BIPV SOLUTIONS IN RESIDENTIAL RENOVATIONS TOWARDS NEARLY ZERO ENERGY DISTRICTS

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Abstract

The current building stock is formed by about 160 million buildings in EU-25 that represent about 40% of the energy consumption and 36% of the EU's total CO2 emissions. The construction of new buildings represents only 1-1.5% of the building stock so the focus needs to be put on renovation of existing buildings in order to achieve substantial impact in terms of energy saving and GHG reduction.

In this sense, the propose of R2CITIES project, funded by the European Commission through its Seventh Framework Programme, is to develop and demonstrate replicable strategies for designing, constructing and managing large scale district renovation projects for achieving nearly zero energy cities. These results will open the way for new refurbishments on a European scale within the framework of new urban energy planning strategies.

One of the innovations within R2CITIES is the implementation of Building Integrated Photovoltaic Solutions (BIPV) for districts retrofitting, used for replacing conventional building materials with the advantage of generating electricity providing at the same time passive benefits as heat insulation, daylight entrance or acoustic comfort.

Onyx Solar has studied the behaviour of the PV ventilated façade in three European demonstration sites located in Kartal (Turkey), Genoa (Italy) and Valladolid (Spain). In addition, it is expected to obtain an innovative urban mobility concept related to the renovation at district level focused on the development of a PV Parking-Lot for public lighting and charge of electric vehicles. This paper is focused on explaining the main BIPV solutions and its application for R2CITIES.

1 Introduction

The energy consumption existing model based on fossil fuels is completely unsustainable. Not only because the energy increasing demand is reducing the estimated reserves, but also for the clear evidences of environmental affectation on account of their use (pollutants global warming, etc.). The most efficient alternative energetic solution, the nuclear generation, supposes a radioactive pollution risk that many citizens are not willing to assume.

Specifically, as the result of the energy waste, 40% of greenhouse gas emissions and 38% of global energy demand, come from buildings. This puts us in a current case mix of climate change with obvious consequences, and where buildings located in large urban areas have a critical role.

Thus, the commitment of different governments and supranational organizations, establish pre-agreements to promote renewable clean energies and guaranty on a long term basis the sustainability of earth resources.

Within this framework, the new European Directive on Energy Saving in Buildings (European Energy Performance of Buildings Directive-EPBD) was published, setting the objective of reducing the annual building energy demand to a critical value of 70 kWh/m^2 by the year 2020.

Similarly, the 2020 Energy Plan "A strategy for competitive, sustainable and secure energy", published by the European Commission, established the following key objectives:

- 20% cut in Europe's annual primary energy consumption by 2020.
- Reducing overall greenhouse gas emissions by 20% compared to 1990 levels.

- Achieving the 20% share for renewable energy sources (RES) in the gross final energy consumption.

On the other hand, governments are analysing the possibility of promoting the photovoltaic energy integration in buildings. This solution provides immediate energetic savings in the actual net electric consumption and economic feasibility on medium-long term basis; it should be taken into account that photovoltaic systems suppose an additional saving cost in transportation and energy distribution, one of the main limitations of the access to effective energy sources.

2 High-value photovoltaic solutions for smart cities

2.1 Building Integrated Photovoltaic Solutions

Essentially, Building Integrated Photovoltaics (BIPV) refers to photovoltaic cells and modules which can be integrated into the building envelope as part of the building structure, and therefore can replace conventional building materials, rather than being installed afterwards. In this model, photovoltaic elements have been presented in the project from the beginning, as a part of the integral design. Thus, BIPV solar modules have the role of a building element in addition to the function of producing electricity. The wide variety and the different characteristics of the available BIPV products make possible the replacement of many building components, mainly in façades and roofs.

The building envelope guarantees a border between the inner building environment and the outer climate. Moreover, the envelope provides a waterproofing layer to the building. Thus, façades and roofs take over regulation and control functions in relation to the daylight, ventilation, energy, etc.

When BIPV modules are planned to be integrated in the building envelope, they should be considered during the design phase in order to obtain the most appropriate products.

Additionally, there are other BIPV features that must be considered. Some of them are:

- Acoustic protection.
- Thermal insulation.
- Visual refraction of the cover.
- Aesthetic quality (colour, appearance and size)
- Safety glasses.
- Waterproofing.
- Sun protection.

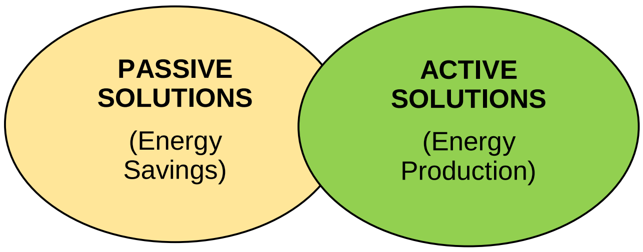

Figure 1. Multifunctional concept of BIPV solutions. Source: Onyx Solar

2.2 Type of BIPV Integrations

Together with the evolvement of the integration of modules in the architecture, the new BIPV products are capable of fully replacing some building components: construction elements of the building envelope (roofing, façade cladding and glazing surfaces) and architectural elements (porches, balconies or canopies). The main examples of BIPV integration are summarized in the following pages.

2.2.1 Photovoltaic Skylights and Curtain Walls

Photovoltaic skylights and curtain walls ensure optimization of the energy generation providing at the same time bioclimatic properties and thermal comfort inside the building, as most of the ultraviolet and infrared rays are absorbed by a silicon-based material that acts as a sunscreen. In addition, it is possible to design and manufacture double and triple glazing where the outer glass is photovoltaic and the passage of natural light is allowed. Moreover, low emissivity (low-e) layers can be added in double and triple glazing in order to avoid energy losses, reducing the cooling needs and generating an improved inner comfort.

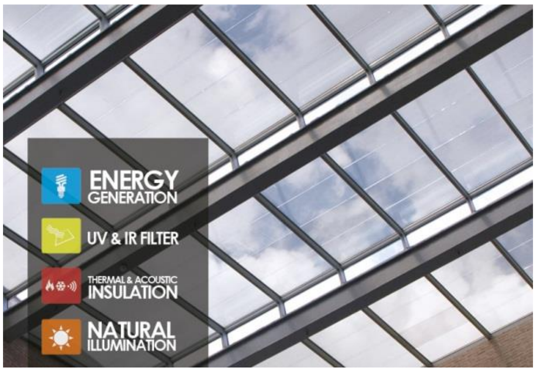

Figure 2. Skylight PV Integration. San Antón Market, Madrid (Spain). Source: Onyx Solar

Traditional glass used in skylights and curtain walls can be replaced by photovoltaic glass, optimizing the envelope performance and allowing on-site energy generation. In this type of integrations, photovoltaic glass should have a transparency degree in order to permit the entrance of natural light into the building. The semi-transparency is achieved by a laser process on fully-opaque thin film modules. For projects requiring specific conditions as thermal insulation, insulated solar glass units can be considered, in order to comply with building specifications.

Figure 4. PV Curtain Wall scheme and real integration in Guadalhorce Headquarters, Málaga (Spain). Source: Onyx Solar

2.2.2 Photovoltaic Ventilated Façade – Double Skin

A PV ventilated façade is a multi-layered building envelope, consisting of an outer layer made of photovoltaic glass that is mechanically connected to the inner layer using a substructure and a ventilated air gap which contains the thermal insulation. The air cavity allows controllable ventilation of the system. The outer layer can be installed a certain time after the building completion, as an energy efficient measure.

The ventilated air chamber and the application of insulating material increase the acoustic absorption and reduce the amount of heat absorbed by buildings. In the air gap, the density difference between hot and cold air creates a natural air flow that heats up through a chimney effect. That is a natural ventilation system that helps to eliminate heat and moisture, increasing interior comfort.

The outer PV layer allows generating solar energy for its use to cover the building demand. PV technology is integrated in an aesthetic manner being a perfect choice for replacing conventional materials such as regular glass, ceramic or stones with a great final result. Amorphous silicon technology typically used for the PV layer can be treated to obtain a transparency degree so when it is covering windows natural light can pass through the building.

On the other hand, this solution can lead to savings among 25-40% of the total building energy consumption. Depending on the façade orientation, the building location and the photovoltaic technology used, the electricity generated by a single square meter of the PV ventilated façade can vary between 40-200 kWh per year.

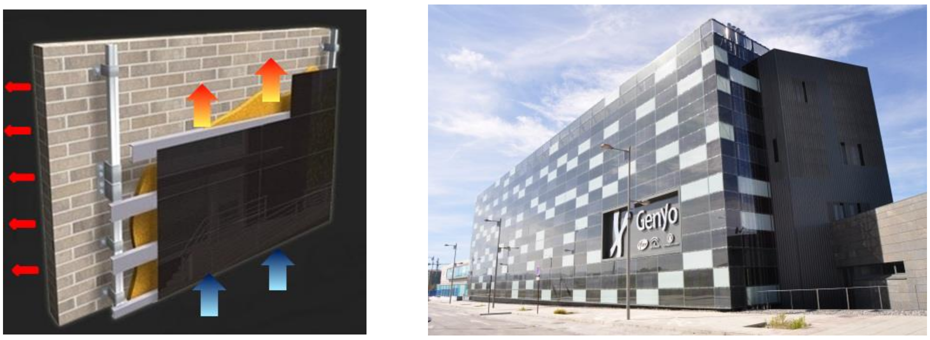

Figure 3. PV Ventilated façade scheme and double Skin PV real integration in Genyo Building, Granada (Spain). Source: Onyx Solar

2.2.3 Photovoltaic Walkable Floor

This innovative 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 PV tiles comply with the anti-slip regulation and supports 400 kg in point load test.

As previous solutions explained, the PV walkable floor combines passive elements (avoiding CO2 emissions) with active elements (for power generation), significantly reducing the environmental impact of the building.

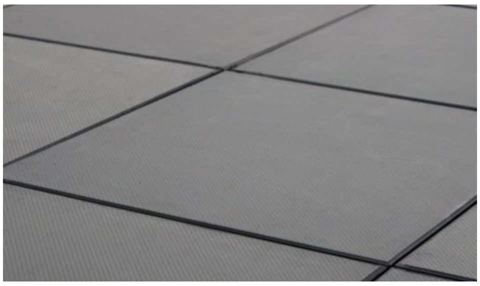

Figure 6. Photovoltaic Walkable Floor. George Washington University, Virginia (USA). Source: Onyx Solar

2.2.4 Photovoltaic Canopies and Parking Lots

A photovoltaic canopy is a constructive solution used in urban environment that combines power generation with solar protection properties against adverse weather conditions. The energy generated by the PV system can supply nearby buildings or can be injected into the grid, achieving a significant economic benefit.

Some important factors that must be taken into account when designing the canopy are the orientation, the minimum slope, dimensions or wind and snow loads.

Figure 5. Photovoltaic Canopy. BART Station, San Francisco (EEUU). Source: Onyx Solar

With respect to PV Parking lots it is possible to add new functionalities apart from the traditional use for protecting vehicles against weather conditions. In this case, the solution consists of a parking structure where the PV installation guarantees on-site power generation that can be used to satisfy different needs such as street LED lighting or supplying the batteries of an electric car.

The aesthetic sense of this solution seeks maximum energy production and maximum protection from adverse weather conditions, such as rain and wind. For this reason, a locking structure integrated in the module could be proposed, formed by a mobile timber panel over the outer face of the photovoltaic panels. The cover is designed with a minimum slope, being capable of easily evacuate the rainwater and at the same time, versatile in any orientation, thus location losses never exceed 8%.

Figure 7. Photovoltaic Parking Lot Design and real project in Lamezia Terme, Italy. Source: Onyx Solar

3 The role of Onyx Solar in R2CITES European project

3.1 R2CITIES Project Objectives

The current building stock is formed by about 160 million buildings in EU-25 that represent about 40% of the energy consumption and about 36% of the EU's total CO2 emissions. The construction of new buildings represents between 1-1.5% of the building stock while the removed buildings represent about 0.2-0.5%. Assuming that this trend will continue in the period ahead, the focus needs to be put on renovation of existing buildings in order to achieve substantial impact in terms of energy saving and GHG reduction. Taking into account that the number of refurbishments accounts roughly 2% of the housing stock per year, we can estimate that around one million dwellings are refurbished every year.

The purpose of the R2CITIES project is to develop and demonstrate replicable strategies for designing, constructing and managing large scale district renovation projects for achieving nearly zero energy cities. These results will open the way for new refurbishments on a European scale within the framework of new urban energy planning strategies. R2CITIES aims to develop and demonstrate an open and easily replicable strategy for designing, constructing, and managing large scale district renovation projects for achieving nearly zero energy cities. This project is coordinated by the research centre CARTIF and has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

Three demo sites will be addressed for demonstrating the framework and associated impacts by developing real cases going beyond current market standards but ensuring the replicability of the concepts deployed. This ambitious renovation plan of three residential districts, will involve more than 57,000 m2, more than 850 dwellings and more than 1500 users, with a potential of energy consumption reduction close to 60%.

3.2 PV Parking Lot: Towards Smarter Urban Mobility

Onyx Solar, as a partner of R2CITIES project, has developed a study of PV solutions for the improvement of the energy performance of buildings at district level. In this context, PV solutions must be analysed not only for their integration in building envelopes, but also for their contributions to the district. In this paper, the current paper will focus on the description of the PV Parking Lot proposed for the demo site in Valladolid, as part of R2CITIES project.

Regarding BIPV integration, it is possible to study its involvement at district level based on two different concepts: energy management systems and urban mobility. A new concept of energy management system must be evaluated, allowing that the energy produced by the BIPV systems located in selected buildings, would be distributed and consumed by all the district inhabitants.

European cities increasingly face problems caused by transport and traffic. The question of how to enhance mobility while reducing CO2 emissions and pollution is a common challenge to all major cities in Europe. The implementation of energy efficiency technologies, as photovoltaic canopies in bus stops or photovoltaic parking lots, is a recommended solution to improve the quality of urban mobility.

3.3 Introduction to the Electrical Vehicle Market in Spain

In the EU, transport sector represents a final energy consumption of 377 million tons of equivalent oil (Mtoe), which accounts a 33% of total final energy consumption. In Spain, with a consumption of 42 Mtoe, this percentage is as high as 43%, with the added effect of an exclusive dependence on oil, which comes from a few countries with enormous geopolitical instability. In particular, the car consumes almost the 30% of the total oil demand. Currently, there are 900 million vehicles in circulation, of which about 30 million are registered in Spain and nearly three quarters correspond to cars.

Now more than ever, the respect to the environment and energy efficiency are being considered. In this respect, the electrification of transport seems to be the response to the need for greater energy efficiency and lower emissions. It is important to identify how the electrification of transport can contribute to achieving the objectives of energy efficiency set by 2020. The forecast for the next decade is the evolution toward smaller vehicles, environmentally friendly and easily manageable for the urban use. This future sustainable mobility pattern is planned to offset the negative effects of pollution and congestion in cities.

One of the key elements for the success of electric mobility in urban environments is the selection of those cities that can provide "a priori" better conditions for the use and implementation of electric vehicles, as well as support for the creation of favorable conditions to build and operate a network of stations for electric power supply.

The electrical producers are forcing the charging system mainly at night, in the periods with less demands of energy (valley hours). Obviously this can be a problem for the development of electric car infrastructure. Given this data, it is necessary to provide other solutions to the charge in the valley hours. In situ generation associated to parking facilities zones are postulated as a compatible solution for an overnight charging of electric vehicles.

3.4 Analysis of the Electric/Hybrid Vehicle Industry in Valladolid

Within the Smart City strategy, Valladolid City Council is boosting the growth and the future of electric vehicles in the automotive sector in their jurisdiction. So, with the cooperation of the government and the private sector, and within the framework of the European, National and Regional Strategy, they are improving the charging point infrastructure and performing priority actions to promote the electric vehicles industry with the objective of increasing the demand and exploit the economic potential of this new market.

The measures that are being implemented in Valladolid are explained below:

- Development of a network of electric charging infrastructure that support the progressive introduction of the electric vehicle, public and private.
- Adaptation of local regulations to facilitate the widespread implementation of the electric vehicle and its infrastructure.
- Adoption of positive actions to encourage the use of electric car and plug-in hybrid vehicle, in addition to the conventional model, but promoting a progressive change towards electric mobility.
- Private sector involvement in the electric vehicles introduction.
- Progressive introduction of electric vehicles in the municipal fleet, in public transport companies and the contractors of public works.
- Promotion and dissemination of electric mobility and its benefits.

3.5 PV Parking Lot Proposal

After a deep study of the Urban Mobility Plan of Valladolid and considering the increased use of electric vehicles in the city, Onyx Solar has considered that one of the most suitable photovoltaic solutions that should be proposed for Valladolid demo site is a PV Parking Lot.

This solution consists on a photovoltaic parking structure where the PV installation guarantees on-site power generation to supply the batteries of an electric car. The intervention is focused on the design of a parking module for two cars and a photovoltaic integration on the deck.

3.5.1 PV Technology Selection

For the Parking-lot PV integration, the technology selected is the mono-crystalline silicon for the following reasons:

- Due to the location, orientation and planned placement, photovoltaic glass does not provide the best exposure to solar radiation (understood as such direct solar radiation in optimum angle) so it becomes critical to exploit the available area to install the most power as possible. Technology of mono-crystalline silicon is, in this context, the one that provides the best results in terms of kWp/m² installed.

- Crystalline silicon technology allows to configure an optimal glass structural composition for the replacement of traditional finishes carport in parking (based on sandwich panel or folded metal sheet), providing an aesthetic value to the intervention and minimizing costs.

The following glasses have been designed to cover the parking lot, optimizing the available surface due to the existing geometry of the three parking spaces:

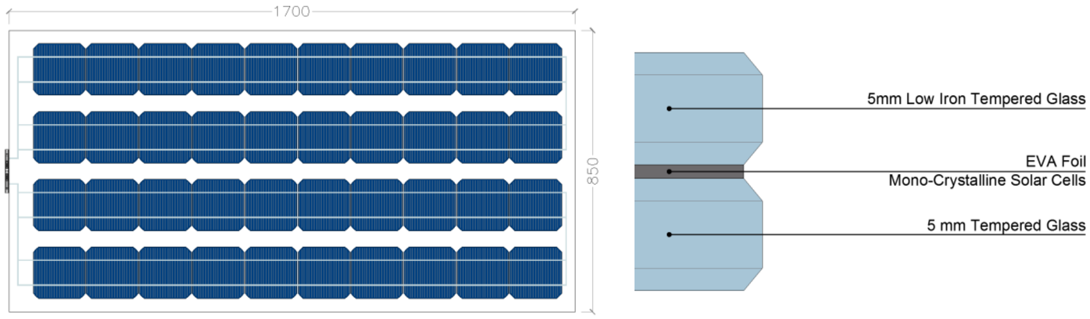

Figure 8. PV glass designed for the Parking Lot: plant and section. Source: Onyx Solar

3.5.2 PV Structural Requirements

Different approaches can be considered to solve the structural needs for the implementation of the parking lot with a charging point for electric vehicle.

In this sense the following limiting factors have been considered:

- Minimum power installation.
- Orientation of parking spaces that define the geometry of the installation.
- No volumetric invasion of the lane restrictions.

In the parking lot system proposed for Valladolid, three parking spaces will be covered achieving a final installed power of 4.17 kWp.

Different types of solutions were studied for the primary structure mainly based on two materials, metal and plywood. For both solutions, the secondary structure would be based on skylight constructive systems available on the market, allowing a watertight facing.

3.5.3 PV estimation production

The energy production estimation for the PV parking lot is shown in table 1.

Table 1. Energy Generated by PV Parking Lot in Valladolid. Source: Onyx Solar

Month	Ed	Em	Hd	Hm
January	5.90	183.00	1.72	53.32
February	9.93	278.00	2.87	80.36
March	14.94	463.00	4.33	134.23
April	17.70	531.00	5.19	155.70
May	21.45	665.00	6.40	198.40
June	24.23	727.00	7.37	221.10
July	25.32	785.00	7.75	240.25
August	22.23	689.00	6.78	210.18

September	17.20	516.00	5.18	155.40
October	11.61	360.00	3.45	106.95
November	7.17	215.00	2.12	63.60
December	5.48	170.00	1.63	50.53
Yearly average	15.26	465.17	4.57	139.17
Total for year		**5582.00**		**1670.02**

- Ed: Average daily electricity production from the given system (kWh)
- Em: Average monthly electricity production from the given system (kWh)
- Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)
- Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

The energy production of the Parking-Lot system will achieve 5582 kWh/year, based on an active integration area of 34.8 sqm with a nominal power installed of 4.17 kWp. The electric car mileage thanks to the energy generated can be estimated at 41,348 km/year.

Taking into account the accumulation system based on 4 batteries of 260 Ah 12V, it is possible to accumulate at least 7488 W (with a deep discharge of 60%), this means that we will have a current value of 32.55 Ah. If one Electric Vehicle consumes 10Ah in the charging time, we can feed one Electric Vehicle each day during 3 hours.

4 Conclusions

BIPV systems are energy efficiency measures that can replace conventional materials in the building envelope such us façades, skylights and produce energy from the sun and at the same time, avoiding CO_2 emissions to the atmosphere. These smart solutions can be easily implemented not only at building level, also at city level.

The PV parking lot is a perfect system to be implemented in Smart Cities as this solution allows the energy generation on-site and provide public services to inhabitants. As an example of this innovative system, a photovoltaic parking lot solution will be built in Valladolid, under the scope of the European Project R2CITIES. The parking lot will generate free energy that could be used for public lighting consumption but also, it will include a free charging point for electric cars, providing a double value to the community.

It has been proven that BIPV solutions are valuable energy efficient measures that improve the energetic behaviour of buildings in a sustainable and aesthetic way. According to this, all stakeholders involved in the construction sector such as owners, banks or municipalities should support the implementation of this type of smart solutions in buildings and Smart Cities.

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