SLICE - Solar Lightweight Intelligent Component for Envelopes: application for the ICARO pavilion

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Abstract

In the ongoing race to reduce polluting emissions, a significant contribution is made by the introduction of intelligent building management systems. The European directive 2002/91 on energy performance in buildings already invited us to look at a new generation of almost zero energy buildings. Research in the field of multifunctional facades offers the opportunity to provide an immediate response to improving air quality and, at the same time, optimizing the use of resources. In fact, adaptive facades can be traced to one of the most effective strategies to efficiently manage the interactions between external and internal environments to maximize winter heating, summer shading and natural ventilation, sound insulation, daylight transfer, glare-free, and interior comfort for the occupants. Nowadays, adaptive enclosures are not only able to interact with the environment and the user but allow the energy needs of buildings to be reduced by integrating technologies to produce energy from renewable sources. The contribution will present the latest developments of an innovative kinetic device for architecture, carried out by the University of Catania; it is the result of a multidisciplinary research project involving important local industrial companies. The component consists of a composite material substrate with integrated high-efficiency photovoltaic technology. The results shown below made it possible to evaluate the use of the designed component in light and stand-alone architectures, representing a valid solution to reduce the impact on the territory even in fragile contexts.

Keywords: adaptive architecture, innovative envelope, photovoltaic, composite material, lightweight architecture

Classification matches: 2.2. Digitalization, robotics and industrialization for sustainable buildings, 2.7. Building efficiency and User-Centered Design

1. Introduction

In recent years, scientific research and the production market focused their attention on adaptive, highly flexible and lightweight architecture components. This phenomenon becomes more important if these experimentations concern materials that improve the sustainability of architectural objects both in the production phase of the components and during their use. The purpose of this line of research is to reduce energy costs by reducing the weight of the elements used and by simplifying the mechanical components.

Kinematics and adaptability are characteristic properties in the definition of intelligent envelope systems. As kinetic architecture, we define "buildings or building components with variable mobility, localization and/or geometry" [1]. The use of smart materials can be a simplification in the adaptive components but limits the possibility of controlling the movement if you consider that they are calibrated on specific thermophysical environment conditions. This is the case of the Shape Memory Polymers, which change their shape only under certain temperature variations [2]. On the other hand, the movement must be managed through an actuator; it presupposes the use of energy deriving from the network or produced on-site. This last case guarantees the potential self-sufficiency of the system if the integration of the adaptive component with energy production systems is reached.

The most promising field of application seems to be that concerning small residential modules (the so-called tiny houses), exhibition pavilions and, in general, light flexible multipurpose architectures.

With the introduction in the 1990s of amorphous flexible silicon cells, experiments aimed at offering new solutions for the integration of solar technology in building components began. The first photovoltaic textile structure called "Under the sun" dates to 1998 (Fig. 1a). It was built in the Cooper-Hewitt National Design Museum in New York and consists of a 9.7 m high enclosure equipped with amorphous silicon solar cells of 120 μm thickness, encapsulated and laminated on shaped fabric panels [3].

Ackermann & Partner Architects in 2011 designed the roof for the AWM Carport waste disposal warehouse, providing 220 three-layer ETFE cushions to cover a total surface area of 9600 square meters (Fig. 1b). The project includes thin-film photovoltaic modules inserted in the central layer with mechanical fastening devices in order to maintain certain flexibility and reduce the risk of deformation, that is due to the bending or stretching of the cushion. The outer membrane of the cushion protects the modules and allows the correct solar radiation with its high transparency. It can be opened to facilitate the maintenance and replacement of defective cells [3].

Fig. 1 | (a) Under the Sun Pavilion - Cooper-Hewitt National Design Museum 1998 [4], b. Ackermann & Partner Architects - AWM Carport 2013 [5], c. Kennedy & Violich Architecture - Soft House 2013 [6], d. Carl Stahl Architektur - Peace and Security Building of the African Union Addis Abeba 2015 [7]

Among solutions of photovoltaic systems in the building, the so-called BIPV (Building Integrated PhotoVoltaic), there is the "textile solar system" developed for the prototype Soft House in Hamburg, designed by the Kennedy & Violich Architecture studio [8]. The building has a wooden load-bearing, which is characterized by a dynamic façade with solar shielding with vertical bands. These ones are made with a semi-transparent and highly reflective PTFE fabric which has been superimposed on eight thin-film photovoltaic cells (Fig. 1c). The responsive system generates the rotation of the bands to follow the solar path, thanks to the kinematics integrated into the anchoring systems of each band. The individual façade elements are able both to convert solar energy into electricity and regulate the luminous flux in indoor environments. To achieve this goal, the building is provided with a Building Management System (BMS). The shading level can also be controlled manually by users.

Another very interesting building is the work carried out by the Carl Stahl Architektur GmbH for the Peace and Security Building of the African Union Addis Ababa (2015). The building has a large central open space that is covered by a photovoltaic veil, created using a 25x20 meter shading system with 445 transparent blue organic photovoltaic (OPV) modules. It is capable of providing enough energy for the interior lighting of the building (Fig. 1d).

Within this framework, the research presented here aims to develop a responsive, intelligent component in flexible composite material for adaptive envelopes. SLICE (acronym of Solar Lightweight Intelligent Component for Envelopes) is capable of producing energy if connected to a charging and handling system; it would offer the opportunity to create dynamic building envelopes and innovative temporary architectures.

2. Previous stages of the SLICE research and state of the art

The SLICE (Solar Lightweight Intelligent Component for Envelopes) research project started five years ago with an overview which drives the opportunity to develop innovative solutions on the use of foldable components, to get to the responsivity of architecture. In fact, foldability gives the shielding component a high degree of transformability connected to its kinematics; at the same time, it allows the increase of the mechanical performance because fold gives the material in the direction of the same a stiffening that takes the name of "resistance by shape" [9]. Moreover, through responsivity, it is possible to take into consideration the needs of the users. Through it, it is possible to reach different achievements, such as reducing energy costs, improving comfort, having accessibility, and so on.

The acquired knowledge suggested focusing our attention on the choice of the base material as well as the selection of the type of kinematics and the integration of photovoltaics into the foldable component in order to obtain a component capable of producing the energy necessary for its motion.

2.1 Material

The first phase of the research aims to create first samples of a small size composite material made by hand with a hot press, trying different fabric reinforcements (linen, carbon fibers and glass fibers) and two different matrices in thermoplastic elastomer, the styrene-ethylene-butylene-styrene (SEBS) and ethylene vinyl acetate (EVA) and testing different possible stratifications. The choice of the material to be used for the reinforcement was oriented towards natural fabrics and, in particular, the Biotex Flax fabric made up of flax fibers, and the fiberglass fabrics. Other fiber fabrics result in poor cohesion between the matrix and the reinforcement. The best performing stratigraphy is made up of a lower layer in EVA, a reinforcement fabric in Biotex, and an upper layer in EVA.

In collaboration with a local SME (Meridionale Impianti S.p.A.), who is a research project partner, production parameters (time and temperature of the lamination process) and stratigraphy composition (matrix and reinforcement layers) were defined, creating larger samples (about 20 cm x 40 making use of the vacuum production process in a single laminator.

For preliminary evaluations, the samples were subjected to visual and touch analyses and further analysis with the cross-section method. Finally, the samples that exceeded these analyses were subjected to a mechanical characterization process with a monoaxial tensile test [10, 11]. The results of the mechanical characterization tests show characteristics of the composite material comparable with those of the composite materials commonly used in Textile Architecture [12].

2.2 Post-production process

Once the lamination process was validated, the work was addressed to the definition of the folding procedure. The idea was to use a thermoforming post-production process to bring the material to the glass transition temperature (T_g) in order to re-melt the polymers present in it.

Preliminary, with the collaboration of another SME research partner (NTET S.p.A.), a sheet metal mold was made in order to define the folding process. It consists of two 90 ° V-shaped parts, obtained by pressing-bending two sheet metal sheets with a thickness of 0.8 mm, held in position with butterfly bolts, heated with four heated plates equipped with thermocouples, for temperature monitoring (Fig. 2a). This first solution was used to quickly analyse the definition of process parameters, as the thermocouples allowed precise control over the temperature trend in the parts of the mold. At the end of the experimentation, the definitive cycle parameters were set at 120 ° C of temperature and 15 min of duration. Based on these results, a multi-panel mold called "conformer" was designed for the pre-bending of large composite samples. It consists of stainless steel sheet plates (type 304b stainless steel). The composite is folded, alternating it with the panels characterizing the mold; the package obtained is tightened by means of stringent and subjected to heating in the oven (Fig. 2b). This pre-folding technique takes advantage of a considerable reduction in production times and costs. For the heating of this type mold, the same processing parameters previously identified were set [13].

2.3 PV technology integration

In order to make the component self-sufficient from the energy point of view, new samples in composite material were made integrating into it photovoltaic cells. Starting from the stratigraphy of the composite material developed, an experimental phase was carried out aimed at the implementation of the material through the integration of high-efficiency photovoltaic technology.

In recent years, this field of research has focused on the development of the exploitation of solar energy, to implement the structure of current solar cells and to search for new types in order to increase their efficiency, as well as pursuing the use of materials and technologies to break down the production costs. One of the most widespread and promising technologies in the sector is based on silicon photovoltaic cells or called first generation cells: photovoltaic panels based on monocrystalline and polycrystalline silicon cell modules dominate the market from the early years of the system's industrialization. The experimentation activity was focused on the possibility of increasing efficiency values, thanks to the use of new light-absorbing materials. In the cycle of only eight years, the efficiency increases from 4% in 2012 to the current higher theoretical value of 23%.

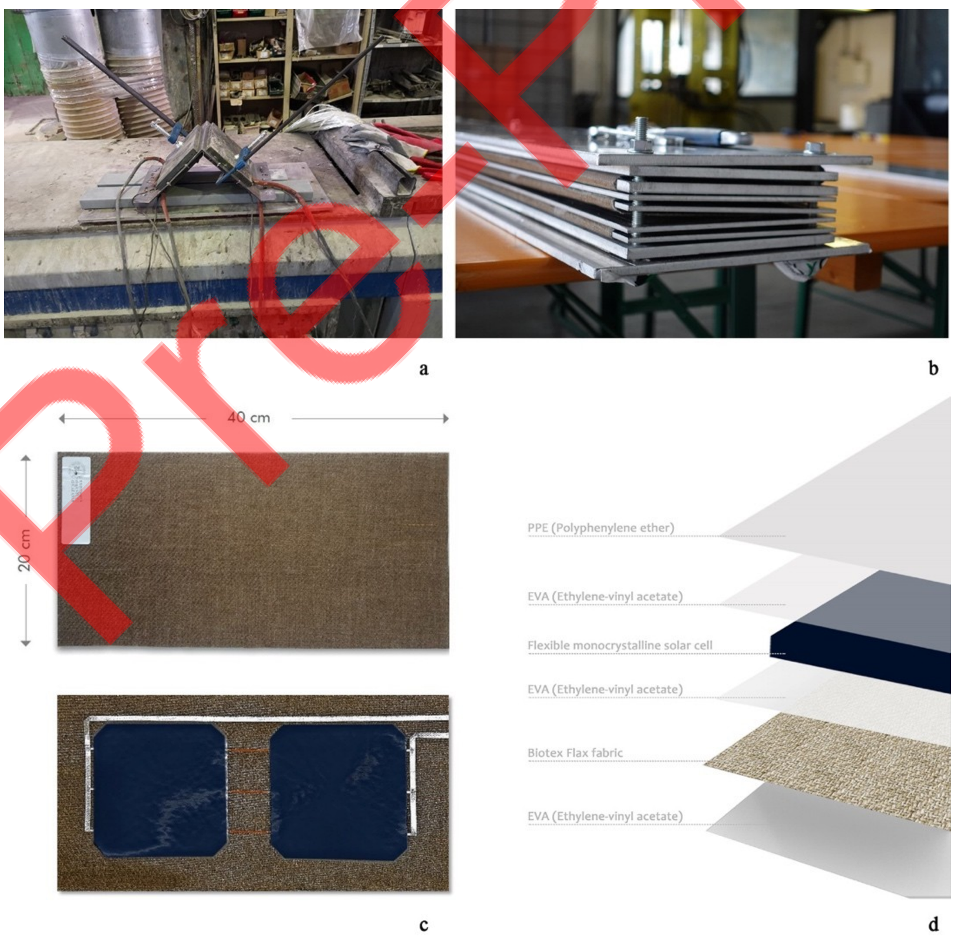


Fig. 2 | (a) sheet metal mold consisting of two 90 ° V-shaped parts, (b) preparation of the "conformer" multi-panel mold, (c-d) sample of the material with integrated photovoltaic cells and relative stratification [13].

So, the choice fell on flexible monocrystalline silicon cells produced by SunPower, of the c60 type with proprietary Maxeon technology. They are cells with dimensions of 125 mm x 125 mm, with a thickness of only 165 μm ± 40 μm, with contacts placed at the inner layer (back contact).

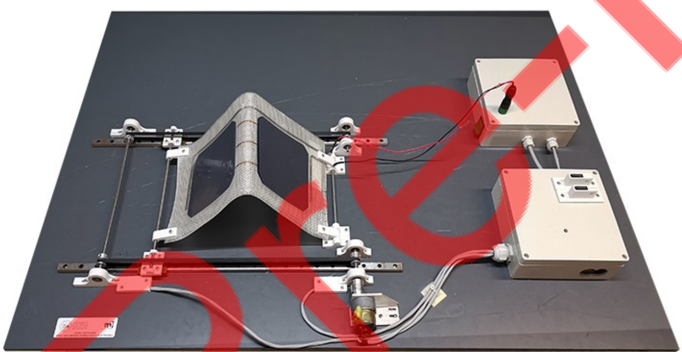
For their integration in the foldable elements, the photovoltaic cells have been positioned in correspondence with the flat parts and not with the folds. The cells are however subjected to bending stresses because the composite has a certain flexibility. The greatest criticality consists in the electrical connection between the different cells, which must necessarily pass through the folds.

The use of PPE layer was also tested in order to optimize the integration of photovoltaic cells into the composite. PPE is a thermosetting polymer usually used in the production of photovoltaic panels as a coating layer, extremely waterproof, with excellent resistance to atmospheric agents and dirt, as well as to numerous chemical compounds.

The best performing stratigraphy is made up of a lower layer in EVA, a reinforcement fabric in Biotex, the interposition of the photovoltaic cells between two upper layers of EVA and final coverage, limited to the areas of the photovoltaic cells only, with PPE layer [14]. The photovoltaic cells were connected in series using flexible copper braid wires at the folding lines, spaced at least 3 cm apart and connected to the poles through the adoption of rigid dog bone tabbing wires (Fig. 2c-d).

2.4 Prototyping

Two 1:1 scale prototypes have been developed aimed at simulating the operating cycles of the component. The first one (Fig. 3), called SLICE 1.0 was realized in order to test the system's charging and handling cycles, with simple bellows folding of dimensions 20 x 40 cm. It was equipped with two photovoltaic monocrystalline silicon cells SunPower Gen I and fiberglass reinforcement. The prototype was also tested with the use of a sunlight simulation lamp to verify the correct functioning of the electrical connections after the lamination and folding processes. The results were compatible with the sum of the voltage values from the technical data sheet of the individual cells, allowing the influence of the PPE coating layer adopted to be considered negligible.



Dimensions and weight	20 x 40 cm; 139 g
Matrix	EVA SKC Films EF2N
Reinforcement	Fibra di vetro
Photovoltaic cells	SunPower Maxeon® Gen I
Charging circuit	ST Microelectronics ST SPV1040T
Battery	3.7V 2250 mAh 8.33Wh litio
Microcontroller	Arduino Mega 2560

Fig. 3 | The first prototype equipped with fiberglass reinforcement and monocrystalline silicon solar cells [13].

The second prototype (Tab. 1), called SLICE 2.0 was built for a test campaign in environmental conditions. In this case, the automation system was subjected to a profound upgrade to add a complete package of adaptive functions. A panel of dimensions comparable to a standard window for a standard room was adopted as the shielding element. SLICE 2.0 is equipped with no. 12 photovoltaic cells according to a circuit of 4 parallel branches, each of which is composed of 3 cells connected in series. This method of electrical connection was adopted to facilitate the arrangement of the cells in the layers and in such a way as to guarantee an output voltage value adequate to the values in which the charging board with ST Microelectronics SPV1040 chip adopted for the prototypes operates. In order to be applied to the prototype, the composite fabric was subjected to the defined thermoforming process with the metal conformer. The Arduino source code has a list of instructions distributed in a hierarchical manner to obtain a finite state machine, usually known as a multitasking machine [15]. In this way, the prototype can recognize three different operating scenarios, called Comfort Mode, Energy Mode and Manual Mode, and react adaptively on the basis of predetermined cases, strictly connected to the need to ensure an adequate level of indoor comfort or optimize the production of energy from the incorporated photovoltaic cells.

The Comfort Mode has the purpose of privileging the comfort conditions within the rooms, ensuring an adequate level of lighting by moving the component, adjusting its position both in order to ensure good lighting and to avoid potential glare situations. Energy Mode is activated when the proximity sensor does not detect the presence of users in the room. In this case, for maximizing the electrical energy production, the component movement to its complete extension. The Manual Mode is a maintenance mode, developed to allow complete control of the component by the user precisely for maintenance and / or cleaning activities on the frame or device.

Sample	100 cm × 68 cm; 1.5 kg
Composite	Biotex Flax, 400 g/m^2 Composites Evolution Ltd. EVA SKC Films EF2N DUN-SOLAR PPE
Silicon cells	SunPower Maxeon® Gen I
Linear guides	550 mm Mini MGN12H
Belts	Tiptiper 2GT-6
Pulleys	20 Teeth Bore 5 mm GT2 SIENOC
Gear motor	POLOLU-2205 150:1 Micro Metal Gearmotor LP 6 V
Lithium battery	4500 mA, 3.7 V
Charging circuit and additional module	ST SPV1040T battery by ST Microelectronics TC4056 IZOKEE 1A 5 V micro-USB
Control board	Arduino Mega 2560
Analogic light sensor	Adafruit GA1A12S202
Infrared proximity sensor	PIR HC-SR501
Rain or snow sensor	Raindrops Module MH-RD
Current sensor	ACS712-20 A
LCD display	HD44780

Tab. 1 | Components of SLICE 2.0. prototype.

Fig. 4 | Example of SLICE 2.0 prototype installed on a window [16].

The test campaign (Fig. 4) was preceded by a preliminary sensor calibration phase, performed to verify the right functioning of the code. The identification of the threshold values defined for opening and closing were checked, as well as the verify of the designed power and the capacity of the battery.

The tests highlighted some constraints of the SLICE 2.0 prototype because, in some cases, the values obtained did not correspond to the expected values. So, it was observed that the charging board did not have suitable dimensions, and as a consequence, it was not possible good store the energy produced by the PV cells. For this reason, the development of this research foresees the redesign of the recharging system and also the addition of an MPPT (Maximum Power Point Tracker) controller, which will allow the photovoltaic cells to operate at their point of maximum power [16].

The analysis of the technical data of the panel also suggested the prospective to use the surplus of energy produced to power the technological components of the environment where this is installed, so like as a BIPV solution.

3. Advancement of SLICE

SLICE project has undergone a further phase of development thanks to the synergy established with the EWAS project - An Early Warning System for culture heritage [17], already developed for some years by the University of Catania. One of the goals of EWAS project is the construction of a multipurpose architectural module for the valorization of cultural heritage. To this aim, an innovative technology called ICARO (Innovative Cardboard Responsive Object) was developed, based on the use of a panel consisting of corrugated cardboard boxes connected to a frame made of wooden elements. The combination gives rise to a light and sufficiently resistant elements to create sustainable architectures. The absence of foundations or other infrastructural works and the prevalence of dry building technologies makes the module suitable for use in fragile areas, such as archaeological sites, precisely.

This technology will be tested through the realization of a prototype pavilion. It will be placed in the coming months at the Megara Hyblaea test site; it is one of the oldest Greek colonies in Sicily, located near Augusta. The ICARO pavilion represents a micro-architecture to show the peculiarity of the site through multimedia capable of giving responses to the visitor's needs in sensory terms. Resting on the main north-south route, it divides two important monuments of the site: the south temple, dating from around the 7th century BC, and the prytaneum, from the 6th century BC, a place intended for city magistrates. The technology developed in the experiments illustrated so far, responding to the requirements of flexibility, lightness, low costs, high efficiency and durability, in fact, lends itself to application on energy self-sufficient temporary architectures.

In order to cover the energy needs of ICARO, the external cladding system of the pavilion will feature SLICE modules, used as a BIPV system for the production and storage of electricity for powering the technology. With this aim, a new prototype named SLICE4ICARO was designed.

4. Methodology

The SLICE4ICARO prototype is mainly characterised by the enhancement of the production chain as well as the electrical storage of the power generated.

In this specific case, an off-grid or stand-alone photovoltaic system was designed based on the installation of an inverter with MPPT and the connection of a battery pack to allow the operation of the pavilion during the opening hours of the archaeological park to visitors. The power of the batteries and the number of modules to be installed on the facade of the pavilion were designed by comparing different usage scenarios in relation to the expected loads for powering the technological services and the use of multimedia content.

The project of the electrical system represented the starting point for a test campaign aimed at obtaining useful data to validate the effectiveness of the proposed solution under real environmental conditions.

The tests were carried out at the University of Catania, on the premises of the DICAR (Department of Civil Engineering and Architecture). The two samples were placed on the terrace of a building of the University Campus of Catania, while the charge controller was placed inside an adjacent room. For the purposes of the tests, two different configurations were monitored: panels positioned vertically and horizontally.

The charge controller used for the tests is an MPPT Epeever Triron 1206N, which has a module that includes an RS485 port, which through a USB to RS485 cable (CC-USB-RS485-150U) can be connected to a PC and monitored in real time through proprietary software.

The charge controller was instead connected to a 12V 24 AH / 10h "Prime AGM VRLA" battery. A 100W light bulb was used as the load to simulate the basic absorption of technological components serving an office environment. The PC was equipped with a remote management software and a webcam that made it possible to carry out a constant monitoring and check on the correct functioning of the load (switching on-off the lamp) and on the instantaneous external light conditions.

5. Results and discussion

Two SLICE4ICARO samples were made with the stratigraphy already adopted in the previous steps [12]. The location of the embodied photovoltaic cells has been defined by considering the previous results. Specifically, each panel is equipped with 15 monocrystalline silicon photovoltaic cells, connected in series and distributed over three strings of five elements. Each one of them is connected and welded to the adjacent one through dedicated bus bars (dog bones). At the end of each group of five cells, a linear bus bar was applied to connect to the next string. The technical characteristics of each panel are shown in Table 3.

Dimensions and weight of the single panel	105 cm x 65 cm; 1.8 kg
Single panel power	49.5 W
Single panel voltage	8.55V
Current	5.8 A
Matrix	EVA SKC Films EF2N
Reinforcement	Biotex Flax, 400 g/m2 Composites Evolution Ltd
Additional layer	DUN-SOLAR PPE
Photovoltaic cells	SunPower Maxeon® Gen I
Charging circuit	MPPT Epeever Triron 1206N
Battery	Prime AGM VRLA" da 12V 24AH/10h

Tab. 2 | Datasheet of SLICE4ICARO prototype.

A set of tests were carried out on the prototype. According to this aim, it has been installed at the university campus of Catania. The Energy production was monitored for about three months. Figure 6 shows the two PV samples, which have an active surface of 0.469 m^2.

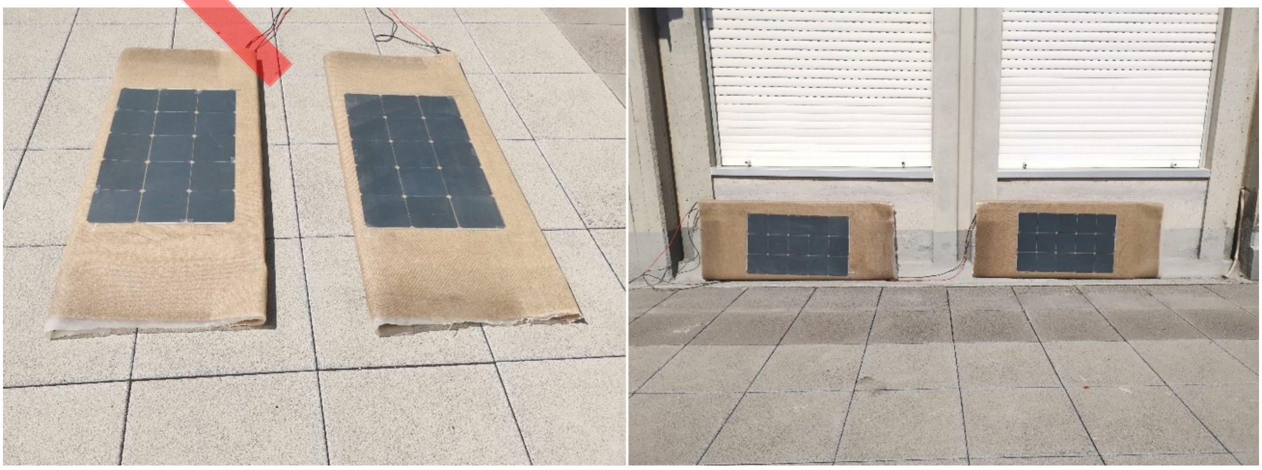


Fig. 5 | Positioning of SLICE4ICARO panels for testing.

Figure 6 show the solar irradiance in Catania city, derived by the PVGIS database [18] for a horizontal and 90° tilted surface with azimuth 30°, in agreement with the panels installed.

Fig. 6 | In-plane solar irradiation for a horizontal and vertical surface with azimuth 30°.

Looking at this data is evident that the installation of the PV panels with a tilt angle of 90°, allows obtaining a more constant power production all year round, privileging the power production during the winter months.

Figure 7 shows the daily variation of the components of irradiance for a horizontal surface in February and a vertical surface in March.

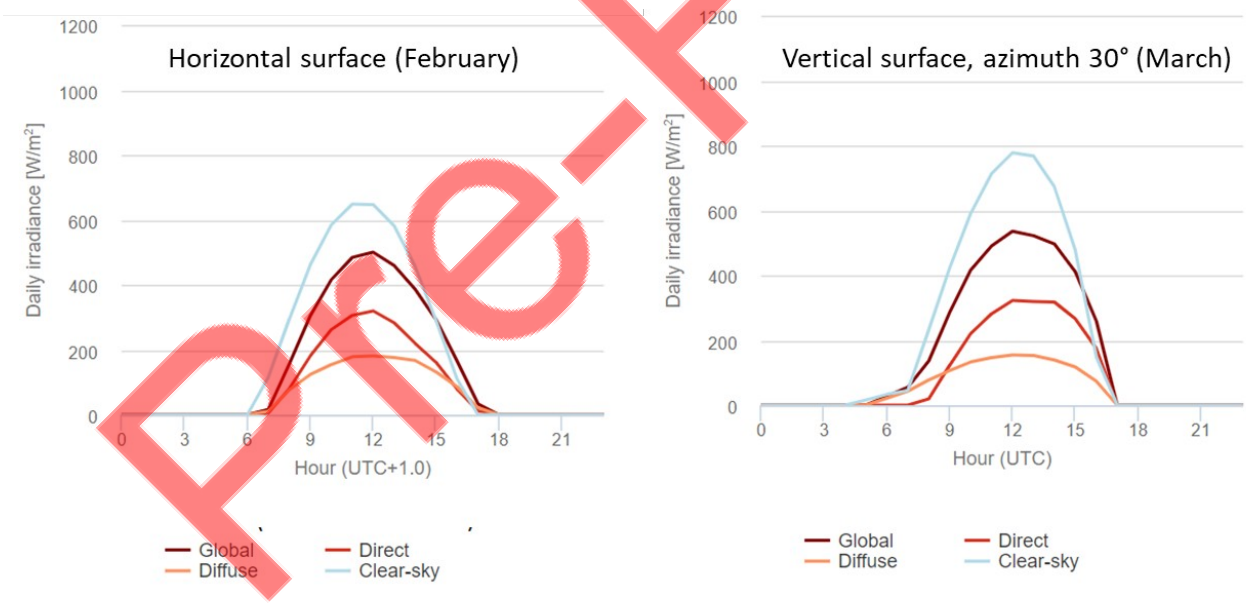


Fig. 7 | Global, Direct, Diffuse and Clear Sky irradiance for horizontal (February) and vertical surface (March)

From the assumptions made during a preliminary analysis of the system, considering the various losses due to connections by welding, the type of installation and the prototype state of the entire components, the electrical efficiency of 14% was assumed for the whole system.

Figure 8 shows the observed power production during the period of the survey.

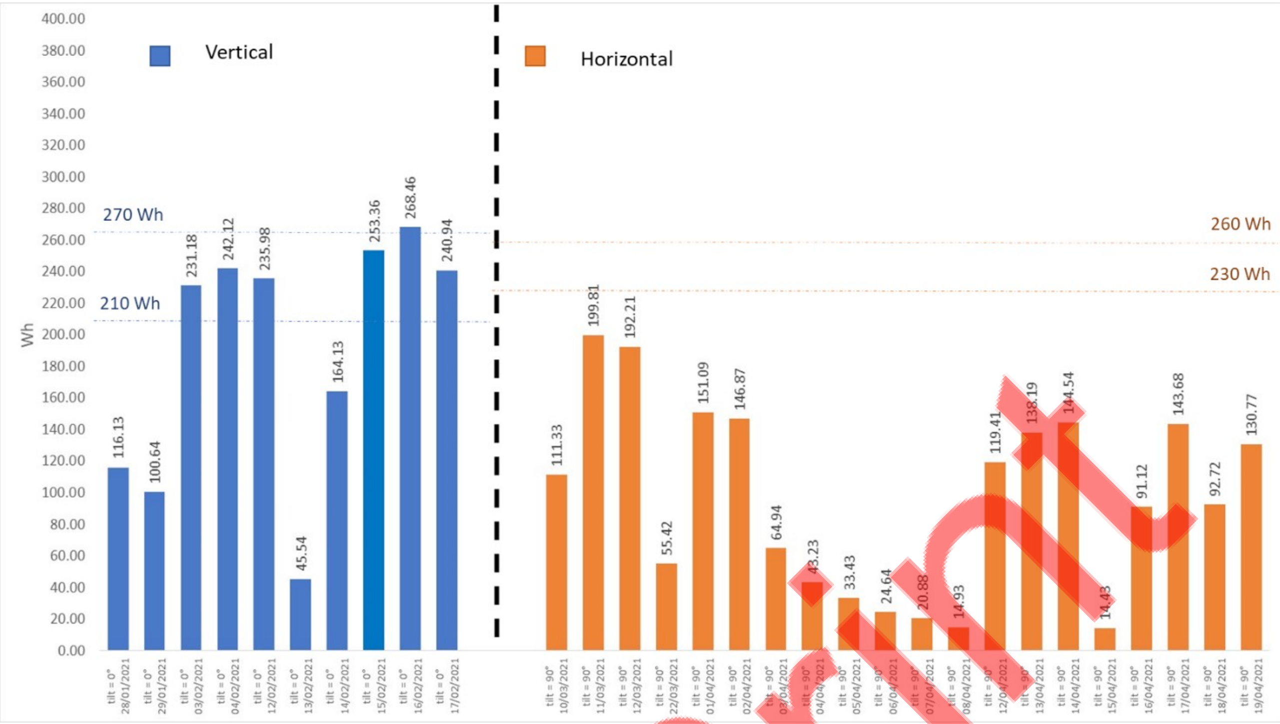


Fig. 8 | Power production for each of the investigated period.

The power production with the panel installed horizontally has a maximum value of 268.46 Wh, and it is higher than 230 Wh for the other five days. For the remaining days, the less power production might indicate that those days were almost cloudy days.

Considering that during February, the average daily solar irradiation for a horizontal surface is about 3.21 kWh/m^2, the tested PV system might provide an energy production of about 210 Wh. This result indicates that during those days, the solar irradiation was slightly higher than the average value. Otherwise, assuming the solar irradiance clear sky conditions, that is 4.15 kWh/m^2, the tested PV system should give a power production of about 270 Wh which is in perfect agreement with the observed maximum power production.

Thus, it is possible to assert that the performances of the PV panel are quite in line with the design conditions.

With the aim of evaluating the electrical performance of the whole system, the observed power production has been compared with the theoretical power production calculated using the solar irradiation data measured by the weather station installed at the laboratory of Environmental Technical Physics of the University of Catania [28], [29]. Such comparisons have confirmed the good agreement between expected and effective power production when the PV panel are installed horizontally.

Subsequently, the power production whit the PV panel installed vertically is commented.

The power production with the panel installed vertically is higher than 190 Wh for two days (March 11th and 12th), with a max value of 199.81 Wh, while for the remaining days, it is always lower than about 150 Wh.

Thus, considering that during March, the average daily solar irradiation for a vertical surface is about 3.55 kWh/m^2, thus the tested PV system should provide a power production of about 233 Wh. This result indicates that the system underperforms in comparison with the design conditions showing a loss of power production of about 30 Wh, which is about 15% of energy losses.

Such underperforming is even worst when the solar irradiance clear sky conditions are assumed as a reference, that is 4.00 kWh/m^2. In this case, the tested PV system should provide a power production of about 260 Wh, showing a loss of power production of about 60Wh, which is about 30% of energy losses.

For the rest of the period, the system has power production that is in the range of 150 Wh, even when almost clear sky conditions were observed. This means a loss of production of about 40% in comparison with the design conditions.

The first justification for such loss of power production is certainly due to the partial shading of the PV cells, which of course, gives rise to a reduction in the performance of the PV panel.

In addition to this effect, other power losses emerge as the conversion efficiency declared by the MPPT manufacturer decreases for low production values.

In general, lower performance of the panel was detected for variable weather conditions and predominantly diffuse radiation. Further losses of efficiency are attributable to the higher temperatures compared to STC conditions. SunPower cell factory data indicate a 0.32% reduction in efficiency for degree centigrade deviations from STC (1000 W/m², AM 1.5g and cell temperature of 25°C).

6. Conclusions

In recent years, scientific research and production market focused their attention on adaptive, highly flexible and lightweight architecture components. The acquired knowledge suggested focusing the attention on the choice of the base material as well as the selection of the type of kinematics and the integration of photovoltaics into the foldable component. The most promising field of application of them seems to be that concerning small residential modules (the so-called tiny houses), exhibition pavilions and, in general, light flexible multipurpose architectures. In fact, in order to cover their energy needs, it is possible to image lightweight flexible photovoltaic panels used as a BIPV system for the production and storage of electricity for powering the technology.

Thanks to a synergy among two research projects which involve the University of Catania, called SLICE and ICARO, it was designed a new prototype, namely SLICE4ICARO. It consists of a module of composite materials with photovoltaic cells embodied in it. It will be used as part of the external cladding of a pavilion, as a BIPV solution, for the production and storage of electricity.

The prototype has been recently tested. On the base of the results, it is possible to assert that the performances of the PV panel are quite in line with the design conditions. Hence, the technology will be used in the real scale realization and the pavilion will be placed in the coming months at the Megara Hyblaea test site, that is one of the oldest Greek colonies in Sicily, located near Augusta.

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9. Author Contributions

Conceptualization, A.M. and G.R.; Data curation, A.G.; formal analysis, A.M.; funding acquisition, V.S.; investigation, A.M. and G.R.; methodology, V.S. and A.G.; project administration, V.S. and G.R.; resources, V.S. and A.G.; supervision, V.S. and A.G.; validation, A.G.; visualization, A.M.; writing-original draft, A.M.; writing-review & and editing, G.R. and V.S. All authors have read and agreed to the published version of the manuscript.

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