RINGS-BIPV PROJECT: ANALYSIS OF PV SOLUTIONS FOR RETROFITTING BUILDINGS UNDER MEDITERRANEAN CLIMATE CONDITIONS

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ABSTRACT: The energy renovation of buildings addressing improving their thermal envelope can also integrate photovoltaic systems. Building Integrated Photovoltaics (BIPV) assumes the double functionality of BIPV modules, which are photovoltaic generators and building elements in the role of conventional materials. The ongoing research project *Renovation INnovative Global Solutions with Building Integrated PhotoVoltaics* (RINGS-BIPV), with two multidisciplinary Spanish teams from CIEMAT and the Polytechnic University of Madrid (UPM), respectively, aims to provide efficient energy rehabilitation solutions that include BIPV systems and to improve the modeling and simulation of BIPV systems. The outcomes will help architects and other stakeholders in the decision-making processes to incorporate BIPV solutions at both building and urban scales.

Keywords: BIPV, Energy retrofit, Solar irradiance simulation, PV forecasting, Zero Energy Buildings.

1 INTRODUCTION

Aligned with the objectives established by the European Commission, the Convention on Climate Change, and the UN Sustainable Development Goals, the energy-efficiency renovation of the Spanish building stock, which currently consumes about 30% of the total final energy in Spain, is a priority of the National Energy and Climate Integrated Plan (PNIEC); being the significant increase in renewable energy sharing another key objective, building-integrated photovoltaics (BIPV) appears as the best option for combining the energy retrofitting of buildings with locally produced renewable electrical energy.

However, and despite the potential of BIPV in retrofitting projects, this is still an emerging technology. One main reason is the lack of information and accessible tools to help in the BIPV system design and construction processes: a better understanding of BIPV products and systems and their behavior in rehabilitation projects is needed. The ongoing research project *Renovation INnovative Global Solutions with Building Integrated PhotoVoltaics* (RINGS-BIPV), with two multidisciplinary Spanish groups from the Spanish Centre for Energy, Environmental and Technological Research (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, CIEMAT) and the Polytechnic University of Madrid (Universidad Politécnica de Madrid, UPM), respectively, aims to provide efficient energy rehabilitation solutions and to achieve further progress in the modeling and simulation of those BIPV systems. The outcomes will help architects and other stakeholders in the decision-making processes to incorporate BIPV solutions at both building and urban scales.

Building-Integrated Photovoltaics assumes the double functionality of BIPV modules, which become building elements in substitution of conventional materials. Ventilated façades or other construction systems considered when renovating the building envelope can easily include BIPV modules as construction elements. Many examples worldwide illustrate the design and constructive possibilities of BIPV modules and systems [1]. The challenge is that the energy requirements, including the electrical, thermal, and optical ones, should be combined with the constructive ones [2]. Moreover, as the European Standard EN 50583 (parts 1 and 2) details, a BIPV module has to fulfill one or more construction functions according to the Construction Products Regulation. While improving the framework affecting BIPV at European and national scales, products, and systems, there are several reasons for BIPV to stay as a niche market in Spain, as analyzed in the framework of the IEA PVPS Task 15 devoted to BIPV [3].

One of the main weaknesses is the lack of information exchange due to few communication opportunities and low trust among the construction and photovoltaic stakeholders. Aware of that, RINGS-BIPV project will contribute to developing BIPV solutions for building retrofitting but also will improve the BIPV modeling and simulation existing capabilities for a better holistic design, helping in the decision-making process.

2 PROJECT DESCRIPTION

2.1 Team background

CIEMAT team acts as the coordinator of the RINGS-BIPV project. Being experts in testing, characterizing, and modeling photovoltaic (PV) modules and systems, the group is involved in international committees related to PV, BIPV, and solar resource assessment and forecasting, e.g., IEA-PVPS Task 15 and Task 16, IEC TC82, and EERA JP-PV. CIEMAT's main activity in this project is related to the improvement of testing and modeling of BIPV modules and BIPV systems for a holistic simulation of the energy behavior of buildings. Solar radiation incident on the different surfaces available in urban topology is another important part of this project. CIEMAT team has relevant expertise in modeling solar radiation components, transposition models, forecasting solar irradiance, and solar resource assessment, the basis to identify the solar potential on buildings and infrastructure.

The UPM team has been working in recent years on national and international projects aimed at promoting urban regeneration and energy transition in cities. One important research topic of this team is renewable distributed energy generation with photovoltaic solar energy integrated into the built environment.

The UPM founded the project *INTEGRA: Zero energy buildings, an integrative methodology for their design*, with the aim of strengthening the research plans of young researchers by supporting the study of how to design and build zero energy buildings. In the same line, the past year UPM started the project *Transition towards an emission-free university TULE* to support the energy transition of the university by promoting collaborative research between research groups and departments.

2.2 Main objectives

The RINGS-BIPV project intends to deliver further solutions in BIPV systems through research in two main aspects: the design and performance of BIPV solutions and the BIPV modeling, simulation, and forecasting. It aims to contribute to the definition of PV construction technological units and subsystems for renovation projects, adjusting the design to the needs of representative building typologies. The possibilities for flat and sloped roofs, ventilated façades, curtain walls, skylights, and external devices are explored, looking for a good balance between energy performance, ease of use, costs, and architectural quality.

In this area, led by the UPM team, there are two particularly innovative research lines: i) the integration between photovoltaic systems and heritage buildings that require preservation due to their historical, architectural, cultural, or aesthetic value and ii) the combination of photovoltaic systems with Nature-Based metropolitan Solutions (NBS).

Regarding the first line, decision-making concerning BIPV solutions is especially challenging in protected historic urban districts, being in those cases especially important to set the specific requirements for BIPV systems about the constructive, energetic, and visual impact (e.g., texture, grain, color, size).

With regard to the second line, combining photovoltaics and NBS is an interesting area of research, since PV elements and green roofs and façades have traditionally been considered mutually exclusive solutions. However, this combination achieves an ideal symbiotic relationship in which both the promotion of biodiversity and, in general, the ecosystem services provided by vegetation and the production of on-site renewable energy are enhanced, providing the buildings that integrate them with a wide range of environmental, health, aesthetic and economic benefits.

In parallel to the work developed by UPM, CIEMAT focuses on another key aspect of the design of the BIPV system: PV generation forecasting. The energy yield, or energy generated by a PV system over a period, is mostly a function of the received solar irradiation but second-order factors such as module temperature or soiling can play a role, depending on the boundary conditions. BIPV generation forecasting is a more recent activity and entails other difficulties, such as the importance of partial shading and a more complicated determination of the PV module temperature. The adaptability of current forecasting schemes of solar radiation to the BIPV context might play an important role in planning retrofitting and other BIPV actions.

2.3 Work packages and activities

The project is structured through a set of work packages covering the identification of needs, analysis of current standards, assessment of BIPV solutions, characterization of specific systems, and development of new modeling capabilities in both solar cadasters and BIPV systems (Figure 1).

Aware of the lack of dissemination of useful and practical information among BIPV stakeholders, this project dedicates a specific work package to promote the developed BIPV solutions and other outcomes of the project, as well as to serve as a bridge between the construction and the photovoltaic sectors in reference to BIPV. The website https://rings-bipv.com/ will update the main results, while dissemination includes publications, workshops, conferences, and courses.

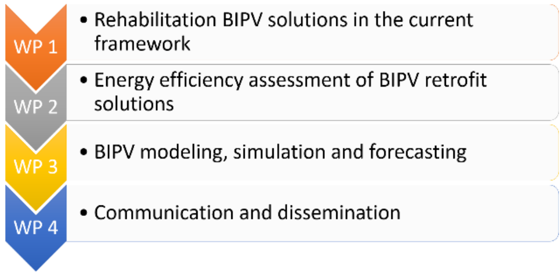

Figure 1: Structure of the project in work packages.

2.4 Experimental work

In order to fulfill the main objectives of the RINGS-BIPV project it is crucial to design specific experimental facilities and test mock-ups to study the performance of the different BIPV systems. The following are some of the experimental facilities of this project:

CIEMAT's Building 42 facility integrates a 27 kW BIPV ventilated façade, having five PV arrays at the top of the south, east and west façades. Three 4 kW PV arrays (each one with 2 parallel strings of 7 modules -7s x 2p- electrical configuration) are on the east façade, another 4 kW array (7s x 2p) on the west one, and one 8 kW array (7s x 4p) on the south façade. The main electrical parameters (i.e., output current, voltage, and power) and the relevant meteorological variables have been monitored since 2016. The in-plane irradiance (*POA*) has been measured at each cardinal point with reference cells.

Two testing cabins are designed to study the performance of semi-transparent PV windows, including their thermal performance and the validation of temperature models (Figure 2).

Figure 2: Testing cabins for BIPV windows and west view of the CIEMAT's BIPV ventilated façade.

The *BIfacial CANopie* (BICAN) testing facility is designed to study the performance of bifacial modules when applied as PV canopies on rooftops. The experimental setup includes ten modules, two of them as references. Reference bifacial modules provide front, rear, and total irradiance by blocking the light to selected strips of cells. In addition, ten reference cells measure front and rear irradiance at different points.

Also, a colored BIPV façade system has been mounted to test the performance of such modules under real operation in a ventilated façade configuration (Figure 3).

Figure 3: Colored ventilated façade developed in the project at CIEMAT.

3 PRELIMINARY RESULTS

3.1 Performance ratio of BIPV systems

Considering the monitored available data from the three BIPV systems of the CIEMAT building, the evolution of the daily performance ratio (*PR*) shows no significant tendency since 2017. *PR* characterizes the efficiency of a PV system when compared to the theoretical performance with the absence of losses. In this case, temperature is the most impacting parameter on the west façade of the building, while partial shading is a challenge on the east one due to nearby deciduous trees. All these effects are analyzed in the project.

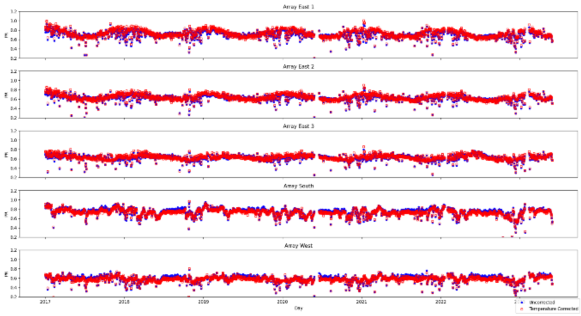

Figure 4: Daily Performance Ratio (*PR*) of the CIEMAT building BIPV arrays since 2017. The temperature-corrected *PR* is also included.

3.2 PV generation forecasting

Photovoltaic generation forecasting directly based on time series data from one of the BIPV vertical façades has been studied using machine learning algorithms based on decision trees. The forecasting scheme employs the *skforecast* library from the *Python* environment, which facilitates the implementation of different schemes for both deterministic and probabilistic forecasting applications [4].

4 REFERENCES

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