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BIPVdSHADING

BIPV Dynamic Solar Shading System for Transparent Façades

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Summary

The project demonstrates the market for a highly aesthetic and prefab BIPV dynamic shading technology by realising the system in a real building and facilitating a technical and economic appraisal with activities aimed at validating the market introduction of the product. An integrated approach involving a multidisciplinary consortium of key partners combine scientific and economic value creation in Switzerland with good prospects of implementation in conformity with the Energy Strategy 2050. Starting from a TRL5 and validating cost-effectiveness, energy efficiency and reliability of the product, the technology innovation of this BIPV solution will demonstrate the technology consistency with low process and maintenance costs in the real full-scale building and in compliance with a TRL7. Demonstrating the aesthetic, energy and economic benefit ratio, this BIPV system will also be capable of attracting users' interest for high replicability.

Riassunto

Il progetto ha lo scopo di dimostrare il potenziale di mercato di un dispositivo di ombreggiamento dinamico BIPV di elevato valore estetico e prefabbricato, oltre che di facilitare la sua valutazione tecnica ed economica con attività volte a convalidarne l'introduzione sul mercato. Un approccio integrato che coinvolge un consorzio esperto e multidisciplinare, si prefigge di coniugare la creazione di valore scientifico ed economico in Svizzera con solide prospettive di implementazione in conformità con la Strategia Energetica 2050. A partire da un TRL5 e convalidando la competitività dei costi, l'efficienza energetica e l'affidabilità del prodotto, l'innovazione tecnologica di questa soluzione BIPV dimostrerà la competitività della tecnologia mediante bassi costi di processo e di manutenzione in un edificio reale conforme a un TRL7. La dimostrazione del rapporto tra benefici estetici, energetici economici per questo sistema BIPV sarà inoltre rivolto ad attrarre l'interesse degli utenti per un'elevata replicabilità.

Contents

Abbreviations

PV: photovoltaics

BIPV: building integrated photovoltaics

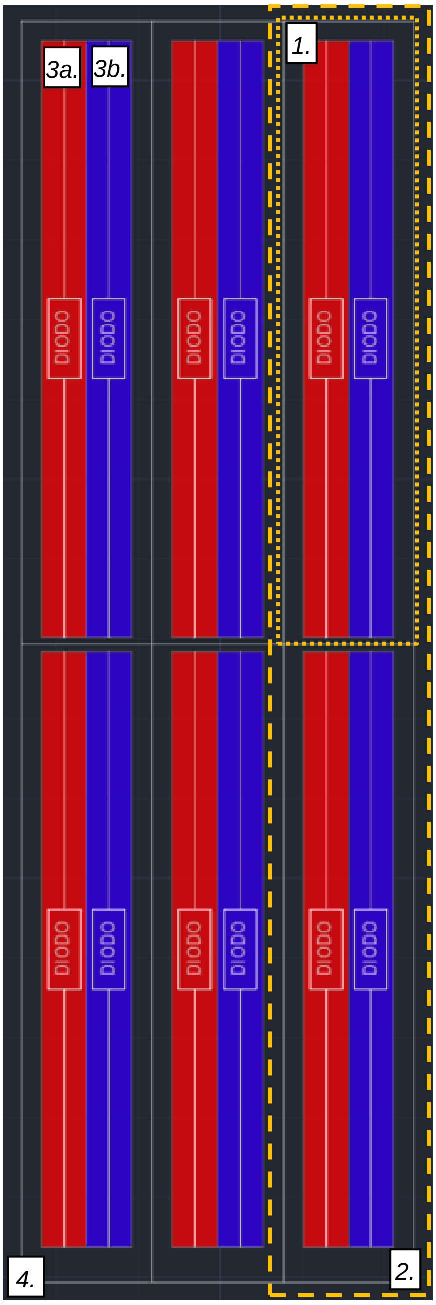
PVSD: photovoltaic shading device

TRL: technology readiness level

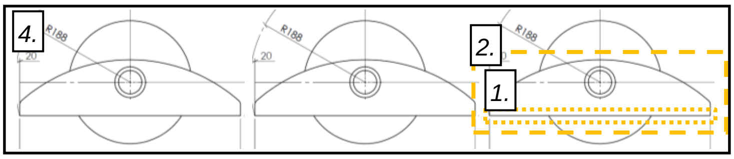
nZEB: nearly zero energy building

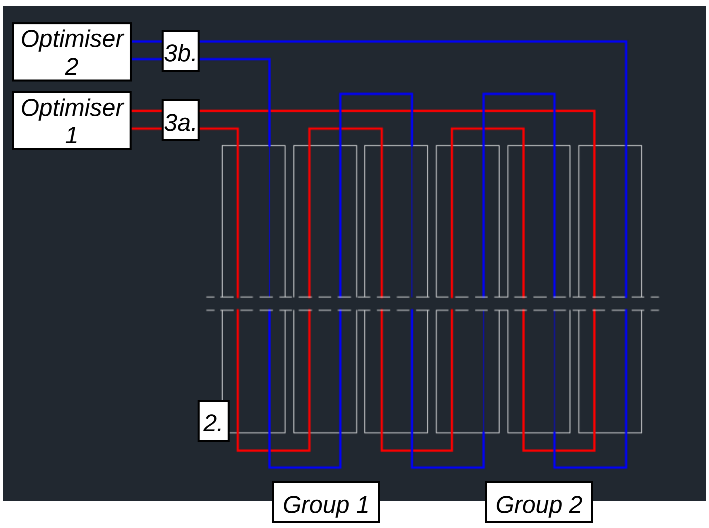
NPV: net present value

Taxonomy



ID	DESCRIPTION (pilot installation)
1.	PV module: photovoltaic glass-glass module made of 22 or 28 c-Si cells. Each PV module is made of two strings of 11 or 14 cells.
2.	PV slat: multifunctional kit including PV module and metal extrusion; each PV slat is bonded with two PV modules.
3.	String: vertical red hatch made of 66 or 84 cells in series (left string, "3a") and vertical blue hatch made of 66 or 84 cells in series (right string, "3b").
4.	Group: union of three PV slats in the façade, controlled by one motor.





1 Introduction

1.1 Background information and current situation

The building industry is responsible for about 40% of the CO_2 emissions globally. Without changes to current trends, global CO_2 emissions are set to increase in the following years. To mitigate catastrophic consequences, international directives are pushing towards a decarbonisation roadmap to improve the quality of cities and the health of citizens. Among other strategies to move toward nearly zero energy buildings (nZEB), the use of photovoltaic shading devices (PVSD) contributes to reducing the energy footprint by protecting buildings from direct solar radiation and overheating while producing renewable electricity on-site and increasing the users' thermal comfort. Even though the potential of PVSD is considerable, the sector's development is still scarce and few studies or products on the topic are available, especially considering the application of PVSD in buildings. Firstly, the solution bridges the building skin and the building integrated photovoltaic (BIPV) complexity with technology and a process that involves different competencies and non-conventional construction and management challenges. Secondly, conventional BIPV shading solutions' high initial costs discourage investments, particularly by investors who have experience in the traditional solar industry where photovoltaic (PV) is a means for producing electricity and many advantages as architectural and functional elements of the construction are not considered.

1.2 Purpose of the project

In this context, the project team has previously developed and engineered the technology with a validation of the small-scale multifunctional product at the technology readiness level (TRL) 4. In particular, the basic technological components have been further engineered to establish that the pieces will work together in a design system configuration similar to the final application. The project's scope is to achieve a technological readiness enhancement and demonstrate the substantial implementation of PV dynamic solar shadings by optimising the technical and economic aspects for a TRL7.

1.3 Objectives

The project demonstrates the techno-economic potential of a highly aesthetic and prefab BIPV dynamic shading technology by realising the system in a real building and facilitating a technical and economic appraisal with activities aimed at validating the market introduction of the product. After validating the technology in a relevant environment at TRL5/6 and assessing the cost-effectiveness, energy efficiency and reliability of the product, this BIPV solution will demonstrate the technology consistency with process and maintenance cost targets in the real full-scale building and in compliance with a TRL7. Demonstrating the aesthetic, energy and economic benefit ratio, it is expected to attract users' attention by offering high replicability. To this end, the following goals were set:

- Holistic technology assessment towards a cost reduction;
- Technology validation (from TRL 5 to TRL 6);
- Technology demonstration (from TRL 6 to TRL 7);
- Replicability and market exploitation strategies.

This interim report presents the results achieved in the intermediate phase (2022). Further analysis and results will be shown in the following reports. The next interim report is expected to be published in November 2023.

2 Description of the demonstration facility

2.1 Context

The photovoltaic generation system of Franklin University in Sorengo is made up of several production plants of different types. The project's first phase was completed in 2018 when 45.60 kWp were installed on two flat roofs. This part of the plant has already been commissioned and tested and supplies approx. 51'000 kWh/year of energy to the building. In 2020 the building owner wanted to upgrade the current photovoltaic system by exploiting the surface area of the new flat roof and the auditorium facade. 66.42 kWp were added to the existing system for a conventional rooftop installation. 18.36 kWp is the PVSD capacity that will be added to the facade. The total power of the PV generation will correspond to 130.38 kWp. The new building will also supply thermal energy to the entire complex via a new heat pump and will be equipped with a home automation system. The overall estimate of energy production will be approx. 150'000 kWh/year.

Figure 1 Franklin University Campus in Sorengo; the BIPV system is installed on the new auditorium's facade on the complex's west side.

2.2 BIPV system for the new auditorium of Franklin University in Sorengo

The first project challenge was to integrate the new production plant, in the form of a PVSD integrated in the facade, with the existing PV rooftop system, defining all the necessary details with the electrical designers, engineers and architects. The spaces assigned to the various appliances, the various passages of the cables from the surfaces to the technical rooms, the modification of the new electrical panels to integrate the production plants and all the aspects related to safety in the electrical field were therefore defined. The design and sizing of the production plant were developed on the basis of the PV modules used. The latter, having been made to measure for the project by Sunage, have non-standard technical and electrical specifications for which it was necessary to carry out a dedicated study for sizing.

BIPV generation system

After analysing the solar potential and the feasibility of making active the building volume with a dynamic shading system, an in-depth study was conducted to assess the impact of shading on PV modules. From the result obtained, the use of power optimisers became indispensable. The system consists of two SolarEdge inverters connected to the PV modules on the ground and first floor. As previously defined, the groups of PV modules are equipped with power optimisers to manage shading. They guarantee maximum production and safety (blocking voltage). In addition, power optimisers significantly reduce wiring (Figure 2).

Due to the curved facade and the different orientations, the PV slats have been divided into groups. After a thorough study, it was decided to control three PV slats simultaneously, thus forming 21 active groups with 63 PV slats per floor. Each group will be managed by a motor, which will simultaneously regulate the position of each group of PV slats. The PV slats are made up of two PV modules in series divided in half on the vertical axis to overcome the problem of shading carried over from one PV slat to the other at the extremes of opening. The plant also includes a non-active part on the east side of the pavilion, in which PV slats have been installed but not electrically connected due to low irradiation. The non-active PV slats work as a supply in case the active PV slats break or malfunction. Further details of the BIPV system and PV slats are available in the chapter "Taxonomy".

BIPV Control system

The movement of the PV slats is managed by a PLC, which manages all the various processes through dedicated programming and a specific algorithm: solar tracking and manual control. The solar tracking function refers to a solar calendar based on the location's geographic coordinates. The rotation limits of the PV slats, the start and end times and the movement accuracy (accuracy 0.1°) are defined remotely with software specifically implemented. The PLC is connected to the KNX home automation system of the building, which allows the user to manually intervene in the position of the PV slats to adjust the light intensity in the environment or position them for maintenance.

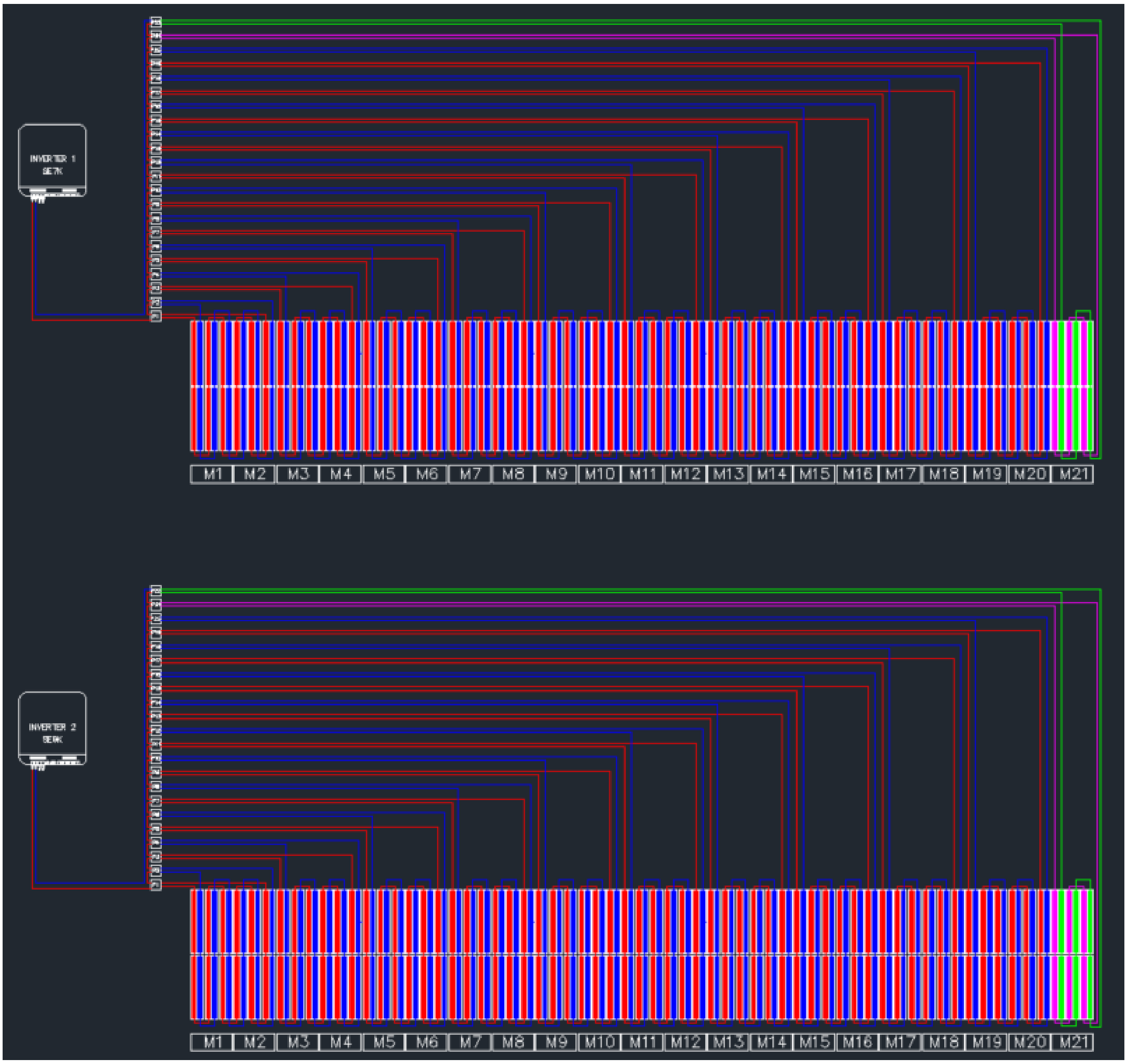


Figure 2 Electric schema BIPV installation. Up: first floor; down: ground floor. Mn represents the group which is managed by a motor.

3 Holistic technology assessment (WP3)

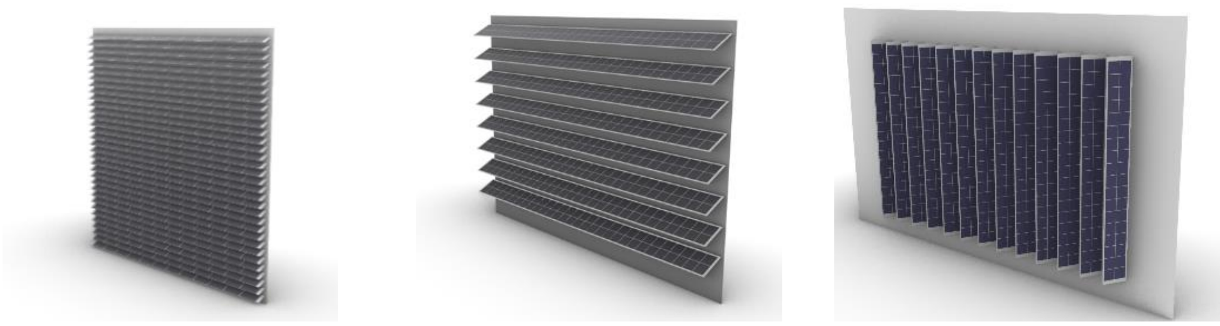
This study identifies under which energy and economic conditions a PVSD is cost-competitive by evaluating the most influencing parameters typical of its application context. The goal is to define the maximum current investment of a PVSD to achieve a net present value (NPV) equal to zero in 15 or 30 years. This activity assesses cost competitiveness scenarios in relevant architectonic situations and at different conditions (climate conditions, control system, orientation, technological systems), which are crucial for a BIPV system. The results allow the definition of the key elements that ease the replicability of the technology at different conditions with a perspective towards the technology market introduction. The holistic technological assessment identifies the status of PVSD technologies and builds up a benchmark for cost-reduction activities. The study is structured in three sections: i) the current (2022) status of PVSD and its analysis in terms of the status of the research, ii) an investigation of the potential energy production for PVSD performed at different conditions of solar irradiation and iii) an economic analysis, which serves to compare PVSDs in terms of cost competitiveness and cost-effectiveness. The study aims to assess only the energy performance of PVSD in terms of PV generation. Even though PVSDs affect different aspects of the building envelope (e.g., thermal, daylight, etc.), this activity focuses on the energy generated. In this report a brief extract of the whole methodology and study results is reported.

3.1 Literature review

Even though the interest in PVSDs has increased during the last few years and PVSD systems are taking the attention of architects and engineers because of their multi-functionality few studies on the topic and a limited number of industries are available and active today. The investigation on PVSD for transparent facades is conducted to present an exhaustive overview of the current state of the art of PVSD within the literature. This analysis, which includes quantitative and narrative or more qualitative components, is intended to provide the conceptual frameworks and state-of-the-art and synthesise diverse results in the extant body of research and industry by analysing papers and market available products on PVSDs. Based on this study, a scientific article titled "Paper review and performance analysis of external systems as photovoltaic shading devices" is under publishing and is available on request. Preliminary results of the activity are presented in 3.4.

3.2 Assessment of the photovoltaic energy potential of PVSD

PVSDs are envisioned as building elements capable of combining electricity generation with the typical advantages of external shading system devices, such as daylight and visual comfort improvement, as well as protection from summer overheating of large glass façades. This study focuses on different PVSDs (Figure 7) with the goal to investigate their potential energy production and compare them systematically. The PVSDs analysed in this activity consist of external dynamic venetian blinds, horizontal louvres (both dynamic and fixed) and dynamic vertical louvres. Moreover, these systems have been simulated in different climate conditions to provide energy production values needed to investigate their economic profitability in different locations. The results are presented in Table 1.



External PV venetian blind | Horizontal PV louvre | Vertical PV louvre

Figure 3 Schematic illustration of PVSDs selected for the energy analysis.

3.3 Maximum investment for cost-effective PVSDs

This activity advances a cost-benefit study of the PVSDs in the form of market-available products and energy performance in different scenarios. This task's goal is to define the maximum present investment (IMax) in the purchase, installation and management of a PVSD to achieve a NPV equal to zero in 15 or 30 years. The analysis defines a cost benchmark for PVSDs to assess a potential cost. The maximum investment, which is normalised considering the shaded window area, is calculated considering the variables:

- variation of the energy potential for the PVSDs assessed in 3.2;
- variation of the self-consumption ratio (60%, 70% and 100%);
- variation of the discount rate (4% and 7%[1]);
- electricity tariff: withdrawn 0.2631 CHF/kWh, injected 0.11 CHF/kWh.

When the investment (cost of purchase, installation and management) in a PVSD, under the calculation conditions, is below the maximum current investment, the investment can be considered favourable. The results are shown in Table 2 and Table 3. PVSDs are systems that produce electricity and replace the functions of conventional shading devices. Hence, the maximum investment for PVSD can be considered an extra cost compared to a traditional conventional system. The extra cost approach is based on the idea that an investment in a BIPV project should only be assessed based on the extra cost that BIPV represents compared to a competing conventional solution. It is quantified by summing the cost of making the cladding "active" and the associated accessories such as cabling, inverters, etc. The method of the additional charge (extra cost) has been discussed within the BIPV Status Report 2020[2] and within the report Integrierte Solaranlagen[3] promoted by Energie Schweiz. It is the basis from which the economic effectiveness of BIPV systems is calculated.

3.4 Consideration of the holistic technology assessment

Literature review

The studio reveals that PVSDs require a customised design in each climate and environmental condition with regards to the tilt angle, the blind spacing, and width to maximise the benefits between energy production and energy savings. Indeed, the tilt angle that maximises the energy production of PVSD does not always guarantee the overall electricity benefits. The mutual shading effect between slats, in the case of louvres, window blinds and multiple repeated PVSD, increases by increasing the width of the slat. It influences the decrease in energy production. Significant shading effects are also registered by decreasing the tilt angle of PVSD. However, PVSDs are less sensitive to PV blind angle than PV blind spacing. Finally, implementing optimal control methods for PVSD increases PV efficiency, maintaining user comfort.

Energy potential of PVSD

The external PV venetian blinds have the lowest yield in comparison with horizontal and vertical louvres: up to 39% lowest yield in comparison with south-oriented horizontal louvres and up to 41% lowest yield in comparison with south-oriented vertical louvres. This is mainly due to the self-shading effect between the slats and the control strategy. These considerations indicate that there might be some shortcomings in using south-oriented thin slats with reduced interspaces to produce electricity. The analysis also reveals that the yield of south-oriented horizontal PV louvres is about 35-38% higher when the angle is maintained at 50° instead of 15° since the self-shading is very limited and the slats have better exposure to solar radiation.

Maximum investment for cost-effective PVSD

The maximum present investment in purchasing, installing and operating a cost-effective vertical PV louvre, defined as a NPV after 15 years, is about 250-400 CHF/m2 for a south-facing solar tracking installation depending on the boundary conditions. The maximum present investment of a cost-effective external PV venetian blind, defined as a NPV after 15 years, is about 80-200 CHF/m2 and, after 30 years, 100-300 CHF/m2. The maximum investment is considered an extra cost compared to a traditional conventional system[2].

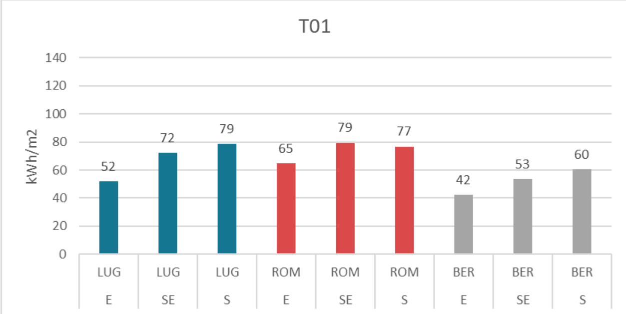
[1] Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity, 2019, E. Vartiainen et Al.

[2] Building Integrated Photovoltaics: A practical handbook for solar buildings' stakeholders, 2020, P. Corti et Al.

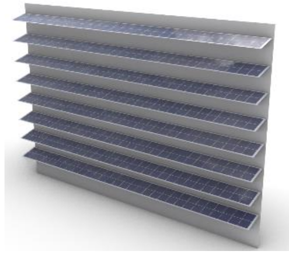
[3] Integrierte Solaranlagen Handlungsanleitung zur energetischen wirtschaftlichen Bewertung, 2020, C. Renken et. Al.

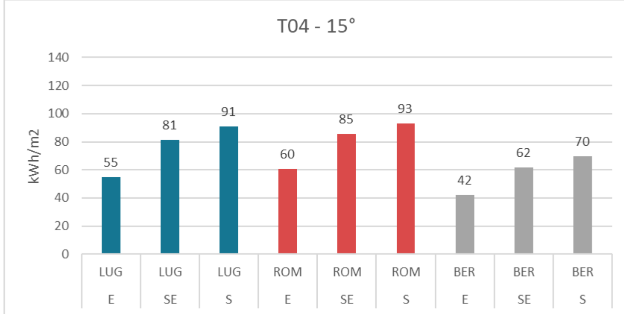
Table 1 Energy yield (kWh/m2) for different PVSD typologies. In the X axis, the different climate conditions (Lugano, Rome and Berlin) and orientations (east, south-east and south).

External PV venetian blind, d/l 4:3, dynamic system (T01)

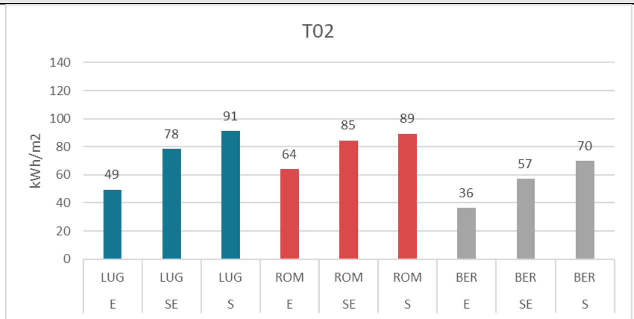


Horizontal PV louvre, d/l 0.95, fixed 15° (T04)

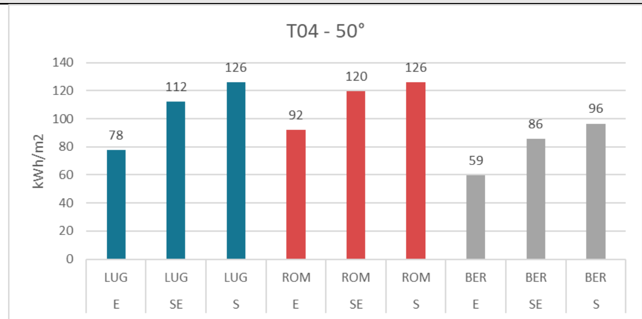




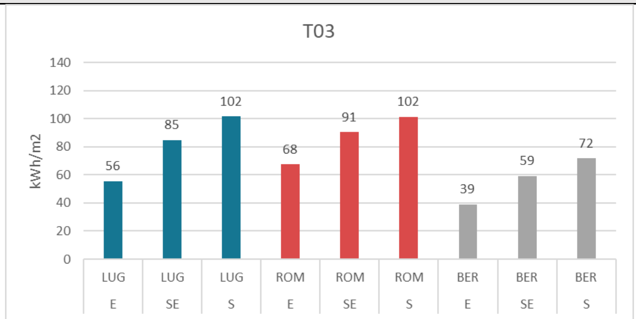
External PV venetian blind, d/l 1:1, dynamic system (T02)



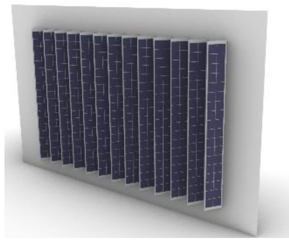
Horizontal PV louvre, d/l 0.95, fixed 50° (T04)



Horizontal PV louvre, d/l 0.95, dynamic system (T03)



Vertical PV louvre, d/l 0.95, dynamic system (T05)



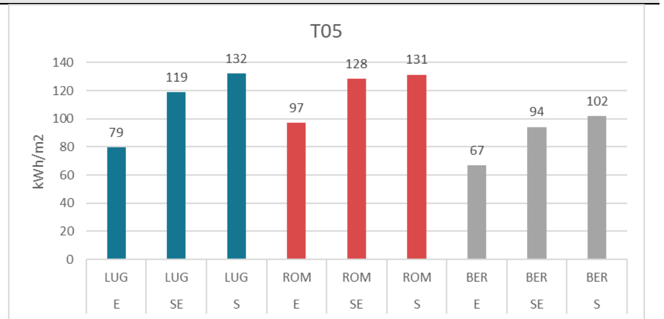


Table 2 Maximum investment (CHF/m2) for cost-effective PVSD to achieve an ROI in 15 years. In the X axis, the different climate conditions (Lugano, Rome and Berlin) and orientations (east, south-east and south).

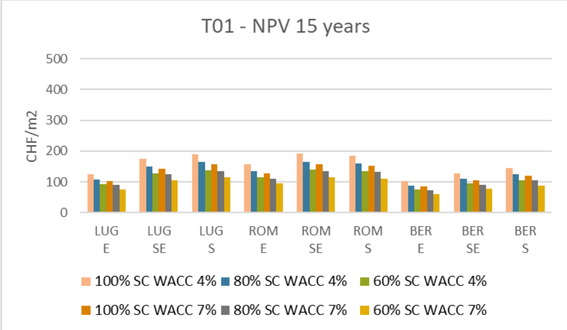
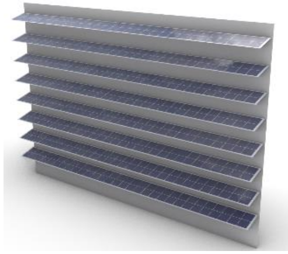
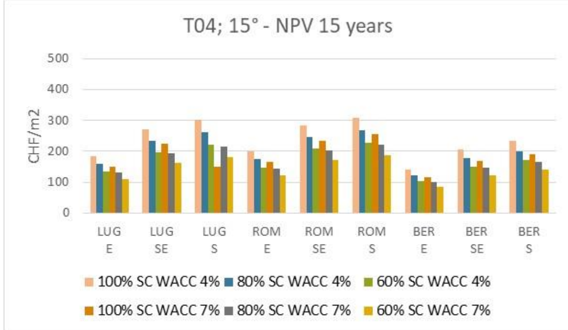
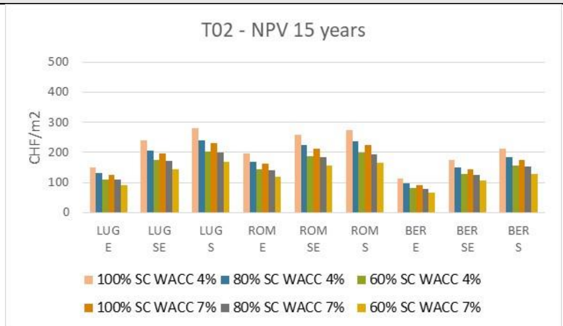
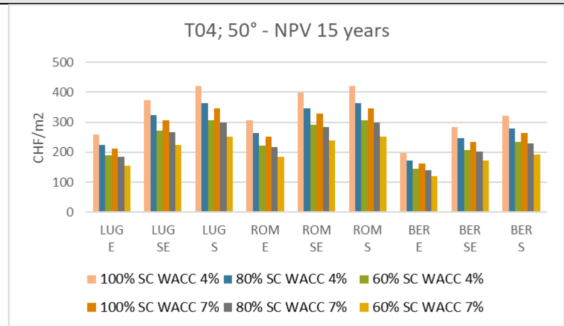
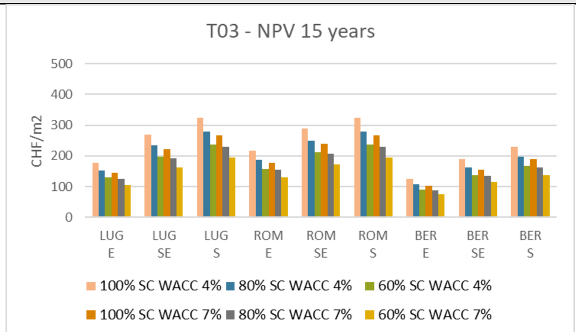
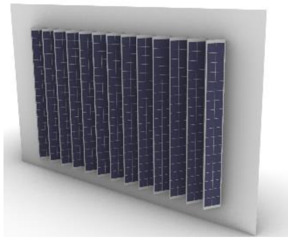
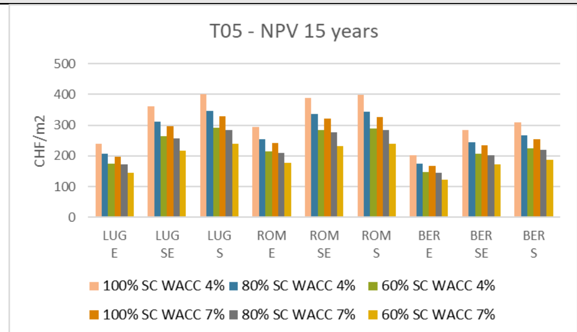
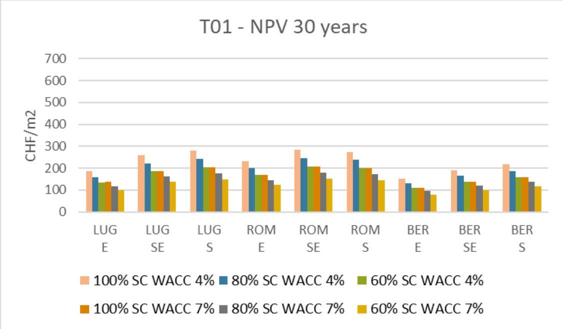
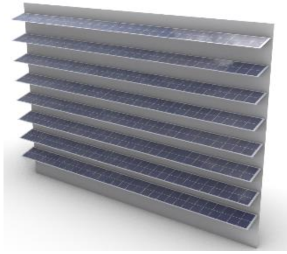
External PV venetian blind, d/l 4:3, dynamic system (T01) – 15 years		Horizontal PV louvre, d/l 0.95, fixed 15° (T04) – 15 years	
			
External PV venetian blind, d/l 1:1, dynamic system (T02) – 15 years		**Horizontal PV louvre, d/l 0.95, fixed 50° (T04) – 15 years**	
			
Horizontal PV louvre, d/l 0.95, dynamic system (T03) – 15 years		**Vertical PV louvre, d/l 0.95, dynamic system (T05) – 15 years**	
			

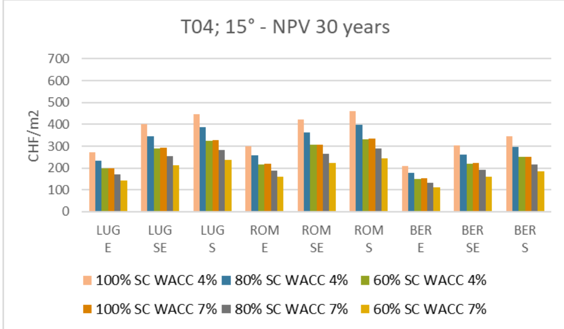
Table 3 Maximum investment (CHF/m2) for cost-effective PVSD to achieve an ROI in 30 years. In the X axis, the different climate conditions (Lugano, Rome and Berlin) and orientations (east, south-east and south).

External PV venetian blind, d/l 4:3, dynamic system (T01) – 30 years

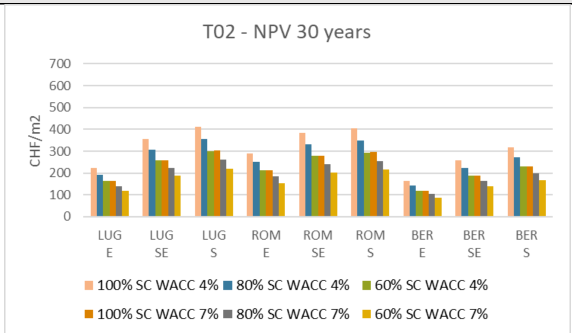


Horizontal PV louvre, d/l 0.95, fixed 15° (T04) – 30 years

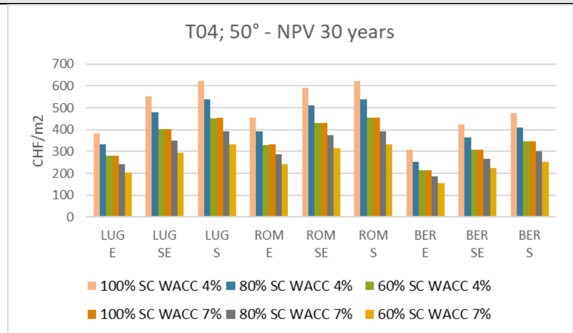




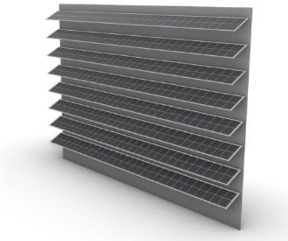
External PV venetian blind, d/l 1:1, dynamic system (T02) – 30 years

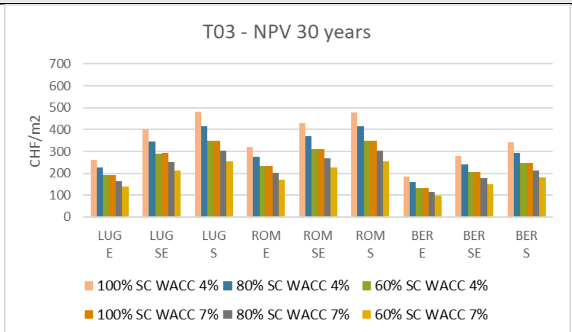


Horizontal PV louvre, d/l 0.95, fixed 50° (T04) – 30 years

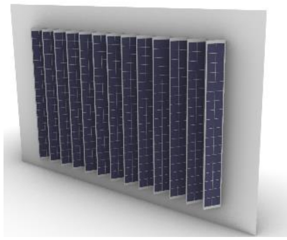


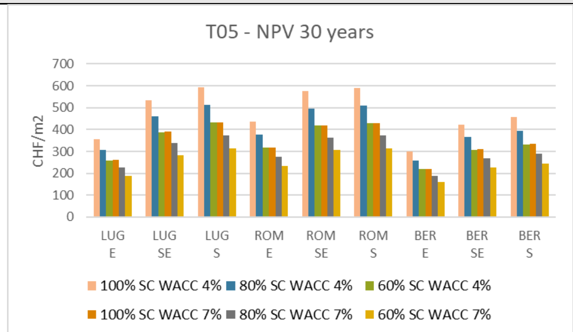
Horizontal PV louvre, d/l 0.95, dynamic system (T03) – 30 years





Vertical PV louvre, d/l 0.95, dynamic system (T05) – 30 years





4 Technology validation

Small-scale samples of PV modules have been manufactured to replicate the large-size pilot system installed at Franklin University in Sorengo. The manufacturing of the PV modules was carried out by the project partner Sunage. Two PV module types have been manufactured to compare the energy performance: optimised and standard PV modules. The optimised PV module, also used on the pilot installation, has been engineered to increase the shading tolerance and avoid mismatching into the PV modules due to the slats' self-shading. Indeed, the internal electrical circuit of each optimized PV module has been subdivided vertically into two electrically independent "columns". The standard PV module is not engineered to increase the shading tolerance and the internal circuit of the module has not been divided into electrically independent columns. Both modules have the same mechanical structure, as shown in Table 4. The PV modules have been tested in SUPSI PVLab to ensure reliability for typical operating conditions of PVSD. The tests were aimed at detecting BIPV maximum temperatures in non-conventional scenarios by combination of the temperature test (IEC61730-2 MST21) with shading scenarios (IEC TS 63140 “Partial shade endurance testing”)[4]. Results showed an operation temperature reduction of up to 3 °C at non-conventional shading scenarios for the optimised PV module against the standard PV module (Table 5). The electrical schema and the configuration of the probe are shown in Figure 5.

Table 4 Features of PV modules

OBJECT	DESCRIPTION
Front glass	Float satin glass thickness 4mm uniform Suncol colour "Bianco Traffico"
Encapsulant	POE
Cell type	n°12 c-Si cells 158.75x158.75 mm; ribbon black; 2 strings of 6 cells
Back glass	Float clear thickness 4mm
Number of PV module	Optimised PV module: n°3 ¦ Standard PV module: n°3
Weight	23.75 Kg/m2
Thickness	9.5 mm (-0.5mm / +1.5mm)
Dimensions	1147 x 350 mm
Nominal power	34 Wp per module

Table 5 Temperature comparison at non-conventional shading scenarios.

PV module	Max. temperature 1000W/m2	Max. temperature Moving shadows (NTP-EL01)	Max. temperature Hot spot testing
Standard	60.0 °C	58.0 °C	76.0 °C
Optimised	59.9 °C	56.0 °C	73.0 °C

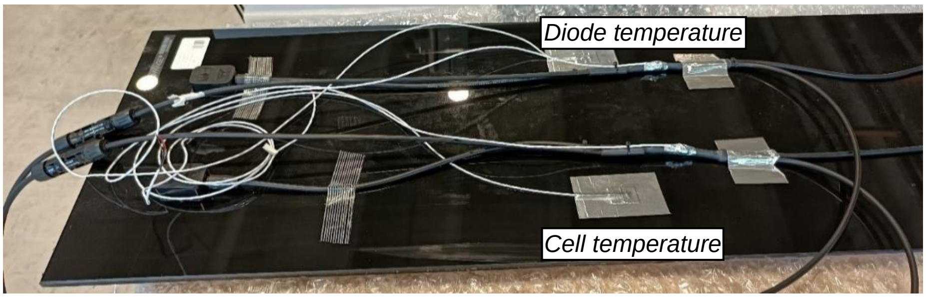


Figure 4 Back of an optimised PV module with probes (PT100). The air cavity temperature is measured with probes installed on the metal slat.

[4] The test methodology is described in BIPVBOOST H2020 project. D5.2 Report on specific performance-based laboratory testing procedures for BIPV products (www.bipvboost.eu)

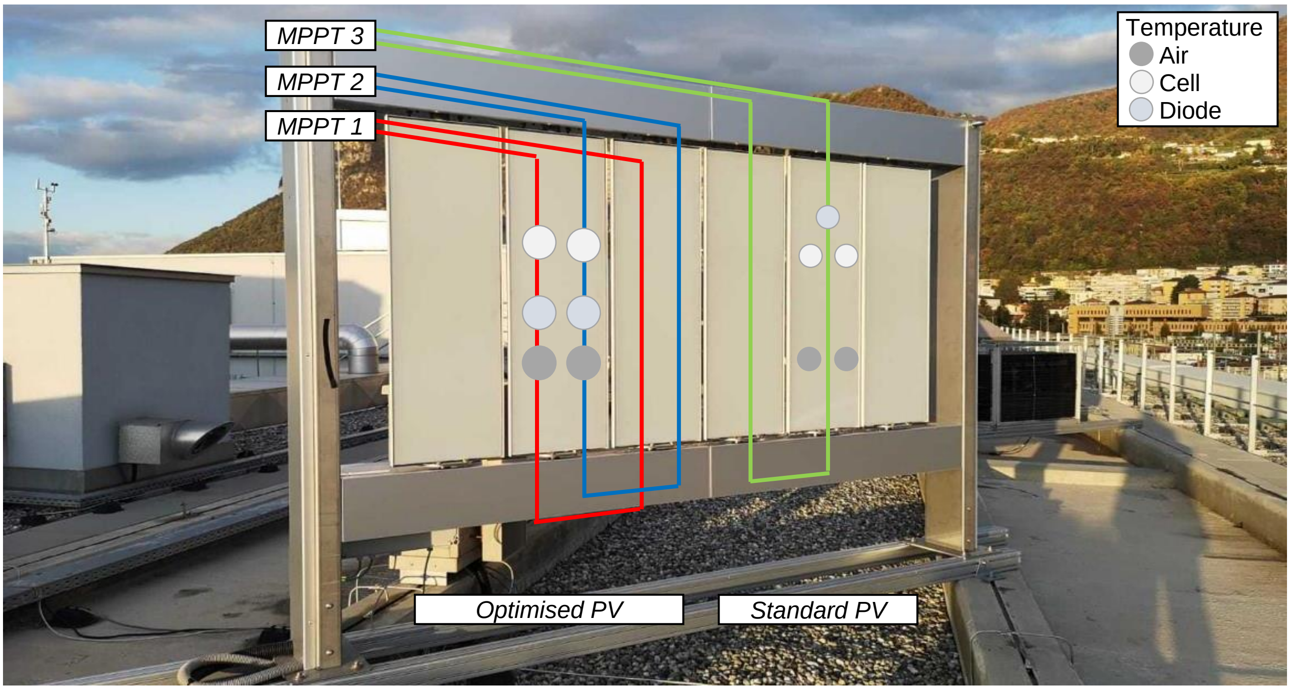


Figure 5 Electrical and probes schema of the mock-up installation in Mendrisio.

The mock-up, realised to validate the technology in a relevant environment in compliance with **TRL 6**, is built and equipped with small-scale solar tracking, similar to the system used for the pilot project, necessary to perform most monitoring activities. The control system guarantees the synchronous movement of six PV slats. The system can also be moved manually. The energy production is measured with MPPT. The temperature of the air cavity, cells and diodes are measured with PT100 sensors. At this stage, also the monitoring system is in operation and it'll be running for a period of one year. The monitoring activity is aimed at validating the system from an energy perspective and comparing optimised against standard PV slats. The monitoring analysis will also represent the reference for the cost analysis, maintenance assessment and comparison activities between the optimised and standard PV slats. Table 6 shows some of the planned monitoring activities also in relation, where relevant, with the real demo building.

Table 6 Activities planned for mock-up monitoring.

ID	ACTIVITY	DESCRIPTION ACTIVITY	PERIOD
1	Overall energy production and temperature behaviour	To monitor and compare the total energy production and the temperature (diodes, air cavity and cells) of the optimised and standard PV slats during one year of operations.	Full-year
1a	PV layout comparison	To monitor and compare the hourly energy production and the temperature (diodes, air cavity and cells) of the optimised and standard PV slats at specific irradiation conditions. Specific masks to simulate shadowing will be used to stress diodes and create unconventional shadowing solutions.	Clear sky winter Clear sky summer
2	Handling system assessment	To monitor and compare the hourly energy production of the optimised PV slats in the following control conditions: - Fixed system - Sun-tracking system	Two consecutive days at similar conditions.
3	Maximum temperature definition	To monitor and compare the maximum temperature of the optimised and standard systems with the temperature measured indoors at specific shadowing situations	Clear sky south-east and east oriented
4	Pilot installation comparison	To monitor and compare the temperature (diodes, air cavity and cells) of the mock-up optimised PV slats against the Franklin University-optimised PV slats	Mock-up and pilot with the same sun-tracking system

5 Technology demonstration

Demonstrating the technology in a real operation building environment ensures the TRL enhancement **from TRL 6 to 7**. Along with the manufacturing of the PV modules, the off-site assembly of the PVSD component and the on-site construction of the building skin system were completed in the first reporting period, so that the next analysis will allow performing cross-referenced benchmarking between the controlled outdoor environment (mock-up) and the "as-built" condition in the real building (pilot installation) according to the project KPIs. The PV slat manufacturing process involved the participation of a large group of stakeholders, which define the AIL consortium partners. The consortium developed the engineering, manufacturing and installation of the BIPV system at Franklin University. The PV modules were manufactured by the project partner Sunage according to the features shown in Table 7 (upper part). The PV module has been optimised to increase the shading tolerance, as described in 4. The slats are realised with a loadbearing metal extrusion made of aluminium according to a specific shape which optimises their static resistance (Table 7, down and Figure 6). 126 PV modules of about 81 Wp have been installed on the first floor and 126 PV modules of 64 Wp on the second floor (Table 8).

Table 7 Features of PV modules (up) and slat (down).

PV MODULE (Partner: Sunage)[5]	
Front glass	Float satin glass thickness 4mm uniform Suncol colour "Bianco Traffico"
Encapsulant	POE
Cell type	First floor: n°28 c-Si cells 158.75x158.75 mm; ribbon black; 2 strings of 14 cells Second floor: n°22 c-Si cells 158.75x158.75 mm; ribbon black; 2 strings of 11 cells
Back glass	Float clear thickness 4mm
Number of PV modules	First floor: 126 ¦ Second floor: 126
Weight	23.75 Kg/m2
Thickness	9.5 mm (-0.5mm / +1.5mm)
Dimensions	First floor: 2310x350mm2 ¦ Second floor: 1830x350mm2
Nominal power	First floor: 81.44 Wp per module ¦ Second floor: 64 Wp per module

SLAT (Partner: AIL consortium – Kummler+Matter, Poretti & Gaggini)[5]	
Material	Aluminium EN AW-6060
Weight	5.46 Kg/m
Shape & thickness	See Figure 6
Dimensions	First floor: 4630x360mm ¦ Second floor: 3670x360mm

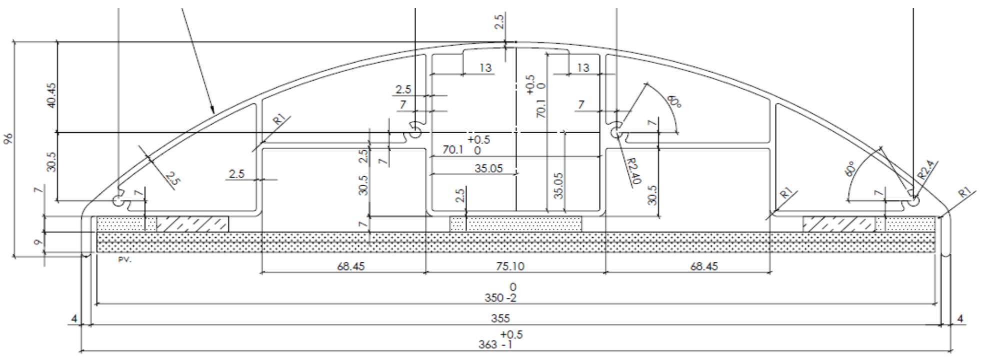


Figure 6 Shape and dimension PV slat.

[5] Further details on the stakeholders' involvement will be presented in the next interim report (2023)

Table 8 Specific of the BIPV system.

SECOND FLOOR	
N°1 inverter	SolarEdge SE7K
N°42 power optimisers	SolarEdge P404
N°63 PV slats, each made of 2 PV modules	Each string is composed of 6 PV modules in a series of 11 cells (66x2)
N°21 motors	N°1 motor manages three PV modules
N°63 reducers	
The string on the first floor (42 optimisers) has a power of 8.064 kWp with a safety voltage of 42 VDC	
FIRST FLOOR	
N°1 inverter	SolarEdge SE7K
N°42 power optimisers	SolarEdge P404
N°63 PV slats, each made of 2 PV modules	Each string is composed of 6 PV modules in a series of 14 cells (84x2)
N°21 motors	N°1 motor manages three PV modules
N°63 reducers	
The string on the second floor (42 optimisers) has a power of 10.261 kWp with a safety voltage of 42 VDC	

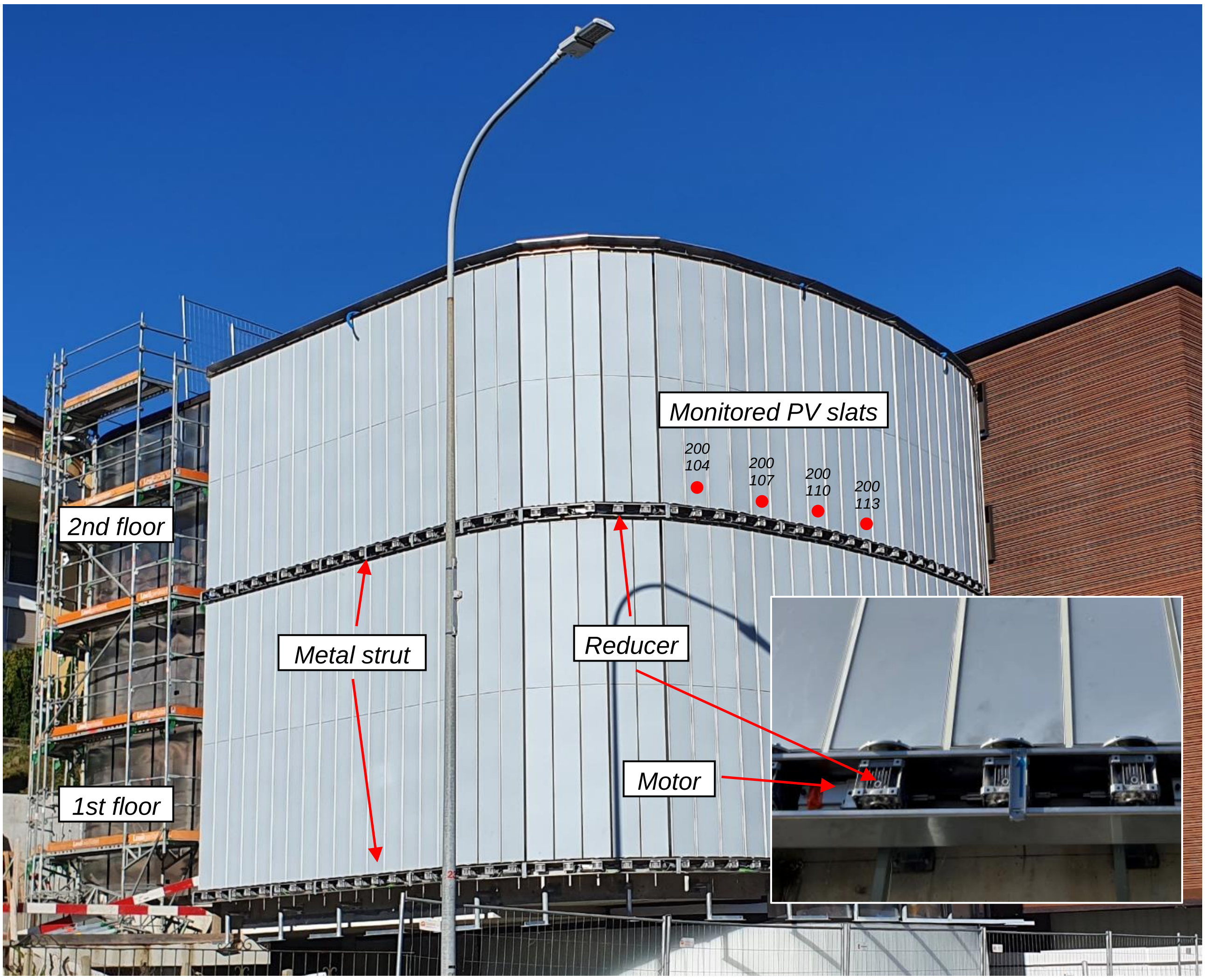


Figure 7 Monitored PV slats and handling mechanical system on the façade.

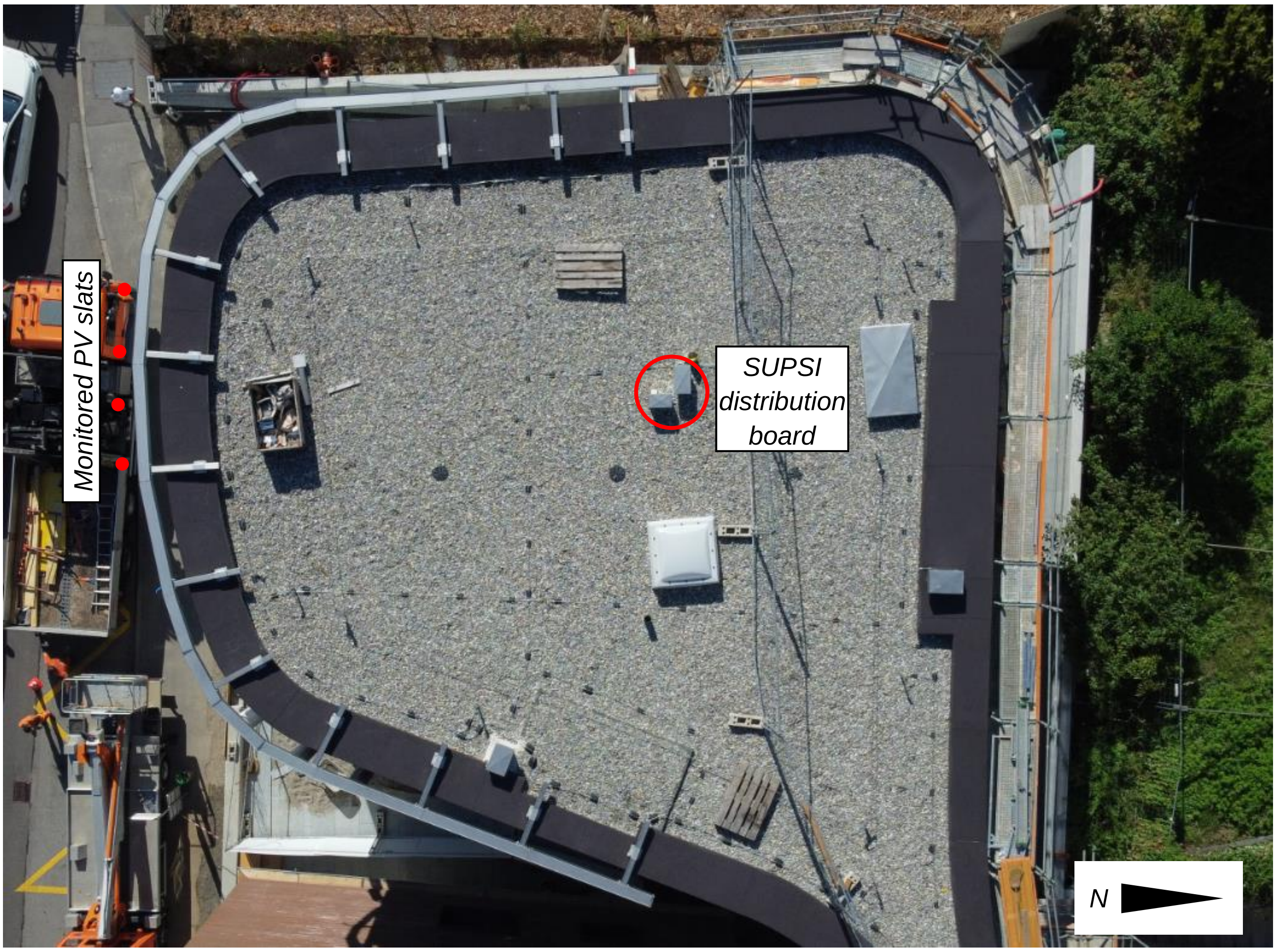


Figure 8 Franklin University rooftop. The distribution board of SUPSI serves to collect the monitored data.

Figure 9 PV slats mounting process.

Monitoring PV system

The whole PV system monitoring will include the existing rooftop system and the BIPV façade system (Figure 10). The production data of various inverters will be available to be analysed individually through the Solarlog monitoring system. The SolarEdge inverters will be connected to the network, and the dedicated portals will be activated. The data will also be made available via the API protocol to perform real-time performance analyses. The Solarlog system will be able to notify alarms related to the inverters and any PLC malfunctions. Two consumption meters have been installed to measure the energy absorption of the control panel and the monitoring system. The building energy consumption will be also monitored through the electricity measuring point of the Utility company AIL in order to have the global picture of electricity generation and self-consumption.

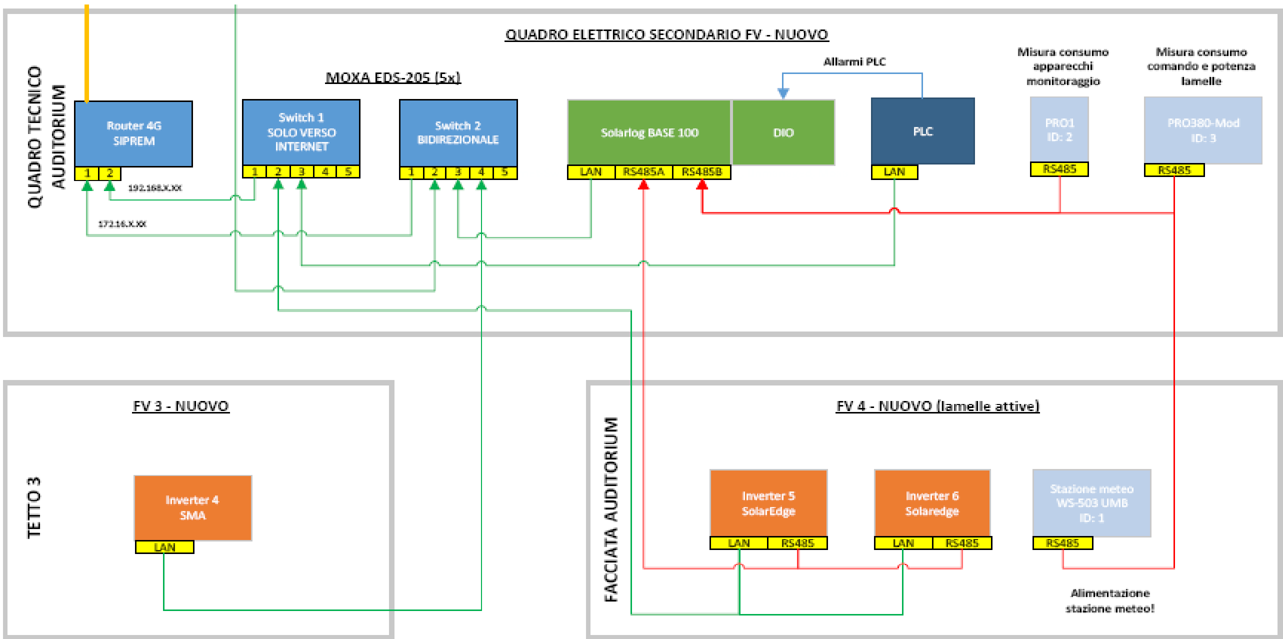


Figure 10 PV system monitoring schema (traditional PV rooftop system and BIPV system)

Monitoring PV slats

The representative parts of the pilot installation are equipped with a dedicated control system (2.2). Four PV slats have been equipped with sensors to monitor the temperature and the humidity of the air cavity, the temperature of cells and diodes. Such a detailed monitoring of the PV slats will help to assess the system performance from an energy perspective in a relevant environment. The monitoring analysis will also support cost analysis, maintenance and lifespan assessments. Table 9 shows the monitoring activities performed on the selected PV slats.

Table 9 Monitoring activities on the pilot installation.

ID	ACTIVITY PV SYSTEM	DESCRIPTION ACTIVITY	PERIOD
1	Overall energy production	To monitor and compare the total energy production of the PV slats (1st and 2nd floor) during two years of operations.	Two years
2	Overall energy consumption	Energy consumption of the control panel and the monitoring system	Two years
ID	ACTIVITY PV SLATS	DESCRIPTION ACTIVITY	PERIOD
1	Maximum temperature definition	To monitor the temperature and humidity of the PV slats (PV slats 200.104 and 200.110) during two years of operations.	Two years
2	Pilot installation comparison	To monitor and compare the temperature (diodes, air cavity and cells) of the PV slats against the mock-up and indoor measured values	Mock-up and pilot with the same sun-tracking system set-up

6 Evaluation of results and next steps

In this project's first phase, an innovative dynamic photovoltaic shading device was engineered and manufactured, combining the functions of renewable electricity generation (PV modules) with solar protection (metal slats) in a unique element. The PV modules have been engineered to increase the shading tolerance and avoid mismatching due to the slats' self-shading. Before being integrated into the facade system, small-size samples of PV modules were tested in SUPSI PVLab to ensure reliability in typical operating conditions. The tests showed a temperature reduction of up to 3 °C at non-conventional shading scenarios compared to traditional PV modules.

The solar tracking photovoltaic shading device was first installed in an outdoor mock-up at SUPSI to test its operation and assess its performance and reliability, and then in the building façade of the new pavilion of Franklin University, resulting a flagship example of highly aesthetic photovoltaic shading systems realised in Switzerland. The installation, testing and monitoring of the technology in real operating conditions represents a pilot installation for achieving new information, assessing KPIs and performance to increase the TRL and ensure the system market penetration.

The holistic technology assessment lays the foundations for developing a methodology of energy-economic evaluation for the shading system which will be used to build the analysis of replicability and market exploitation strategies.

Due to the consequences of the pandemic and the recent conflict in Ukraine, materials supply delays have been encountered, especially concerning the realisation of the PV slats and the system support structure on the facade. The delay was quantified in at least 11 months concerning the planned delivery. It affected both the system for the pilot building (Franklin University) and the mock-up installed on the outdoor facility of SUPSI. In addition to the delay in procuring the material, the project has suffered a significant increase in prices. The economic analysis planned for the next interim report (2023) will then consider the cost items, including such an increase (material and delays), by splitting them from other costs.

The next interim report is expected to be published in November 2023. The activities which are planned to be included are the followings:

- Final results of mock-up monitoring to achieve the TRL 5-6 by ensuring the PV slats' energy efficiency in typical operating conditions (one year);
- Intermediate results of pilot building monitoring to achieve the TRL 7 by demonstrating the technology in a relevant environment (two years);
- Construction site analysis, which includes an analysis of the stakeholders involved in the process, the definition of time and procedures and calculation of the costs to define the final user cost of the technology and demonstrate a cost reduction in terms of O&M, installation and dismantling;
- Set-up of a preliminary monitoring digital platform for data monitoring and management.