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ASPECTS OF INTEGRATED PHOTOVOLTAIC BUILDING USING MULTI OBJECTIVE OPTIMISATION

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Abstract: *Within the context of renewable sources of energy, solar energy has been devoted to improvement photovoltaic technologies and using a system orientated to energy performance, based to solar energy. In present the solutions can be challenging when finding overall factors performance between design methods and choosing the system of BIPV, although with limited specifically conditions. This paper observed the BIPV system with the fundamental researches in photovoltaic literature. It is addressed for practitioners interested in the design, analysis and performance evaluation.*

Key words: *energy, building integrated photovoltaics, BIPV, PV technology*

1. Introduction

The concerns regarding the environmental impact due the excessive use of fossils fuels, the use of renewable sources of energy is positioned in top of concerns of all states regardless of their development levels, considering the global energy context, so it is necessary to be aware that their use is no longer an alternative form, however the role of the science and research is planning an important role in the energy industries technological advancement must rapidly reduce carbon emissions, the effect of greenhouses gases already having an negative impact, irreversible on the environment.

Because of their sustainable character, photovoltaic technologies are capable of preserving resources, of entire ensuring security and diversity of energy supply and providing energy services, without environmental impact. Photovoltaic electricity in combination with energy conservation schemes, are required today of the biggest environmental concerns, although it is a problem to consider now and in the future. Today the cost of PV electricity is still too high for power productions in utility grids, however PV electricity will become cost-effective in the near future, PV electricity have already their own market and it is in continuously increasing [17]. The building sector consumed around 30- 40 % of energy from the total energy produced in developed countries and contributed over 25 % of CO_2 emissions, especially in EU where there are about 160 million buildings, most of them having been designed and built without taking

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into account the passive energy efficiency strategies as well as the integration of RES (Renewable Energy Sources), for satisfying active energy demand, in this sense energy can be considerably reduced once with the development effective solutions, to improve significant problems of the energy. BIPV systems can solve partially the energy demands in buildings for all types, new residentials buildings, industrial buildings, commercial and historical buildings, by introducing PV panels integrated in buildings to produce and store electricity[8]. PV technology are considered rapidly growing, in comparation to other renewable sources, and, as a result, numerous studies have been conducted on this topic. As part of these studies, Building Integrated Photovoltaics (BIPV) systems play an important role in generating electricity. Some review studies have already been conducted in the literature regarding BIPV systems, but they either provide a very general overview without sufficient detail or are focused on a specific country or application type [14].

BIPV systems were also considered as building integrated energy storage systems and were divided into three subgroups: BIPV systems with batteries, BIPV stand alone, grid-connected BIPV systems and PV- Trombe walls. For grid-connected BIPV systems the grid was considered as an infinite cycle battery with a huge capacity.

BIPV building integrated photovoltaic use a concept in witch photovoltaic elements assume the function of power generation, and the role of covering components and elements that have a significant influence of the heat transfer trough the building envelope [8], using the roof, walls, facades and windows (opaque, translucent, transparent). The vision is that the BIPV system can generate electricity from renewable solar energy by photovoltaic conversion. BIPV incorporates PV functionality into conventional building materials and in parts of the building envelope. The technology is increasingly being incorporated into new and existing buildings as a main or auxiliary source of electrical power. The main advantage of a building BIPV system is that the initial cost can be offset by reducing the amount of building materials and labor cost that normally will be used to construct the part of the building that BIPV modules are replacing, BIPV combine function with form [19]. All obstacles that still hold back are not technical, therefore it’s only a matter of time until BIPV support will be the next power generation and will transform for a concept to a product itself. The researches opportunities for the BIPV systems of the future were investigated in this article, and PV development progress and its impact on BIPVs, new materials and solutions for BIPVs were discussed by giving examples from the literature. Low production cost, low environmental impacts and high efficiencies were considered as key factors for future BIPV systems. It was mentioned that retrofitting and relatively easy installation of BIPV’s are very important because of the huge volume of existing buildings [13].

2. BIPV Systems

PV systems used on buildings can be classified into two main groups: building attached PVs (BAPVs) and BIPV systems. It is rather difficult to identify whether a PV system is a building attached (BA) or building integrated (BI) system, if the mounting method of the system is not clearly stated.

BAPVs are added on the building and have no direct effect on structure's functions [4]. On the other hand, BIPVs are defined as PV modules, which can be integrated in the building envelope (into the roof or facades) by replacing conventional building materials [6].

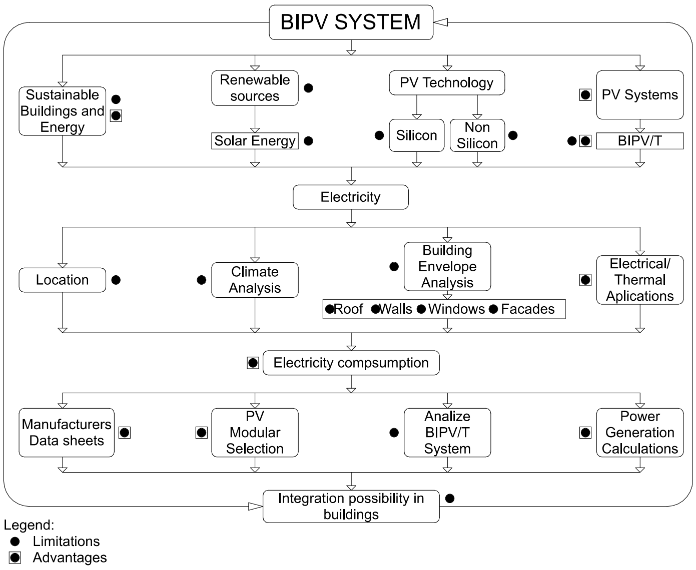

Fig. 1. *BIPV application objectives*

A theoretical BIPV system is schematically illustrated in Fig. 1, the system can be integrated to the facade, walls and windows of the building. During this process it absorbs the heat of PV modules, reducing their temperature which results in an improvement in their efficiency and lifetime. In some applications, a fan and an air duct is employed in the system in order to draw the heated air into the building to reduce the heating loads in winter months. Such systems are called hybrid systems, or BIPV/T, and benefit from solar energy to provide both electrically and thermal energy.

When we choose the BIPV system integrated in buildings, besides the investment cost a decisive role is played by the installation of thermal-technical aspects.

The appreciation of these features will be very different depending on the type and utility of buildings, climatic conditions, location, construction mode as well as aesthetic considerations. Taking into account the large number of factors it cannot be avoided that in a decisive case a thorough synthesis of the advantages and limitations of the system will be needed, the decisions being very different even in cases where the results obtained are the same.

Anyway, from the different systems analyzed in earlier researches to the various integrated systems already result in some of the preferred areas of use that are outlined in this article. A schematic review is presented of those considerations that are important in choosing the system that has an impact on the building's functionality, and can be considered as an integral part of the energy system. There are many parameters that need to be considered for the integration of PVs into the buildings envelopes and they are shown in Fig. 1.

The categorization of BIPV systems can be made according to the solar cells type, applications type or their names in the market. Solar PV technologies are also divided into two sub categories, silicon based and non-silicon based, while roof and facade integration are the only two types of application. On the other hand, the categorization described in [13] was used for the products in market.

The BIPV products were divided into four categories, foils, tiles, modules and solar cell glazing, in Ref. [13], according to the description of the manufacturer or the material that is replaced by the BIPV product.

Evaluation of BIPVs involve several properties, solar cell efficiency = $P_{max}/(\phi A)$ where ϕ is the input solar radiation standard, G=1000W/m^2, and A is the solar cell surface area in m^2, maximum power point P_{max} in W or Watt- peak (Wp), open circuit potential or voltage U_{OC}, short circuit electrical current I_{SC}, fill factor FF= $P_{max}/(U_{OC}I_{SC})$= $(UI)_{max}/(U_{OC}I_{SC})$, band gap E_g [15] usually $1,1<E_g1,9$ eV and quantum yield Φ= number of photo-electrons divided by number of photons. The values reported by solar cell manufacturers are mainly obtained according to standard test conditions (STC) or nominal operating cell temperature (NOCT).

Only a few materials meet the conditions [2].

Building application refers to experiments applied on the building or performed in the laboratory. Various analyses of prototypes or systems were performed. In general, module efficiency is low at high temperatures. Many studies are made in order to solve this fundamental problem. According to these studies, efficiency is increased by heat absorption at the back of the PV.

In order to create this, studies were conducted such as using air or fluid to create a forced convection, opening alternative inputs between hot and cold area in PV, provide fresh air, PV's air gap changing and air gap to set the optimal level. In this way, increase in both the annual production and module life can achieved. Otherwise, shadowing effect, ambient temperature, the direction of the building and the slope of the PV have a significant effect in order to achieve higher power output and efficiency in the building applications [6].

2.1. Analysis materials and cells using in BIPV

PV cells are using different materials, and so display differences when it comes to efficiencies and costs. Materials for efficient solar cells must have characteristics matched to the spectrum of available light.

Some cells are designed to efficiently convert wavelengths of solar light that reach the Earth surface.

However, some solar cells are optimized for light absorption beyond Earth's atmosphere as well. Light absorbing materials can often be used in multiple physical configurations to take advantage of different light absorption and charge separation mechanisms.

Most commonly, the materials used for the production of PV cells are monocrystalline silicon, polycrystalline silicon, amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium selenide/sulfide (CIGS), novel technologies introducing new materials and methods, such as silicon quantum dot solar QD cells [11].

The annual production volume for all kinds of solar cell is expected to exceed 100 GW/year around 2020. The future of c-Si solar cells and modules is to break through the efficiency barrier of 25%.

To realize theoretical efficiency in c-Si based on single homojunction and a bulk silicon energy under E_g= 1.1 eV is 30% under global AM 1.5 illumination, so this ideal efficiency limit based on existing Schockly and Queisser solar cell theory.

Classification of PV cells and confirmed terrestrial cell an submodule efficiencies measured under global AM.1.5 spectrum 1000 W/m^2 at 25. [1] [10] Table 1

Technology Classification	**Material**	**Cell Efficiency** [%]	**Area** [cm]	**FF** [%]
Monocrystalline m-c-Si Polycrystalline p-c-Si	Silicon			
	Si crystalline	25	4	82.8
	Si multi crystalline	20.04	1.002	80.9
	Si thin film transfer	16.7	4.017	78.2
	Si thin film module	10.05	94	72.1
Amorphous, Nanocrystalline Si	Silicon			
	Si amorph	9.5	1.070	63.0
	Si nanocrystalline	10.01	1.199	76.6
Thin film Chalcogenide	CIGS (cell)	19.4	0.994	80.3
	CIGS (submodule)	16.7	16.0	75.1
	CdTe (cell)	16.7	1.032	75.5
Multijunction III-IV group Based arsenides, phosphide	GaAs (thin film)	26.1	1.001	84.6
	GaAS (multi crystalline)	18,4	4.011	79.7
	InP (crystalline)	22.1	4.02	85.4
Photochemical Dye Sensitized cell	Type of thin film, titanium, dioxide, nanoparticles, not by silicon	10.03	1.004	65.2
Organic	Organic polymer	5.15	1.021	62.5
	Organic polimer submodule	2.05	223.2	59.1
Multijunction	GaInP/ GaAs/ Ge	32	3.989	85
	GaInP/ GaAs	30	4	85.6
	GaAs/ CIS(thin film)	25.8	4	-

Also nanowire (NW solar cells) have gained attention, due their performance and processing benefits, nanowire polymer P3HT - hybrid solar cell, which promise a further improvement of the cells efficiency in the future. The third Generation under (GCEP) Global Climate & Energy Project with many others groups participating to develop high efficiency PV solar cells based on three novel third generation concepts: Hot carrier solar cells, plasmotic photovoltaics and nanostructure materials based on CSG (Crystalline silicon on glass) [1,12]. The researches paths for possible new PV technologies that may initiate and advance into new innovations, and which may be developed into BIPVs, may be found in miscellaneous fields, ultralow cost and low medium efficiency organic based modules, ultra-high efficiency modules, solar concentrator (Hight Concentration PV

Technology HCPV) high-end and ultra-efficient multijunction concentrator, whilst the other is organic photovoltaic technology, or solar trapping systems embedded in the solar cell surface and material beneath, and flexible lightweight inorganic thin film solar cells, and several others some of them yet to be discovered. The former has achieved efficiencies of nearly 43% [15]. Best research-cell efficiencies for the multitude of different solar cell technologies. Data compiled by Lawrence Kazmerski, National Renewable Energy Laboratory (NREL), Golden, Colorado, where recent researches of the BIPV solutions shows that more demanded in the construction market is the multifunctional PV facades, in this sector. France is considered as flourishing market for integrated systems because nearly 85% of installed PV systems are integrated into the building's roof and facades [1], transparent and semitransparent facades. It was shown that semitransparent facades can replace convectional materials such as glazing systems integrated with PV cells, polycrystalline silicon thin film solar cells on glass is new generation of poly-Si film, although are many problems to solved, however on long term is a large potential for cost reductions, in the case of success [9], due to the large amount of viable mounting surfaces, using transparent solar cells can provide good daylight availability, reduce the solar heat gain through the building envelope improving energy efficiency and reducing the electric consumption of a building [16]. The ONYX company has already launched the first colored photovoltaic glass adapted to construction standards so photovoltaic energy can be integrated as any other building construction material, or combined with them into buildings and it is already patented. The system consists on the installation of photovoltaic tiles, triple laminated glazing units based on a-Si solar cells to be integrated as a walkable floor. The most desirable way to produce electricity by integrating PV with smart windows in a way that PV can provide shading while the windows block solar radiation. Technologies of electrochromic, gas chromic, liquid crystal and electrophoretic or suspended-particle devices were examined and compared for dynamic daylight and solar energy control in buildings. [3]

2.2. Tools and methods for design implementation

Simulation studies are of great importance for the analysis of the BIPV and BIPVT systems. Simulation work has increased in academic studies with improvement and expansion of recent technology [13]. As a result of these developments, analysis and design of BIPV systems becomes easier. Examples of such co-simulations include: the integration of Radiance with ESP-r; FLUENT with ESP-r and TRNSYS and EnergyPlus [5]. THERM is another program developed to estimate the potential for BIPV by developed a method using readily available statistical data on buildings from European databases.

Based on country-specific data on building characteristics and irradiation we can estimate the BIPV technical potential in EU [7] [20].

The integration of the cells on the facades would mean that the support structure system needed would be facilitated on the buildings surfaces. This structure is not only meant to support exterior envelope modules will probably require the construction of new support structures. The latter may not be possible, due to increases of structural loads that can damage the existing buildings structure and materials. Furthermore, new materials proposed for an integration into an already existing structure should be in a harmonic relationship with the existing ones, increasing the architectural values in each case. The new structures should also have a character that can be easily identified as a new addition, without compromising the structure. Heated air passes behind the support structure can have a positive effect during cold months. The exterior skin protects the brick facade from rain and the modules, but can also provide air flow at their back side, reducing their heat [8]. As a side effect, the air passing behind the modules will be heated, and a part of this heat will be transferred to the building. This could be a positive side effect during the long cold winters. The whole system would be an additional exterior layer, which also provides protection from water infiltration to the brick facade and thus extending its lifespan. The draw-back of this approach is that it doesn't solve the glare and overheating issues that have been mentioned [18].

3. Conclusions and Analysis

BIPV directly dependent of electricity generation, relating factors, temperature analysis and location variables. These are important issues to study for the performance of the system, selection of PV technology for the success of any PV power project. The new PV technologies are available, but not all of them are used for commercially PV use, hence c-Si, p-Si, a-Si, CISG, CdTe from reputed manufacturers are widely used for commercial PV power projects. The requirements of BIPV systems directly depend on energy prediction outputs, using different PV technologies, operating temperature, which plays an important role in the conversion process, depending on the decreasing temperature, $T_{c,}$ while the numerical parameters are not only material dependent but also for the entire system.

Functional requirements are mainly focused on shadow limitation, optimal orientation and compatibility with existing insulation materials (for ventilated facades solution).

Thermal envelope benefits depend on the design and PV glass configuration, factors whitch could produce energy savings. Furthermore, heat recovery applications can be implemented in combination with building envelope solutions as preheating air flow for the winter seasons. Daylight entrance is in direct correlation with the design of semi or transparent PV technologies (glass), according to the lighting needs of the building.

Aesthetical added value associated with a comforting visual aspect own of the silicon technology integrated in constructive solutions as ventilated facade or double skin.

The purpose is to provide general concepts of different technologies that use solar energy in interaction with solid structures of buildings using PV technologies.

References

1. Jayrama Reddy, P., *Solar power generation, technology, new Concepts & Policy* CRC Press New York, 2012.
2. Vadan, I., Cziker, A.C.: *Sisteme modern de conversie a energiei/ Modern systems for energy conversion,* UTPRESS Cluj- Napoca ,2017, p.186.

3. Baetens, R., Jelle, B.P.: *Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A state-of-the-art review,* Solar Energy Materials and Solar Cells 94, 2010, p. 87 -105.
4. Barkaszi, S., Dunlop, J.: *Discussion of strategies for mounting photovoltaic arrays on rooftops*, Sol. Energy 2001 p. 333–338.
5. Beausoleil- Morrison, I., Kummert,M.: *Modeling of the new ESP-r and TRNSYS co-simulator for modelling solar buildings* Elsevier, Energy Procedia, 2012, p. 505-514.
6. Biyik, E., Araz M.: *A key review of building integrated photovoltaic (BIPV) systems Engineering Science and Technology*, an International Journal 20, 2017, p. 833–858.
7. Defaix, P.R. , Van Sark, W.: *Technical potential for photovoltaics on buildings in the EU-27,* Sol. Energy 86, 2012, p. 2644–2653.
8. EkoeA Akata M. A., Njomo D.: T*he effect of buildind integrated photovoltaic system (bIPVs) on indoor air temperatures and humidity (lath) in the tropical region of Cameroon* In: *Future cities and environment,* Online, Springer, 2015.
9. Fuhs W., Vaseashta, A., Dimova D.: *Silicon thin Film solar cells* et al. Springer, Netherlands, 2005, p. 293.
10. Green A, Hishikawa G.: *Solar cell efficiency tables (version 51).* Prog Photovolt Res Appl., 2018, p. 1-12.
11. Green, A., Conibeer, M.A .: *Progress with silicon based tandem cells using group IV Quantum dots in a dielectric market proc 23rEU Solar energy Conf d'*Valencia, 2008,
12. Jelle, B. P., Gustavsen A.: *The path to the high performance thermal building insulation materials and* solutions of tomorrow, Journal of Building Physics 34, 2010, p. 99-123.
13. Jelle, B.P., Breivik, C.: *The path to the building integrated photovoltaics of tomorrow*, Energy Procedia 20, 2012, p. 78–87.
14. Kong, X., Lu, S.: *A review of building energy efficiency in China during ''Eleventh Five-Year Plan*".
15. Parnell, B.P.: *Nanotechnology and the potential for a renewable solar future* Nanotechnology Perceptions ,RsearchGate, 2014, p. 180-187.
16. Stouffs, R., Janson P.: *Semitransparent building transparent building integrated photovoltaic* (CAADARIA), 2013, p. 127-138.
17. Pietruszko, M.: *Photovoltaics in the world.*In*:Nanostructured and advanced materials.*A. Vaseashta, D. Dimova et. al, Springer, Netherlands, 2005, p.241.
18. Bikos, N.: *Thesis in the Master Degree Program* Sweden 2012.
19. http://www.bipv.com. Accessed: on 06-08-2018.
20. http://www.inhabitat.com/new-quantum-dot-solarcells-houd-double-efficiency.