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ECONOMIC AND TECHNICAL FEASIBILITY OF A PHOTOVOLTAIC SYSTEM IN A UNIVERSITY BUILDING

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ABSTRACT

The use of renewable sources for electric power production can compensate the ever increasing energy demand in buildings. This article shows a study on the feasibility – both from the economic and technical point of view, of a photovoltaic system to be built on the premises of a university faculty. After a historical analysis on the building's consumption – both on a yearly and monthly base, which highlights the need for an autonomous electric power production system, the difficult task of the technical optimization was undertaken with the aim of minimizing the impact or visual interference of the plant. A series of simulations allowed estimating the right compromise between producibility of the system and its visibility, in order to obtain the maximum yield and the smallest disturbance. Photo-realistic renders also show the final configuration of the building equipped with the plant and its visibility from the surrounding characteristic observation points.

Keyword: Photovoltaic system, grid connect, payback time, visual impact, balance of system, study of the shadows and the sun path.

1 INTRODUCTION

Usually the concept behind a photovoltaic plant consists in being able to catch as much sunlight as possible. In most of the cases, a photovoltaic generator should have the most adequate sunlight exposition, mainly choosing an orientation to the South and avoiding shadowing. However, depending on the eventual architectonic restrictions of the site where the photovoltaic generator is set, different settings can be applied and some shadowing allowed provided that an adequate estimation be undertaken beforehand [1].

Energy losses due to such occurrences, affect negatively the cost for the produced kWh and the payback time of the investment inclusive of all the correlated costs needed for the realization of the system [2].

The design for the realization of a photovoltaic system was motivated by the study of the building electric energy consumption. Such a study, on yearly and monthly basis, evidenced the consumption peaks due to the intense use of air conditioning systems, both for heating in winter and for summer cooling. The latter peaks are overlapping with a time when there is more sunlight, in terms of both daylight amount and time then, simultaneously, to a greater hypothetical electricity production through a photovoltaic system.

The following histograms in figures 1 and 2 show the historical series of the consumption on both yearly and monthly basis from year 2003 to 2007 supplied by the of Energy manager service of the University of Palermo.

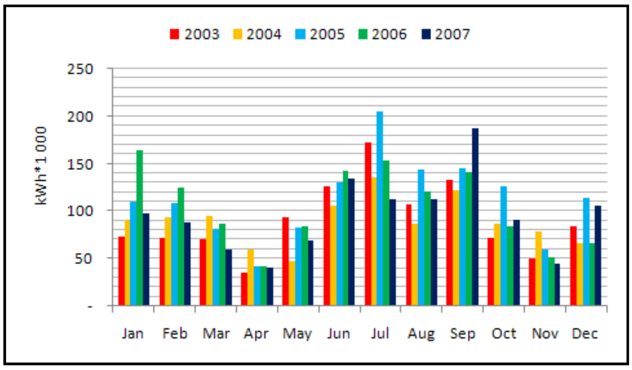

Figure 1. Study of the yearly consumption: (2003-2007)

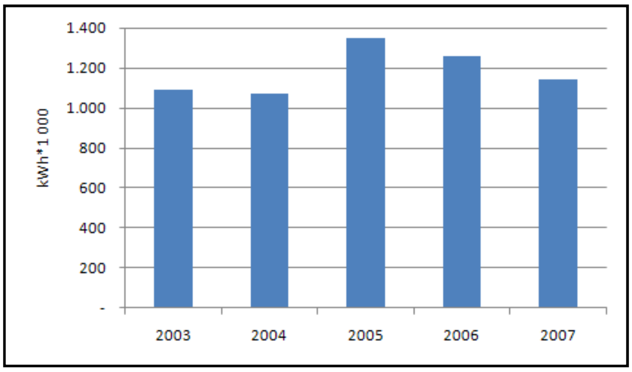

Figure 2. Yearly consumption trend (2003-2007)

2 THE PLANT

The plant - a grid-connect type, classified as a 'partially integrated system', exploits a 'three-phase medium voltage' connection [3].
The used photovoltaic module, whose mark and model are intentionally omitted for commercial reasons, have high performance standards and average costs.
Each module has 72 mono-crystalline silicon cells with new generation back-contact technology and a design that is suited for every environment, may it be a historical or modern building as in this case.
These modules have a certified efficiency of 18.1%, which puts them at the top of the commercial products of this kind. In addition, the reduced voltage -temperature coefficient of the module and its elevated rendering under low-brightness conditions ensure an exceptional supply of energy for watt of power peak also increasing the energy production with the lengthening of the daylight period.
Table 1 below shows the electric characteristics given by the builder and their relative testing conditions, while figure 3 shows the graph of the typical current/voltage curves according to the module spectral irradiance and temperature, as reported on the technical data supplied by the constructor.
The remarkable surface available on the roof of the building allows setting up 324 photovoltaic modules on 28 strings of various modulation. The central part of the roof is occupied from the air-conditioning equipments for the building.
The figure 4 shows the photovoltaic system layout placed on the roof of the building.

Table 1. The photovoltaic panel data-sheet

Peak Power (+/-3%)	Pmax	225 W
Nominal voltage	Vmp	41.0 V
Nominal current	Imp	5.49 A
Open circuit voltage	Voc	48.5 V
Short circuit current	Isc	5.87 A
Max. system voltage	IEC	1 000 V
Temperature coefficients:		
	Power	– 0.38% / °C
	Voltage	– 132.5 mV / °C
	Current (Isc)	3.5 mA / °C
Fuse nominal		20 A
Peak power for unitary		181 W / m²
Test working conditions		
Temperature	– 40°C + 85°C	
Max load	240 kg/m^2	
Impact resistance	Hail – 25mm (1 in) @ 23 m/s	
Certifications	IEC 61215 - safety test IEC 61730	

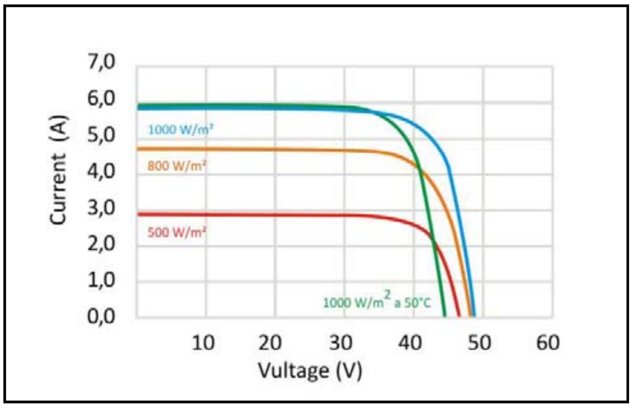

Figure 3. Current/voltage characteristics

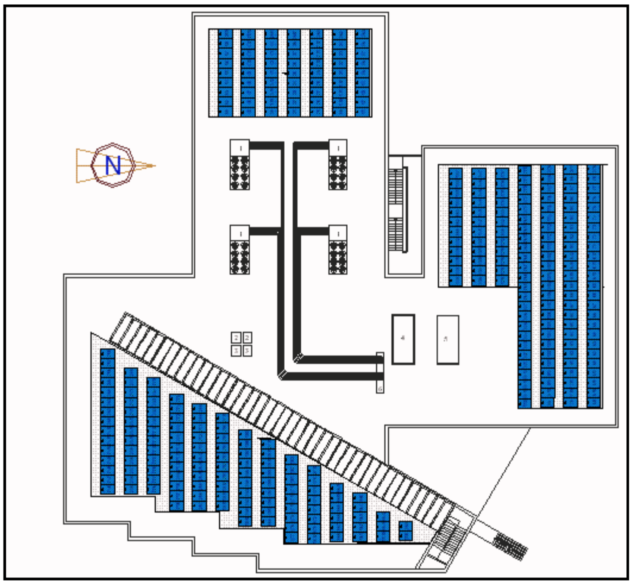

Figure 4. Layout of the photovoltaic plant on the building roof

2.1 Available Power

The first aspect to be considered is the insolation amount for the site under investigation, given latitude, longitude and altitude, an univocal value for the annual medium radiation for a square meter surface on the plane of the modules is obtained by referring to the azimuth values and the inclination of the photovoltaic modules. The sunlight availability for the installation site can be obtained from the climatic data on all the Italian localities. As seen in the following pages, the module 20° tilt was a precise choice thus preventing the sight of the photovoltaic modules from the outside in order not to alter building aesthetics, while it was possible to perfectly orient the azimuth at 0° South, being the building perfectly aligned on the North-South axis.In particular the adopted inclination allows the shortening of the distance in-between the parallel rows with respect to the standard inclinations used at the latitudes of this region, thus considerably reducing the reciprocal and unavoidable shadowing among the several rows of the system. Moreover in order to take into account the radiation surplus due to reflectance of the surfaces in the area, the average monthly albedo values [4] were identified and the estimated value (0.20) resulted almost constant throughout the twelve months of the year. The yield losses due to of the potential high temperatures, that are not negligible, are conditioned by the local weather, the module characteristics and the way they are set up. In the case under investigation, in spite of a good ventilation, such losses, accentuated in the central months of the year, are approximately estimated to 9%. The following figure 5 shows the average of the direct and diffused daily solar irradiation per month on the horizontal plane [5] for Palermo (latitude 38°11′67″, longitude 13°36′19″, altitude 14 m.).

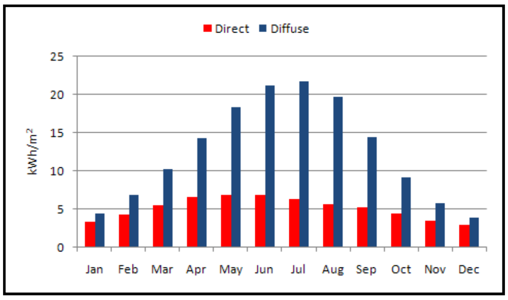

Figure 5. Annual solar irradiation on the horizontal plane for the city of Palermo

Then it was needed to define what were the overall loss to be considered, including those due to the used components. These losses were analysed with a parameter named BOS (Balance Of System) [6]. In this case we have:

$$T_l=[1-(1-LR-LS)(1-LM–LT)(1-LDC)(1-LI)]+LAC$$

Where:

L_R = Reflection losses
L_S = Shadowing losses
L_M = Mismatching losses
L_T = Losses due to temperature
L_{DC} = Losses along the DC cables
L_I = Inverter losses
L_{AC} = Losses along the AC cables.

Having obtained the BOS value, which in this case is 0.7497, it was possible to calculate the overall efficiency of the photovoltaic system, which is the yielded production (η) of the photovoltaic modules for the performance of the BOS, that is:

$$\eta = \eta_{\text{module}} \cdot \eta_{BOS} \qquad (1)$$

Tables 2 and 3 below report a summary of the general and technical characteristics of the suggested equipment, while in Table 4 shows the simulated of electricity production monthly and daily.

Table 2. General data

Overall surface area of the modules	528.35 m^2
Yearly sun insolation on the horizontal plane	1 620.90
Shading coefficient	0.97
BOS	74.97 %

Table 3. Technical data

Total power	98.82 kW
Total number of modules	324
Total number of inverters	1
Yearly annual energy	128 039.24 kWh

Table 4. Simulated of electricity production kWh

	Gen	Feb	Mar	Apr	May	Jun
Average daily	187.65	258.65	361.78	448.84	533.71	568.02
Average monthly	5 817.15	7 242.21	11 215.18	13 465.20	16 545.01	10 040.04
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average daily	570.56	500.40	396.43	302.61	204.55	171.59
Average monthly	17 687.36	15 515.45	11 892.95	9 380.91	6 136.56	5 319.29

3 THE SOLAR PATHS

To better study the problems arising from a possibly unfavorable urban environment, it was attempted to understand how the volumes of the existing buildings surrounding the roof of the building in question could affect the plant photovoltaic potential [7]. As a general rule, it can be said that urban areas with buildings not far from each others, but with similar heights, are ideal to install photovoltaic systems on roofs. To study the photovoltaic efficiency, it is essential to relate the installment site to the solar paths. In addition to a careful analysis of the skyline seen from the top of the building through simulation programs an initial assessment can be carried out by identifying the projection of the shadows cast by some objects in a year span. In fact the shading may cause rather expensive, temporary or permanent efficiency reductions. The problem of managing the shading is given by the dynamism of the shadows that move over the equipments following the sun orientation. This movement can be predicted and exactly calculated through the study of the shadow paths. Figures 6 and 7 below show pictures from the top of the building object of this study, while Figures 8a-d present a series of photo-renders with the insertion of photovoltaic panels on top of the building with the relative monthly shading referred to the sunshine time span.

Figure 6. View from the outside of the building

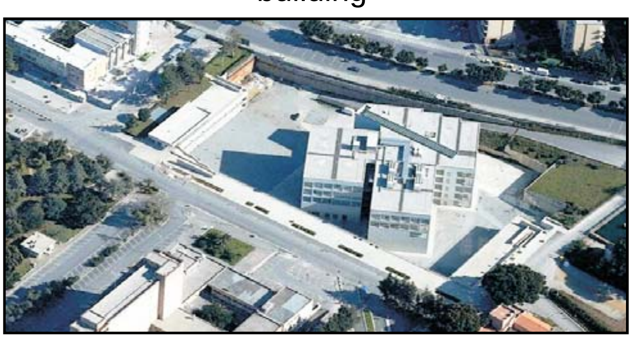

Figure 7. View from the top of the building

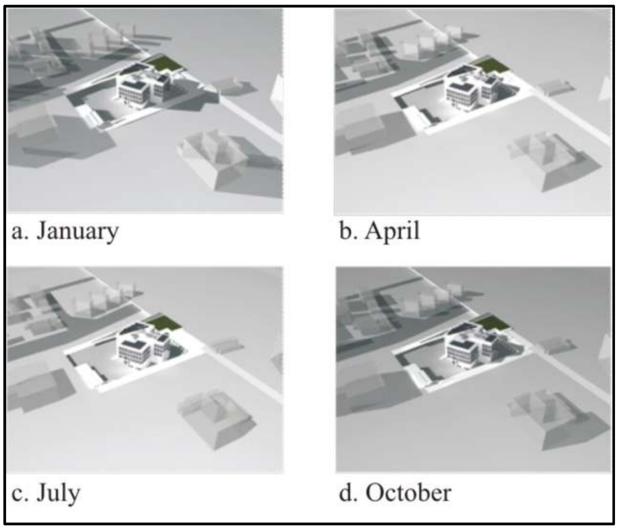

Figure 8. Monthly study of the shadows

4 THE VISUAL IMPACT

In this study case a lot of attention is given to the urban fabric and the particular value of the building of modern architectural design built in the late 90', which houses the new headquarters for the Faculty of Architecture of the University of Palermo. A series of photo-simulations permitted to ascertain from which points around the university building it was possible to see the photovoltaic system set on the roof. This study, carried out beforehand the sizing mentioned earlier, justified the current set up with the photovoltaic modules tilted on a 20° angle and sacrificing some electric energy production to favor the building aesthetics. The system is invisible from the street, even though the building stands on a lower ground. Also the photovoltaic plant results invisible from any spot inside the university campus wherefrom it can be seen. Yet it is seen from far away, since the pattern altitude changes. In any case, at that distance the negative effect of the photovoltaic strings on the skyline results negligible. Moreover, the sub-urban and peripheral area where the university campus is built does not preclude photovoltaic installments. Figure 9 below shows a photo simulation of the building within its context and the relative points of view of the photo simulations, while figures 10 a-h, represent the various points of view. It should be noted that the plant is barely visible in Figures 10 g and h. Also a particular of the installed panels can be seen in figure 10i.

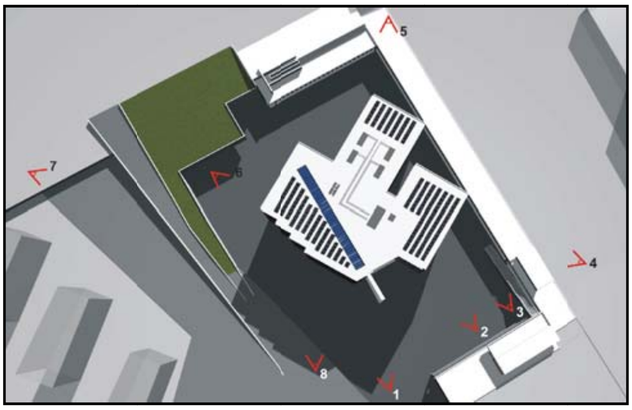

Figure 9. Under the photographic optical cone.

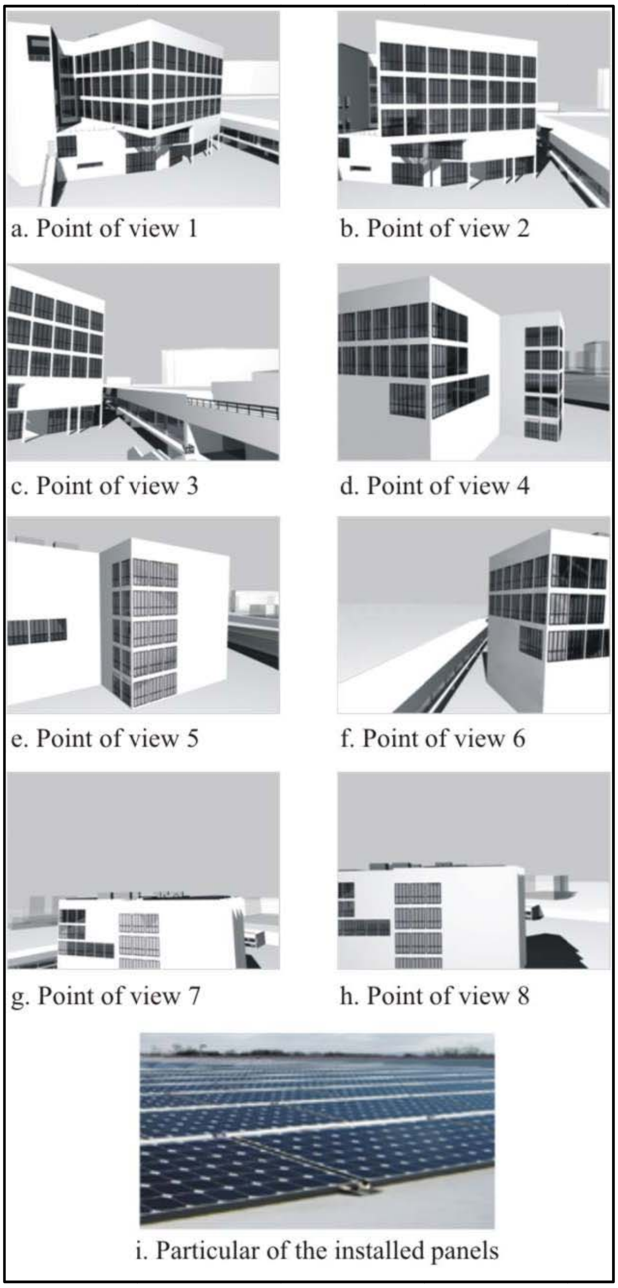

Figure 10. Estimation of the plant visual interference through photo simulation

5 THE ECONOMIC PICTURE

This section shows a synthesis of some indicators of the economic study carried out on a thirty-year work projection for the plant. The basic incentive fare, as determined by Article 6 of the Ministerial Decree n. 244, 19 February 2007, amounts to € 0.40 kWh. This law recognizes the incentive for a period of twenty years after the system starts to work.

For briefness sake, here is reported only the cash flow indicator, based on the payback time. This method is frequently used for its simplicity of computation; it allows calculating the time in which the capital invested in a productive component with a medium-long working life is returned through the net cash flows generated by alternative investments; the one with the shorter "return period" is chosen, since from that moment on, the instrumental asset starts giving gross profits.

This indicator, calculated by taking into consideration a yearly 0.90% efficiency loss, maintenance costs along with the inverter replacements in the tenth and twentieth year which is distributed on the entire life of the plant, indicates that an investment return is to be expected by the eleventh year of production. Figure 11 below shows the bar chart of this indicator.

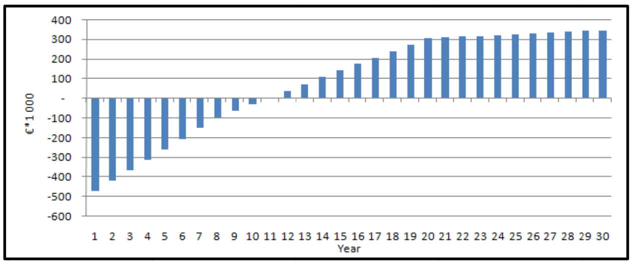

Figure 11. Cumulative cash flow

6 CONCLUSIONS

The use of renewable energy sources for electricity production, including photovoltaic generation, can mitigate the growing 'hunger' for energy in the developed world and contribute to the safeguard and respect of the environments and the people living in them. This system, designed a fair compromise between production and architectural aesthetics in mind, allows an investment return in a few years. Moreover, the environmental benefits achievable through the adoption of photovoltaic

systems are proportional to the amount of energy produced Assuming that this is to replace the energy produced through conventional sources, the equivalent of 2.56 kWh of hydrocarbon fuels are burned on average when one kilowatt-hour of electricity is produced; so approximately 0.53 kilograms of carbon dioxide are released into the air as calculated according to the emission factor of the Italian electricity mix at distribution.
It then can be said that each kWh produced by a photovoltaic system avoids the release of 0.53 kg of CO_2.

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