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Architectural Forming and Economic Analysis of BIPV System for the Faculty of Engineering Buildings in Mansoura University

تشكيل معمارى وتحليل إقتصادى لنظام الخلايا الكهروضوئية المتكامل لمبانى كلية الهندسة- جامعة المنصورة

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الملخص

في الآونة الأخيرة، ازداد الوعي والجدل حول تأثير الثورة الصناعية والتكنولوجية على البيئة وصحة الإنسان الذي نتج في الأساس من الإستخدام المفرط للوقود الأحفوري، وعند النظر فى تطوير إستراتيجية مصادر الطاقة في مصر خلال القرن الواحد والعشرين، فإنه من الضروري إستبدال هذا الوقود الأحفوري بالطاقة الشمسية كأحد أكثر مصادر الطاقة المتجددة الواعدة والمتاحة، حيث تعتبر مصر واحدة من دول الحزام الشمسي التي تحظى بكثافة عالية من الإشعاع الشمسي المباشر من الشمال إلى الجنوب، والذى يدعم مجموعة متنوعة من تطبيقات الطاقة الشمسية، ويعتبر قطاع المبانى القائمة في مصر مسؤولاً عن استهلاك كمية كبيرة من الطاقة للإضاءة والتدفئة والتبريد، وحيث أن عدد المباني القائمة أعلى بكثير من عدد من المباني التي يجري بناؤها، في حين أن العديد من هذه المباني القائمة تحتاج إلى تحسينات، مما يوفر فرصة جيدة لإستخدام تقنيات تكامل الخلايا الكهروضوئية من أجل الحد من إستهلاك الطاقة الأولية وانبعاثات الغازات الضارة. وفي الوقت الراهن، تتوافر تقنيات الخلايا الكهروضوئية بأسعار تنافسية نسبياً، حيث يتم تحويل الأشعة الشمسية إلى طاقة كهربية مباشرة مع توفير بديل نظيف وصديق للبيئة للحد من الأثر البيئي للمباني، إلا أن السبب الرئيسي لضعف الإقبال على تطبيق تكامل تلك التقنيات فى المبانى هو صعوبة توفير البيئة المعمارية المهيأة للتكامل مع إعتبارات التصميم الشمسي المطلوبة. لذا، فإن الهدف الرئيسي من الورقة البحثية هو تمهيد السبل الممكنة للمعماريين والمهندسين لإستخدام الأنظمه الكهروضوئية المتكاملة بالنهج المبتكر الذى يمكن أن يخدم الوظيفة المزدوجة من التركيز على التعبير المعمارى وتوليد الطاقة، ومن ثم تقديم نموذج التشكيل المعماري والتحليل الإقتصادي لنظام الخلايا الكهروضوئية المتكامل لمبنى جامعي قائم في مصر (قسم الهندسة المعمارية في كلية الهندسة بجامعة المنصورة)، الأمر الذى قد يشجع السلطات المسؤولة ومتخذي القرار ومشغلي المباني القائمة في مصر لتنفيذ الممارسات المستدامة والحد من الآثار البيئية للمباني على مدى دورة الحياة الوظيفية لها.

Abstract

Recently, we have become more conscious about the impact of the industrial and technological revolution on the environment and human health which is basically due to the use of fossil fuel. In the development of energy sources in Egypt for the 21st century, it is necessary to replace by solar energy as one of the most promising and available renewable energy sources. Egypt is considered one of the solar belt countries with high intensity of direct solar radiation from north to south which provides a variety of solar energy applications. In Egypt existing building sector is responsible for use of large amount of energy for lighting, heating and cooling. As the amount of existing buildings is much higher than the number of buildings being built, while many of these existing buildings need improvements. This provides an opportunity to use photovoltaics (PVs) integration technologies to reduce primary energy usage and greenhouse gas emissions. At the moment, PVs technologies are available in relatively competitive prices; solar radiation is converted into electricity providing a cleaner, environmentally friendly alternative to reduce the environmental impact of buildings. The main reason for these technologies to stay unpopular is the lack of good architectural quality that meets the desired design considerations. The main aim of this paper is to pave possible ways for architects and engineers to use the building integrated photovoltaic (BIPV) systems with innovative approaches which can serve the dual function of emphasis on the architectural expression and power generation. Introduce a model of architectural forming

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and economic analysis of BIPV system for an existing campus building in Egypt (the Architectural Department in the Faculty of Engineering in Mansoura University). This will encourage the responsible authorities and operators of existing buildings in Egypt to implement sustainable practices and reduce the environmental impacts of buildings over their functional life cycles.

Key words

Solar Energy; Photovoltaic; Building Integration; BIPV; Life Cycle Cost.

1- Introduction

The growing demand in energy and concern about depleting natural resources and global warming has led the governments worldwide to consider alternatives to the use of fossil fuel for energy production. For Egypt, the future of energy is challenging. The local demand for energy is rapidly growing where the two major energy sources, oil and natural gas, are in a precarious situation.[1]

Existing buildings account for over 40% of the world’s total primary energy use and 24% of greenhouse gas emissions.[2] The use of PV in buildings is becoming of critical importance to prepare fossil fuel energy shortages and reduce global warming impacts and associated environmental costs. In this regard, it is important that we must consider PV systems not only as technological systems for energy production but also as elements that make an important contribution to the architectural design where they can enhance the architecture, accentuate it and distinguish it from the mass.[3]

2- Aims of the research

This study aims at approaching the following:

- Discussing and illustrating the existing condition of the Egyptian buildings and the need for renewable energy.
- Emphasizing the role of solar energy in solving energy problems and fostering the effective role of architecture in disseminating and developing solar energy strategies in Egypt (BIPV, in particular).
- Promoting the use of BIPV system in existing buildings as an aesthetic element that will help in solving energy and fossil fuel emissions problem in Egypt.

3- Methodology

This paper is determined to study the potential approach for developing the Egyptian existing campus buildings with the use of BIPV systems. The study is divided into three main sections:

1- Analytical study: in collaborative effort with authors two and three, this study mainly stems from theoretical studies carried out by the first author through her Master Thesis.

2- Conducting academic research about existing buildings in Egypt - campus buildings in particular, solar energy potential, PV architectural integration challenges, and studying successful international experiments to draw out practical criteria for the applied study.

3- Applied study: presented in the architectural forming and economic analysis of BIPV system for an existing Egyptian campus building (the Architectural Department in Faculty of Engineering at Mansoura University).

4- Egyptian existing building and the need for renewable energy

Existing buildings in Egypt face problems of high energy consumption for mechanical cooling systems, besides a poor indoor environmental quality.[4] Egypt currently experiences frequent electricity blackouts because of increasing demand, natural gas supply shortages, and aging infrastructure.[5] According to the government figures, the commercial sector experienced the most rapid average annual growth over the last five years (10.2%), followed by public utilities (9.4%), and government (8.3%). Peak load demand has increased at an average annual rate of 8.1% over the last 10 years.[1]

During the last few decades, the rate of enrolling students in Egyptian Universities has grown very rapidly, **Figure 1**. To face this growth, buildings have been expanded throughout the Egyptian campuses with focusing only on increasing the capacity of new buildings which had led to wide use of energy to provide well indoor quality. Therefore, it is important to study the feasibility of using BIPV system in existing building to reduce energy use and greenhouse gas emissions, as well as enhance buildings quality.

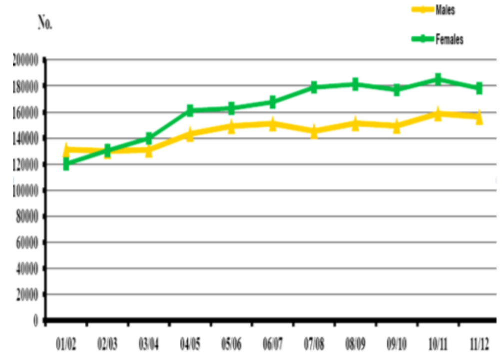


Figure 1: Development of Egyptian Universities Graduates by Sex from 2003/04 to 2011/12. Source: Statistical Year Book of A.R.E., Central Agency for Public Mobilization and Statistics (CAPMAS), 2014.

5- Solar energy in Egypt

Egypt is one of the world's most attractive sites for solar energy where it has averages between 5.4 and more than 7.1 kWh/m^2 of annual daily direct solar radiation, from north to south. The annual direct solar irradiance ranges from 2000 to 3200 kWh/m^2 supported by 9–11 h of sunlight/day, with few cloudy days throughout the year, **Figure 2**. Both the Solar Radiation Atlas and the German Aerospace Center estimate Egypt's economically viable solar potential in the range of 74 billion MWh/year.[1]

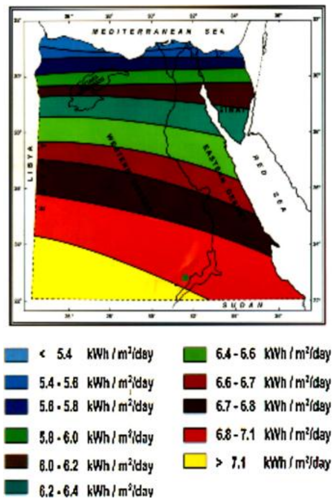


Figure 2: **Distribution of solar energy generation potentials in Egypt.** Source: (Ibrahim, A. 2012).

Photovoltaic technology, Egypt has high PV potential, which is as yet largely unexploited, as shown in **Figure 3**. PV is considered the main power supply for some villages, as part of demonstration projects funded by donor agencies. A feed-in tariff for PV would help to develop the market, but PV local manufacturing is very limited and there is heavy reliance on international suppliers. PV activities have been limited to small applications in remote areas that are not connected to the grid. As nearly 99% of Egypt's population is connected, there does not seem much potential expansion possible in terms of residential demand, unless different patterns of demand and supply are developed for PV technologies.[6]

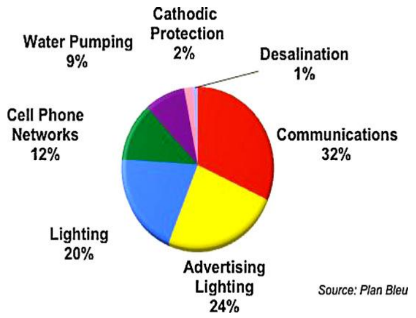


Figure 3: PV applications in Egypt by usage (4000–4500 KWp). Source: (Ibrahim, A. 2012).

6- Architectural integration challenges

Architectural integration is defined as the result of coherent integration of PV technologies simultaneously from all points of view, functional, constructive, and architectural (preserving the global formal quality of the building).[7]

It is very important to underline that one of the main reasons for the rare use of solar energy systems was seen in relation to architectural acceptance. Well-designed solar energy systems could become an important part of the building design and the building's energy balance and thus contribute to both, the energy supply and high quality solar architecture.[8]

Until recently, PV integration used to be synonymous with invisibility. It was actually desirable to hide the fact that the solar elements were different than other building elements.[9] Many architects have never thought about using PV as an architectural expression combining the aesthetic qualities with the possibilities offered by PV systems and have therefore never produced good solutions for architectural integration of PV also, inexperience and lack of PV knowledge by clients, consultants and/or installers.[10]

However, installations on existing buildings unavoidably tend to be more fragmented than on new buildings, since they have to comply with an existing situation. As standardized products are often not applicable, the situation calls for innovative approaches with custom made products. PV is not easy to integrate in existing buildings; The integration process has to be planned according to the situation observed on site which varies from building to building.[3]

7- Application

The Faculty of Engineering at Mansoura University was selected to be the research application for various reasons:

- It has become overcrowded for the high growth rates of enrolled students each year with wide use of energy to provide good indoor environmental quality.
- It is considered one of the largest educational buildings in Egyptian universities particularly with its engineering learning spaces.
- It represents the place of the research where we can get any data or information needed for the application study.
- Optimizing an existing building would help in saving energy, providing new architecture quality for its occupants, in addition to setting recommendations and design guidelines for future campus buildings.

7-1 Analytical study

The selected site is the Faculty of Engineering which is located in Mansoura University in Mansoura City. This is an area with an educational character, comprised by six paralleled blocks connected all together by a longitudinal spine and extending additional large blocks in the North and East. The six paralleled blocks with exposed facades mainly at the north, south, and west, **Figure 4**. This means that the PV integration facade would face south. The Department of Architecture is located at block 2, the exterior surfaces of the block are with white and black color finish, and while small parts like the staircase differ; having a yellow bricks and white colored finish. The volumes are cubic, and in conjunction with the simplicity of the morphology, they result in a uniform character for the whole area, **Figures 5** and **6**.

Figure 4: Satellite map of the Faculty of Engineering, Mansoura University. Source: (Google Earth, 2014).

Figure 5: Existing condition of the south view of the Department of Architecture.

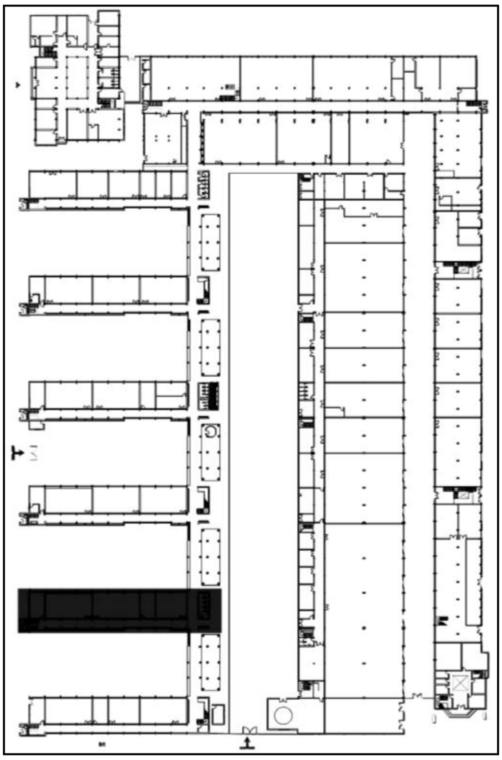


Figure 6: Plan for the Faculty of Engineering, where the Department of Architecture is shaded.

Environmental data

It is very important to collect climatic information with the limitations determined by each specific location. This information is required for the integration and the calculations of the system. In order to define and analyze meteorological data of Mansoura city, **Meteonorm** program is used which could create a weather data file to be used in the other programs for solar applications and system design at any desired location in the world, Table 1.[11]

Table 1: Meteonorm general information for Mansoura city

Name	Mansoura, EG, -
Type	Interpolated city
Latitude/ Longitude	31.05° North, 31.08° East, Time Zone from Greenwich 2
Data source	MN6 1717 WMO Station Number, Elevation 0m

7-1-1 Shadow analysis

Shading analysis is necessary in order to define the available and more productive locations for PV modules. To do so, the analysis was carried out through the Autodesk Ecotect Analysis program. A "visualize model" for the engineering faculty was created in the program based on the technical drawings provided by the Engineering Management of Mansoura University. This software performance is based on a weather data file for Mansoura City which is created by Meteonorm in order to get visual illustrations for the desired time period of the study, **Figure 7**.

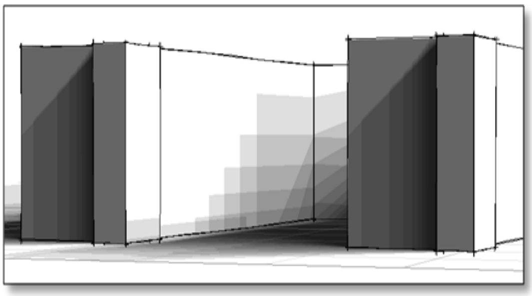


Figure 7: Shadow annual range on the south facade, Autodesk Ecotect Analysis.

7-1-2 Energy requirements

In order to design a BIPV system, the electricity load must be determined. This will dictate the size of the system, and in a later stage, whether we can or not cover this load. According to the Maintenance Management Unit of Mansoura University (MMU), the average electricity consumption of the Department of Architecture was about 116KWh/day in 2014 with kWh price EGP0.366.[12]

7-1-3 System orientation

Orientation and tilt are the most important factors affecting PV system efficiency. Fixed-mount PV array orientation is described by two angles:

- Slope angle: the angle between the array surface and horizontal.
- Azimuth angle: the angle between the normal to the array surface due south is zero; east is negative; west is positive.

To maximize annual energy production of PV arrays, designers specify a slope angle that is equal to the location's latitude and an azimuth angle of zero, or slightly positive.[13] So, the optimal orientation in this case is a slope angle 30° with an azimuth slightly positive.

7-1-4 System configuration

This research aims to design a BIPV system for an existing campus building. So, we can use the utility as a backup and installing a grid-connected PV system which has several advantages, reduced installation costs particularly the cost of batteries, ease of installation, reduction in complexity and maintenance, and at times when PV facade produce more electricity than the building needs the excess energy will be exported to the national grid.

7-2 Design processes

7-2-1 Product selection

Mono-crystalline or poly-crystalline modules were considered to be more suitable than amorphous in this application due to their greater efficiency, their durability and the appearance of the cells. The aesthetics offered by the poly-crystalline cells determined their choice over the mono-crystalline, particularly taking into account the large area of the array. After the determination of the energy requirements, the analysis was continued into the research for products available in the market. The selection of the PV module was done with the help of catalogues from various dealers and the best in terms of performance, dimensions, cost and aesthetics were selected.

The Sun module Plus SW 250 Vario poly is selected for PV integration application which characteristic by the blue and shiny desirable appearance, the regular patterns formed by the cells, and the clear anodized aluminum frame which make the panel more expressive with a high-technical character. Furthermore, the size of the module satisfied the aesthetic concern, **Figure 8**.[14]

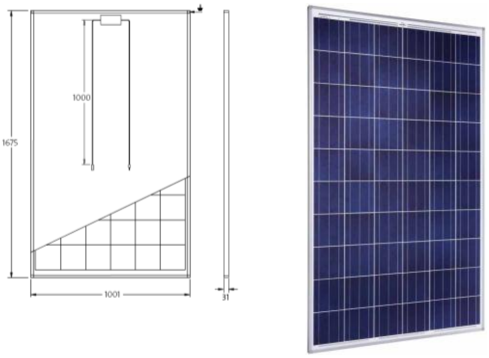


Figure 8: Sunmodule Plus SW 250 Vario poly appearance and dimensions. Source: SolarWorld brochure, www.solarworld.com, accessed on March 30th 2015.

Table 2: Basic information of the selected PV module. Source: SolarWorld brochure, www.solarworld.com, accessed on March 30th 2015.

Dimensions	
Length, Width, Height	1675 mm, 1001 mm, 31 mm
Weight	21.2 kg
Frame	Clear anodized aluminum
Component materials	
Cells per module	60
Cell type	Poly crystalline
Cell dimensions	156 mm x 156 mm
Performance under Standard Test Conditions (STC)	
Maximum power Pmax	250 Wp
Maximum power point voltage Umpp	30.5 V
Maximum power point current Impp	8.27 A

7-2-2 The Proposed Structure

The integration design followed the principle of Rainscreen Façade (ventilated/cold facade), which provides a ventilated space between the PV modules and the building to ensures that the modules are well ventilated to maximize their efficiency and for the wiring trunking, **Figure 9**. Detaching the PV system from the building also has more possibilities to increase the architectural value, where the structural elements of the system can be parts of the design, rather than serve only as supports. Also, the continuation of the relationship from the interior to the exterior has been a driving factor towards the final design approach.

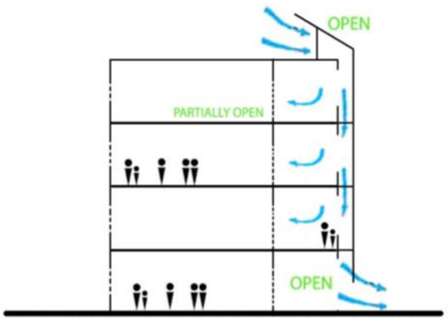


Figure 9: Sectional diagram show ventilation flow after BIPV system installation.

7-2-3 System sizing

As mentioned the average annual energy consumption in the department is equal 116 KWh/day. Assuming 85% efficiency for the system, the total energy per day that should be provided by the PV array is then: 116 x 1.15 = 133.4KWh/day. By conducting a realistic performance check for the Sun module Plus SW 250 Vario poly in Mansoura University under the actual environments conditions where solar radiation and the resistance are constantly changing, we measured the voltage and the current across the different solar radiation and resistance and put the results into tables. The representation of IV curve is drawn showing the maximum power (Pmax) at different levels of solar radiation during the day, **Figure 10**.

In this way the actual output watt hour of the solar module can be collected as shown in **Figure 11** and used to determine the PV array size. The number of PV modules needed = 133.4 / 1.91 = 69.84. So, to cover the energy requirements for the Department of Architecture, it should be powered by at least 70 modules. PV (Area) = No. of modules × the size of module = 70 × 1.675 × 1.001 ≈ 117 m^2.

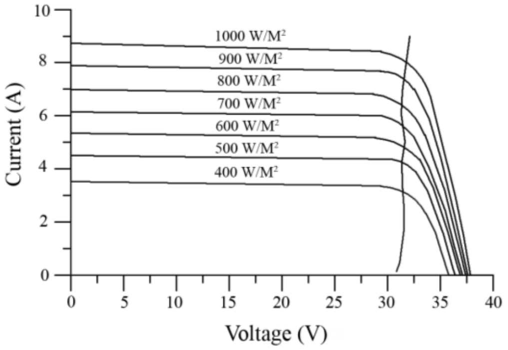


Figure 10: PV module I-V curves in varying solar radiation: the line intersects the knee of the curves is where the maximum power point is located.

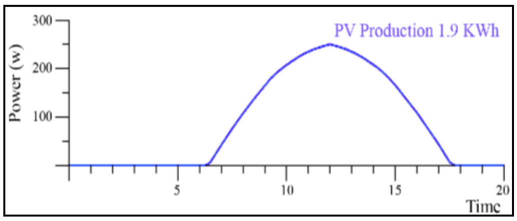


Figure 11: Pmax-Time curve shows the maximum power generated by the module in the site for a clear day in May.

7-3 Proposal BIPV integration form

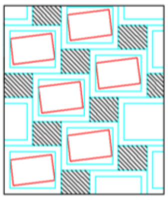
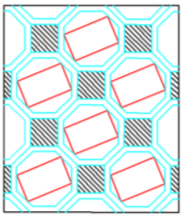
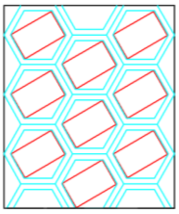
7-3.1 The proposed unit and distribution

The hexagonal shape is considered the most efficient unit form, as it allows the minimum use of material, the least unusable spaced when connected, and the good integration between the forms and the PV modules, **Table 3**. The hexagonal shape is determined to be regular with one meter for each side which provides the suitable area for the selected PV module.

The hexagons distributed with the honey cells concept allows the hexagons to interlock and form amazing grid for PV installation according to the shadow analysis conducting before for the south facade taking into account arranging PV modules at a distance which prevent shading of one row to fall on the row behind it, **Figures 12, 13** and **14**.

Figure 12: Visualization of the proposed BIPV system on the South façade.

Table 3: Comparison between the possible unit forms showing that the hexagonal shape is the most efficient form.

	1. The rectangular shape Unusable area = 20% Frame = 32% Void = 48% No. of PV modules = 6
	2. The octagonal shape Unusable area = 17% Frame = 30% Void = 53% No. of PV modules = 6
	3. The hexagonal shape Unusable area = 0 % Frame = 42% Void = 58% No. of PV modules = 9
▨	Unusable area
—	Frame
—	PV module

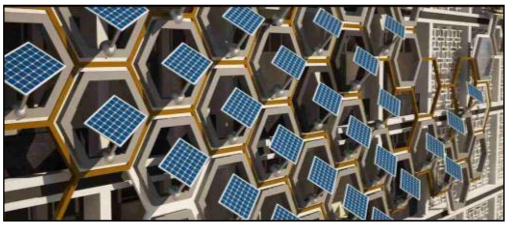


Figure 13: Close view on the PV modules.

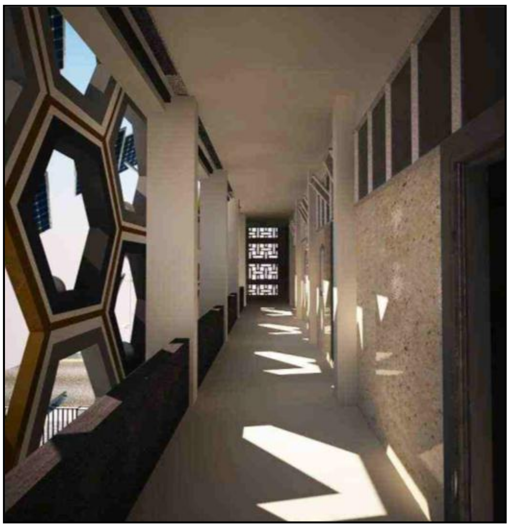


Figure 14: View from the porch on the 3rd floor looking south.

7-3-2 Area integration proposal

Since the uniformity characteristics of the Engineering Faculty, it becomes interesting to show the integration over the all six blocks. The result has an obvious feeling of uniformity, which follows the existing design principles imposed by the area, maintaining the repetitive character of the site, **Figure 15**.

Figure 15: Visualization of the proposed of uniform integration BIPV system.

7-4 Economic analysis and life cycle cost calculation

- The price of PV modules is the most costly component of the BIPV system, we choice sun module Plus SW 250 Vario poly module, which costs EGP2340.80, according to the current market price. As mentioned above, to provide the total energy requirements, the department should be powered by at least by 70 modules. So, PV modules will cost: No. of modules × the price of module = 70 × 2340.80 = EGP163856.
- As calculated, the BIPV system needs inverter of 20KW. The Sunny Tripower 20000TLEE PROJECT is selected for the system which costs EGP42112.4.
- Using Maximum Power Point Tracking (MPPT) to obtain the maximum power from the PV arrays this will cost EGP8000.
- The initial cost of PV system = PV array cost + inverter cost + MPPT cost = 163856 + 42112.4 + 8000 = EGP213968.4.
- Life cycle cost = initial cost of PV system + installation cost = 213968.4 + 45000 ≈ EGP260000.
- The life cycle output energy = 116 ×365×25 = 1058500 kWh.
- The cost of 1 kWh from the PV system = 260000/ 1058500 ≈ EGP0.25.
- As we calculate the cost of 1 kWh from the BIPV system equal EGP0.25, while the cost of 1kWh from the national grid equal EGP0.366. We should take the state electricity subsidy for the campus buildings into account.The BIPV system will sometimes provide the utility grid with excessive power, especially during vacations that will allow crediting any excess electricity against future utility bills and help eliminate the emerging problem of blackouts in Egypt.

8- Conclusion and recommendations

This paper attempted at showing how PV system can form a high-quality, creative and environmental friendly architecture. Conclusion and recommendations of this paper can be summarized in the following:

- Photovoltaic systems are considered one of the most environmental friendly power generation systems, which reduce using of fossil fuels and CO_2

emissions. Furthermore, they do not cause pollution over their life cycles.

- The integration of PV systems into a building must be a part of an architectural approach. PVs have the potential to be more than just power generating elements, but also carriers of aesthetics and ideas which can increase the architectural value.
- Existing buildings need innovative approaches, since the BIPV systems integration has to be planned according to the situation observed on site which varies from building to building and from place to another.
- From an economic point of view, BIPV system is still relatively expensive as a result of importing PV cells from Europe in hard currency plus shipping cost. So, it is highly recommended to support the local industry in Egypt especially because the strategic stock of silica (sand) which used in the manufacturing PV cells is available in Egypt, added to the yearlong sun in most parts of the country. The state's subsidies and incentives will be very important drivers to reduce costs of this technology and encourage its wide range of architectural application and design integration.

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