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ScienceDirect

Energy Procedia 115 (2017) 239–252

Energy Procedia

www.elsevier.com/locate/procedia

International Conference – Alternative and Renewable Energy Quest, AREQ 2017, 1-3 February 2017, Spain

Building Integrated Photovoltaic Retrofitting in Office Buildings

Salwa El Gindi* [a], Ahmed Reda Abdin [b], Ayman Hassan. [b]

[a] *Department of Architecture,Faculty of Engineering,Modern Sciences and Arts University,Egypt*
[b] *Depatment of Architecture,Faculty of Engineering,Cairo University,Egypt*

Abtract

The research main goal is to optimize the utilization of innovative renewable energy solutions focusing on the use of BIPV as an alternative to reduce dependency on fossil fuels and consequently reduce buildings carbon emissions.

A feasibility analysis of a building scale photovoltaic system retrofitting is conducted for an office building. A series of PV system options will be assessed in terms of the costs and projected energy production of several PV systems through renewable energy simulations modeling software, PVSOL premium. Different types of PV module and different types of mounting structure will be selected for the feasibility analysis based on an analysis of the current PV industry standards. Each system's output capacity (kW) will be calculated, annual energy output (KWh) and initial project cost for these different systems will then be modeled in PVSOL premium.

Peer-review under responsibility of the organizing committee of AREQ 2017.

Keywords: building integrated photovoltaic;retrofitting;office buildings.

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1. Introduction

The extensive use of fossil fuels has increased the concentration of greenhouse gases around the Earth, resulting in the increase in global temperatures and environmental degradation. Energy conservation has become an urgent issue due to the depletion of fossil fuels and the increased concentration of carbon emissions. Great attention has to be made to reduce energy demand of office buildings through applying energy efficient measures and maximize energy usage

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* Corresponding Author: Tel: +201221863366
Email Address: Salwagindi@hotmail.com

1876-6102
Peer-review under responsibility of the organizing committee of AREQ 2017.
10.1016/j.egypro.2017.05.022

produced by PV. The working hours of office buildings is suitable for the function of PV due to the fact that office buildings are mostly operational during daytime when the energy production from PV is high. Office buildings are often characterized by vast glazing facades

There is a great possibility of integrating renewable energy technologies in Egypt especially solar energy technologies. This suggests that much improvement has to be made to enhance the RE deployment and there is a need for more comprehensive approach and feasibility study to explore how to use existing RE technology to reduce fossil fuel energy consumption.

2. Retrofitting of office buildings

2.1. Need for retrofit

Today the increased demand for intelligent and dynamically responsive facades led the human thought away from the exaggerated cultural expressions that prevailed in architecture. Now the emphasis is on a facade that is climatically sensitive, sensibly reflecting local culture, while integrating innovative techniques to enhance the building's performance on various levels. These levels cover multilateral building aspects such as structural safety, energy consciousness, sustainability, and human psychological comfort. In order to compete with the desirability of new buildings and their provision of comfort, the existing stock is considered for retrofitting. Wigginton and Harris (2002) argue that considering buildings for retrofitting stems from a consciousness to allow buildings to strive for a state in which they were at the highest level of operational activity with the least expenditure on energy. Therefore, considering buildings for retrofitting is analogous to the biological system of evolution were survival is not only for the fittest but the non-survival of the unfit. Wigginton and Harris (2002) also warn against the naive assumption that developing nations will support and accept less comfort and commodities than the developed world has become accustomed to since the end of the nineteenth century. This increase in energy consumption will dictate not only an increase in energy production through renewables but on methods to reduce energy consumption and applying energy efficient measures by retrofitting the existing building stock.

2.2. Scale of retrofit

An enormous amount of energy is wasted because building equipment is operated improperly and unnecessarily. Rule of thumb is that they require a medium level refurbishment every 50-60 years and a major refurbishment every 120 year. At both break points, a decision has to be made as to whether the building is of sufficient quality to merit retrofit. For many modern buildings, due to life expectancy of building materials, the time of the first overhaul occurs much sooner than with traditional buildings-after 25-30 years rather than 50-60 years (Cowan 1962-63). From a structural dimension, (Highfield 2000) identifies six levels of building envelope retrofit.

(1) Retention of the entire existing building structure, together with its internal subdivisions, and upgrading of interior finishes, services and sanitary accommodations. In most low-key rehabilitation schemes, existing stairs would be upgraded in preference of installing lifts, and simple heating and cooling systems would be used, in conjunction with natural ventilation.
(2) Retention of the entire existing external envelope, including the roof, and most of the interior, with minor internal structural alterations (inserting elevators shafts, or altering staircases) and upgrading of interior finishes, services and sanitary accommodation.
(3) Retention of the entire existing external envelope, including the roof, with major internal structural alterations and upgrading of finishes, services and sanitary accommodation, but with major interior structural alterations such as insertion of new floors where the original storey height permits.
(4) Retention of all the building's envelope walls, and complete demolition of its roof and interior, with the construction of an entirely new building behind the retained facade.

(5) Retention of only two or three elevations of the existing building, and complete demolition of the remainder, with the construction of an entirely new building behind the retained facade walls. This
(6) Retention of only one elevation, a single facade walls, and complete demolition of the rest.

2.3. Integrated energy efficient retrofitting strategies

(Burton 2002) stated that an energy conscious retrofitting scheme is achievable by integrating architectural strategies and appropriate technologies. In this research it is argued that reducing energy consumption targets are not enough to sustain the use of a retrofitted building and that any technical solution proposed must be balanced and reassessed with user comfort criteria. The strategy of attaining an energy conscious retrofitting may be divided into three phases.

Phase one

This is a primary step towards qualifying a building as a whole or its facades for a retrofitting scheme. Building audit Highfield, (2000) recommends that considering a building for retrofitting does not start unless a comprehensive audit on its structural state is carried out. It is vital that any building being considered for retrofitting is subjected to a detailed survey in order to ascertain the likely cost of any structural repairs and their effect on the feasibility and speed of retrofitting. Highfield (2000) argues that a building will not be considered for retrofitting unless 'Rehabilitation and re-use will only be substantially cheaper than demolition and new construction where a suitable building is chosen which is in a reasonable physical state, and which does not require excessive structural alterations in order to adapt to its proposed newuse. Energy audit involves the systematic collection and analysis of energy data from a particular facility for implementing energy conservation measures. Energy Audit is defined as "The verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption". Energy Audit is an effective energy management tool. By identifying and implementing the means to achieve energy efficiency and conservation. not only can energy savings be achieved, but also equipment/system services life can be extended. All these mean savings in money. There are many variations of energy audits; each type is distinguished by the level of details involved and the depth of the analysis undertaken. It's important to select the appropriate audit type for the facility concerned

(1) User demands Occupants' needs has to be discussed, including thermal comfort through different seasons.
(2) building physics Examining the existing building physics reveals opportunities to adapt the building to its local climate to provide users' comfort with least dependence on mechanical systems. since finding the appropriate energy conscious retrofitting options depends on technical solutions provided to integrate the building and its systems to reduce energy consumed to provide comfort to occupants.
(3) Climate is considered to assess possible building adaptation to its local climatic constraints and opportunities to maximize the use of passive measures to decrease energy consumption while responding to occupants' needs.
(4) Regulations determine alternatives to comply with thermal codes while providing occupants' comfort.
(5) Economics (Pugh, 1991) lists that retrofitting decisions are basically based on its economic return which pays back when: It extends significantly the life of a building in the range of 30-50 years. The difference in rental value between new and retrofitting is narrow. Redevelopment costs are high. However, decisions of retrofitting only based on economic values have created many arguments on real value of buildings from a social, cultural and psychological perspective. (Galbraith 1971) puts this discussion into focus by drawing analogies to the construction of Taj Mahl in India 'A modest structure at modest cost would have provided durable and hygienic protection for the mortal remains of Mumtaz Mahl. It rejoiced the whole world and surely was sound economy. Our test should be similar. The most economical building is the one that promises to give the greatest total pleasure for the price'
(6) Analysis of consequences The interaction between the building, the climate and user demands is complex. Fine tuning these demands to comply with codes and economics is a further challenge for the design teams. If the consequences are incompatible or unacceptable conditions are predicted, then an iteration process starts by

re-evaluating the demands. If consequences are acceptable and agreed upon within the design teams, then the scheme is moved to the next phase where basic technical demands may be considered.

Phase two.

At this stage basic technical requirements are studied. These technical requirements are examined seeking options that may integrate passively to building and its systems to enhance the performance in providing user comfort.These technical options are then analyzed using quantified variables deducted from phase one and tested by various methods such as simulations, experimentation and mathematical modelling.Basic technical demands

(Kendrick et a1. 1998) developed office building retrofitting criteria based on office energy consumption levels.The level of retrofitting chosen will depend on a variety of economic, structural and legislative constraints. The first level is often the most desirable because it is significantly cheaper, and produces faster accommodation than the other three levels. However according to the classification it is more appropriate to conserving energy in buildings that originally have less levels of energy consumption. Following this classification, and in light of understanding of the office building energy consumption in Cairo, this research aims to look at possible retrofitting options on level four as they are suitable for the higher energy consuming office buildings. Introducing possible changes to building facade materials by addition or substitution to enhance the facade thermal performance to decrease cooling loads on the mechanical systems.

The basic technical solutions recommended by (Kendrick et al. 1998) in (Table 1), recommends opening windows for natural ventilation to reduce energy consumption in moderate climates. There is difficulty of providing natural ventilation during working hours in Cairo and therefore all strategies to improve natural ventilation. Renewing lighting systems is assumed as an energy conscious measure. However, PV retrofitting for office building facade was considered in this research as an option for energy conscious retrofitting.

Table 1 Retrofit levels according to building loads based on (Kendrik et al.1998).

Heat gains (W/m^2)	Level of retrofit	Action
5-20	Level 1 Minor retrofit	opening windows, install blinds, redesign interior
20-25	Level 2 Intermediate retrofit	opening windows, install blinds, redesign interior, renew lighting system.
25-35	Level 3 Major retrofit	opening windows, install blinds, redesign interior, renew lighting system, using stair cores as stacks,building management system to control night cooling with motorized windows/vents.
35-45	Level 4 Complete retrofit	opening windows, install blinds, redesign interior, renew lighting system, usingstair cores as stacks, building management system to control night cooling with motorized windows/vents, radical change to air flow path by adding atriums, use of double facades.

Phase Three

Considers reaching a balanced decision on retrofit options balanced by user satisfaction analysis. User satisfaction and environmental psychology aspects underpinning the relationship between occupants and facades has to be taken into consideration.

3. PV integration in office buildings

Nearly 90% of the world market of PV cells is dominated by crystalline silicon in its multicrystalline and monocrystalline forms. The most important features of PV cells are their efficiency, long-term stability, and extremely low cost. PV cells made of monocrystalline have generally been used because of their high efficiency. However, the cost of silicon constitutes a significant proportion of the total cost of a solar cell. Thus, great efforts have been made to reduce these costs and increase the growth of a more chipper PV cell made by multi-crystalline silicon. Further-more, with the scarcity and raised price of silicon, crystalline ribbon technologies have been tremendous activities as well.

The development of crystalline silicon thin-film PV cells is an inherent possibility for cost reduction, and there are various overview articles that describe the ongoing research activities in the different approaches. The amorphous silicon type PV cell is one of the earliest products that appeared in the market. When it was created, the high expectations placed on this material were curbed by the relatively low efficiency that had been obtained and by the initial light induced degradation for this kind of solar cell. Recently, however, the amorphous PV cell has cemented its place in consumer applications with the benefits of flexibility of usage and good aesthetic reason. After partly solving the problems of light induced degradation, amorphous silicon entered the power market. The visual appearance of thin film modules makes them attractive for facade applications. According to (Hwang, Kang, & Kim, 2012) the monocrystalline silicon PV panel (SunPower SPR-220) has the highest efficiency among the selected PV panels. It can cover 6% of the electric energy consumption of a building if all exterior is surrounded by PV panels without any gap for window openings. The amorphous type (Uni-solar PVL-136) shows the lowest efficiency, and the maximum expectation is lower than 3% and the maximum expectation of electric energy production in these cases is 3.33% Sun-Power. The maximum expectation with the monocrystalline silicon PV panel does not satisfy the 6% reduction of the building's electric energy consumption. Therefore, a novel approach is needed, such as using more efficient PV panels and reducing the system load by using wires and inverters.

Taeyon Hwang, Seokyoun Kang, Jeong Tai Kim them (2012) conducted a study on integration of PV system in office buildings.

This study analyzed the maximum electric energy production according to the inclination and direction of photovoltaic (PV) installations and the effects of the installation distance to the module length ratio.

They proved that the electric energy production due to the use of the PV system can cover approximately 1–5% of the electric energy consumption of a typical office building in Korea in terms of proper combinations of the following installation factors: inclination, module type, installation distance to module length ratio,and direction. However, if in the building all measures, currently known and technically available would be implemented, the percentage of covering by PV can be significantly bigger.

Panopoulou,I.(2008) conducted a research on PV retrofitting of a building in Greece. Panopoulou,I stated that a successful integration of BIPV into a building (residential or public) requires technical and architectural knowledge. Most of the systems in use are roof mounted, failing to take advantage of the design opportunities offered by BIPV systems now adays. Close cooperation at the design stage between architects and manufacturers can lead to better integration with less conservative but in the meantime more potentially risky ideas.

The problems of financing and ownership of photovoltaic systems should be undertaken by energy companies and governments through tax incentives and subsidies as well as support policies. This will result in reduced pay-back periods for the consumer and in a steady growth of the sector, while high-quality installations will be delivered.

3.1. PV integrated in shading devices

Over the last century the proportion of the office buildings' envelope that is transparent has increased significantly (Bizzarri, Gillott,& Belpoliti, 2011). Due to low thermal insulation property of glass in comparison to mass opaque building materials the larger the transparent fraction of the building's envelope the more important is the control of solar energy inflow, in order to keep thermal and visual conditions indoors in acceptable levels. Transparent facades need an additional control system, one that helps avoid solar radiation during the overheated period, allows enough thermal loads during the underheated period and ensures comfortable visual conditions during operating hours.

Due to the fact that passive design is most of the times not totally efficient for the control of solar and thermal gains, additional active systems are used to balance the interior thermal and visual comfort conditions. As a result, today's buildings are dominated by technical systems for heating, cooling, ventilation and artificial lighting often resulting in high conventional energy consumption (Karkanias, Boemi, Papadopoulos, Tsoutsos, &Karagiannidis, 2010) and high CO2emissions (Meggers et al., 2012).PV shading devices can help limit the overall energy consumptionin two ways: by reducing direct solar gains during the overheated period and by producing electricity to be utilized for the function of cooling, heating and lighting systems.Integration of PVs in shading devices is an intermediate solution falling between the BIPV (Building Integrated Photovoltaic Panels)and BAPV (Building Attached Photovoltaic Panels) systems as were described by Peng, Huang, and Wu (2011). This integration of PVs has the advantages of the BIPV, is architecturally "clean" and attractive and offsets the cost of the shading material and the advantage of BAPV: in case they are damaged the buildings' internal functions not affected.

Various researchers tested PV systems integrated in Building (BIPV) in many applications. Especially the Integration of PV in shading devices has been researched in different latitudes and geometrical, architectural relations

(Kang, Hwang, & Kim, 2012). More specifically, PV modules applied as shading devices have been designed and used in many buildings all over the world. Since 1996, in Albany University PV modules have been used as sunshades providing 15 kWp of energy simultaneously reducing cooling loads (Eiffert & Kiss, 2000). The combination of produced electricity with the improvements in the indoor quality conditions makes the use of BIPV on shading systems a very promising application of building technology (Bloem, 2008).

since most shading devices are non-vertical surfaces, Cronemberger, Caamano-Mart n, and Vega Sanchez (2012) argued that "for non-vertical facades the solar potential represents between 60% and 90% of the maximum global solar irradiation, even when facing south, indicating that the use of sloped building envelope surfaces, such as atriums and shading elements on facades and windows should be promoted". Various geometrical configurations of PV shading systems have been tested by researchers according to their efficiency and applicability possibilities.

BIPV can be installed as external venetian blinds facing south with an appropriate inclination, reducing maintenance costs due to the lack of user involvement with the system. Another solution is internal PV venetian blinds requiring less supporting structure (Reijenga, 2002).

Due to the fact that external shading systems have proved to be more efficient in terms of lower thermal loads penetration in the interior (Olgyay & Olgyay, 1963), Energy production for different geometrical configurations of external Shading systems with integrated PV facing south (canopy, canopy inclined,Brise soleil systems, surrounding shade) were examined according to their energy production and the resulting indoor visual and thermal comfort conditions. Systems of "surrounding shade" and of "canopy inclined single" proved to be the least energy consuming (Mandalaki, Zervas, Tsoutsos, & Vazakas, 2012).

Another important factor when assessing different geometrical cofigurations of PV shading systems is the simulation tool used or the measuring method of the real installation followed. Differences in the calculated values of energy production would emerge because of two reasons: due to different algorithmic equations used for estimating the energy production and due to differences in the reference conditions (Word Energy Council, 2013).

Relevant research of PV modules used in south facade is presented by Bloem (2008). Ninety-nine PV poly-crystalline Si modules are mounted in a horizontal spandrel enclosure on the south façade of an office building and are simulated with TRNSYS. This structure works as a window shading system with power 36 W in Standard Test Conditions (STC). Natural ventilation was assumed in the module enclosure via vents in the upper and lower surfaces. Due to the fact that the technical data provided by the PV industry is based on standardized measurements under laboratory conditions described in IEC 61215 (2005), when comparing laboratory data, the same STC should be kept. These are described as Standard Reference Environment (SRE) and are the following: Tilt angle: At normal incidence to the direct solar beam at local solar noon, total irradiance: 800 W/m2, ambient temperature: 200 C, wind speed: 1 m/s, electrical load: 0 A (open circuit, thus no current owing), open rack mounted PV modules with optimized inclination. The conversion from STC to outdoor open rack conditions is studied and indicates an error of about 2% for p-Si PV-modules (Anderson,Bishop, & Dunlop, 2000).

Bloem (2008) also studies the influence of the increase of the air flow rate to the electricity production of the PV vertical windows using the computational fluid dynamic software FLUENT. An increase in the electricity production is observed with the increase in the air flow.

The positive effect of PV shading systems to visual comfort in the interior of a building has been proven: Bloem, Colli, and Strachan (2005) presented an analysis based on simulation results using Esp-r software for three European areas: Greece (Athens), Spain (Barcelona), Italy (Milan) and they proved that apart from over-heating, PV applied as shading devices can also reduce the effect of glare. A basic parameter when examining different PV systems integrated in shading devices is the technology of PVs used. In order to make the shading devices more competitive in the market the glass content of the PV louvers was minimized. Weight reduction was achieved by substituting glass components of PV modules (at least in part) by flexible membranes (ZSW, 2007). The only disadvantage was that these types of flexible PV modules have a lower efficiency factor due to the type of material of the PV used. Amorphous silicon was used to substitute glass PV components, in order to make them flexible. Due to their disadvantage of low efficiency. The progress in the market penetration of these types of systems is not the one anticipated, as can be seen for example in Korea,according to Hwang et al. (2012). None of the PV panels examined are made of amorphous silicon PV cell whose efficiency is much lower than monocrystalline and multi-crystalline (Kang, Hwang, &Kim, 2012).

Assessment of energy production from PV cells

M. Mandalaki, S. Papantoniou, T. Tsoutsos (2014) conducted a study on the assessment of energy production from photovoltaic modules integrated in typical shading devices.

The main objective of this study is concentrated in the evaluation of three well known available tools used to estimate the energy production of the PV panels integrated in shading systems. The tools available were divided into simple simulating tools, to more complete simulating tools and to measurements of real PV installations. Three processes have been followed in order to reach the afore-mentioned objective:

The work carried out was an analysis in the subject of solar energy production by PV modules integrated in typical shadings devices and the methods of evaluation used. It is concluded that the method of evaluation used depends on the desired accuracy of the results and the comparative or absolute research done. The theoretical efficiency of 12% used in simple model equation is accurate enough only for simple geometrical configurations of shading devices. It is noteworthy however, that even the complete model, in relation to real market products, is accurate enough only for simple geometrical configurations. For more complicated geometries other types of research are needed. For venetian blind systems, for example, only the in situ measurements are accurate enough when exact values of energy production are needed. For systems with integrated PV that produce energy only through reflected solar radiation both simple simulation model done with a sensitive application and complete model of real market products are accurate enough.

3.2. Semitransparent PV

several studies were conducted highlighting the potential of semi-transparent photovoltaics. These devices are characterized by peculiar application-qualities, establishing themselves as an alternative to glazing systems. In addition, they can offer the active-function of producing energy.

A consequence of this active action is the passive feature: the capacity of partially reducing solar radiation transmission. This peculiarity becomes relevant for particular architectural typologies.

Offices or public buildings in general, often characterized by vast glazing facades. In these cases, the semi-transparent PV devices optimize their function by counterbalancing their limited photovoltaic performance, given by the inappropriate position (high tilt angle on facade), with the passive function, which helps reduce the energy demand for the cooling system.

This consideration increases the interest for these technologies overall in relation to northern European climates, where the lower solar azimuth allows for steeper applications, while Mediterranean countries usually prefer inferior tilt angles for photovoltaic plants (from 30 to completely horizontal).

For instance, the Norwegian University of Science and Technology (NTNU) has been refurbished by applying a second skin on the original facade of the building. The 16 kWp facade, reducing sunlight transmission, allows a 10–15% space cooling-energy reduction.

Regarding rooftop application, the Stillwell Avenue Station, Coney Island, New York (by the architectural firm Kiss & Cathcart) is distinguished by a 2730 amorphous-silicon modules system integrated to the roof structure. The PV plant produces about 240 MWh yearly, and has the capacity of partly reducing the direct solar radiation thanks to its partial transparency (25% solar transmission).

These examples show how the photovoltaic integration modifies the building envelope, its volume and structure, thus changing its energy performance. The semi-transparent characteristic of these particular devices makes them suitable for HVAC integration, with the objective of optimizing thermal-exchange processes.

Concerning the architectural integration of such devices, it is important to discuss the manufacturing processed performed to achieve the semi-transparency characteristic. Such aspect is essential for these particular PV systems. PV's sustainability has been recently proved by several Life Cycle Assessment (LCA) analysis (Bizzarri &Morini, 2006, 2007; Frankl, 2001; Frankl & Masini, 2002; Keoleian & Lewis, 2003; Knapp & Jester, 2001)); however, such studies do not include the industrial processes aimed to achieve semitransparency, which can heavily influence the entire LCA. The preliminary analysis, in researches are still partial because of the difficulties of recovering significant and precise data from manufacturers. Nevertheless, it has stated once more the necessity of classifying these PV devices in relation to the industrial process of acquiring a degree of semi-transparency.

Giacomo Bizzarri A, Mark Gillott B and Vittorino Belpoliti (2011) conducted a study on the potential of semi-transparent photovoltaic devices.they highlighted the necessity of developing new devices with semitransparency characteristics, and also high efficiency.

They presented a review of the semi-transparent photovoltaic Technologies. The evaluation of the different typologies highlighted how the specific photovoltaic material and the manufacturing process to achieve semitransparency are the most significant parameters to adopt for a product classification. They proved the energy savings and environmental benefits achievable thanks to the application of such devices.

The investigation has resulted in the development of several semi-transparent crystalline-silicon PV devices adopting the gap-cell alternation method. Such succession transparent segment – opaque PV segment is achieved thanks to a simple manufacturing process, by outdistancing standard crystalline silicon cells (typically 10 cm ×10 cm or 12.5 cm ×12.5 cm) on a glazing layer. The obvious consequence is a longer production process to complete the PV module. However, the extra procedure does not compromise the product's overall energy cost.

The aesthetical appearance of such products recalls architectural components such as sun-shading systems or brise soleil.

The application and aesthetical peculiarities, rather than the technical ones, are the characteristics that qualify the diverse products on the market. In fact, the devices' energy performance is nearly equal: the semiconductor is often crystalline silicon, and the cell layout basically established, with similar alternation gap-PV cell.

Among the most interesting product, we find the so-called custom-products, items that are designed to be flexible to the client's need. A remarkable example of such a technology is the Optisol module by Scheuten Solar. The conventional mono-crystalline silicon cell assures a high energy performance (16%); however, the innovation consists of its ductility of application: the manufacturer has created a module that can be used either on rooftop or on a facade, as applied on the Akademie Mont Cenis di Herne in Germany, thanks to the possibility of having it in different colours, shapes and dimensions.

4. Potential of PV integration in the energy retrofit of a case study

Previous works (Bizzari & Federico,2005) demonstrated how energy retrofit, adopting PV devices shows interesting results considering energy and environmental benefits.

The following part of the research will present the results of an energy retrofit simulation for applying PV panels on the façade of an office building in Cairo.
Different PV integrations are simulated to determine the possible energy production from these systems.The aim is to analyse the maximum electric energy production according to the orientation and inclination of photovoltaic.
PVSOL premium software was used to simulate different integrations and determine the energy production in each case. The building was modelled in PVSOL to determine shadow losses.
Also an economic analysis conducted and carbon emission reduction is calculated for each case.
The building is composed of seven floors. The height of each floor is 3.5 m. The building length is 64 m and width is 13 m.

- An energy analysis was conducted by designbuilder software to determine energy consumption patterns of the building.

- The available area was calculated for facades and roof to determine the possible area for installing PV modules.
- Three possible integrations were simulated to assess energy, cost and carbon emission reductions.

(1) Installing PV modules on the roof and west elevation.
(2) Installing PV modules on the roof, west elevation with PV integrated in shading devices.
(3) Installing PV modules on the roof and south elevation.

Case 1:
Roof mounted and west elevation PV installation.
The available area for both roof and west elevation were calculated.

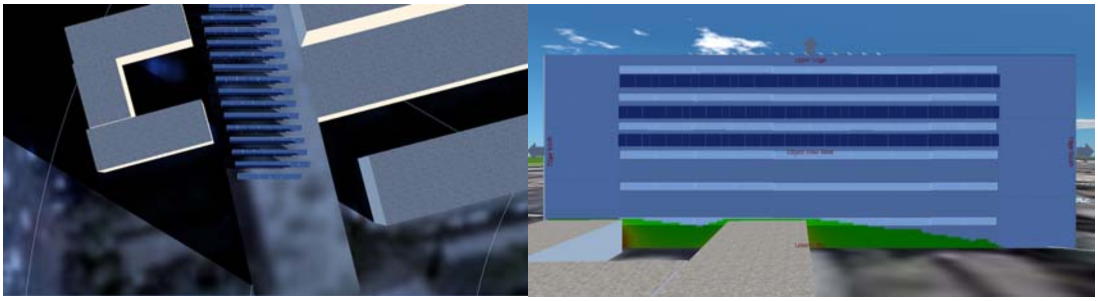

Fig. 1. (a) roof mounted PV system; (b) west elevation PV.

Table 2 Results for roof and west elevation PV installation.

Case 1	Roof and west elevation PV integration.
Climate data	Cairo(1986-2009)
PV Generator output	61.75 kwp
PV Generator surface	405m^2
Number of PV modules	247
Number of inverters	10
The yield	
PV Generator Energy(AC grid)	68,554 KWh
Spec.Annual yield	1,110 KWh/KWp
Performance ratio(PR)	76.4 %
Calculation of shading losses	4% / year
CO2 Emissions avoided	41,013 Kg/year
Cost	
Total investment costs	92,625 $
Return on assets	5.83%
Amortization period	12.4 years
Electricity production costs	0.07 $/kwh

Table 3 Results for west elevation PV integration.

West elevation PV installation	
PV modules	144*SOLON Blue 220/16(250 Wp)
Inclination	90°
Orientation	West 257 °
Installation type	Roof parallel
PV generator surface	236 m^2
PV generator output	36 KWp
Global radiation at the module	1061.8 KWh/ m^2
PV generator Energy (AC grid)	27,768 KWh/year
Spec.Annual Yield	744.6 KWh/KWP
Performance ratio(PR)	75.2 %

Table 4 Results for roof PV integration.

Roof mounted PV installation	
PV modules	103*SOLON Blue 220/16(250 Wp)
Inclination	30°
Orientation	South 180 °
Installation type	Mounted Roof
PV generator surface	168.9 m^2
PV generator output	25.75 KWp
Global radiation at the module	1986.1 KWh/ m^2
PV generator Energy (AC grid)	40784.8 KWh/year
Spec.Annual Yield	1583.9 KWh/KWP
Performance ratio(PR)	75.2 %

Table 5 Inverters.

Inverters	
Inverters (west elevation)	6 * powador 7.8 TL3
Manufacturer	KACO new energy
Configuration	MPP 1+2 :2X12
Inverter 1(roof mounted)	3 * powador 7.8 TL3
Manufacturer	KACO new energy
Configuration	MPP 1+2 :2 X 13
Inverter 2 (roof mounted)	1 * powador 7.8 TL3
Manufacturer	KACO new energy
Configuration	MPP 1+2 :2X12

Case 2:
Roof mounted and west elevation with PV modules integrated in shading devices.

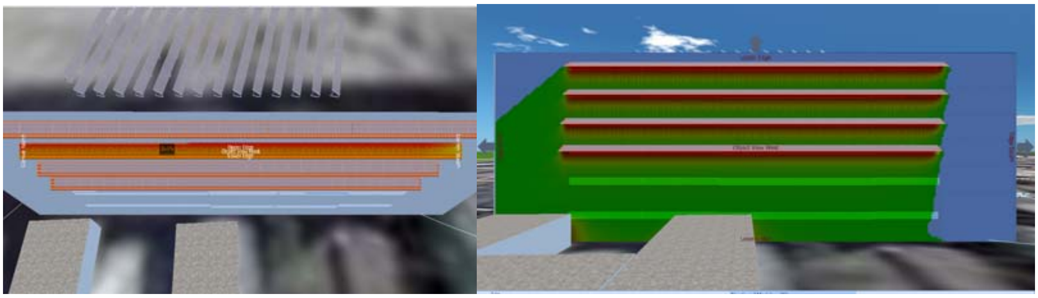

Fig. 2. (a) shading frequency in shading PV system; (b) shading frequency on west elevation.

Table 6 Results for roof and west elevation PV installation.with PV integrated in shading devices.

Case 2	Roof and west elevation PV integration with PV integrated in shading device
Climate data	Cairo(1986-2009)
PV Generator output	90 kwp
PV Generator surface	595m^2
Number of PV modules	363
Number of inverters	14
The yield	
PV Generator Energy(AC grid)	76,537 KWh/year
Spec.Annual yield	843KWh/KWp
Performance ratio(PR)	54 %
Calculation of shading losses	32.1/ year
CO2 Emissions avoided	45,757 Kg/year
Cost	
Total investment costs	136,125 $
Return on assets	2.46%
Amortization period	17 years
Electricity production costs	0.09 $/kwh

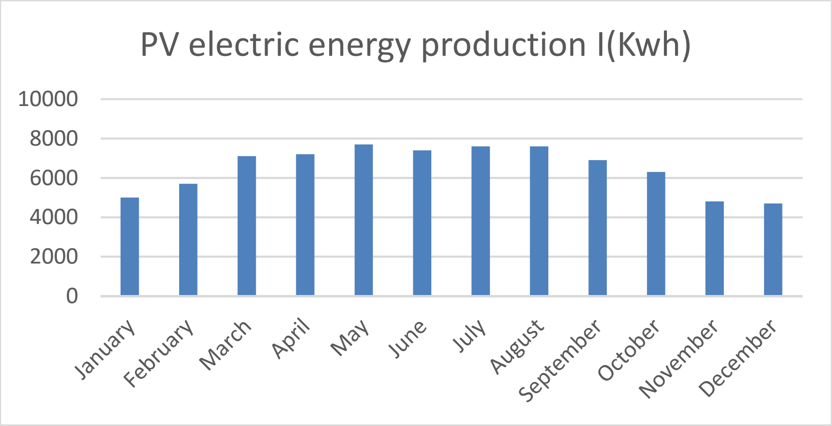

Fig.3 PV electric energy production

Table 7 Results for PV integrated in shading devices

PV integrated in shading device	
PV modules	116*SOLON Blue 220/16(250 Wp)
Inclination	30°
Orientation	West 257 °
Installation type	Roof parallel
PV generator surface	190.4
PV generator output	29 KWp
Global radiation at the module	1783.8 KWh/ m^2
PV generator Energy (AC grid)	25456 KWh/year
Spec.Annual Yield	787.3 KWh/KWP
Performance ratio(PR)	44 %

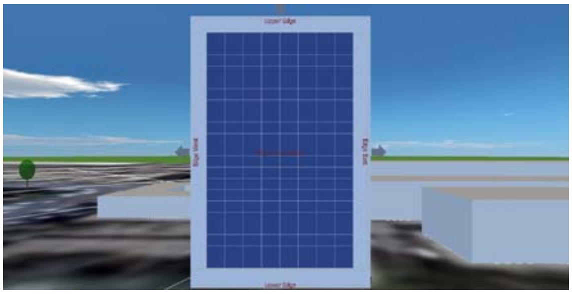

fig.4 PV installation in south elevation.

Table 8 Results for PV integrated in south elevation

PV integrated in south elevation	
PV modules	168*SOLON Blue 220/16(250 Wp)
Inclination	90°
Orientation	South 164 °
Installation type	Roof parallel
PV generator surface	275.5 m^2
PV generator output	42 KWp
Global radiation at the module	1115.8 KWh/ m^2
PV generator Energy (AC grid)	34948.9 KWh/year
Spec.Annual Yield	832.1KWh/KWP
Performance ratio(PR)	74.3 %

5. Conclusion

The research presents a review of photovoltaic technology.

An energy retrofit operation with PV modules have been simulated for an office building. The evaluation of different configurations highlited the effect of installation factors like orientation and tilt angle on electric energy production.PV integrated in roof and in south elevation showed better energy production levels.followed by shading device installed in west elevation with inclination angle of 30°while west installations was the least..PV modules can contribute to reducing electric energy consumption in office buildings by choosing appropriate orientation,tilt angles and module types.

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