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Building Integrated Photovoltaics for Energy Load Reduction and Supply

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ABSTRACT

Photovoltaics as an environmentally friendly source of energy are still considered as an economically expensive method of electricity production. However, replacing the conventional elements of the building envelope (façade, shading devices, skylights, etc.) with PV modules, the total cost of a built construction is remarkably reduced. The main aims of this study to use building integrated photovoltaic (BIPV) system beside its functions that has mentioned above, to reduce the energy consumption from the cooling load of buildings in warm climate regions. The paper investigated the optimum integration of the photovoltaic system into the building envelope that could produce a reasonable power output and minimizes the heat gains in warm climate regions. The simulation software Autodesk Ecotect Analysis was used to simulate three main PV integrations, window sunshade, roof screen and double skin façade into an assumed office-building model located in the city of Benghazi, Libya. The simulations provided good information for analyzing the potential contribution of the BIPV system on the energy saving according to the PV thermal performance and the power supply generated from the sun, and the final discussion results in choosing the sunshade PV integration as the optimum integration that could produce a reasonable power output and minimizes the heat gains in warm climate regions.

Keywords: *building integrated photovoltaic, energyconsumption, coolingload, poweroutput.*

1. Introduction

There is plenty of information around about the suitability and characteristics of timber, masonry, glass, steel and concrete construction, and other building industry materials, but what do we know about "photovoltaic construction"? What kind of material is this, which has become available to architects in square meters of building envelope surface?

Architects as a consultant for customers, they must carefully design the function, the aesthetic and the technical of the building. Therefore, in the case of building integrated photovoltaic, the consideration at the primary design of the project will result in a useful integration. For some integration systems such as facade and atrium, it is significant to know the thermal properties of PV materials. Thus, architects should have the knowledge and the techniques to promote PV integration in the building's envelope.

2. Solar and Energy in Libya

At any location, the information on solar energy properties and the meteorology parameters play an important role for studying, planning and designing solar energy applications. Libya is located in the heart of North Africa with 6 million occupants distributed over an area of 1,750,000 Km^2, 88% of its area is desert areas, the high inherent of solar in the Sahara desert in the south could be used to produce electricity by both thermal and solar energy conversions Photovoltaic. The daily average of solar radiation on a horizontal plane is 7.1kwh/m^2/day in the coastal region and 8.1kwh/m^2/day in the southern region, with sun period of more than 3500 h /annum [10].

The high potential of solar energy in Libya could be considered as a future source of electricity, in hot climatic conditions, a substantial share of electricity goes to theair-conditioning of buildings [6].

3. Building and Energy Consumption

Buildings generate significant impacts on the environment during their life cycle; these impacts come from the energy consumed during the occupation of the building and from the materials used for the construction. However, the fossil fuels from are not inexhaustible, and burning them discharges carbon dioxide (CO_2), one of the main greenhouse gases, which are believed to be responsible for global warming. Buildings consume 42% of the world's total energy, responsible for all atmosphere emissions with about 40%, and 30% of all building materials used; all these can be substantially influenced by architects and engineers [13].

To design a building, environmentally friendly and perfect energy conversion system, it could be hard to create something more effective than the PV cell. In the Photovoltaic cell, a gadget exploits an energy source that is the most plentiful of those available on the planet [2].

4. Building and PV Interaction (BIPV)

The first installation of building-integrated Photovoltaics (BIPV) was realized in 1991 in Aachen, Germany [1]; the photovoltaic elements were integrated into a curtain wall facade with isolating glass. After finishing the first BIPV installation, the demand for modules constructed for building-integration grew rapidly.

For general energy supply, it will be necessary to integrate a large photovoltaic system. The architectural treatment of large areas of photovoltaic and selecting from vireos types of modules will be the key design considerations, vireos shapes, vireos colors or vireos textures of modules to be applied to face off the building. For buildings with energy independent, the accurate size of the photovoltaic system will be depended on the system efficiency and the yearly output that could be generated. The designer will have to carefully design the building around the integrated system to accommodate a specific number of modules [9].

To qualify a project as 'well-integrated', building quality and the technical performance of the photovoltaic system have to be done in a professional way, and of course, the architectural quality has to be of a high standard. A poorly integrated PV system on a good designed building might be disturbing, but a poorly integrated PV system on a poorly designed building is clearly worse. Similarly, an elegant PV system will not necessarily improve the overall design.

The building envelope provides a number of possibilities for the integration of PV. According to Stark, 2009, the main options are [12]:

- Roofs integration.
- Facades integration.
- Solar Control (Sunshade elements) integration.

If designers have to decide a single PV integration into the building envelop to save costs, in this case, what is the optimum integration of the photovoltaic system into the building envelope that could produce a

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reasonable power output and minimizes the heat gains in warm climate regions?

5. Methodology withData Collection and Analysis.

The answer for the main study question that been asked, will be discussed by using computer simulation of three main different PV integrations into an assumed office building in Benghazi city, Thus the first step of this discussion should be outlining the features of the software program that will be used to simulate the building module and then analyzing the weather data of the location of the office building will be situated by using this program.

5.1. The Software Program

'Autodesk Ecotect Analysis', integrates an interactive design and 3D modeler with an expanded range of environmental analysis tools, which enables designers to simulate their building performance from the primary stages, a time when simple decisions can have long-term effects on almost every performance feature of the final project.

5.2. Location Data

The city of Benghazi, Libya Latitude: (32°07'12"N), Longitude: (20°04'12"E), Altitude: 131 m. The assumed office building will be situated in the heart of Libya's second largest city, Benghazi, on the Mediterranean Sea.

5.3. Weather Analysis

Summer's season in Benghazi is warm and dry; winter is mild with infrequent rain, spring and autumn are the finest times' year round. The following table (1) show the years average weather condition readings for Benghazi. As it can be seen, a notable high average temperature during June, July, August and September, thus the highest energy using for air conditioning system will be in these months.

Table 1. Solar surface meteorologyof Benghazi [7].

Variable	J	F	M	A	M	J	J	A	S	O	N	D
Insolation, kWh/m²/day	2.71	3.64	4.90	6.36	7.14	7.93	7.97	7.26	5.92	4.40	3.06	2.47
Clearness, 0 - 1	0.49	0.53	0.57	0.63	0.65	0.70	0.71	0.70	0.65	0.59	0.52	0.48
Temperature, °C	14.76	14.62	15.90	18.73	21.83	24.63	25.96	26.90	25.91	23.34	19.85	16.31
Wind speed, m/s	6.41	6.79	6.65	6.31	6.05	5.61	5.75	5.65	5.64	5.23	5.86	6.45
Precipitation, mm	69	36	24	7	4	0	0	0	3	21	28	60

5.4. The Assumed Office Building Parameters

The shape of the building is a simple rectangular with dimensions of 35m long, 14m wide and 14m high. Four-story building with total living space area equal 1960m^2, exterior wall area (excluding glazing area) is 1485m^2; the area is 376 m^2, and the roof area is 490m^2, with a whole volume amount to 6860 m^3, Figure (1).

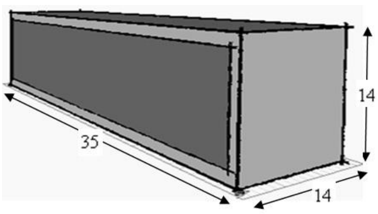

Fig. 1: The assumed office building parameters.

The building materials and properties were extracted from the wide choice of materials standard data available in the Ecotect program.

The maximum number of staff could use this office is 210 member (9.3m^2/person), the comfort temperature is 22°C, fresh air rate is 20 CFM/person, the office equipment is 22W/m^2, the lighting levels are fluorescent lights, 20 W/m^2, with a full air conditioning system (Ecotect).

The common type of material for external wall in Libya is (Concrete Block Render), 20mm externally rendered, 150mm concrete block with 20mm plaster inside, with an overall U-value 1.830 W/m^2.k (Ecotect), Figure (2).

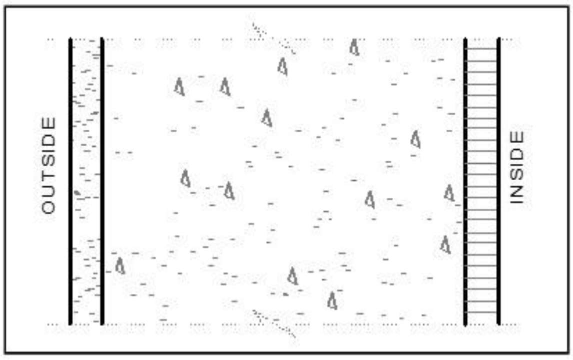

Fig. 2: The external wall (Concrete Block Render).

The common type of material for roof in Libya is (Concrete Roof Asphalt), 6mm asphalt cover, 200mm concrete Light weight, 600mm air gap and gypsum, with an overall U-value 0.720 W/m2.k (Ecotect), Figure (3).

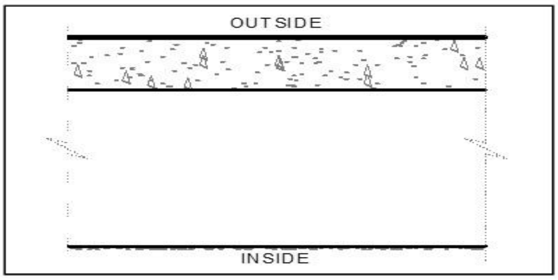

Fig. 3: The roof (Concrete Roof Asphalt).

The window is double-glazed with aluminum frame, 6mm glass standard, 30mm air gap, 6mm glass standard, and theU-value is 2.70 W/m^2.k (Ecotect), Figure (4).

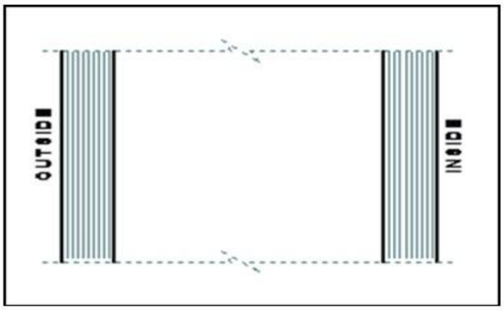

Fig. 4: The window double-glazed with aluminum frame.

5.5. Simulate The Building Model

Once the building parameters and the envelope data are defined and uploaded into the program, and the location weather data as well, the window side of the building will be faced the south, the simulation of the model is performed using the Ecotect program to calculate the energy loads for cooling demands during the peak period of the warmest months in the year, June, July, August and September.

Figure (5) shows the first simulation for the base model without any PV integration, this reference model will be used as a foundation to compare and level the result of each of the next integrations of the PV into the building envelope.

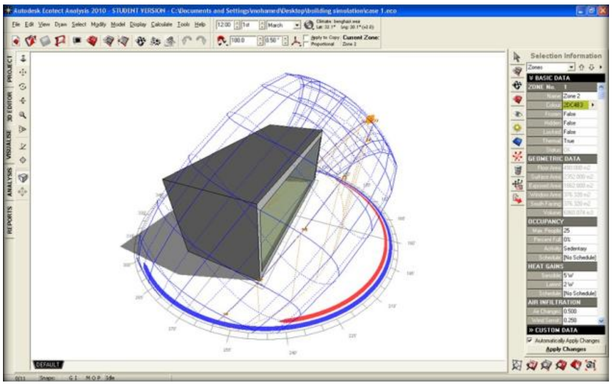

Fig. 5: The reference model simulation (Ecotect).

Figure (6) illustrates the energy calculations for cooling and heating along the year. To focus on the peak energy demand for cooling periods; it is obvious that the most demand usually during July and August months, Figure (7).

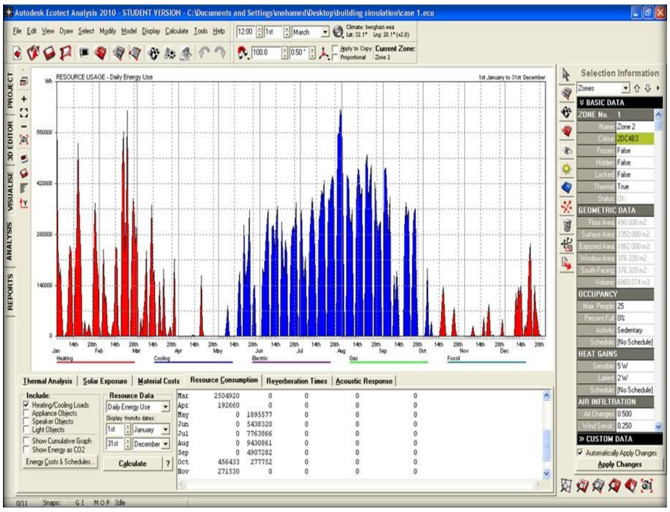

Fig. 6: The energy calculation for cooling and heating periods (Ecotect).

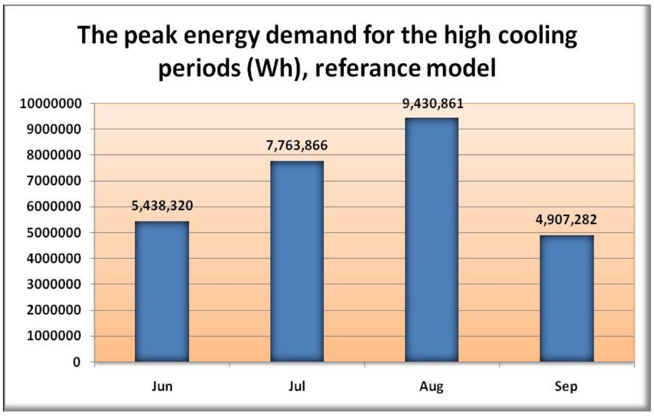

Fig. 7: The peak energy demands for cooling periods (Ecotect).

5.6. Simulate the Building Model in Different PV Integrations

Using the same reference model parameters to integrate the PV into the building envelope in three main different ways to compare their results with the base model result and Figuring out the optimum integration that will be answering the study question.

To start the simulation, the type of the PV module needs to be chosen, thus, among a hundreds of the good quality PV module producers, the decision is been made to choose Schottsolar company, and The reason for this choice is the company's attention to the issue of thermal and the high temperature of the PV modules.

5.6.1. Simulate the Building Model with the PV WindowSunshades Integration

The PV module that has chosen to be integrated into the building as window sunshades from Schott Company will be SCHOTT POLY™180, with nominal power ≥ 180W, the cell type is polycrystalline, and the module dimensions are 1.62m×82m [11].

The total area of the PV modules is 110.692 m^2, that means 84 modules distributed in four floors as illustrated in Figure (8), and these modules should produce a total power equal 15,120W, the approximately total cost of these modules will be amounted to $13,144 [8].

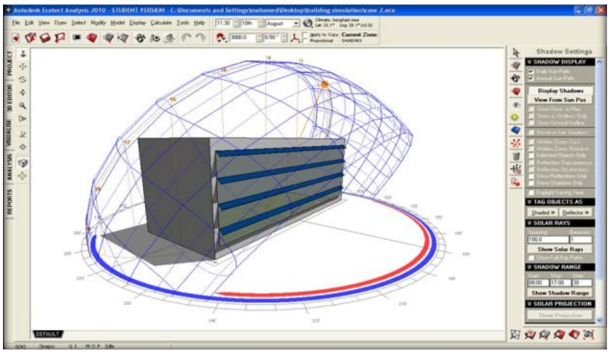

Fig. 8: The PV integrated into the building as windowsunshades (Ecotect).

The photovoltaic cell's ideal tilt is derived from the degree of latitude of the location, therefore, the optimum tilt of the shading PV modules to receive the maximum solar radiation calculated with this simple formula: tilt = 0.9 × latitude, thus, the optimum tilt will be equaled to 29◦ (the city latitude 32.1 × 0.9), [4].

Figure (9) illustrates the energy calculations for cooling and heating along the year for this integration. The peak energy demand for cooling periods that illustrated showed a good reduction in this integration, especially in July and August months when it is compared with the reference model results.

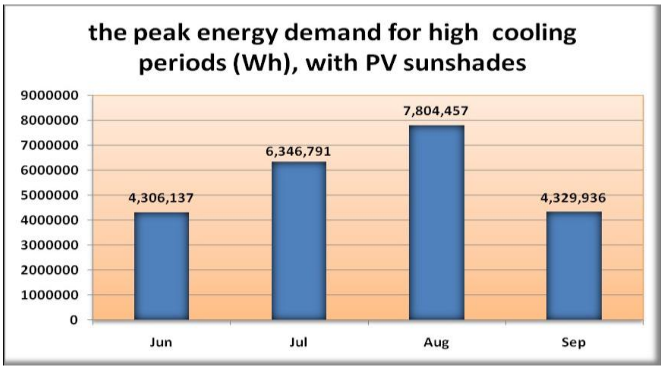

Fig.9: The peak energy demands for cooling periods with the sunshades integration(Ecotect).

The PV modules energy output in this integration was calculated by using Ecotect program and the total energy output will be equaled 6,590,813Wh per annum. Figure (10) illustrates the daily solar collector calculations according to this integration (Ecotect).

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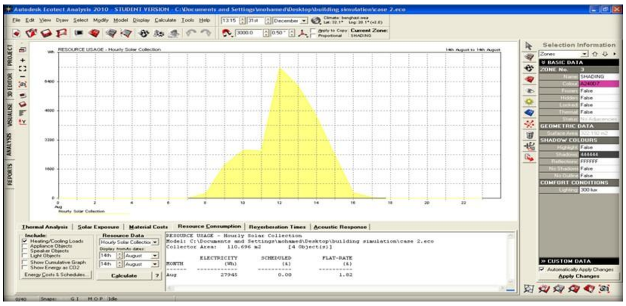

Fig.10: the daily solar collector calculations with sunshade integration (Ecotect).

5.6.2. Simulate the building model with the PV integrated as a screen over the roof

The same PV module that used in the previous integration will be used in this one as well; the total area of the PV modules is 416 m^2, which means 317 modules integrated into the building as a screen over the roof, with 3m high to get a useful space underneath it as illustrated in Figure (11). These modules should produce a total power equal 57,060W; the approximately total cost of these modules will be amounted to $49,620[8].

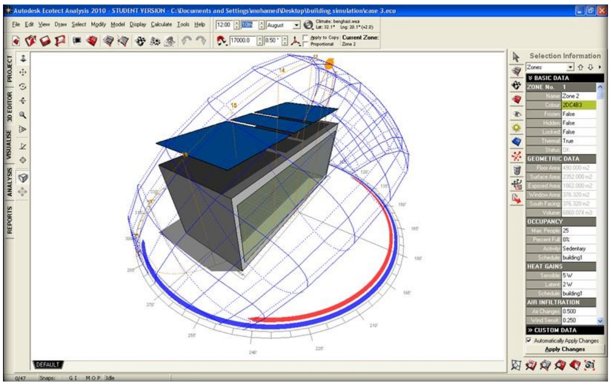

Fig. 11:the PV integrated into the building as a screenover the roof (Ecotect)

Figure (12) illustrates the energy calculations for cooling and heating along the year for this integration. The peak energy demand for cooling periods that illustrated showed just a slightly reduction in this integration when it is compared with the reference model results.

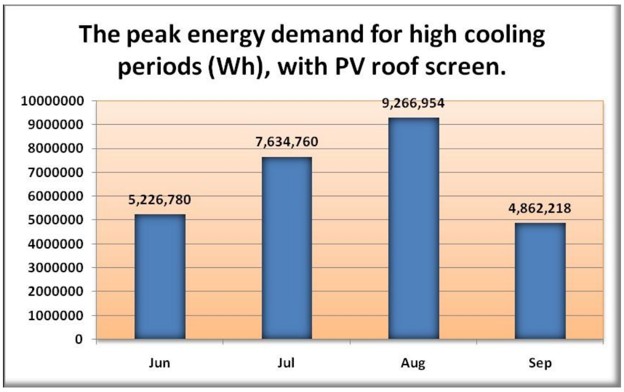

Fig. 12: the peak energy demands for cooling periods with the PV roof screen integration (Ecotect).

The PV modules energy output in this integration was calculated and the total energy output will be equaled 35,542,735Wh per annum. Figure (13) illustrates the daily solar collector calculations according to this integration (Ecotect).

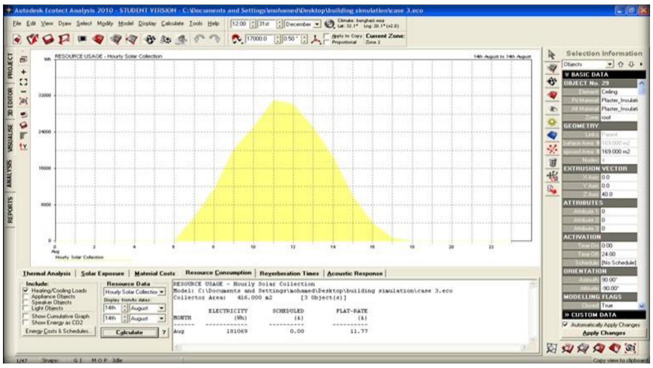

Fig. 13: The daily solar collector calculations with the PV roof screen integration (Ecotect).

5.6.3. Simulate the building model with the PV as double skin facade integration

As the position of The PV module needs transparency and thermal resistance, therefore, the PV module type that has chosen to be integrated into the building as double skin facade with air gap equals to 20cm, will be from Schott Company as well with a see- through effect, semi-transparent thin film with a-Si cells SCHOTT ASI™100, with nominal power ≥ 100W, and the module dimensions are 1.108m ×1.308m, the U-value will be 1.4 $W/m^2.k$ [11].

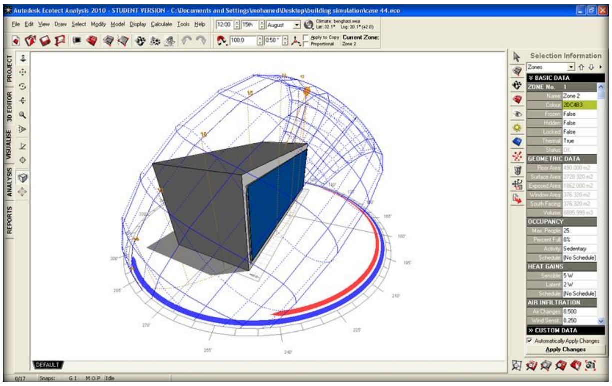

Fig. 14: The PV integrated into the building as a double skin façade (Ecotect).

The total area of the PV modules is 376 m^2, which means 260 modules integrated into the building as a screen over the roof, as illustrated in Figure (14) above. These modules should produce a total power equal 26,000W; the approximately total cost of these modules will be amounted to $22,610 [8].

Figure (15) illustrates the energy calculations for cooling and heating along the year for this integration. The peak energy demand for cooling periods that illustrated showed a little reduction in this integration when it is compared with the reference model results.

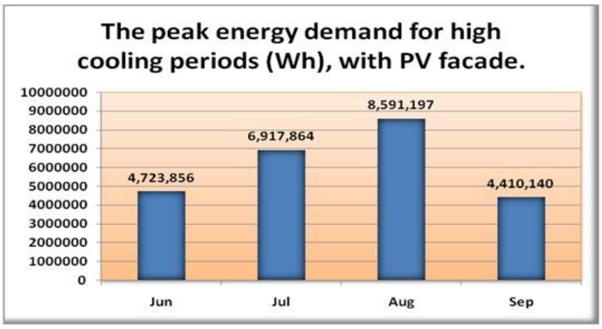

Fig. 15: The peak energy demands for cooling periods with the PV as double skin facade integration (Ecotect).

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The PV modules energy output in this integration was calculated and the total energy output will be equaled 1,901,537Wh per annum. Figure (`16) illustrates the daily solar collector calculations according to this integration (Ecotect).

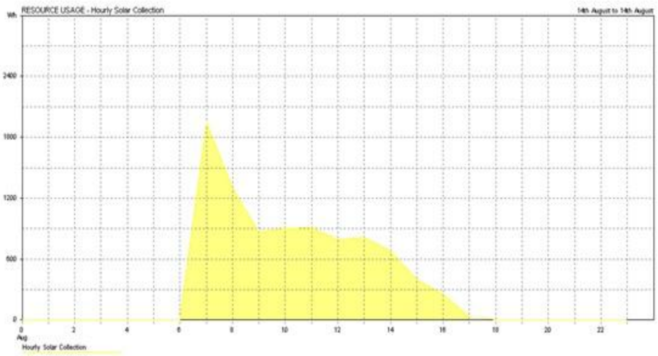

Fig. 16: The daily solar collector calculations with the PV as double skin facade integration(Ecotect).

6. Results discussion

The simulations provide good information to analyze the potential contribution of the BIPV system on the energy saving according to the PV thermal performance and the power supply generated from the sun.

6.1. The PV thermal effect:

Reducing the cooling demands during the peak load of the summer months was the first issue of these different types of integrations. Therefore, the effect of each type of PV integration will be discussed. Figures (17,18 and 19) show the energy saving after integrate three different types of PV modules compared with the reference model.

It can be seen that the window sunshade integration resulted in significant reductions in the amount of the summer months solar radiation entering into the building spaces, this reflected to a good saving in the energy with overall 17.26% reduction when it is compared with the reference model. The other integrations (roof screen and double skin façade) are not good saving as much as the sunshade integration with 4.83% and 10.52% respectively.

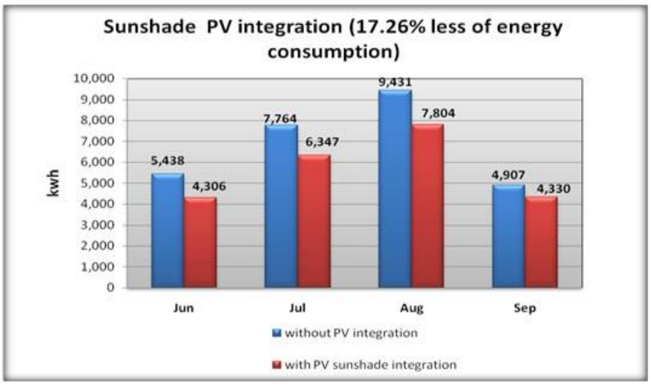

Fig. 17: The energy saving during the peak cooling load with sunshade PV integration.

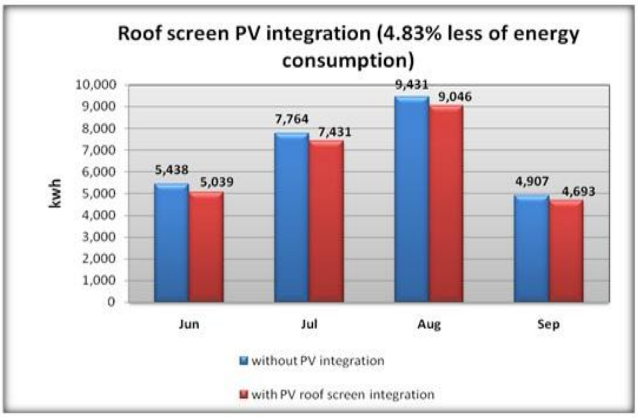

Fig. 18: the energy saving during the peak cooling load with roof screen PV integration.

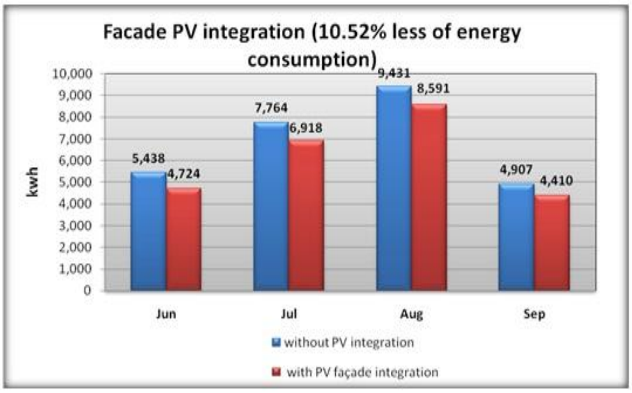

Fig. 19: The energy saving during the peak cooling load with double skin façade integration.

6.2. The PV Solar Power Generation

The second performance that should be discussed after the thermal effect is the solar power generation from the three types of integrations. Figure (20) shows the output energy that could be used as renewable clean energy from each type of the three integrations.

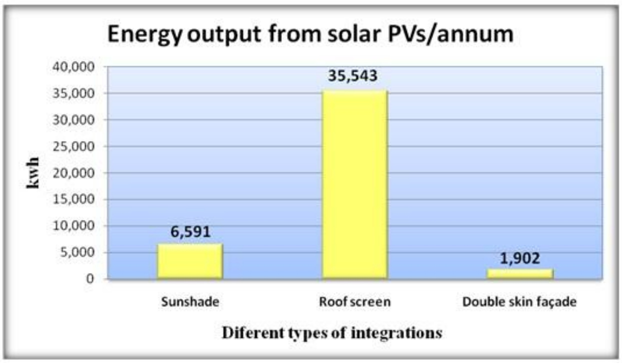

Fig.20: The annually energy output from the different types of the PV integrations

It is obvious that the roof screen PV integration has the higher output of energy with 35,543kwh, which could cover the peak load of cooling demand and more, while the other types of integrations are very low. If the PV area of each type is taken into account in the three integrations, as showed in Figure (21), it can be seen that the double skin façade has the lowest efficiency, and the reason behind that is the tilt of the PV modules 90◦.

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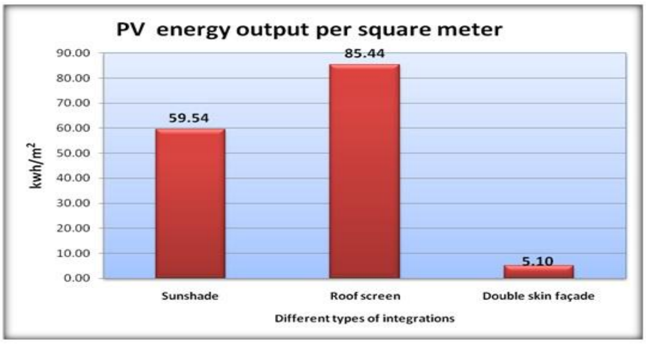


Fig. 20: The annually energy output from the different types of the PV integrations / m^2

Most of the solar radiation can be generated from the summer solar where the useful tilt can be figured according to the altitude of the building location, and according to Benghazi city altitude, the maximum output will be in the tilt between 0◦ to 35◦. The output energy from the sunshade PV is still reasonable compared with its area.

6.3. The cost of the PV Modules and the Power output

According to the power output and area of the PV module, the cost of the total modules in each of integrations was calculated according to Gupta, 2010, that mentioned before and which resulted in Figure (21) below [8].

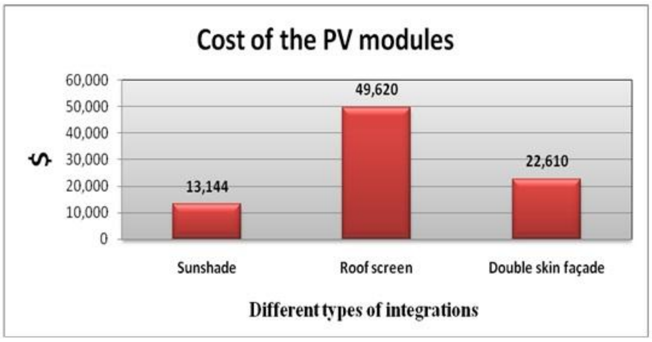


Fig. 21: The PV modules cost of the different types of integrations

On one hand, it can be seen from the above Figure that the cost of the roof screen PV integration is very high compared with the other integrations because of the PV modules area, on the other hand, the cost of the energy output from this integration will be the minimum as showed in the Figure below, this output cost can be figured out according to the lifetime of the PV modules (±25 years) and the total power output during this period with the total cost of the PV models ($/kwh) in the different types of integrations, Figure (22).

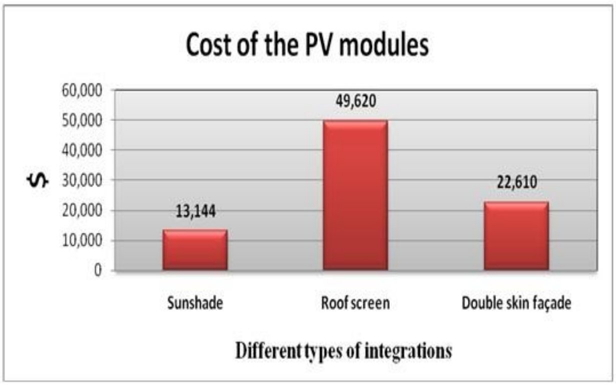


Fig. 22: The output cost of the different PV types

6.4. The different PV integrations and the CO_2 emissions reduction

The CO_2 emissions that could be saved from the reduction of the energy which converted according to Defra, 2015; it is obvious that the roof screen is the higher saving, Table (2) [3].

Table 2: The annually PV modules CO_2 reduction of the different types of integrations (kg/year).

CO_2 emissions reduction (kg/year)	Sunshade	Roof screen	Double skin façade
From the PV thermal effect	2,595	727	1,582
From the PVsolar output	3,599	19,406	1,048
Both thermal & solar	**6,194**	**20,133**	**2,630**

6.5. The Different PV Integrations and the Comfort:

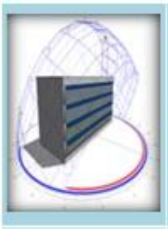
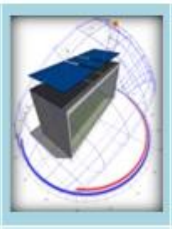
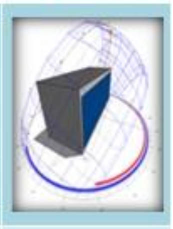
Concerning the day lighting, in an office building, artificial light accounts for a high percentage of energy use, lighting levels are set to improve the performance in an office environment. In warm and sunny climate like the assumed office building location, it is not practical to install big area of windows especially south facing, as the heat gains could be high from the direct solar radiation and the building cooling throughout the day. Another issue might be occurred from the direct solar radiation that is the glare and the visual comfort. However, the direct solar radiation can be controlled by using an optimum size and tilt of the PV sunshade device, and this integration can protect the area of windows from the solar radiation during the summer months and its glare, while the winter direct solar radiation can still pass through the windows area and maintain a good passive solar for heating and good level of visual comfort, furthermore, will offer a uniform distribution of light and good thermal performance, especially the office spaces that close to the windows. According to the previous results, Sunshade PV has succeeded in these issues with good performance while the double skin façade PV could be quite good at the building thermal performance, but not efficient with the visual comfort. Roof screen PV integration has no effecting on the building comfort.

7. Conclusion and recommendations

The simulations provided good information for analyzing the potential contribution of the BIPV system on the energy saving according to the PV thermal performance and the power supply generated from the sun, and the final discussion results summarized in the table (3) below, to evaluate the different PV integrations and choose the optimum one.

It can be seen that the double skin façade has the lowest performance, and the reason behind that is the tilt of the PV modules 90◦, and most of the solar radiation can be generated from the summer solar and the useful tilt during this period. According to Benghazi sun path and altitude, the useful tilt in the overall should be in between 0◦ to 35◦. Thus, this type will not be succeeded.

Table 3: The performance of the different types of PV integrations (summary)

Costs & Benefits	Sunshade PV	Roof screen PV	Double skin façade PV
			
Energy reduction by thermal effect during the peak cooling load	17.26%	4.83%	10.52%
PV energy total output (kwh/year)	6,591 kWh/year	35,543 kWh/year	1,902 kWh/year
PV modules total budget ($)	$13,144	$49,620	$22,610
PV energy output (kwh/m2)	59.54 kWh/m^2	85.44 kWh/m^2	5.10 kWh/m^2
Cost of the PV power output ($/kwh) for 25 years lifetime	$0.08/kWh	$0.06/kWh	$0.47/kWh
CO2 emissions reduction (kg/year)	6,194 kg/year	20,133 kg/year	2,630 kg/year
Their effect on the building Comfort	Very good effect	No effect	Quite good effect

It is obvious from the summary table above that the Sunshade PV integration has a good performance in thermal effect, PV energy output per square meter and cost of the PV power output per kWh. Furthermore, it has a very good effect on the building comfort with low system budget, if it is compared with the roof screen integration.

The roof screen PV integration has a significant advance in the total PV energy annually output and CO_2 emissions' reduction, this advance has happened because of the medium storey building of the assumed office model that has used in the simulation, where the façade is similar to the roof area, and the space for the sunshade PV integration is limited. This advance can be completely opposite in the case of tall office buildings, which nowadays are more common due to the lake of the land space. Therefore, in this case, the roof space will be limited and the roof screen PV productivity as well, whereas the sunshade integration will have plenty of space, and its productivity will be multiple. For these reasons, the sunshade PV integration is the optimum one that could produce a reasonable power output and minimizes the heat gains in warm climate regions, and this choice is the answer of the study question.

Finally, a significant recommendation for further future research in this subject area is to use the Ecotect simulation program in focusing on the different types of sunshade PV integrations such as simple fixed, moveable or the louver one, in order to maximize their total power output and CO_2 emissions' reduction.

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