWh/m2 at four arbitrary orientations: horizontal, tilted by 30, 60, and 90 degrees. The graph demonstrates how the season and orientation affect the amount of solar energy that any orientation receives. As shown in Figure-11, the horizontal system receives its maximum solar radiation in the summer, while the tilted systems receive higher radiation values in the winter than the horizontal one. Also, increasing the tilt angle of the PV system increases the amount of solar energy collected in winter. The optimum angle system, 30 degrees, receives the highest annual radiation among all systems, while the vertical one receives the lowest radiation values. Figure-12 represents the annual solar radiation captured by the proposed four orientations. In general, tilting the solar system by the tilt angle of the location can increase the annual radiation received by the system. In Cairo, tilting the system by about 30 degrees over the horizontal can increase the average daily solar radiation on its surface to about 6.5 kWh/m^2.

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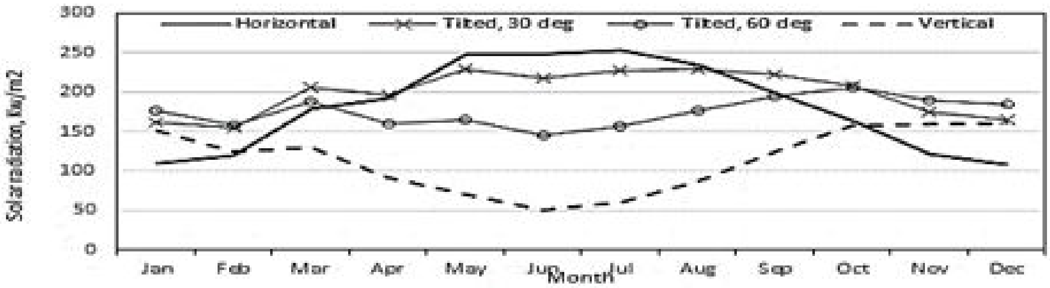

Figure-11. Total monthly incident solar radiation in kWh/m2 on PV modules at different orientations.

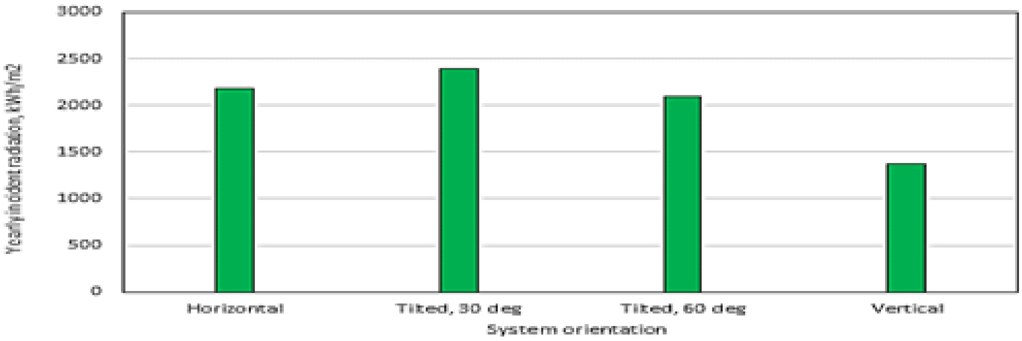

Figure-12. Annual solar radiation is captured by different orientations.

5. ARCHITECTURE ANALYSIS

The Energy Building has a rectangular-shaped building floor plan with four rectangular modern facades, two of which are narrow facades facing west and east orientations, while the others are longitudinal and face north and south orientations. The existing building facades were built upon the point cloud model generated from the 3D laser scanner survey and currently have outside mounted air conditioning (AC) ducts that serve the ground floor research area, randomly installed AC compressors that serve offices at different floor levels, and sets of exposed vertical plumbing pipelines. Shapes (1, 2, 3, and 4), as shown in Figure-13.

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Figure-13. Existing building elevations.

Architectural treatments for the existing attached service elements are necessary in order to convert an existing building envelope into an electrical power-generating element. The research proposes to begin with aligning the mounting level of AC compressors attached to the facades under window sills and covering them with aluminum louvers, as shown in Figure-14. Vertical steel ducts and aluminum louvers will cover the plumbing vertical pipes. Attaching horizontal and vertical ducts merges easily with the current facade design.

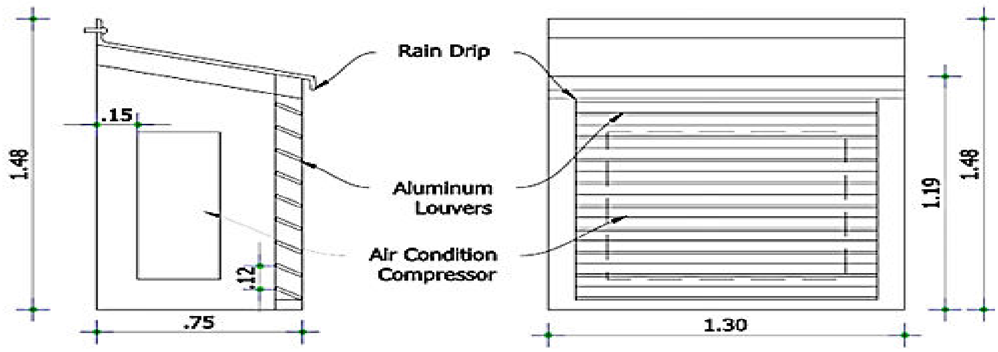

Figure-14. Air condition compressor cover.

The architectural PVP fixation alternatives were done using modular polycrystalline solar panels of dimensions 1.58 m x 0.8 m x 0.03 m available in the Egyptian market (Figure-15). The roof PVP panel fixation was common in the three alternatives. South façade PVP panels were installed on metal frames vertically and on various inclinations on the solid parts of the elevation, as well as on top of the windows to act as shading elements.

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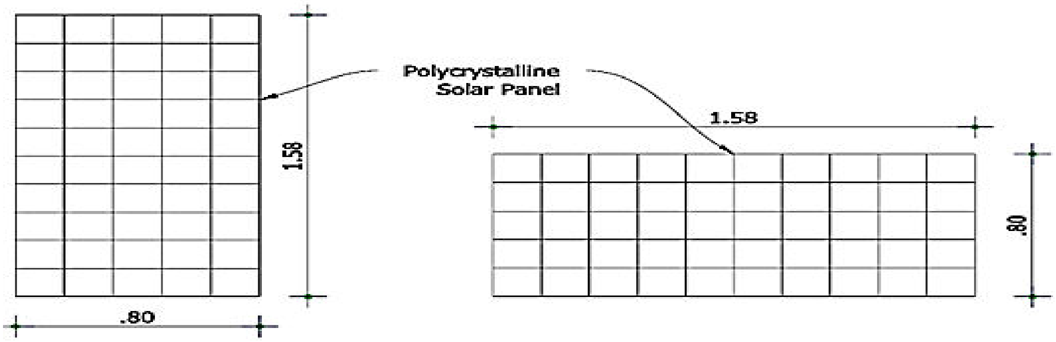

Figure-15. Polycrystalline solar panels.

5.1 Architecture Installation

Electrical generating photovoltaic (PV) panels are to be vertically mounted using steel frames under window sills either directly on the existing walls, leaving an air gap, or to be mounted above the horizontal aluminum louvres AC compressors covering the duct, leaving an appropriate distance for AC compressor ventilation. On the south-facing facades, PV panels are to be mounted as a shading device above window lintels. Rood-mounted solar panel number and distribution are common for the three alternatives: 123 PVP units mounted at 30° with a panel exposer area of 157.5 square meters and 208 PVP units mounted at 180° with a panel exposer area of 266 square meters. While the solar panel distribution on the south façade varies according to architectural shape design, as shown in Figure-16-a.

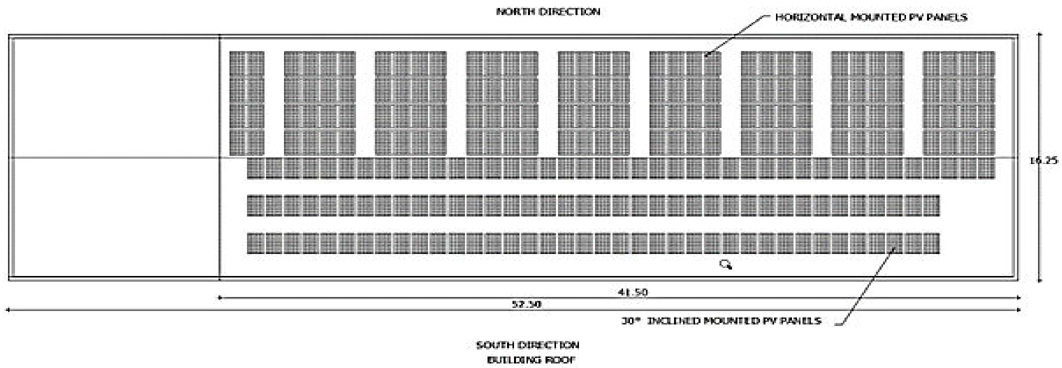

Figure-16a. PVP panels roof distribution.

5.2 The First Alternative

The first architectural PVP installation alternative was built basically on the maximum amount of electrical power that can be generated by covering the solid parts of the façade by PVP, as shown in Figures (16-b) to (22).

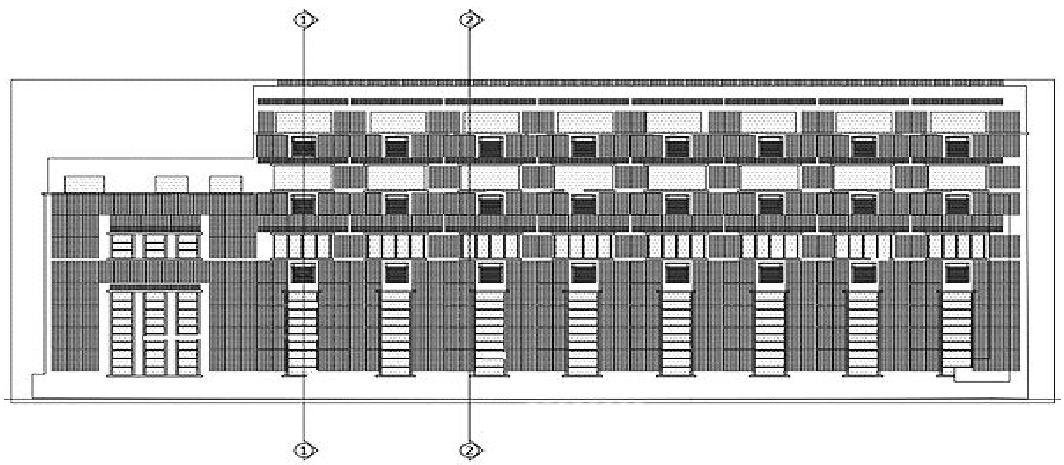

Figure-16. B: Alternative # 1 PVP panels elevation distribution.

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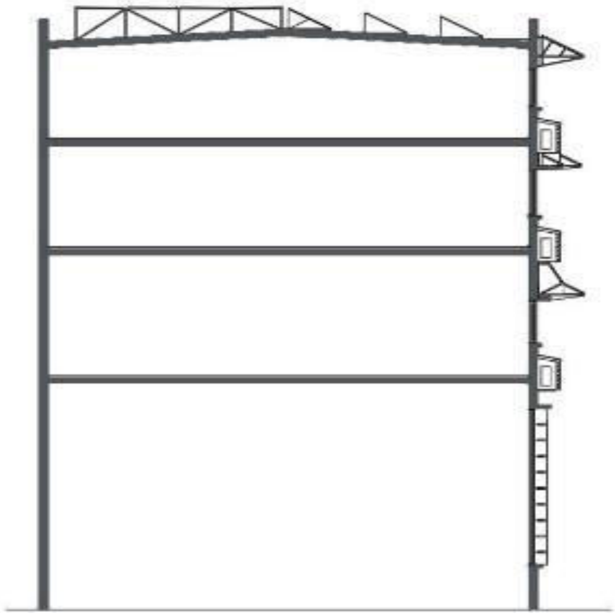

Figure-17. Alt # 1 - Section 1-1.

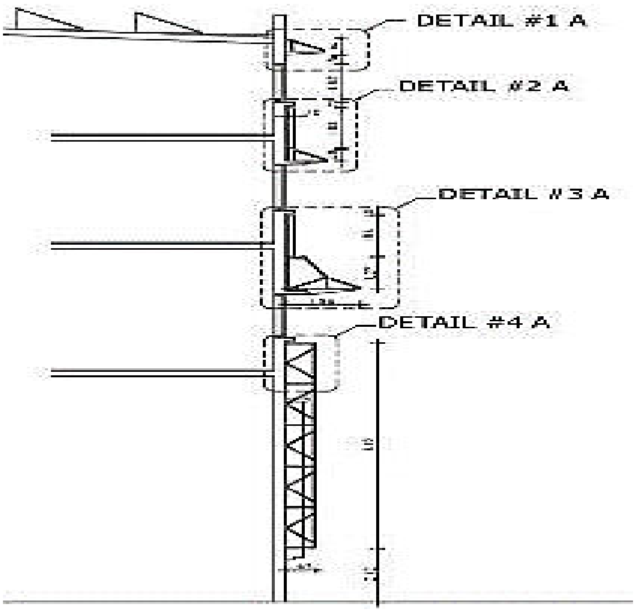

Figure-18. Alt # 1 - Section 2-2.

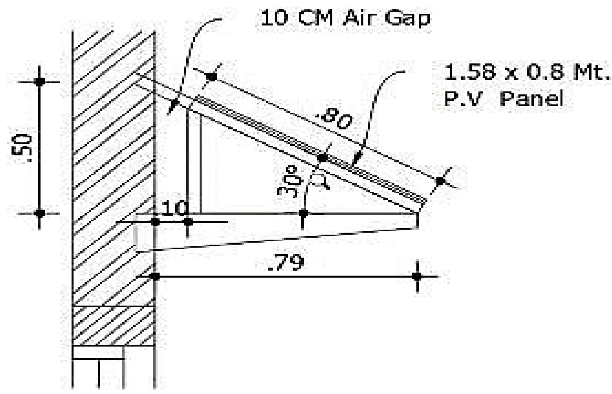

Figure-19. Detail # 1 A.

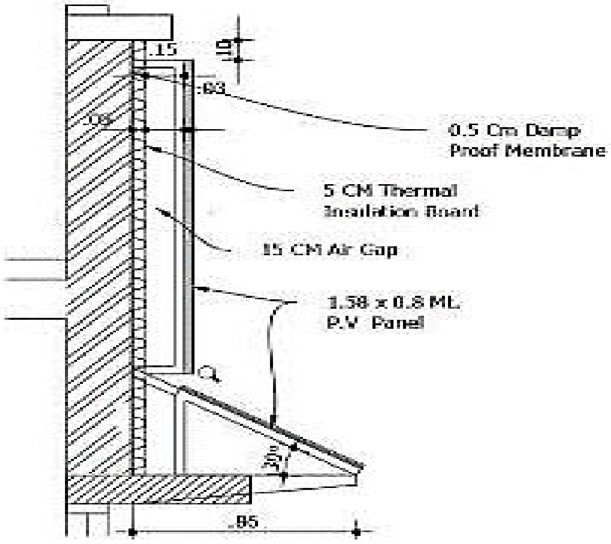

Figure-20. Detail # 2 A.

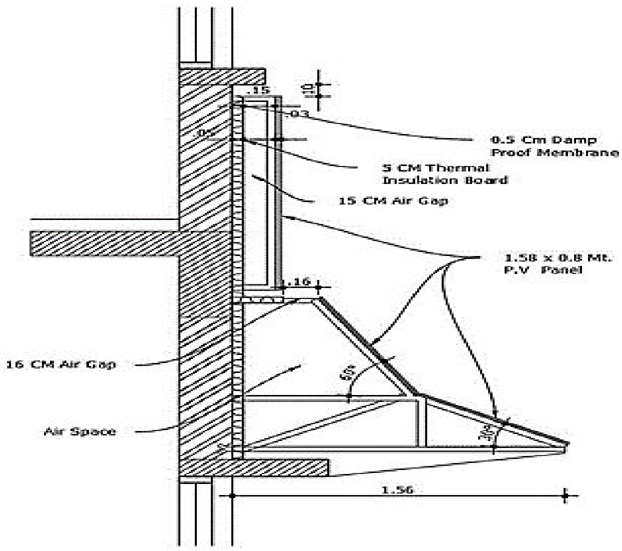

Figure-21. Detail # 3A.

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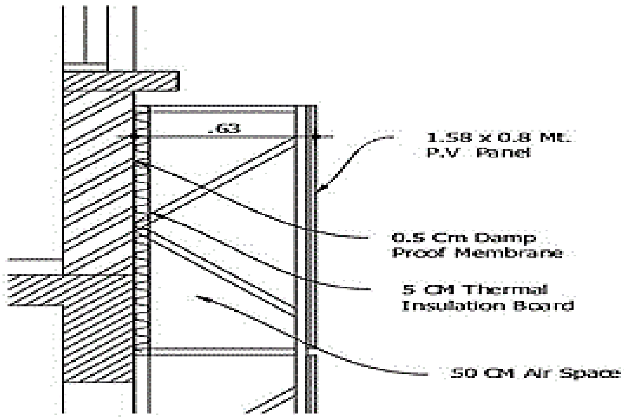

Figure-22. Detail # 4 A.

Solar panels for the first alternative

- 78 PV South Elevation Panels inclined on 30° - 78 x (1.6x0.8) = 100 Sq Meters.
- 27 PV South Elevation Panels inclined on 60° - 27 x (1.6x0.8) = 34.5 Sq Meters.
- 342 PV South Elevation Vertical Panels - 342 x (1.6x0.8) = 438 Sq Meters.

Total Exposer area including roof panels for Alternative No. 1 996 Sq meter.

5.3 The Second Alternative

The second architectural PVP installation alternative was built basically on distributing PVP to match the architectural style despite having the maximum amount of electrical power that can be generated by covering the solid parts of the façade by PVP as shown in Figures (23 to 26).

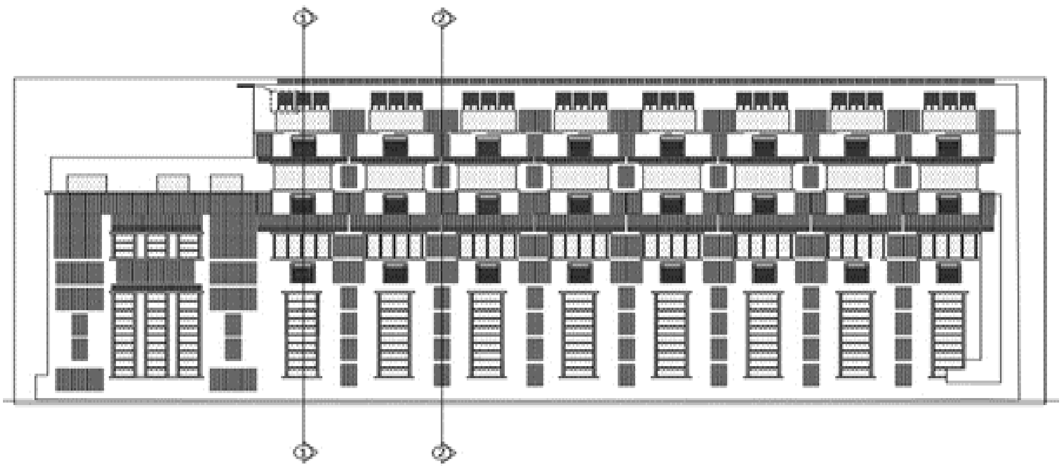

Figure-23. Alternative # 2 PVP panels Elevation distribution.

Solar panels for the second alternative:

- 24 PV South Elevation Panels inclined on 30° - 24 x (1.6x0.8) = 31 Sq Meters.
- 54 PV South Elevation Panels inclined on 30° 54 x (1.6x0.8) = 69 Sq Meters.
- 27 PV South Elevation Panels inclined on 60° 27 x (1.6x0.8) = 34.5 Sq Meters.
- 182 PV South Elevation Vertical Panels 182 x (1.6x0.8) = 233 Sq Meters.

Total Exposer area including roof panels for Alternative No. 2 791 Sq meter.

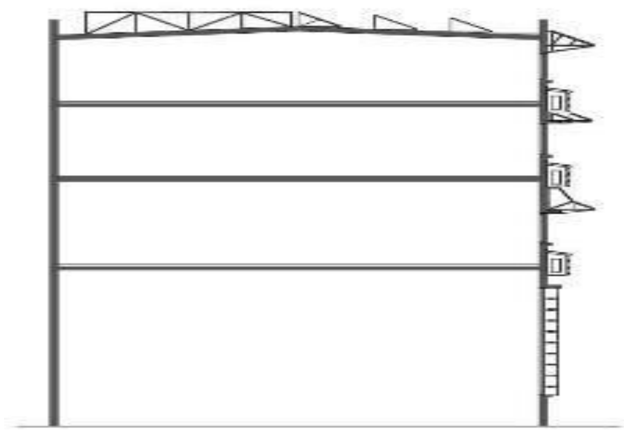

Figure-24. Alt # 2 - Section 1-1.

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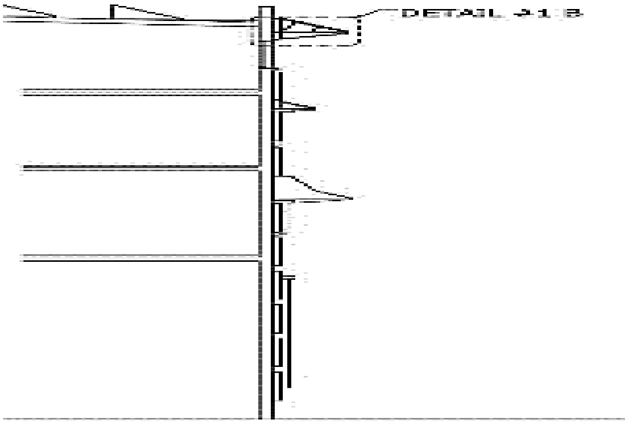

Figure-25. Alt # 2 - Section 2-2.

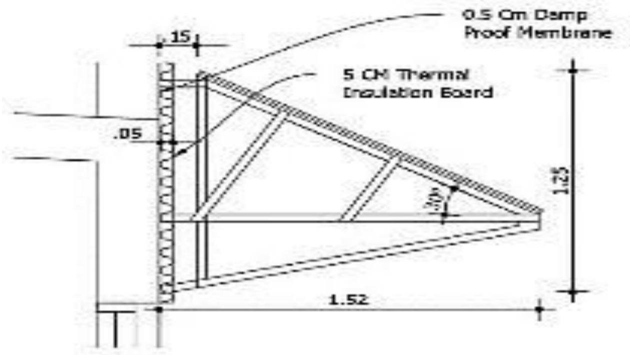

Figure-26. Detail # 1 B.

5.4 The Third Alternative

The third architectural PVP installation alternative was built basically on distributing some PVP vertically on accordions to match the verticality of window louvers despite having the maximum amount of electrical power that can be generated by covering the full solid parts of the façade by PVP as shown in Figures from (27 to 30).

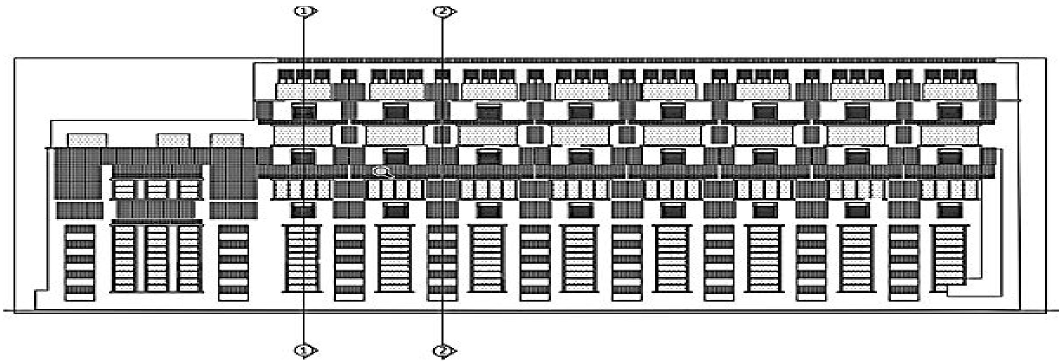

Figure-27. Alternative # 3 PVP panels Elevation distribution.

Solar panels for the third alternative

- 31 PV South Elevation Panels inclined on 30°
  31 x (1.6x0.8) = 10.24 Sq. Meters.
- 54 PV South Elevation Panels inclined on 30°
  54 x (1.6x0.8) = 69 Sq. Meters.
- 72 PV South Elevation Panels inclined on 60°
  27 x (1.6x0.8) = 92 Sq. Meters.
- 138 PV South Elevation Vertical Panels
  138 x (1.6x0.8) = 177 Sq. Meters.

Total, Exposer area including roof panels for Alternative No. 2 772 Sq. Meters.

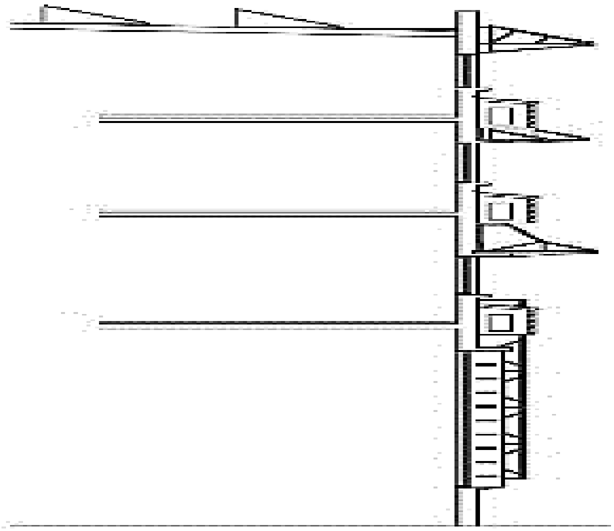

Figure-28. Alt # 3 - Section 1-1.

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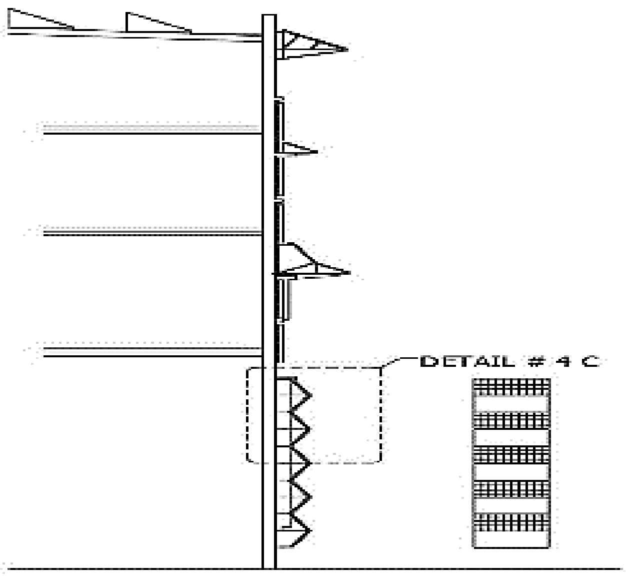

Figure-29. Alt # 3 - Section 2-2.

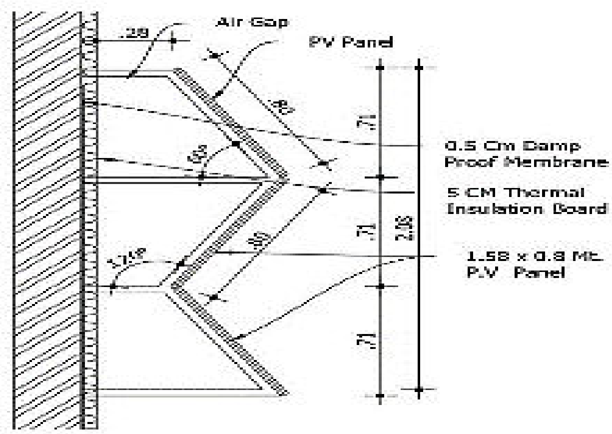

Figure-30. Alt # 3 - Detail # 4 C.

6. GENERATED ELECTRICAL ENERGY

Three alternative configurations of PV modules were considered as shown in Table-2, while Table-3 indicates the electrical parameters of each PV module.

Table-1. Three alternative configurations of the PV modules.

Orientation	Alternative 1		Alternative 2		Alternative 3	
	PV modules	Area, m^2	PV modules	Area, m^2	PV modules	Area, m^2
Horizontal	208	266	208	266	208	266
Tilted, 30 deg	201	257.5	201	257.5	208	266
Titled, 60 deg	27	34.5	27	34.5	27	34.5
Vertical	342	438	182	233	138	177
Total area, m^2	996		791		772	

Table-2. Electrical parameters of the PV modules.

Item	Value
Module power	185 W
Cell technology	Monocrystalline
Short circuit current	5.5 A
Open circuit voltage	44.8 V
Maximum power current	5.1 A
Maximum power voltage	36.4 V
Maximum system voltage	1000 V
No. of cells	72
No. of cells in parallel	1
Dimensions	80.8 x 158 x 0.35 cm
Weight	15.4 kg

The generated electrical energy by any PV system depends mainly on the amount of incident solar radiation, system orientation, the season of the year, efficiency of the PV panels, and other system components.

Equations (1 and 2) describe the generated energy from any PV system [26].

$$\eta_{PV} = \frac{P_{PV}}{A_{PV} \times 1000} \quad (1)$$

$$E_{PV} = A_{PV} \times \eta_{PV} \times H \times T_C \times \eta_{inv} \quad (2)$$

Where:

- η_{PV} is the PV system efficiency,
- P_{PV} is the PV system power in W,
- A_{PV} is the PV system area in m^2,
- 1000 is the standard test condition of solar radiation in W/m^2,
- E_{PV} is the daily generated electric energy from the PV system,
- H is the daily incident solar radiation in kWh/m^2,
- T_C is the effect of temperature and other losses in the PV system, and
- η_{inv} is the efficiency of the power inverter [26].

According to equations (1 and 2) and the corresponding incident solar energy in each orientation,

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the electric energy can be calculated for each system orientation. Figure-31 shows the average daily generated energy per one kilowatt of PV installed in the four PV orientations.

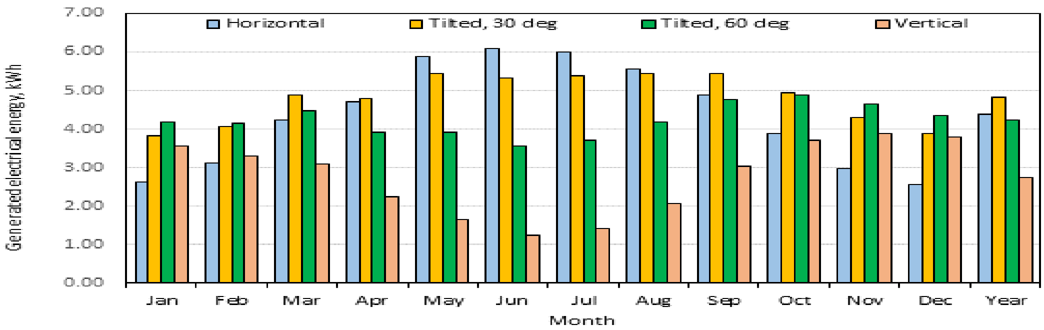

Figure-31. The average daily generated energy per one kilowatt PV installed for the four orientations.

From the figure, we can conclude that:

- Due to the high elevation angles of the sun in summer, the output energy from the horizontal panels is maximum in the summer season, more than its values in winter. It gives more than 6 kWh/kwp in summer and about 2.6 kWh/kwp in winter, with an annual average of 4.38 kWh/kwp.
- Given that Cairo is located at a latitude of 30 degrees above the horizontal, the tilted panels perform at their best throughout the year. This configuration gives more than 5.44 kWh/kwp in summer and about 3.8 kWh/kwp in winter, with an annual average of 4.81 kWh/kwp.
- Increasing the tilt angle of the PV panels more than its optimum tilt of 30 degrees reduces the system output energy, as shown in 60- and 90-degree tilted systems.
- The total monthly generated electrical energy in MWh of the PV system of the three alternatives is dedicated to Tables (4-6).

Table-3. The total monthly generated electrical energy in MWh of the PV configuration in alternative 1.

Month	Horizontal MWh	30 deg. Tilted MWh	60 deg. Tilted MWh	Vertical MWh
Jan	3.13	4.41	0.65	6.99
Feb	3.37	4.24	0.58	5.83
Mar	5.07	5.63	0.69	6.05
April	5.42	5.35	0.59	4.26
May	7.00	6.27	0.60	3.27
Jun	7.02	5.95	0.53	2.38
July	7.16	6.21	0.58	2.80
Aug	6.62	6.27	0.65	4.05
Sept	5.64	6.06	0.72	5.78
Oct	4.64	5.69	0.76	7.30
Nov	3.45	4.79	0.70	7.39
Dec	3.05	4.49	0.68	7.46

Table-4. The total monthly generated electrical energy in MWh of the PV configuration in alternative 2.

Month	Horizontal MWh	30 deg. Tilted MWh	60 deg. Tilted MWh	Vertical MWh
Jan	3.13	4.41	0.65	3.72
Feb	3.37	4.24	0.58	3.10
Mar	5.07	5.63	0.69	3.22
April	5.42	5.35	0.59	2.26
May	7.00	6.27	0.60	1.74
Jun	7.02	5.95	0.53	1.27
July	7.16	6.21	0.58	1.49
Aug	6.62	6.27	0.65	2.16
Sept	5.64	6.06	0.72	3.08
Oct	4.64	5.69	0.76	3.88
Nov	3.45	4.79	0.70	3.93
Dec	3.05	4.49	0.68	3.97

Table-5. The total monthly generated electrical energy in MWh of the PV configuration in alternative 3.

Month	Horizontal MWh	30 deg. Tilted MWh	60 deg. Tilted MWh	Vertical MWh
Jan	3.13	4.57	0.65	4.86
Feb	3.37	4.39	0.58	4.06
Mar	5.07	5.82	0.69	4.21
April	5.42	5.54	0.59	2.96
May	7.00	6.49	0.60	2.27
Jun	7.02	6.15	0.53	1.66
July	7.16	6.43	0.58	1.95
Aug	6.62	6.49	0.65	2.82
Sept	5.64	6.27	0.72	4.02
Oct	4.64	5.89	0.76	5.08
Nov	3.45	4.96	0.70	5.15
Dec	3.05	4.65	0.68	5.19

Table-6 and Figure-32 indicate the total monthly generated electrical energy in MWh of the proposed three alternatives; While Figure-33 shows the annual generated electrical energy in MWh of the proposed three alternatives.

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Table-6. Total monthly generated electrical energy in MWh of the proposed three alternatives.

Month	Alternative 1	Alternative 2	Alternative 3
	Generated energy MWh	Generated energy MWh	Generated energy MWh
Jan	15.18	11.91	13.21
Feb	14.02	11.29	12.40
Mar	17.44	14.61	15.79
April	15.61	13.62	14.51
May	17.14	15.61	16.37
Jun	15.88	14.77	15.36
July	16.74	15.43	16.11
Aug	17.59	15.70	16.58
Sept	18.19	15.49	16.65
Oct	18.39	14.98	16.37
Nov	16.33	12.87	14.24
Dec	15.67	12.18	13.56
Year	198.19	168.46	181.14

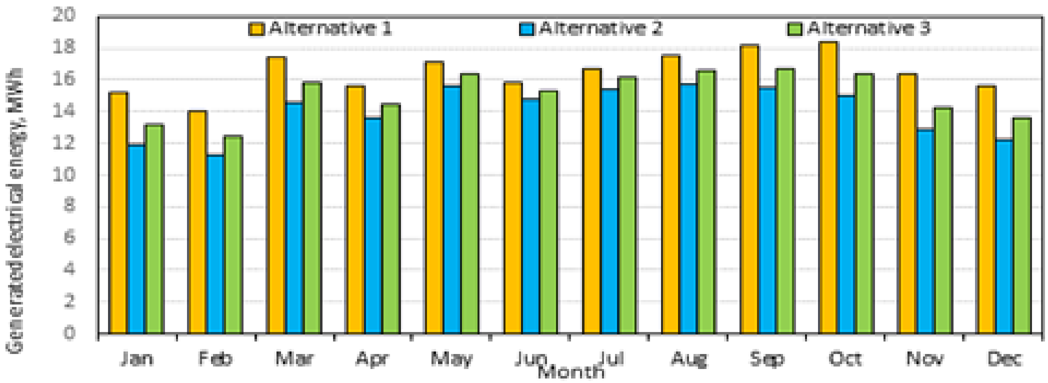

Figure-32. Total monthly generated electrical energy in MWh of the proposed three alternatives.

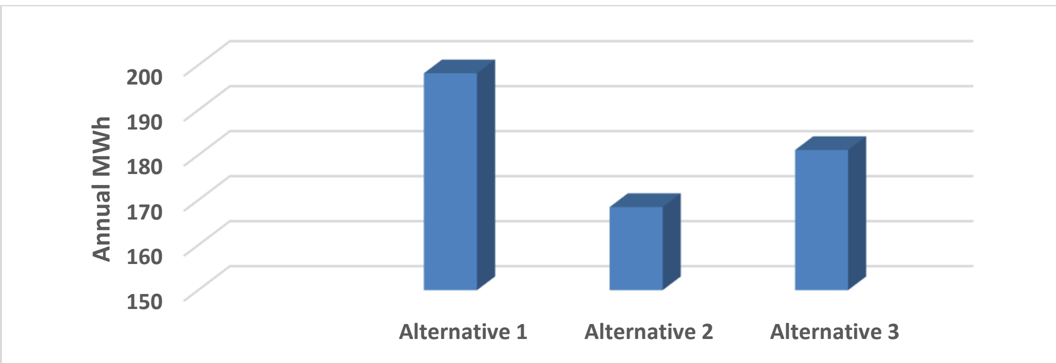

Figure-33. Annual generated electrical energy in MWh of the proposed three alternatives.

From Table-2 one can see that there are 208 PV panels are installed horizontally in all proposed alternatives, with constant generated energy of 61.55 MWh/year. For all proposed alternatives, it can be seen that the horizontal panels give their maximum energy in the summer months due to the higher elevation angles of the sun, while their output decreases in the winter. Contrary to the horizontal panels, the tilted ones generate more energy in winter due to the lower elevation angles of the sun. The optimum inclination of 30 degrees gives the maximum generated energy all year, while the vertical gives the minimum due to high tilt angles, taking into consideration that the solar windows in Cairo are between 7 and 54 degrees south. It can also be shown that the PV system gives monthly generated electrical energy between 14-18.4 MWh, 11.3-15.7 MWh, and 12.4-16.7 MWh/month for alternatives 1, 2, and 3 respectively, with total annual energy of 198.19, 168.46, and 181.14 MWh/year. Considering the price of electricity in Egypt of 0.048 $/kWh, the total savings from the three proposed alternatives is 9579 $, 8142 $, and 8755 $ for alternatives 1, 2, and 3 respectively.

7. ANALYSIS OF OBTAINED RESULTS

By analyzing the annual amount of solar-generated electrical power for three architectural PVP pattern distributions, it was found that:

- The research is limited to the use of the Photovoltaic panel locally available in the Egyptian market during the study period.
- The maximum amount of electrical power was generated from the roof-installed PVP pattern 123.1 MWh/year, saving 5949 dollars. Roof PVP installation was common in the three study alternatives.
- The building's south façade was utilized to generate additional solar electrical power, to illustrate the PVP building façade merging capabilities three architectural alternatives were done using different types of PVP installations vertical, 60° inclined and 30° inclined sharing air gap between PVP installation level and the solid installation façade surface. The first architectural alternative for the PVP installation pattern on the building's south façade that covers the maximum solid part generates 198.19 MWh/year, saving 9579 dollars. The second architectural alternative for the PVP installation pattern was that some PVP were eliminated to get another South façade look. The electrical power generated was 168.46 MWh/year, saving 8142 $, while in the third architectural alternative, a different PVP installation pattern was used, generating 181.14 MWh/year, saving 8755 $.

8. CONCLUSIONS

Before the integration phase of photovoltaic (PVP) systems, it is advisable to research the solar electric generation capacity of existing buildings. The majority of government buildings in Egypt feature flat concrete roofs and contemporary-style façades. While placing photovoltaic (PV) panels on existing buildings' roofs is commonly selected due to their low maintenance and high electricity generation capacity, there is also the potential to create additional solar power by installing PV panels on the south-facing façade of the building. The design of the PVP installation pattern for building facades should consider the architectural aesthetics of the current building. The novel installation patterns of PVP (photovoltaic panels) provide a harmonious combination of architectural beauty and the practical utilization of solid regions on building facades, resulting in the highest possible electricity generation. Finally, it is recommended that the implementation of the proposed method be included to demonstrate its potential for real-world applications.

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LIST OF ABBREVIATIONS

PV	Photovoltaic
BIPV	Building integrated photovoltaic
BAPV	Building Added photovoltaic
kWh/m^2	Kilo watt hour per square meter
kWh/kwp	Kilo watt hour to kilo watt peak
MWh/year	Mega watt hour per year
MWh	Mega watt-hour
3D drawings	Three-dimensional drawings

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