A conceptual framework on applying BAPV systems to existing educational buildings
Case Study: The Higher Institute of Engineering and Technology-Fifth Settlement

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Abstract

This paper illustrates analyzing the feasibility of developing solar power system in existing educational building by converting it from electric energy to solar energy. This study depending on the fact that educational building has a lot of free spaces that could be used especially that Egypt is enjoying average sunshine hours between 6-12 daily so the development potentials of Solar Energy appear very obvious adding to that the relatively higher cost of fossil energy and its bad impact on the environment. Three methods were combined to ascertain building properties and determine which place were the most suitable for BAPV installations which are analysis study, physical simulation and empirical study The methodology is then tested by applying the steps on the building.

Then a cost analysis had been performed to give actual values for the amount of money saved by retrofitting and installing BAPV systems. Energy simulation program –Design Builder- was used to analyze the energy performance of the case study building and compare it to the retrofitted case to show the amount of electricity saved.

Research Hypothesis

the research hypothesis centered on whether using solar energy in existing educational building can reduce electricity consumption while considering the BAPV cost in order to get the best output of the Return on investment especially that educational building construction rate had been rapidly increasing in the last 10 years according to the strategy of Egypt vision 2030.

Keywords: Renewable Energy (RE), Photovoltaics, Building applied photovoltaic (BAPV), Energy Efficiency, Educational Buildings.

1. INTRODUCTION

Egypt has been known to primarily depend, in all its energy-related activities, on three major sources: oil, natural gas and the hydroelectric power generated from the large dam projects: the High Dam, Aswan I & Aswan II(1).

On the other hand, part of Egypt Vision 2030 is to increase local content in all fields as The Ministry of Electricity and Renewable Energy (MOERE) is playing a strategic role in implementing the government's renewable energy plans as it is working on

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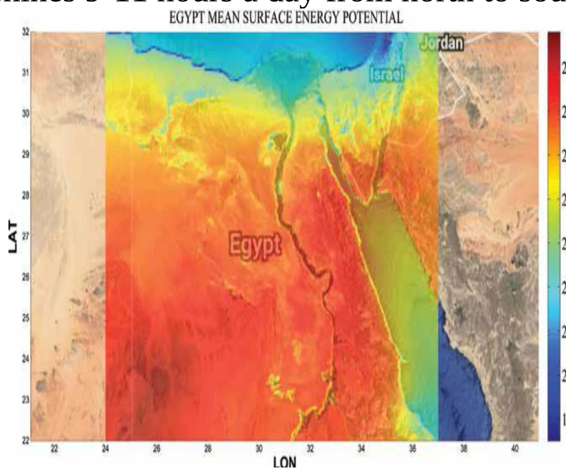
increasing the supply of electricity generated from renewable sources to 20% by 2022 and 42% by 2035, with wind providing 14 percent, hydro power 1.98 percent, photovoltaic (PV) 21.3 percent, wind 14 percent, concentrating solar power 5.52 percent, and conventional energy sources 57.33 percent by 2035. The Ministry of Electricity and Renewable Energy has worked to upgrade Egypt's transmission grids and raised from 2364 km of total length of 500 KV grid in 2014 to 6006 km of total length of 500 KV grid by end of 2020.Table 1

Moreover, in 2014 Egypt had 18 substations of 9800 MVA total 500 KV capacity. By end of 2020, the country had a total of 48 substations of 5450 MVA total 500 KV capacity by adding 30 substations with a total of 44250 MVA (2).

Targeted development indicators	**2016**	**2020**	**2030**
GDP real growth (%)	4.2	10.0	12.0
GDP per capita (USD)	3436	4000	10000
Inflation rate (Consumer price index , annual %)	11.8	8.0	5.3
Industrial development rate (%)	5.0	8.0	10.0
Industry share of GDP (%)	12.5	15.0	18.0
Energy sector share of GDP (%)	13.1	20.0	25.0
Renewables share in primary energy (%)	1.0	8.0	12.0
Renewable in electricity production (%)	1.0	21.0	32.5
Women in workforce (%)	22.8	25.0	35.0
Unemployment rate (%)	12.8	10.0	5.0
Poverty rate (%)	26.3	23.0	15.0
Acute poverty (%)	4.4	2.5	0.0

Table 1: Sustainable Development Strategy: Egypt vision 2030, 2016 (2)

The proposed methodology at the case study can generate around 66,000 kWh /year of electricity as Egypt's Solar Atlas states that it is considered a "sun belt" country with 2,000 to 3,000 kWh/m^2/year of direct solar radiation (3) Fig. 1. The sun shines 9-11 hours a day from north to south Fig. 2, with few cloudy days.



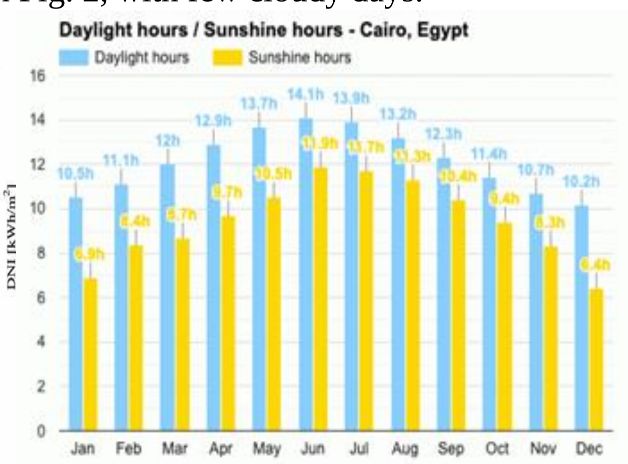


Fig. 1. No of daylight and sunshine hours - Cairo –Egypt (3)

Fig. 2. Solar radiation map of the Egypt: shows the average annual radiation in kWh/m2 year(3)

2. RESEARCH PROBLEM

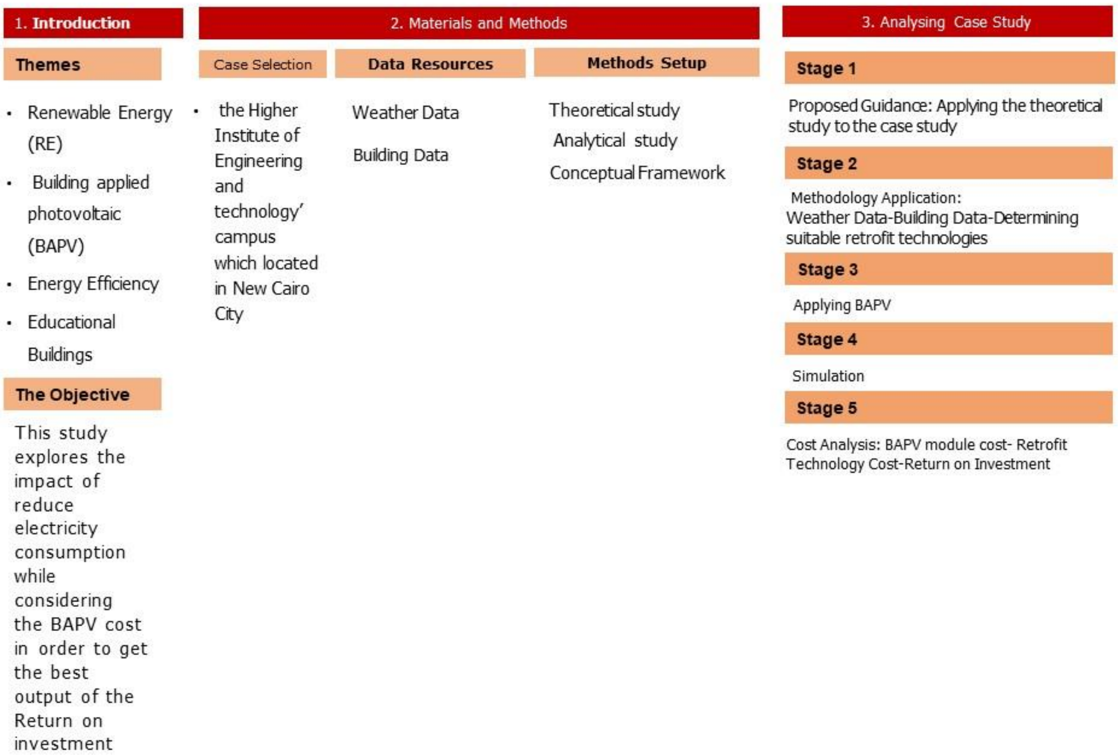
There are two main aspects of the research problem: The first, although Egypt has a very high potential compared to other countries in the world, the installation capacity does not reflect the same value, knowing that Egypt’s economic development hinges on the energy sector, which represents 13.1% of overall gross domestic product (GDP) This strategy involves stepping up the development of renewable energy and energy efficiency, in part through vigorous rehabilitation and maintenance program in the power sector(3).

The second is that There is already an increase in temperature profile all over Egypt in the last 10 years. This aspect of climate change complicates the problem in Egypt because most of the buildings are not well insulated which increases the energy needed to reach thermal comfort to a significant extent (4).

3. METHODS

The methodology of the research contains three methods which were combined to ascertain building properties and determine the most effective place for BAPV installations. These included theoretical analysis, physical simulation and empirical study. The methodology is then tested by applying the steps on the building.

Fig. 3. Research Methodology -Source: the researcher



4. Solar Energy in Educational Buildings in Egypt Energy Development

Launched in 2017 by the United Nations Development Program (UNDP) in cooperation with the Industrial Modernization Center (IMC), the Grid-Connected Small-Scale Photovoltaic Systems project, known as Egypt PV, is funded by the Global Environment Facility (GEF). It aims to remove the barriers to increase power generation by small, decentralized, grid-connected PV systems implemented by households and small- and medium- size enterprises. The project already achieved double its targets by installing 8.5 MW in 2 years. Egypt PV seeks to open markets for small-scale PV systems, which are solar plants with a capacity below 600kW and a life span of 25 years. Many projects have been started to support the use of PV systems in Educational Buildings, for example: Faculty of Science, Alexandria University, located in Moharram Beek-Alexandria City, applying PV in the building was funded by the European Union through ENPI-CBC MED program which is concerned with fostering solar technology in the Mediterranean Region (5). The Building integrated 120 polycrystalline PV panels on its south façade, with thirty-degree angled panel that produce 17.28 KW. These PV panels are grid connected and cover about 8% of the building total energy consumption by producing 26530 KWH/year. Another example: German University in Cairo (GUC) (6), (GUC Solar City) Located in: Fifth settlement, New Cairo City, On 18 April 2016. GUC Solar City represents the state- of -art, All-in-one unique model of sustainable energy Solutions. The site integrated movable polycrystalline PV panels on the land and roofs with angled panel that produce 100 KW grid as in Fig. 3 and Fig. 4.

Fig. 3. PV panels attached on south façade, Faculty of Science, Alexandria University (5).

Fig. 4. PV panels attached on the site of German University in Cairo (GUC)-New Cairo-Cairo (6).

The global solar photovoltaic (PV) installed capacity is expected to register more than 22.91%, reaching almost 3228.73 GW by 2027, up from 766 GW in 2020. The COVID-19 outbreak had a very slight impact on the market growth and negatively affected the supply chain in 2020. In 2021, the global solar PV capacity additions were estimated to be around 107 GW, representing stable growth from 2019 (7).

5. Building Applied Photovoltaic (BAPV)

There are two ways of existed PV on buildings: Building Integrated PV (BIPV) or installing it (BAPV). As shown in Fig 6.

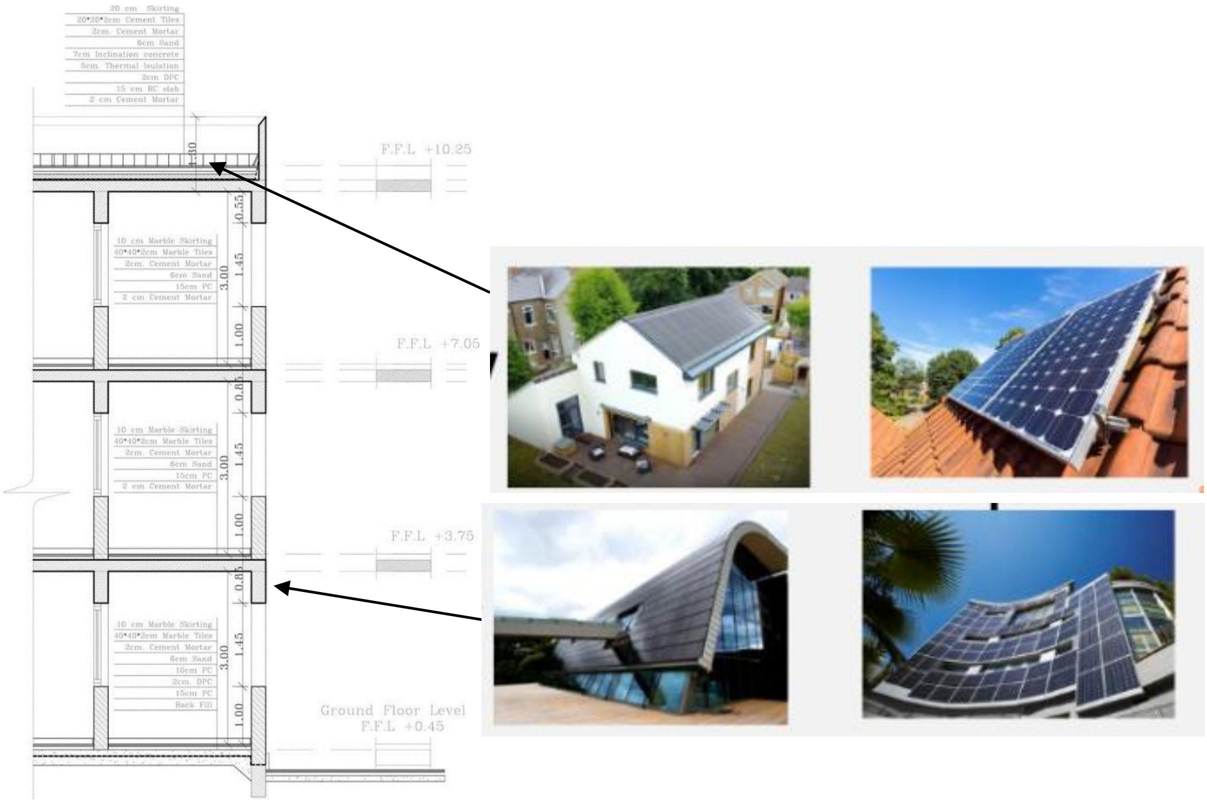


Fig. 6. Case study section with BAPV and BIPV methods (8)

In this research, we had been chosen BAPV (Building Applied Photovoltaics) method which consists of fitting modules to existing buildings.
This selection is due to : BIPV method includes the replacement of the traditional construction element with materials incorporating solar modules which will be more expensive than using BAPV that usually do not increase heat gain to the building and they cause reduction of roof temperature by shading the area from the direct solar obtain (8).

6. Analysing Case Study

6.1 Proposed Guidance

Applying the theoretical study to the case study: the Higher Institute of Engineering and technology' campus which located in New Cairo City by a combination between two approaches: retrofitting approach and BAPV approach.

6.2 Methodology Application:

The building has certain energy performance level and needs a certain amount of electricity to perform.

The research depends on enhancing the energy performance and generating the needed electricity through BAPV panels. This could happen by proposing some changes to the envelope using Egyptian market available products in order to enhance the energy performance of the building and decrease the amount of energy needed to the minimum.

In addition, it will provide the building with the ideal design solution for the building applying photovoltaic panel's location, their quantity, as well as the pricing from the Egyptian market. The use of energy simulation program will determine the amount of energy saved by the retrofit actions and comparing it to the current values in order to verify the proposed methodology. The implementation of the guideline is detailed as follows.

6.2.1 Weather Data

According to Egyptian solar radiation Atlas, New Cairo City annual daily solar radiation about 5.4 KWH/ m^2 which enhanced by about 9 H of sunlight/day, with rare cloudy days during the whole year.

The normal value of annual solar hours was about 3285 hours/ year (1).

6.2.2 Building Data

The selected project is: the Higher Institute of Engineering and technology' campus, located in New Cairo City which consists of administrative buildings, academic buildings ,parking areas, playgrounds and workshops.

The study module is based on selecting only one building from the campus which is the Engineering institute building.

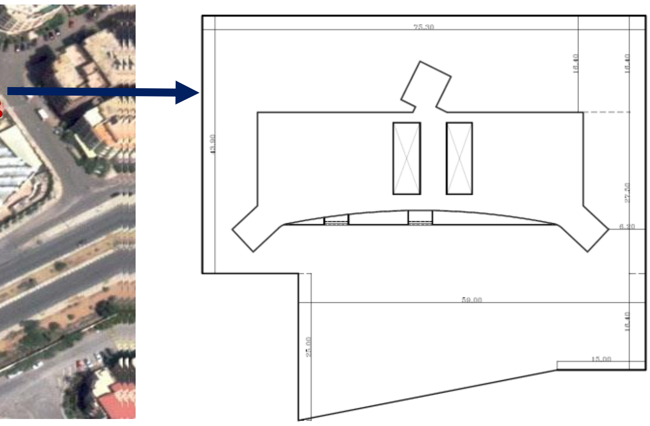


Fig. 7. Case Study Layout Source: Google Maps.(n.d.)- New Cairo academy- (9).

Fig. 8.Mapping available spaces on the selected building- Source: The researcher.

The building preliminary survey showed that the building is south facing and makes an angle of 45 degrees with the South. The roof top and 3D rendering of campus is shown in Fig.8. The building is situated geographically at Latitude 29.995067° North and Longitude 31.436498° East with roof area=1091 m^2 as shown in Fig 5.

The optimum tilt angle is calculated through the following equation, the entire year = (Latitude × 0.76)+3 = (30× 0.76)+3=25.8 degree towards the south direction (9).

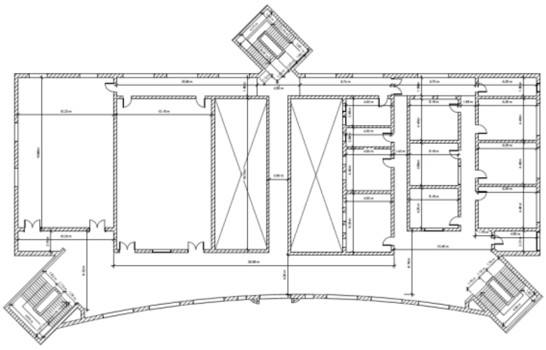



Fig. 9. Case study building façade and typical floor -Source: The researcher

Existing building retrofit plan has many factors which include: building condition, current operating schedule, system efficiency, available retrofit budgets….etc. These factors present different variables with multiple criteria that affect the decision-making process and have an alternate influence on each other (7)The retrofits' type that will be focused on is the energy retrofit, resolving both sides: energy consumption and energy generation (10).By gathering and analyzing the building data, it was found that the building's energy performance can be categorized as poor due to the following:

- The building's vertical envelope is a single wall of 25 cm thick bricks.
- It has single glazed aluminum framed windows and it is leaking so leaking so the amount of heat energy transferred from the outside to the inside is significant.
- No insulation is installed in the outside or the inside of the walls or the roof as its layers is the finishing tiles, the waterproofing membrane, the thermal insulation, and then the concrete slab.
- The HVAC system is split system not central, and mostly in a bad condition.
- There are no sun breakers over the building facades to prevent direct sunlight from entering the interior space.

Fig. 10. Case study Isometric-Source: Author using 3dma program

6.2.3 Determining suitable retrofit technologies

An average consumption monthly rates were detected by Design Builder software (11) where all the building data were inserted and modelled which shows that the annual energy consumption rate is 62,000 KW.h with average monthly consumption = 5,166 kwh/ month as shown in Fig 10.

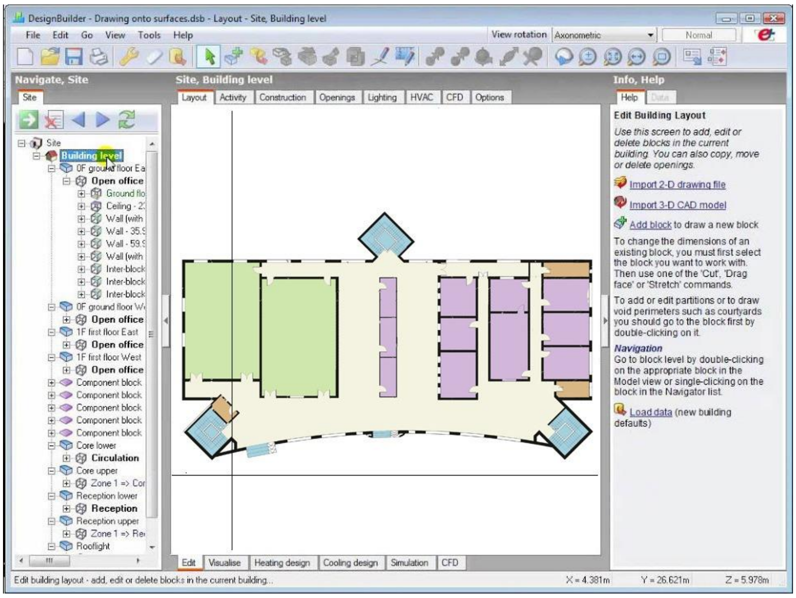


Fig. 11. Analyzing Case study typical floor plan using Design Builder software-Source: Author

And based on the data analysis of the building's envelope, the retrofit technologies that compensate for the ineffectiveness of the current case study status could be presented as follows.

6.2.3.1 Windows glazing type

Based on Egyptian market there are many windows glazing type and according to a recent study in Egyptian market (12) the best window glazed type is :Double grey 6mm-13mm air a U value (W/m^{2}K) =1.772 so The building s' windows will be replaced with double glazed aluminum framed windows as shown in Fig 11.

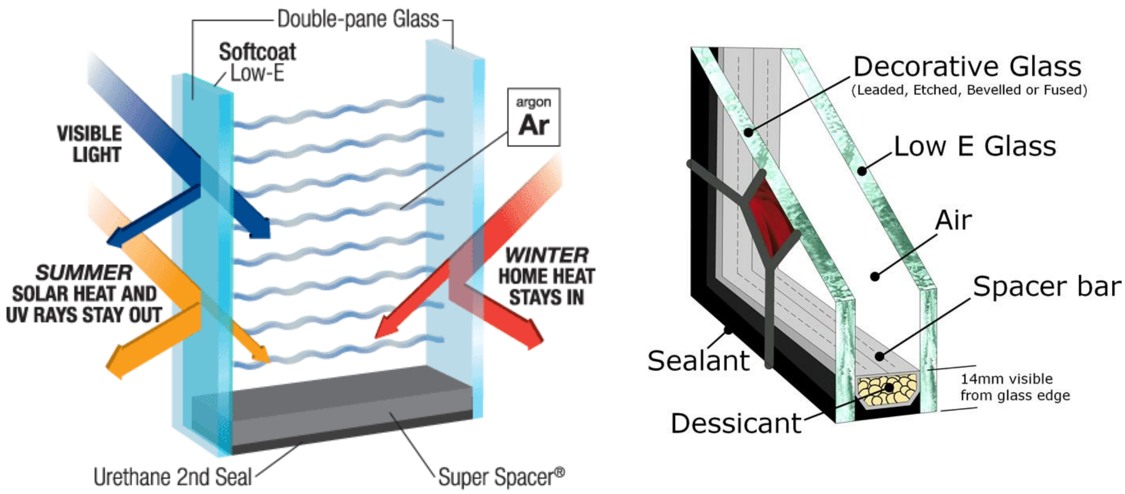


Fig. 12. Double glazed window section (13)

The total glazing area was calculated to be 240 m^2 .Based on field research, the price of the previously mentioned window section ranges from 2200-2600 LE/m^2.
Total price for windows =2200 × 240=528000 le.

6.2.3.2 Wall Insulation

There are a lot of wall insulation types in Egypt s market such as **:** Fiberglass, Mineral (rock or slag) wool and natural fibre (14).
The chosen wall insulation that is more suitable with Cairo's climate and can be applied to existing buildings is compressed Little foam insulation boards available at CMB company (15). The material comes in the form of sheets (250x60cm) thickness ranges from (1-3 cm) the chosen thickness is 3 cm.

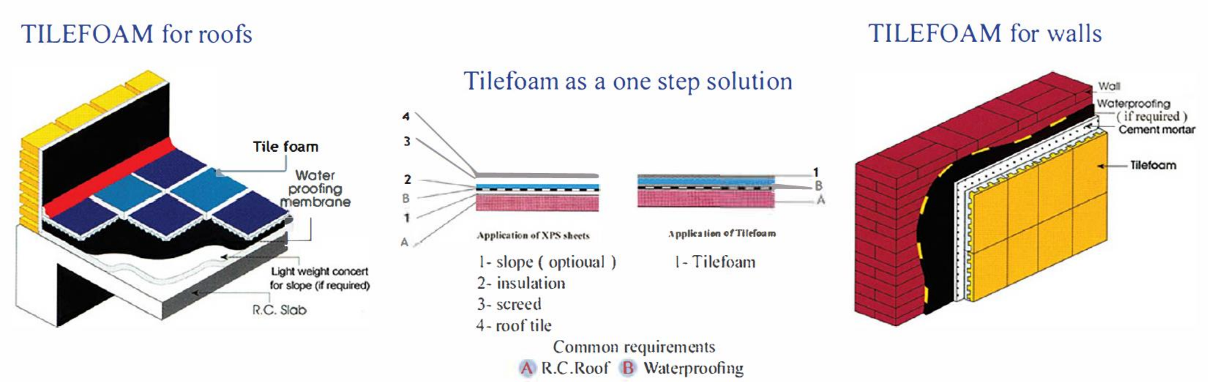


Fig. 13. Tile foam insulation boards layers (13)

To calculate the quantity of tiles needed for the wall cladding, the circumference of the building is multiplied to the total building height -assuming that the material will be installed on the outside of the building.
The total area to be covered is 2550 m^2 then the windows' area is subtracted to have the net area = 2550- 240 = 2574 m^2. The price per m^2 is 128 LE so the total price =2574 × 128=329,472 LE.

6.2.3.3 Roof Insulation

Tile foam (mentioned previously in wall insulation) can be used in roofs as well (14).
Adding to that we don't have to reinstall new tiles after adding the insulation, this tile comes with final finishing which makes this material an appropriate choice for the roof insulation. The tiles are 30x30 cm and thickness (2-5 cm). The market price for the Tile foam is 130LE/m^2. As the case study roof area=1091 m^2, so the total cost=130 × 1091=141.830 le.

6.3 Applying BAPV

A scaled physical map had been created showing Sunset and sunrise angles in the Summer, Winter, Fall and Spring to determine and the arc of the sun depending on the estimated angles throughout the year based on a sun track model shown in Fig. 13, via Sun calc software (16) choosing 4 dates to be calculated (the beginning of every Astronomical Start) which are: 22.December.2020, 22-March-2021, 22-june-2021, 22-September-2021 at 12 o'clock.
The map implements a colour scale to describe the incoming solar energy ranging from blue (1900 kWh/m^2) to red (greater than 2700 kWh/m^2) (16)

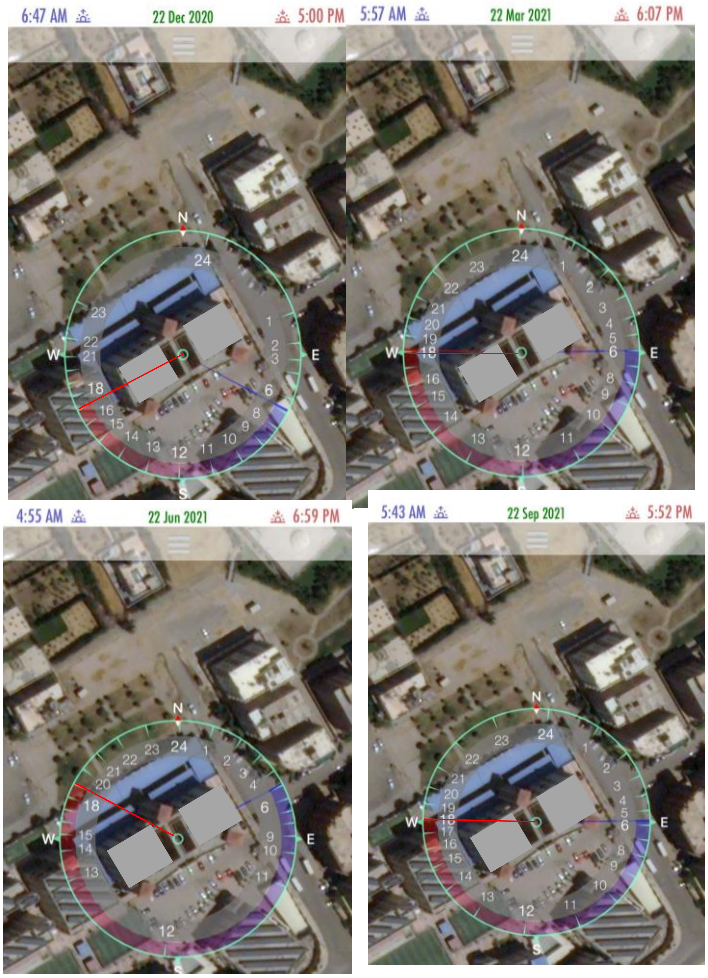


Fig. 14. Sunset and sunrise angles Source :Author via Sun calc software (16)

.We had been chosen: hi Performa series: 144-cell half cut bifacial polycrystalline solar module Fig. 14. because it generates the largest amount of energy in the Egyptian circumstances(17).

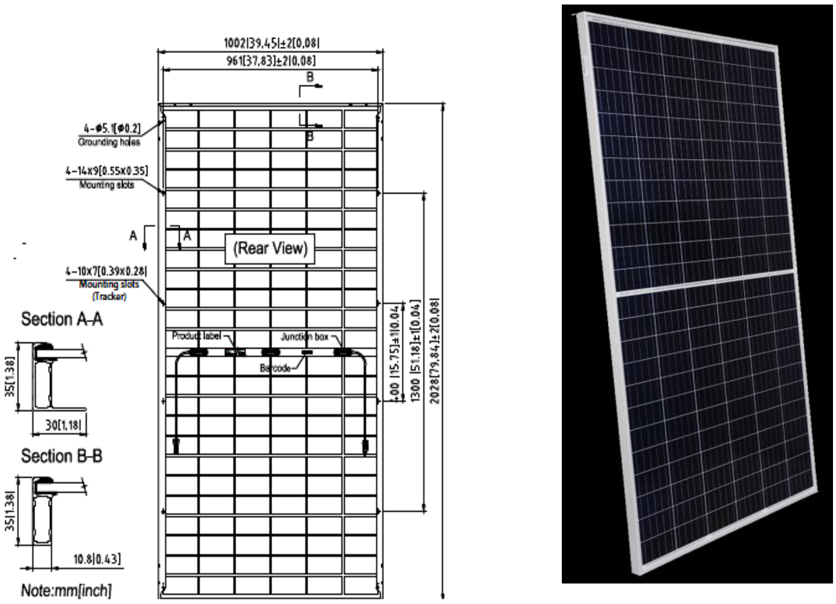


Fig. 15 Selected PV module (18)

The number of modules can be accommodating on the building roof can be calculated by the following formula = No. of module accommodation = Total roof area divided by area of a selected PV module = 96 modules.

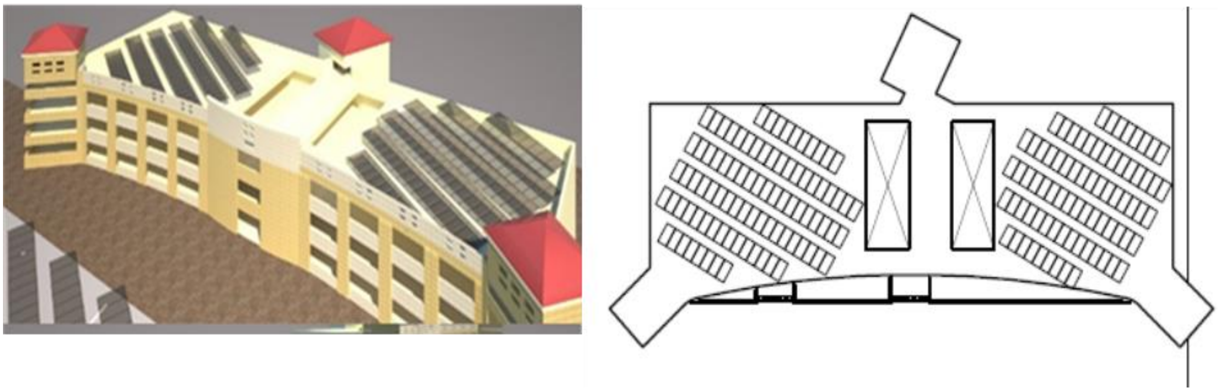


Fig. 16. Case Study Applying PV-The source:: Author using AutoCAD program & 3D max program

7. Simulation

For the retrofit actions to be verified, energy simulation needs to be performed. Using Design Builder software the electricity consumption of the existing educational building with the three retrofit options is done. The retrofit actions are then simulated in order to be able to measure the difference in electricity consumption between the three cases as shown in Table 2.

Models	**Retrofit Technology**	**Annual Energy Consumption**
Model1	Windows glazing type	16000 kwh
Model 2	Wall Insulation	18000 KWH
Model 3	Roof Insulation	11000 kwh
Total 44000 KWH		

Table 2. The three models electricity consumption-Source: The Author

8. Cost Analysis

8.1 BAPV module cost

As mentioned before, the building current situation shows that the annual energy consumption rate is 62,000 KW.h For the PV system to be calculated, the amount of electricity resulted from the simulation (after adding the three suggested retrofits)is 44,000 kWh. Knowing that every 1 kW power station generates 1800 kWh/year, then the building will need a 48 kW station (44,000/1800). As stated by the supplier, for each 1 kW power station 4 panels and a surface area of 10 m^2 is needed and it will cost 20,000 LE. By doing the calculations, the 48 kW station will need 480 m^2 of roof area, which is available for the case study roof as mentioned before. So, the overall BAPV system cost =480000 le.

8.2 Retrofit Technology Cost

Each of the retrofit technologies was discussed in the retrofit technologies section, in the following table the amounts are multiplied by the prices in order to give the total cost.

Models	**Retrofit Technology**	**Unit price**	**Overall price**	**BAPV module cost**	**Retrofit Technology cost+ BAPV module cost**
Model1	Windows glazing type	2600 le/m^2	528000 le	480000 le	576000le
Model 2	Wall Insulation	2310 le/m^2	295680 le	480000 le	343,680
Model 3	Roof Insulation	1091 m^2	141830 le	480000 le	189830 le

Table 3. The three models retrofit technology cost -Source: The Author

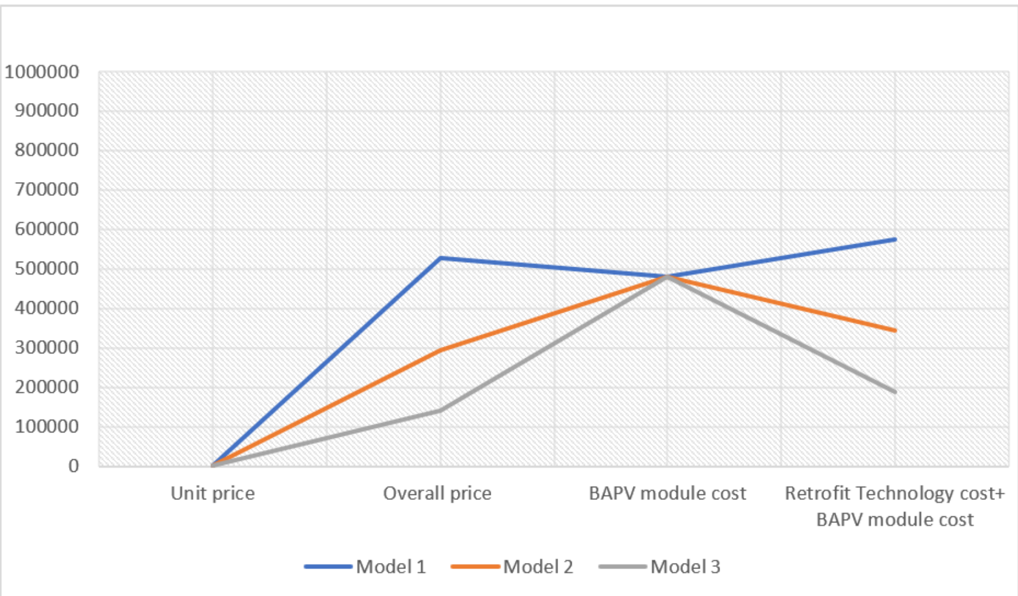


Fig. 17. Comparing the three models Source: The Author

9. Results

Return on Investment

In The envelope retrofit actions decreased the energy consumption from 66,000 kWh to 44,000 kWh as per the simulation results. So, in order to calculate the return on investment for these actions, the price of the amount of energy saved has to be calculated. For the 22,000 kWh saved, the pricing will be referenced from the feed in tariff FIT (19).

An average of 1.5 le/ kWh can be assumed because the amount of energy saved will be typically saved from the high level of consumption in the hot months. The amount of money saved can be calculated as: 22,000 x 1.5 = 33000 LE per year. On the other hand, the amount of energy to be covered by the renewable energy system is decreased from 72 kW station (66,000/1800) to 24 kW station (44,000/1800). Consequently, the difference between the two stations pricing =720000-480000 = 240,000 LE .So ROI can be then calculated as follows:

(retrofit pricing – saved PV station pricing)/ money saved by retrofit every year
For Model 1= 576000 -240,000= 336,000⁄33000=10 years
For Model 2= 343,680-240,000= 103,680⁄33000=3,14 years
For Model 3= 285000 -240,000= 103,680⁄33000=1.9 years

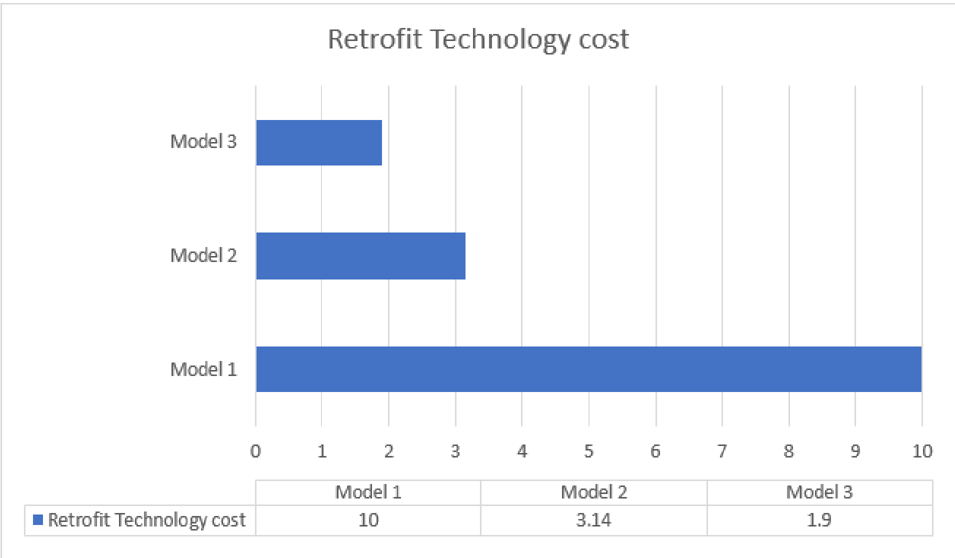


Fig. 18. Retrofit Technology Cost for the 3 model , Source: The Author

The return on investment of the retrofit actions may not be short especially in model 1 but the retrofit actions play a very important role in decreasing the energy use and decreasing the amount of PV station needed.

10. Conclusion

Solar energy is clean and safe compared to the majority of fossil fuels. It does not pollute the air or produce greenhouse gases. Also, in its production there is no concern about flammable gases or dangerous waste such as nuclear energy.

So, this study was set out to introduce a reasonable framework for the energy problem in Egypt with regard to buildings energy consumption.
The buildings' energy efficiency in Egypt is significantly low, from what increases the energy demand that is generated from non-renewable resources. Therefore, the two consideration that have to be explored are buildings' insulation and renewable energy generation. The research has displayed the solar energy potential and concentrated also on the educational existing buildings' status, then it considered BAPV a viable way for the Egyptian energy problem.
Two exiting educational buildings' case studies had been analyzed to g types were discussed to lead the way for the applied case study. At first the stages were applied to the case study building and then simulation results showed that the retrofit actions and the BAPV application were useful and advantageous in terms of electricity consumption saving and money saving.

11. List of abbreviations

- ✓ Photovoltaic : (pv)
- ✓ Renewable Energy (RE)
- ✓ Building Applied Photovoltaic: (BAPV)
- ✓ The Ministry of Electricity and Renewable Energy (MOERE)
- ✓ gross domestic product: (GDP)
- ✓ United Nations Development Program: (UNDP)
- ✓ Global Environment Facility (GEF)

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إطار نظري لتطبيق نظم خلايا الطاقة الشمسية المضافة للمبني في المباني التعليمية القائمة
دراسة حالة : المعهد العالي للهندسة والتكنولوجيا -التجمع الخامس

ياسمين طلعت[3]-مروة عماد [4]

الملخص:

تهدف الورقة البحثية إلي تحليل إمكانية تصميم نظام للطاقة الشمسية في المباني التعليمية القائمة عن طريق تحويلها من مباني تعمل بالطاقة الكهربائية إلي مباني تعمل بالطاقة الشمسية .وتعتمد الدراسة علي أن المباني التعليمية تتمتع بمساحات واسعه يمكن استغلالها لوضع الخلايا الشمسية وخاصة أن مصر تتميز بعدد من ساعات سطوع الشمس يتراوح بين 6-12 ساعة يوميا مما يعزز من إمكانات التنمية للطاقة الشمسية فيها بالإضافة إلي الإرتفاع المضطرد في أسعار الطاقة الغير متجددة وأثرها السيء علي البيئة.

ويوجد إعتبارين رئيسين تم مراعاتهم عند عمل هذه الدراسة: الأول : الزيادة الضخمة في إستهلاك الوقود مقارنة بإمدادات الطاقة المتاحة والثاني :كمية الطاقة المفقودة للوصول إلي الراحة الحرارية داخل المباني .

وتقوم الدراسة علي تحليل الوضع الراهن لكل من المباني التعليمية و قطاع الطاقة في مصر حيث يهدف البحث إلي إمداد المعمارين والمصممين بتقنيات نظم خلايا الطاقة الشمسية المضافة للمبني وخاصة في المباني التعليمية القائمة بالإضافة إلي تحليل الجدوي الاقتصادية لوضع الخلايا في المباني متعددة الطوابق لتحديد مدي فاعليتها بناء علي تحليل التكلفة و إستهلاك الطاقة في المبني .

ولتحليل المبني وتحديد المكان المناسب للخلايا تم عمل دراسة التحليلية ومحاكاة للمبني و عمل دراسة تطبيقية ومن ثم تحليل التكلفة اللازمة لتطبيق نظم خلايا الطاقة الشمسية المضافة للمبني للوصول إلي قيم حقيقية للنظام ومقارنتها بالوضع الحالي وتم إستخدام برنامج لمحاكاة الطاقة : Design Builder لتحليل كفاءة الطاقة في المبني محل الدراسة ومقارنته لحساب كمية الطاقة التي تم توفيرها .

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