Photovoltaic Integration in Buildings
A Case Study in Portugal

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Abstract: - This paper aims at the presentation of a proposal for the integration of photovoltaic technology (i.e. devices that transform solar energy in electricity) in buildings, particularized for the Portuguese context through a case study, a new sport public building in Coimbra. This proposal has been developed in the framework of a Master dissertation, which the main objective is the selection of the most appropriate technological solution for the integration of renewable energy in buildings. The selection of the best solution will take into account the constructive aspects of the building, the building's energy needs and the local availability of renewable resources and market technologies. The economic viability of the selected technology solution is also presented.

Key-Words: - Energy efficiency, Solar photovoltaic, Integration of renewable in buildings, Renewable energies, Solar energy

1 Introduction

Within the framework of sustainable development, the ongoing trend for market deregulation, the increasing importance of distributed generation technologies based on renewable energy sources and the legislation emanating from the Rio Earth Summit (Agenda 21) and the Kyoto Protocol (requiring the reduction of greenhouse gases and crucial in promoting the use of renewable energies), meeting the increasing demand of energy in urban areas is an issue of the highest importance.

It is a well-known fact that, in general, cities are regions of high concentration of energy demand (be it in services, residential sector or transports) and, consequently, responsible for a high amount of greenhouse gases (GHG) emissions, including CO2.

Buildings are generally one of the main energy consumers in the urban context. Globally, buildings are responsible for approximately 40% of the total world annual energy consumption. Most of this energy is for the provision of lighting, heating, cooling, and air conditioning [1]. In Portugal, the building sector has the second highest growth rate of energy consumption, immediately after the transport sector. According to recent data from energy balances of the General Directorate for Energy and Geology [2], residential and services buildings account for about 30% of final energy and more than 60% of all electricity consumed at the national level, that reflects in a greater weight in distribution of primary energy by sector and also a greater share of emissions of GHG.

One way of reducing building energy consumption is to design buildings which are more economical in their use of energy. Passive measures, particularly natural or hybrid ventilation rather than air-conditioning, can dramatically reduce primary energy consumption [1]. However, exploitation of renewable energy in buildings offers the opportunity to diminish energy dependence, reduce pollutant emissions and create new employment.

The main objective and challenge of renewable energy integration in buildings is the incorporation of systems technically and economically viable in collecting and processing of renewable energy sources that are useful for building, contributing to the achievement of energy efficient buildings.

In this paper we present a proposal for the integration of photovoltaic technology in a new sport public building in Coimbra. The selection of the best solution for this specific building takes into account the constructive aspects of the building (location, orientation, construction materials), the building's energy needs (lighting, air conditioning, hot water), local resources viability, market availability and technology maturity.

The paper starts by presenting some considerations of the photovoltaic integration in buildings. Then it presents the case study, before some concluding remarks.

2 Photovoltaic Integration in Buildings

Renewable energies are growing at a much faster pace than the rest of the economy in Europe and worldwide. This and the dramatic oil price increases in 2005 have led to a remarkable re-evaluation of the renewable energy sector by politics and financing institutions [3]. One of the most promising renewable energy technologies is photovoltaic technology (i.e. devices that transform solar energy in electricity). Photovoltaic (PV) is a truly elegant means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm. These solid-state devices simply make electricity out of sunlight, silently with no maintenance, no pollution, and no depletion of materials.

The most common benefits associated with public-sector solar programs include the following: PV can reduce current utility expenses; PV offers predictability of future utility expenses; PV reduces public-sector greenhouse gas (GHG) emissions; Public-sector PV motivates other sectors to deploy solar; PV promotes the creation of local jobs; and PV can provide emergency power benefits for critical municipal services during and directly after a disruption to the electrical grid [4]. According to [1], a 1-kW PV system producing 150 kWh each month prevents 75 kg of fossil fuel from being mined. It avoids 150 kg of CO2 from entering the atmosphere and keeps 473 l of water from being consumed.

Building-integrated photovoltaic (BIPV) electric power systems not only produce electricity, they are also part of the building. For example, a BIPV skylight is an integral component of the building envelope as well as a solar electric energy system that generates electricity for the building. These solar systems are thus multifunctional construction materials. The standard element of a BIPV system is the PV module. Individual solar cells are interconnected and encapsulated on various materials to form a module. Modules are strung together in an electrical series with cables and wires to form a PV array. Direct or diffuse light (usually sunlight) shining on the solar cells induces the photovoltaic effect, generating unregulated DC electric power. This DC power can be used, stored in a battery system, or fed into an inverter that transforms and synchronizes the power into AC electricity. The electricity can be used in the building or exported to a utility company through a grid interconnection [5].

Small scale PV such as that used in buildings can be termed as a micro-generation technology - small scale electrical power generation at point of use - that offers a range of potential benefits to both the homeowner and the network operator. The highly visible nature of PV and the direct and clear coupling between the resource (sunlight) and the level of power generation makes this micro-generation technology one of the best in terms of raising understanding of energy use [6].

3 The Case-Study of a Sport Public Building in Coimbra

The sport public building is new and built according with the highest thermal standards. There is a very high emphasis on improving the building's low energy consumption. Taking 14 meters of height, the building is composed of approximately 2150 square meters that make up two swimming pools (designed us competition pool and learning pool), gym, *jacuzzi* and sanitary facilities.

It main characteristics are: south orientation of the main façade, a flat roof with an available area of 1430 square meters, where solar thermal collectors can be installed and a sloped roof with an area of 334 square meters south oriented. Building design is presented in Fig 1.

One of the main objectives of this work is to find a technical solution to a photovoltaic system interfaced with the available utility grid that provide electricity, taking advantage of the price of energy' sales according to Portuguese legislation for electricity production based on micro-generation systems [7]. The other objective is a BIPV stand-alone, off-grid system consisting of integrating photovoltaic modules into the building façade, in order to improve the efficiency of the building and provide electricity for building's consumption.

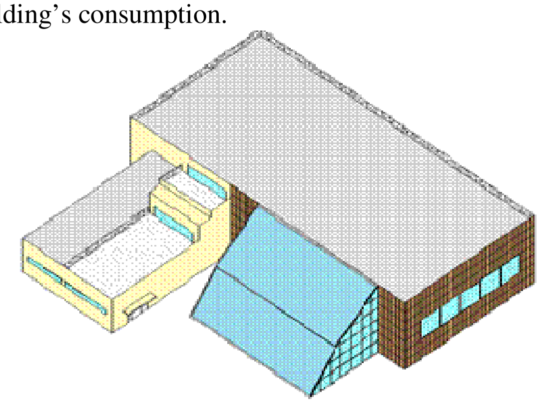

Fig. 1. Building design.

3.1 Installation of photovoltaic micro-generation

To be covered by the Portuguese legislation referred before, the micro-generation unit has to meet some requirements, including:

ISSN: 1790-5095

ISBN: 978-960-474-187-8

- Maximum power to the grid: 3.68 kW;
- Maximum power installed: 5 kW;
- Mandatory installation of a thermal solar collector;
- Low Voltage (LV) contract.

Taking into account all these requirements, the micro-generation unit should sized to a power connection of 3.68 kW. The unit will be composed of several elements, interconnected in accordance with the diagram presented in Fig 2.

The field of collectors consists of a total of 18 photovoltaic solar collectors' hybrid monocrystalline/ amorphous Sanyo. HIT - NKHE - 21 [8], with unit capacity of 210 Wp, connected in parallel, in series of 9 modules, with a total peak power of 3780 W. Collectors must be installed in triangular fixtures integrated into the building's facade with an angle of 35º.

The inverter (to convert the PV modules' DC output to AC compatible with the utility grid) selected for the installation is a utility-grid-connected inverter SunnyBoy, Model 3800PT [8], with a power to the grid of 3680 W and a maximum DC power of 3800 W.

The system has been designed with the software Sunnydesign [9], and its productivity was examined with the software SolTerm [10].

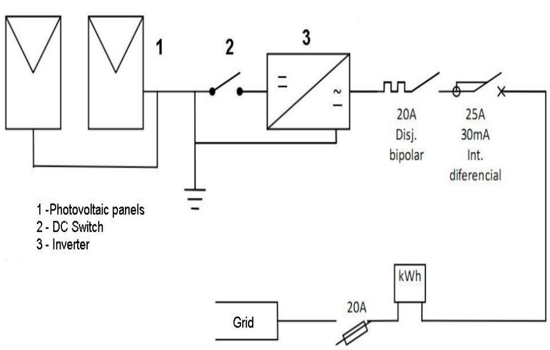

Fig. 2. Photovoltaic micro-generation diagram.

3.2 Analysis of the BIPV installation

To improve building's efficiency, various BIPV technologies will be integrated, as shown in Fig. 3.

For the roof with an inclination of 27 ° Suntech Light Thru panels [11] have been chosen us they increase day lighting opportunities in interior spaces. There will be installed 24 panels of 509 W each, in a total of 12.216 kW installed capacity.

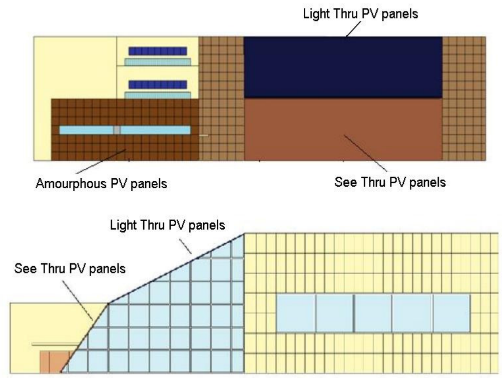

Fig. 3. Distribution of various types of PV modules.

In the roof with an inclination of 55° will be integrated glass panels, which increase day lighting opportunities and allow visibility to the outside. With this type of architecture's solution is intended to create a stand-alone gain system, i.e. solar energy captured and storage will not find in the building's occupied areas and then will have an independent operation. Solar energy will be transmitted to the adjacent areas by conduction through the storage wall or by convection if the same wall has holes allowing air circulation [12] as illustrated in Fig. 4.

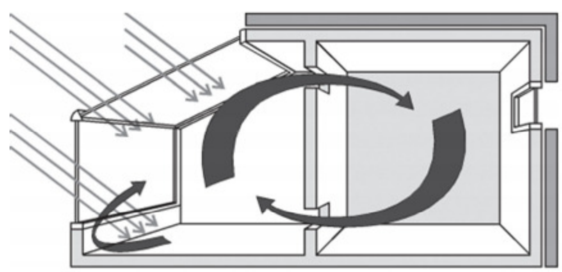

Fig. 4. A stand-alone gain solar system.

In the 200 square meters available area, it was decided to install See Thru Suntech panels [11], with 50 Wp and gross PV surface area of 0.93 sq. meters (0.98 x0.95). Panels will be distributed along 24 vertical rows of 8 panels each, accounting for a total of 192 panels and 9.6 kW of installed capacity.

For the facade of the service area, with an available area of approximately 100 sq. meters, were selected amorphous Kaneka panels [13], with 60 Wp and gross PV surface area of 0.95 sq. meters (0.99 x0.96). Panels will be placed at an angle of 90º, accounting for a total of 110 panels and 6.60 kW of installed capacity.

The BIPV system acts as a low voltage AC generator and is interfaced with the available utility grid. When the solar electricity production is not enough to the building's demand, it will be supplied by the utility grid. Otherwise, solar electricity will be exported to the utility grid. The operation's principle of the BIPV system is sketched in Fig. 5.

The 24 Light Thru panels are connected to 2 SMA, Sunny Mini Central SMC 6000TL [8] inverters (3 strings of 4 panels for each inverter), connected in parallel for a total maximum DC power of 12.40 kW. The projected electrical output of the system is 19789 kWh per year.

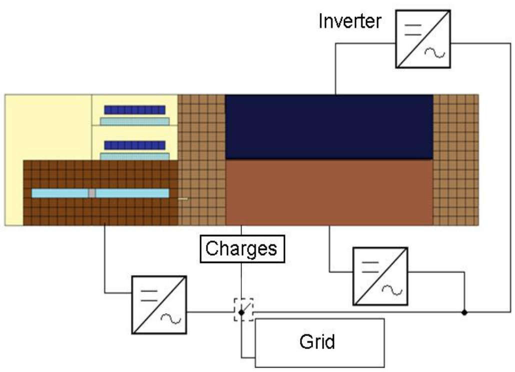

Fig. 5. Wiring of the BIPV installation.

The 192 See Thru panels are connected to 2 SMA, Sunny Mini Central SMC 4600A [8] inverters (16 strings of 6 panels for each inverter), connected in parallel for a total maximum DC power of 10.50 kW. The projected electrical output of the system is 13715 kWh per year.

The 110 Amorphous panels in the facade of the service area are connected to 1 SMA, Sunny Mini Central SMC 6000A [8] inverter (22 strings of 5 panels), with a maximum DC power of 6.30 kW. The projected electrical output of the system is 5627 kWh per year.

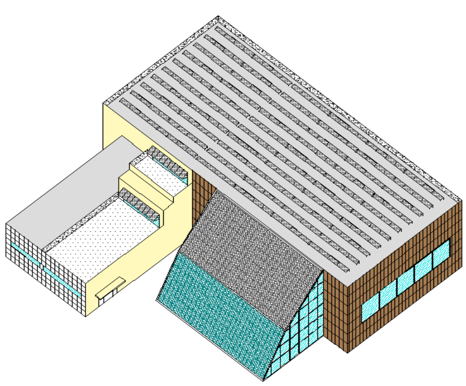

Fig. 6. Integration of all the solar systems technologies.

Fig. 6 depicts the integration of all the solar systems technologies considered for the sport public building: PV micro-generation system, BIPV system and thermal solar systems, also projected to the building but not referred in this paper.

3.3 Economic Analysis

Taking into account the Portuguese legislation for electricity production based on micro-generation systems (the price per kWh for 5 years be equal to the maximum rate imposed on the date of the registration, the forecast price of kWh after 5 years and reducing the price by the end of the remaining 10 years) and based on equipment cost and other assumptions, in a total of €23288.58, we obtained the results of the economic analysis of photovoltaic solar micro-generation presented in Table 1.

From the analysis of the cumulative cash flow, presented in the last column of Table 1, it appears that the simple pay-back system will be 7 years, the Internal Rate of Return (IRR) of 9.8% and the Net Present Value (NPV) of € 5216.

Table 1. Economic analysis results of the PV micro-generation

Year	Maintenance costs (€)	Annual turnover (€)	Annual cash flow (€)	Cumulative cash flow (€)
0	-	2882.18	-20406.40	-20406.40
1	-	3458.62	3458.62	-16947.79
2	-	3458.62	3458.62	-13489.17
3	-	3458.62	3458.62	-10030.55
4	-	3458.62	3458.62	-6571.93
5	-	3458.62	3458.62	-3113.32
6	273.98	2542.40	2304.43	-808.89
7	242.73	2415.28	2172.55	1363.66
8	247.59	2294.52	2046.93	3410.59
9	252.54	2179.79	1927.25	5337.84
10	257.59	2070.80	1813.21	7151.05
11	262.74	1967.26	1704.52	8855.56
12	268.00	1868.90	1600.90	10456.46
13	273.36	1775.45	1502.10	11958.56
14	278.83	1686.68	1407.86	13366.41
15	284.40	1602.35	1317.94	14684.36

For the BIPV installation economic analysis, we used the total cost of the three facilities, €193880.00, and its annual productivity average of 39131kWh, resulting from the sum of the individual yields of the three facilities. The saving costs associated with the integration of this technology to replace other construction materials (metal, glass, stone), in a total of €82520.00, was also considered. The results obtained are presented in Table 2.

From the analysis of the cumulative cash flow, presented in the last column of Table II, it appears that the simple pay-back system will be 18 years, the Internal Rate of Return (IRR) of 1%.

Table 2. Economic analysis results of the BIPV installation

Year	Maintenance costs (€)	Annual turnover (€)	Annual cash flow (€)	Cumulative cash flow (€)
0	-	4695.72	-106664.28	-106664.28
1	-	4883.55	4883.55	-101780.73
2	-	5078.89	5078.89	-96701.84
3	-	5282.05	5282.05	-91419.79
4	-	5493.33	5493.33	-85926.47
5	-	5713.06	5713.06	-80213.40
6	1339.42	5941.58	4602.16	-75611.24
7	1336.21	6179.25	4813.04	-70798.20
8	1393.53	6426.42	5032.88	-65765.32
9	1421.40	6683.47	5262.07	-60503.24
10	1449.83	6950.81	5500.98	-55002.26
11	1478.83	7228.85	5750.02	-49252.25
12	1508.40	7518.00	6009.60	-43242.65
13	1538.57	7818.72	6280.15	-39962.50
14	1569.34	8131.47	6562.12	-30400.38
15	1600.73	8456.73	6856.00	-23544.38
16	1632.74	8795.00	7162.25	-16382.13
17	1665.40	9146.80	7481.40	-8900.74
18	1698.71	9512.67	7813.96	-1086.78
19	1732.68	9893.17	8160.49	7073.71
20	1767.34	10288.90	8521.57	15595.28

4 Conclusion

Renewable energies integration in buildings offers the opportunity to diminish energy dependence, reduce pollutant emissions and create new employment.

We presented a proposal for a technical solution for the integration in a new sport public building of a photovoltaic system interfaced with the available utility grid and a BIPV stand-alone, off-grid system consisting of integrating photovoltaic modules into the building façade, in order to improve the efficiency of the building and provide electricity for building's consumption.

It was found that the photovoltaic technology is a sustainable option, economically viable, financially rewarding and environmentally friendly. This technology offers multiple features, taking advantage of synergies between the materials involved in building construction.

However, our study concludes that these systems will be more attractive to the consumer if there is some financial support, such as those that currently exist in Portugal for micro-generation systems interfaced with the available electric grid.

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