CONTROLLED ENVIRONMENT TEST LABORATORY FOR COMFORT PERFORMANCE STUDIES ON FAÇADE-INTEGRATED BIPV

1, 2 Cristina S. Polo López, 1Luca Tenconi, 1Fabio Lo Castro, 1Stefano Brambillasca, 1F. Javier Neila Gonzalez, 1Estefanía Caamaño Martin, 1Francesco Frontini

1IrCos S.c.a r.l. Research and certification Institute for Sustainable Construction, Legnano, Milano (Italy)
2 Swiss BiPV Competence Centre, SUPSI, Trevano CP 105, CH-6952 Cannobio (Switzerland)
3 U.P.M. Polytechnic University of Madrid, Madrid (Spain)

ABSTRACT: The influence of different façade integrated photovoltaic solutions on the building energy consumption is not easy to assess under real operating conditions. Thermal aspects, inside temperatures or luminance level that can be expected using building integrated PV (BIPV) modules are not well-known. The BIPV Env-lab “BIPV Controlled Environment Test Laboratory” project aims to analyze the whole set of issues that influence the global energy consumption in a building that use BIPV modules. Issues to be analyzed are comfort aspect (thermal and lighting aspects), energy consumption, electricity production, electrical behavior of PV modules and PV systems for vertical integration. Integrated photovoltaic components and the use of renewable energy is already a standard for reducing power consumption, but would also be important to know the possible contribution on the comfort and health of building occupants. This work presents the specific design of the test facility and the methodology employed for BIPV testing in a real context and weather conditions.

Keywords: Building Integrated PV (BIPV), Energy performance, Experimental Methods, Environmental comfort

1 INTRODUCTION

To promote the use of photovoltaic technology in buildings international research programs [1-2] encourage and support solutions that favor the complete integration of photovoltaic devices as an architectural element, the so-called BIPV (Building Integrated Photovoltaic), furthermore facing to next future towards net-zero energy buildings [3].

When a BIPV element replace a construction element absorbs its function as insulation material, as element that protects from weather and environmental conditions (noise, rainfall, wind, heat, shadow, etc.), International organizations are working to establish the most suitable standards and test procedures to check the safety, feasibility and reliability of BIPV systems. Furthermore nowadays, there are no specific rules for complete characterization and evaluation of a BIPV component according to the European Construct Product Directive CPD 89/106/EC and the applicable electro-technical requirements as stated in the low voltage directive 2006/95/EC CENELEC standards [4].

Integrated photovoltaic BIPV components and the use of renewable energy is already a standard for green energy production, but would also be important to know the possible contribution to improve the comfort and health of building occupants. Comfort, light transmission or protection, thermal insulation or thermal/electricity power production are aspects that are usually considered alone, while all together contribute to the building global energy balance. This project aims to study their behavior through a series of experiments in order to define the real influence on comfort aspects and on global energy building consumption, as well as, electrical and thermal characteristics of these devices.

This research project has been carried out within the Framework Agreement between CNR and the Lombardy Region (Italy) “New technologies and tools for energy efficiency and use of renewable sources in civil end-use. WP5: Development and testing of technology solutions using renewable energy”.

Nowadays physical characteristics of BIPV glass façade, like thermal comfort and daylighting properties are not well considered and few studies exist. This study aims to reveal wellness conditions in building that uses photovoltaic BIPV devices, such a BIPV glasses on façade.

2. BACKGROUND

The nominal PV power at the STC (Standard Test Conditions 1,000 W/m2, 25°C temperature and 1.5 AM) which is normally measured in indoor laboratories, identifies the characteristics of the PV module at specific conditions in order to be able to compare different modules and technologies on a first step. The Watt peak is not enough to evaluate the panel performance in terms of Watt/hour of various modules under different operating conditions, which is the really crucial issue, especially for the assessment of investments in a feed-in-tariff regime. Actually, peak power is the price reference for PV module and one of the main selling factors. But it gives no assurance of being able to predict with conviction the energy performance of a certain module in given environmental conditions.

IEC standards, commonly used in Europe to certified PV modules (IEC 61215 and IEC 61646 respectively crystalline and thin-film ‘Terrestrial PV Modules-Design Qualification and Type Approval’), attest the feasibility and reliability of PV modules for a defined period of time and a power decrease also limited. To facilitate dissemination, given the high diversity of shapes and sizes of the PV panels used in this field, the legislation and current standards provides the certification of a single module with standard features and the relevant declaration of conformity, for the following customized products with same characteristics [5-6].

There is also an effort (IEC 61853, ‘Performance Testing and Energy Rating of Terrestrial PV Modules’), still under preparation, to find appropriate test procedures and methodologies to calculate PV modules energy yield under different climate conditions also taking into account specific characteristics of the technology; basically trying to forecast the performance of a module within a short time period during each season [7].
The lack of tests in specific conditions of installation (as façade BIPV devices) means that it is impossible to know the exact effective performance of these systems and the environmental conditions that can lead into the building.

3. Test Facility Criteria

3.1 Approach

Test cells are controlled environments, usually built for testing the thermal properties of new building components such as windows, walls, shading devices, etc. The test cells are thermal insulated in order to prevent not controlled heat exchange with exterior and are equipped with air conditioning systems and monitoring appliances for testing a scale building components under real weather conditions. In these test cells one of the original enclosures may be replaced by the enclosure element to be tested. There are different types: TRE (Test Reference Environment) [8], Hot Box [9], Paslink Cell [10], Test Cell [11], Isotest [12], Test Bed [13], Test Room [14], and Test House [15-16] all of them with similar and unique features.

3.2 BIPV Test Facility for real operating conditions

The “BIPV Controlled Environment test Laboratory” for testing BIPV Photovoltaic façade devices was built according to Test Room criteria (figures 1 and 2). Each one reproduces the internal conditions of a real ambient (office, house, etc.) with an inner surface of nearly 10.00 m². The maximum test room aperture is 2.54 m².

The identical rooms have a sealed envelope that reproduces a low energy building according to the Italian energy policy as well as the building law. The walls of this device limit the thermal exchange between the inner of the test room and the outside. The color of the façade internally, the ceiling and the entrance door is white while the floor of the room is light grey. The experiments have been conducted side-by-side, to compare the results.

3.3 Installation of BIPV modules in demonstration façade

The facade of the building, in which the rooms are installed, faces 30° towards East. Each of the technologies to be tested will be installed on a special window frame that can adapt to the special features of each ones without changing its thermal performances. The installation of the PV units was in all cases simple without spending any extra time fitting these modules compared to ordinary glazing in similar frames. The window frame allows the installation at least as four PV modules at the same time.

The BIPV systems are aesthetically pleasant acceptable solutions. The façade-integrated photovoltaic devices are often 100% glass solutions with a high level of transparency and easily integrated with customizable size that provides natural lighting and ensure even shadow which can also perform an additional function of sun protection. These BIPV semi-transparent components integrated as a window element provides shade that prevents overheating at times of excessive heat, but as static component, likewise avoid the possible solar gains contributions in the cold months. In addition, the temperature of the module varies considerably in certain circumstances influenced by the PV technology installed, solar radiation, mounting system, lack of ventilation, etc. This factor may result in additional heat input in the building highly variable and difficult to quantify. In real operational conditions the solar radiation levels, the temperature and the solar spectrum vary constantly modifying the performance and the energy yield of the modules.

Different kind of BIPV technologies, see-through and light-through, glass modules were selected for the first series of tests (figure 3): mono-crystalline silicon technology, mc-Si, amorphous silicon thin film single junction, a-Si and copper indium selenide thin film technology CIS. All these insulated double glasses were selected with the same transparency and the same heat transfer coefficient (U value) also the low-e glasses are the same.

Figure 3: Customized semitransparent BIPV façade modules selected to be tested in the new BIPV test facility. From right to left, mono-crystalline silicon mc-Si, amorphous silicon thin film a-Si and copper indium selenide thin film CIS.

The modules were installed periodically on the test rooms in order to compare their performance to each other and with a traditional low-emissivity glass in different seasonal conditions. In the future modules with different colors and visual effects can be included for further study.

4. Monitoring System

The test rooms have all monitoring system in which reliable data for the thermal and electrical performance of PV modules can be obtained (figure 4). A special monitoring system for the acquisition of the main indoor environmental parameters has been installed within each test facility. An outdoor monitoring system records the external meteorological data. In particular, different sensors have been placed to detect the following parameters:

- Indoor and outdoor Dry-bulb temperature;
- Indoor and outdoor Relative Humidity;
- Natural wet-bulb temperature;
- Globe thermometer temperature;
- Indoor and outdoor luxmeter;
- Global Solar radiation;
- Air speed;

The lux-meter in the room for measuring illuminance and daylight levels has been placed through the room from the window to the backend of the room. The data is processed and elaborated in order to calculate different comfort index.

**Figure 4:** Instrumentation for environmental monitoring and schematic diagram of data acquisition system for monitoring BIPV façade-integrated devices.

The electrical parameters related to the BIPV façade components analyzed have been also monitored. An electronic load device is used to operate any PV technology to the maximum power point (MMPT, Maximum Power Point Tracking).

5 PURPOSE OF THE WORK

The influence of external climatic conditions and temperature on the electrical characteristics of PV modules and the potential for increasing PV technologies efficiency by improving the heat exchange factor as well as modules possible contribution to total building energy consumption has not been well investigated so far [17]. In addition, further insights into the internal environmental comfort in buildings using integrated photovoltaic technologies are needed and open new research perspective. The experimental set-up facility (testing room) allows studying three different aspects that affect building energy consumption and comfort issues: the thermal indoor comfort, the lighting comfort and the energy performance of BIPV modules tested under environmental conditions. Knowing the energy balance for each experimented solar technology, it is possible to determine which one performs best.

5.1 Thermal comfort assessment

Our perception of comfort is influenced by the variables described in the previous paragraph but also include other aspects like the clothing, activity level, and the demographic character of the subject (age, sex, health, etc.) and the characteristics of the physical environment. The analysis here presented is related to buildings such as offices, dwellings and schools with occupants' sedentary physical activities where metabolic rates vary from 1.0 to 1.3 met, and considering 0.9 clo for the period time presented here (clothing insulation values between summer and winter swaddling).

Two different approaches (figures 5 and 6) were applied to determine the indoor thermal comfort: the static model, based on ASHRAE Standard 55, ISO 7730:1995 [18] and performed by Fanger et al. and the adaptive Comfort Model (ACM), according to the “European Adaptive Standard”, EN 15251:2007-08 [19].

![Figure 5: Example of EAS (European Adaptive Standard) Chart for side-by-side test room’s thermal comfort analysis. Blue and red lines indicate the range for comfort temperatures (lower and upper limit respectively). Green and orange lines represent the fluctuation of the operative temperature (DegC) in the room. Two BIPV technologies were tested.](image)

![Figure 6: Thermal Comfort evaluation for BIPV devices. For the present data series November 2011, in Test room 116 mono-crystalline silicon (m-Si) BIPV glass module was tested while in Test Room 117 amorphous silicon single junction (a-Si) BIPV glass module was tested.](image)

Comfort degree-days allow to quantify the amount of energy required to maintain comfort that can be defined as the time integral of the mean daily outdoor air temperature above a particular base temperature. This methodology allows assessing heating and cooling consumption and quantifies the energy that can be saved or wasted in summer and winter time due to BIPV glazing modules. Further insides and a full description of thermal comfort analysis were presented by authors in [20].

5.2 Illuminance measurements - Lighting comfort assessment

To the glass surfaces is attributed the dual function of allowing visual contact with the external environment and to achieve a satisfactory distribution of illumination in the indoor environment. Today, thanks to
technological innovation a glass element can be characterized as a multifunctional element even with different functions: insulation, ventilation, shielding, visibility, signage and image, changing the amount and distribution of natural light, and even produce energy (heat / electricity).

By assessing the number of hours out of the comfort range in accordance with current regulations [21, 22], it is possible to estimate the energy consumption to achieve the desired lighting levels. The following figures (7, 8 and 9) show some of the results obtained.

5.3 BIPV Energy performance evaluation

Even if the energy consumption for air conditioning and lighting do not differ significantly between each PV technology tested for the week that is presented here, module energy yield is greatly conditioned by the chosen PV technology, as expected (see figure 10). The energy yield of mono-crystalline silicon BIPV modules is higher than amorphous thin film.

6 PRELIMINARY RESULTS

The figures presented above show the results of this analysis where for each test room the performance regarding indoor comfort, energy consumption and power yield of two different BIPV photovoltaic see-through glass technologies with the same transparency level are analyzed.

6.1 Final energy balance – Interpretation of results

The graphic below (figure 11) shows a negative energy balance, due to monitoring period (November) as well as transparency level, tilt and azimuth. It is clear that, lower nominal power (Pn) of modules (85 Wp for m-Si and 31 Wp for a-Si module) means lower energy output of the PV system. Furthermore, for the specified time period of monitoring, the integrated c-Si modules present a lower Performance Ratio (PR) whereas the thin film modules exhibit a higher one.
CONCLUSIONS

This new test facility, the BIPV Controlled Environment test Laboratory, is a small scale demonstration, a demo-site for BIPV façade elements that can be used to streamline the value chain and break overcoming non technological barriers preventing wider use of BIPV.

The outcome of the project will raise awareness of sustainability and has full intentions to disseminate the results of this project as a way to offer a good opportunity to architects and planners to better know the different PV technologies and its features (useful for correct building integration design). It will also be possible to describe and assess the problems encountered for these BIPV products and to have new parameters to implement in BIPV module’s datasheets for increase knowledge for sharing with the industry sector and improve the results spread.

REFERENCES

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