Energy Efficiency of Photovoltaic Façade for Different Latitudes in Portugal

Helenice M. Sacht
University of Minho, School of Engineering, Department of Civil Engineering, Guimarães, Portugal
hmsacht@civil.uminho.pt

Luís Bragança
University of Minho, School of Engineering, Department of Civil Engineering, Guimarães, Portugal
braganca@civil.uminho.pt

Manuela Almeida
University of Minho, School of Engineering, Department of Civil Engineering, Guimarães, Portugal
malmeida@civil.uminho.pt

ABSTRACT: The climate and energy package is a set of binding legislations which aims to ensure the European Union meets its ambitious climate and energy targets for 2020. These targets, known as the "20-20-20" targets, have set three key objectives: a 20% reduction in the EU greenhouse gas emissions, a 20% rise in the share of EU energy consumption produced from renewable resources and a 20% improvement in the energy efficiency. More renewable energies will enable the EU to lower greenhouse emissions and make it less dependent on imported energy. Boosting the industry of renewables will encourage technological innovation and employment in Europe. On this topic, photovoltaic façades are known to be a solution that allows both energy efficiency and environmental performance of buildings. This paper reports on a study of façade systems that have incorporated photovoltaic panels, considering computational simulations for Portugal. The main objective is to analyze the characteristics and parameters that define more efficient systems based on computer simulations carried out by Solterm 5.0. The results show the high potential of the use of the proposed technology in Portugal, especially in the Southern region, because of its latitude. Regarding energy efficiency and environmental performance, inclined polycrystalline silicon solar panels achieved the best results and the most efficient panel was Kyocera KC167G-2, followed by BP 3160. The comparison between simulation results and results provided in the literature shows that the use of computer programs is viable to the analysis of the energy efficiency of photovoltaic systems in façades.

1 INTRODUCTION

The reduction in the CO_2 emitted into the atmosphere, resulting from energy consumption, has been a global concern over the past few years. The European Union has developed a set of documents that aim at regulating the reduction in both energy consumption and emissions of greenhouse gases, increasing the share of renewable energies by 2020 (DIRECTIVE 2010/31/EU, 2010). These targets, known as the "20-20-20" targets, have set three key objectives: a 20% reduction in the EU greenhouse gas emissions, a 20% rise in the share of EU energy consumption produced from renewable resources and a 20% improvement in the energy efficiency.

Photovoltaic façades have been inserted in the context of increasing the renewable energy use and are a solution used for gains in energy efficiency and environmental performance of buildings. Through the building façade it is possible to harness solar radiation energy, contributing to better energy and environmental performance of buildings. In some cases, photovoltaic panels can replace glazed façades, solar protection devices and other elements of buildings (SACHT, 2013).

The main types of photovoltaic cells for use in façades are monocrystalline silicon cells, polycrystalline silicon cells and amorphous silicon cells, also known as thin-films. Monocrystalline silicon cells are the most used in solar cells (Figure 1). The polycrystalline silicon cells consist of a large number of small crystals as thick as a human hair and their manufacturing process is cheaper than that of crystalline silicon (Figure 2) (ALTENER, 2004). The amorphous silicon cells (thin films) are made on a support of glass or other synthetic material, onto which a thin layer of silicon is deposited. The efficiency of this type of cell is lower than that of the crystalline cell, but the current produced is reasonable (Figure 3).

Among the thin films is also the CdTe cell. CdTe material has been used for applications to calculators and solar modules. These modules, usually in the form of glass panels in a brown / dark blue tone, display a good aesthetic aspect. The production cost of a CdTe cell is low for a large-scale production and this technology has emerged as a major competitor in the market for photovoltaic energy production. Its high efficiency of conversion of solar energy into electric energy is one of its main attractions (Figure 4).

Another competitor in the photovoltaic market, also in integrated applications to buildings is the solar cells fabricated from the family of compounds based on copper indium diselenide ($CulnSe_2$ or simply CIS) and diselenide, copper indium gallium (Cu (InGa) Se_2, or simply CIGS), mainly because of their potential to achieve relatively high efficiencies.

Among the commercially available thin films, CIGS modules have shown the best photovoltaic performance, therefore many companies have been investing in this technology (Rutter, 2004). Differently from traditional silicon cells, CIGS cells can be printed on a material roll, facilitating their transport and installation. Their civil construction uses are limitless and they can be applied to façades, roofs, awnings, etc. (Figure 5).

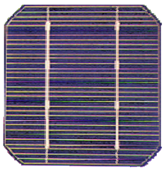

Figure 1. Monocrystalline silicon cell.

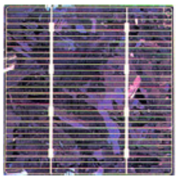

Figure 2. Polycrystalline silicon cell.

Figure 3. Thin-Film.

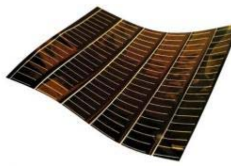

Figure 4. CdTe Cell.

Figure 5. CIGS Cell.

Table 1 shows the efficiency of each technology presented and other types of recent cells.

Table 1. Maximum Efficiency of Photovoltaic Technologies

	Cells	**Eficiency %**
Silicon	Si (crystalline) Si (multicrystalline) Si (thin film transfer)	25,0% 20,4% 19,1%
III-V Cells	GaAs (thin film) GaAs (multicrystalline) InP (crystalline)	28,3% 18,4% 22,1%
Thin film Chalcogenide	CIGS (cell) CdTe (cell)	19,6% 16,7%
Amorphous/Nanocrystalline Si	Si (amorphous) Si (nanocrystalline)	10,1% 10,1%
Photochemical	Dye sensitised	11,0%
Organic	Organic thin film	10,0%
Multijunction Devices	GaInP/GaInAs/Ge a-Si/nc-Si/nc-Si (thin film) a-Si/nc-Si (thin film cell)	34,1% 12,4% 12,3%

Reference: GREEN et al. 2012.

GaAs-based multijunction devices are the most efficient solar cells. Presently, a new generation of multi-junction solar cells with efficiency potential as high as 50% under "concentrated sunlight" has been developed (Peach, 2013). A large number of computational tools have been used for studies on the photovoltaic panels. Gonçalves (2011) compared the results of computer simulations conducted in Portuguese software Solterm 5.0 and case studies for two buildings in Lisbon (Solar XXI and Natura Towers). The values for the energy production were close to those found in systems installed in existent buildings (Table 2). Differences between simulation results and a real situation are expected, however the results from simulation tools approximate those found in real cases.

Table 2. Results provided by Gonçalves (2011).

Characteristics	**Natura Towers**	**Solar XXI**	**Solterm 5.0 Software**	
Area (m^2)	217,4	96,0	100,8	100,8
Cells	Polycrystalline	Polycrystalline	Polycrystalline	Polycrystalline
Manufacturer	-	BP 3160 S	BP 3160	BP 3160
Type of System	Autonomous	Connected to Electrical Grid	Autonomous	Connected to Electrical Grid
Energy Production (kwh/ano)	21925	12108	11776	11740
Energy Production (kwh/ano.m^2)	**101**	**126**	**117**	**116**

The use of photovoltaic panels in inclined planes maximizes the solar radiation absorption. The ideal for the panel position is an inclination approximately equal to the latitude of the location. In the northern hemisphere, photovoltaic panels should face the southern solar orientation (Castro, 2011).

This paper presents part of a study that includes a photovoltaic mobile module (Sacht et. al., 2010; Sacht, 2013). It proposes photovoltaic panels for different latitudes of Portugal and analyzes the characteristics of the most efficient panels regarding energy production.

2 METHODOLOGY

This study includes the development of parameters for a photovoltaic system for façades. Computational simulations were carried out applying Solterm 5.0 software to analyse the energy generation and compare the results.

2.1 *Criteria for the Photovoltaic System*

In the simulations of the PV modules three Portuguese cities (Bragança, Coimbra and Évora) and southern solar orientation, ideal for this type of system in localities of the northern hemisphere were considered. The PV panel was simulated in both vertical and inclined positions. The criterion for the selection of the cities was their geographical location, especially latitude, which is directly related to the solar radiation and solar irradiation. The inclination of the panels is different according to the city. The software allows optimizing the inclination, which is usually close to 30 º for Portugal.

The database of SolTerm 5.0 contains only three types of photovoltaic modules, certified for use in Portugal, therefore only PV panels from this database were used in the computer simulations (Table 3).

Table 3. PV Panels simulated in Solterm 5.0.

PV Panels	BP 3160 	M75S 	KC167G-2 
Manufacturer	BP Solar	Siemens	Kyocera
Technology	Polycrystalline Silicon	Monocrystalline Silicon	Polycrystalline Silicon
Rated Power $_{max}$ (W)	160	74.8	167
Voltage (V)	24.0	12.0	12.0
Open Circuit Voltage (V)	44.2	22.0	28.9
Current (A)	4.55	4.40	7.20
Short Circuit Current (A)	4.80	4.80	8.00
Eficiency (%)	12.7	-	16.0

2.2 *Simulations of Photovoltaic Modules for the Façade System*

The analysis of the photovoltaic cells for use in the façade system was based on the database of SolTerm 5.0 software, which is used in Portugal by legislation to quantify solar energy. It is a guideline of the *"Regulamento das Características de Comportamento Térmico dos Edifícios"* (RCCTE, 2006) code.

2.3 *Solterm 5.0*

Solterm software simulates the performance of solar thermal and photovoltaic systems for climates of Portugal in several locations. It calculates the thermal contribution of the system to the house energy performance, which is then integrated in the energy certification calculations. It also optimizes the solar energy production according to the optimal orientation and inclination. It contains updated information on types of systems, panels, brands and average investment, allowing the assessment of the systems' economic revenue. The software is not free and has been developed by *"Laboratório Nacional de Energia e Geologia"* (LNEG) (National Laboratory of Energy and Geology) and adjusted especially to the climatic conditions and techniques of Portugal.

The simulations required information about the configuration/system design, operation and control strategies, horizontal solar radiation and hourly environment temperature, obstructions and shadings, and technical characteristics of the system components and consumption (INETI, 2007) (Figure 6).

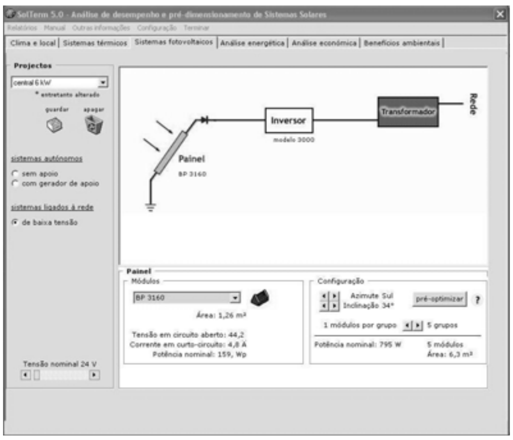

Figure 6. Solterm 5.0 software main screen.

3 RESULTS

This section provides the results of computer simulations for the PV modules in terms of energy production. For a better understanding of the graphs two acronyms have been added next to the panel name: "VE" panel positioned vertically at a 90º angle and "IN" panel inclined at angles near 30º, according to the optimization of positioning by location obtained by means of Solterm 5.0.

3.1 *Energy Production Results*

Results show that for all locations analyzed, the highest energy production was observed with the use of Kyocera polycrystalline panels KC167G-2 and BP 3160, whose values were similar (Figure 7). For Bragança, with the use of inclined modules, the increments in terms of energy production were 57.24% for BP 3160, 52.27% for Kyocera KC167G-2 and 61% for Siemens M75S, confirming that the inclined positioning provides more efficient energy capture.
The lowest energy efficiency was observed for the Siemens M75S panel positioned vertically, whose energy production was 4.6 times lower than the best one (Kyocera photovoltaic panel KC167G 2-inclined).

For Coimbra the increases in terms of energy gains with the inclination of the panels were 60.14% for BP 3160, 56.07% for Kyocera KC167G-2 and 63.52% for Siemens M75S panel. Again, the lowest efficiency was observed for the Siemens M75S panel positioned vertically. For Évora, the increments in terms of energy gains with the inclination of the panels were 63.26% for BP 3160, 56.22% for Kyocera KC167G-2 and 68.46% for Siemens M75S.

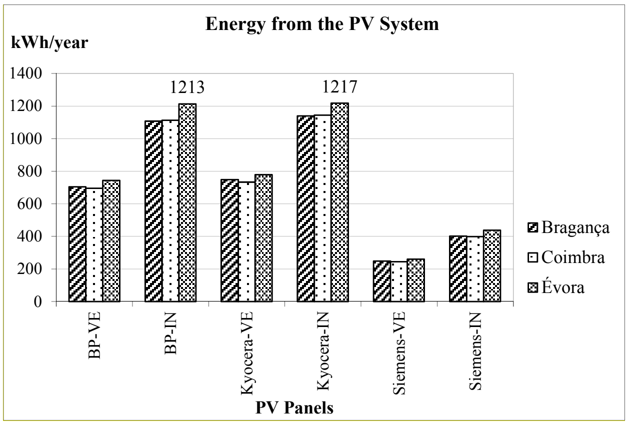

Figure 7. Energy from the PV System (kWh/year).

3.2 *Avoidance of both Primary Energy Consumption from Fossil Fuels and Emission of Greenhouse Gases*

Results of avoidance of primary energy consumption from fossil fuels were also provided by Solterm 5.0. Higher-efficiency panels showed greater savings in the primary energy consumption from fossil fuels (Figure 8). The avoidance of emissions of greenhouse gases was higher for the use of systems with an optimized inclination (Figure 9).

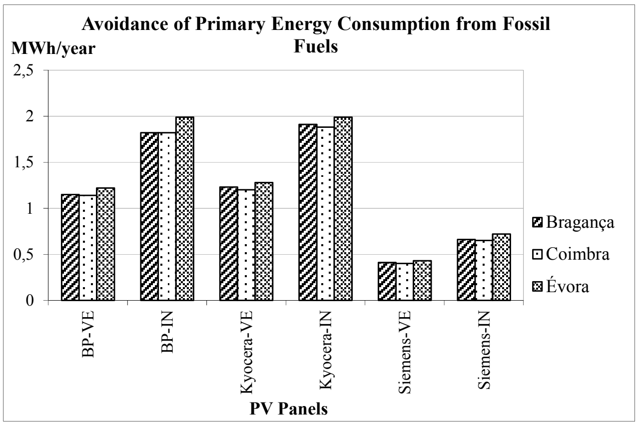

Figure 8. Avoidance of Primary energy consumption from fossil fuels.

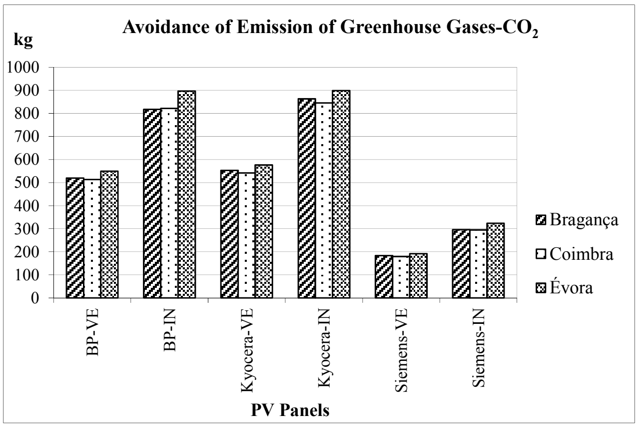

Figure 9. Avoidance of Emission of greenhouse gases.

The results show the best performance in terms of energy generation of Kyocera KC167G-2_ and BP Solar 3160 panels. The photovoltaic Kyocera KC167G-2 panel was the most efficient. Table 1 shows the order of efficiency in the energy production.

Table 3. Order of Efficiency in the Energy Production of Photovoltaic Systems

Order of Efficiency of Photovoltaic Systems
1st Kyocera KC167G-2 – IN
2nd BP Solar 3160 - IN
3rd Kyocera KC167G-2 - VE
4th BP Solar 3160 - VE
5th Siemens M75S – IN
6th Siemens M75S – VE

4 CONCLUSIONS

The use of the photovoltaic Kyocera KC167G-2 panel (polycrystalline silicon) showed the best performance among all, but the performance of BP Solar BP 3160 panel (polycrystalline silicon) was very similar. A general analysis showed an increase in terms of energy gains for the simulations that considered the inclined panels. The primary energy consumption from fossil fuels and the emission of greenhouse gases were reduced with the use of inclined PV panels.

The use of monocrystalline or polycrystalline photovoltaic cells in the systems indicates the most efficient energy generation by SolTerm software, for application in Portugal. The PV modules must be installed in the southern solar orientation (for the Northern hemisphere) and in the northern solar orientation (for the southern hemisphere), as in Brazil, and could be movable to increase the capture of energy.

The photovoltaic panels currently used in façades are positioned vertically. However, the possibility of inclining them as a "Sunflower" may offer higher efficiency in terms of solar radiation capture and increase of energy generation (Sacht, 2013). The mobility of photovoltaic modules for the façades would allow the search for the southern, eastern and western solar orientations (in Portugal) and northern, eastern and western orientations in an adaptation to the system in Brazil. The SolTerm 5.0 database contains only the three types of photovoltaic modules certified for use in Portugal, however many other more efficient modules can be found in the market.

5 REFERENCES

ALTENER PROGRAMA COMUNITÁRIO GREENPRO. *Energia Fotovoltaica - Manual sobre tecnologias, projecto e instalação.* Projecto Europeu. 2004. [on line] [Consult. 05 Jun. 2013] Available in: http://www.portal-energia.com/downloads/guia-tecnico-manual-energia-fotovoltaica.pdf

CASTRO, R. M. G. *Introdução à Energia Fotovoltaica.* [on line] [Consult. 05 Jun. 2013]. Universidade Técnica de Lisboa Instituto Superior Técnico, DEEC / Área Científica de Energia. Available in: http://horabsurda.org/wp-content/plugins/downloads-manager/upload/Introducao_a_Energia_Fotovoltaica.pdf

DECRETO-LEI N.º 80/2006 RCCTE: *Regulamento das Características do Comportamento Térmico dos Edifícios.* Diário da República - Série I-A nº. 67. Lisboa: 4 de Abril 2006.

DIRECTIVA 2010/31/EU. *Relativa ao desempenho energético dos edifícios* (Reformulação). Jornal Oficial da União Europeia L 153 de 19 de Maio de 2010. 2010. p. 14-35.

FREITAS, S. S. A. *Dimensionamento de sistemas fotovoltaicos. Relatório de Projecto* (Mestrado em Engenharia Industrial). Instituto Politécnico de Bragança, Escola Superior de Tecnologia e Gestão. Bragança, 2008.

GONÇALVES, P. M. O. *Estudo da Eficiência Energética de Sistemas de Fachadas com Painéis Fotovoltaicos.* Dissertação de Mestrado Integrado em Engenharia Civil, Universidade do Minho. Guimarães, 2011.

GREEN. M. A.; EMERY, K.; HISHIKAWA, Y.; WARTA, W. DUNLOP, E. D. Solar cell efficiency tables (Version 39). *Progress in Photovoltaics: Research and Applications.* Vol. 20, Issue 1, January, 2012.

INSTITUTO NACIONAL DE ENGENHARIA, TECNOLOGIA E INOVAÇÃO (INETI). *Manual SolTerm versão 5.0.* Lisboa, 2007.

RÜTTER, R. *Edifícios Solares Fotovoltaicos: O potencial da geração solar fotovoltaica integrada a edificações urbanas e interligada à rede elétrica pública no Brasil.* Florianópolis: Labsolar, 2004.

SACHT, H. M.; Bragança, L.; Almeida, M. *Façades Modules for Eco-Efficient Refurbishment of Buildings: An Overview.* In: PORTUGAL SB10 - Sustainable Building Affordable to All. Algarve, 2010.

SACHT. H. M. *Módulos de Fachada para Reabilitação Eco-Eficiente de Edifícios.* Plano de Tese - Programa Doutoral em Engenharia Civil, 2010.

SACHT. H. M. (*in press*). *Módulos de Fachada para Reabilitação Eco-Eficiente de Edifícios.* Tese (Doutoramento em Engenharia Civil). Universidade do Minho. Guimarães, Portugal: 2013.

PEACH, M. *PV researchers develop 43.6% four-junction solar cell.* 28 May 2013 [on line] [Consult. 10 Jun. 2013].Available in: <http://optics.org/news/4/5/37>

THOMAS, R.; GRAINGER, T. *Photovoltaics in Buildings: A Design Guide Report*. ETSU S/P2/00282/REP. 1999.