BIPV in dialogue with history

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market potential demonstrated, niche sector, cost reduction, subsidies, emphasize PV design, normative awareness.

The group "**BIPV in dialogue with history**" is a collection of the historical buildings on which a BIPV system was installed, from the '90s up to now. This permits to analyse a category of buildings that many architects are afraid to approach considering the high restrictions associated with these contexts.
Improving energy efficiency in historic heritage, certainly preserving the value and the historical characters, is a topic of great importance within the challenge of renovation and functional upgrading. The necessity to moderate the use of energy is unquestionable and renovation measures in construction to advance towards climate-neutral energy generation are supported by all countries[2][3][4]. These measures also affect our monuments and historical buildings, as investigated in numerous ongoing research projects (e.g. ATLAS[5], BIPVmeetsHistory[1], ERDF European Transnational Cooperation Programmes) and the activities of the International Energy Agency, IEA EBC Annex 76 / IEA-SHC Task 59[6]. The main aim is to find conservation-compatible energy retrofit approaches and technologies (including RES and solar energies) for historic – not necessarily protected – buildings with an existing low level of energy efficiency and energy comfort. Buildings worth to be preserved that are more than 50 years old and require urgent energy retrofit measures, constitute a considerable part of the total building stock. In Europe, historic buildings built before 1945 represent 30-40% of the total building stock[7] and about 64% of buildings in Switzerland were built before 1980 with a very low energy renewal rate[8]. At the same time, less than 10% of the European building stock has a special value as a material testimony to our past and as a cultural asset: they are listed or protected in inventories. That being said, in most cases, energy improvements are possible in historical buildings. However, in order for this to succeed without losing substance and historical significance, a dedicated engagement with the task is required.

In many cases of "historical" perimeters where the monumental value is objectively limited, there is the possibility and the need to intervene in improving the energy performances of the buildings, often outdated, potentially unhealthy and unsafe, as well as ecologically very impacting. In the current technological framework for BIPV, increasingly oriented towards the "mass customization" of the building industry, the study of ways to integrate technology in sensitive areas may take advantage of an innovative "craft dimension" of technology which, more and more adaptable to the design paradigm of the "micro-intervention" and "controlled transformation", makes available new scenarios of "compatibility", compliant with the degree of "transformability" of these places[9].

New approaches to solar design show that it is possible to achieve optimal use of solar energy - thermal and photovoltaic - while preserving the heritage and architectural quality of the site, based on a careful and in-depth review of the area of study and its solar potential (i.e. constraints, cultural heritage buildings, solar technologies, strategies, economic tools or funding schemes to support spatial planning). In *Fig. 1*, the mediaeval castle Doragno, retrofitted in 2013 by the architects deltaZERO, with the integration of a rooftop BIPV system is shown.
Once recognized a "controlled improvement" as the intervention approach, instead of an undifferentiated performance retrofit, the design process consists of a gradual deepening of knowledge, that starts from the critical reading of typological structures and of constructive, material, spatial, environmental and functional correlation in the considered heritage. After defining the degree of "transformability" (namely, the vocation to be transformed) a comparative assessment between values and needs allow defining the sustainable forms of compatible interventions.

Fig. 1 Doragno Castle, Rovio, Switzerland. Credits: Luciano Carugo.

Realized examples as best practices cases studies (e.g. Swiss or European Solar Prizes) demonstrated the coexistence and the feasibility in the use of these solar technologies to reach the energy efficiency goals of existing buildings and in particular of historical buildings. Twenty-four buildings across Europe renovated in the last decade have been analysed in order to point out the main aspects of solar products so far used in historic buildings. Examples studied show a wide range of applications, from cold roof (67%), skylight (17%), cold façade (12%) and curtain wall (4%) depending mainly on the building uses, public (administrative) or private (residential).

Old buildings in Europe were largely built as steep-roofed houses until the 20th century. Pitched roofs are initially defined by their shape and contours, but also by the construction, by the nature of the surfaces (e.g. opaque slate or tiles in shades of natural red and brown). Examples of good integration of BIPV (cold roof) solar solutions are widespread, and show that from their early years, solar technologies have been well integrated using specific connecting elements or materials and non-active PV solutions, even in any complex roof typology and in some cases, together with solar thermal solutions. In these buildings, mainly private residential buildings, the installed surface and capacity are generally greater because it usually involves complete roof renovation's interventions. Only in some cases, usually due to a higher level of protection and to favour the intact perception of the original building, a part of the roof has been maintained and preserved. It allows reducing the visual impact of the solar system from the public spaces, which generally leads to a higher level of appreciation and acceptance.

A perfect example of this is the residential building Hutterli Röthlisberger, a protected object of cantonal importance, with a well-integrated photovoltaic system and solar thermal collectors integrated under the natural slate panels. The listed, neo-baroque house of the Hutterli Röthlisberger family in Bern / BE from 1898 was extensively renovated and refurbished. Thanks to the energy revamping of the renovation, the total energy requirement fell by 76% from 46.900 kWh annually to 11.100 kWh per year, saving 10,6 tons of carbon dioxide per year. Due to the high level of protection, solar panels are hidden on the sloping roof of the natural slate roofing. On the upper roof area, a BIPV system with an electrical output of 2,7 kWp delivers around 3.200 kWh/y of electricity. The energy renovation strategy combines solar photovoltaic with solar thermal production which equals around 10.000 kWh/y. It is either brought directly to the hot water balloon for domestic water heating, or used for the heat pump in combination with geothermal probes. This challenging energy revamping of a more than 100-year-old listed building was awarded with the Swiss Solar Prize in 2014 and has been worthy of the seal of approval from the Minergie association as showcase ultra-low-energy building.

Fig. 2 Solar Silo building, Basel, Switzerland. Credits: SUPSI-BFE, Caspar Martig.

On the other hand, skylights and curtain walls are in most cases used in public buildings to cover surfaces with semi-transparent BIPV solutions equipped with crystalline and amorphous silicon technologies, which can in some cases contribute to improving comfort through their passive properties, both in summer (shading) and winter (solar gains). In these cases, the covered surface, the installed power and the final yield of the system are usually lower than opaque technological systems. Several examples are shown in different countries across Europe (e.g. Tourism office Alès in France and Bejar or San Anton Market in Spain).

Technological advances of recent years in the BIPV industry led to adapt technical solutions with the objective to improve future integration in historic buildings. Although solar installations can be difficult to reconcile with building regulations, space planning, urban heritage conservation and budgets, more and more new solar products are currently available on the market that would facilitate the integration of these technological systems. BIPV products with new formats, textures and colours, which allows a better integration without interfering with the appearance, the historical value and structural substance of these historical buildings, of monuments tied to preservation, or of urban and rural landscapes. Good evidence are the terracotta solar tiles developed for historical contexts (e.g. Rural House Galley) or the invisible and coloured solar BIPV modules used in the industrial and administrative building of the Solar Silo in Basel.

The coal silo "Kohlesilo" of the Sulzer and Burckhardt machine factory in Basel has been modernized and was completely converted into a multi-purpose building (***Fig. 2***). Innovative coloured customized photovoltaic modules are used, creating a particular visual design to be integrated in the ventilated roof and façade envelope of an industrial refurbished historical building. Green, golden, orange, blue and grey PV modules with monocrystalline silicon solar cells (Kromatix SwissINSO technology) and some standard PV modules in black were used. The 159 m^2 BIPV system is fully integrated and generates 16.400 kWh of solar electricity annually. As part of a research project, this best practice building investigates new approaches for BIPV integration as cladding innovative materials and new energy storage strategies. The electricity produced is stored in "2nd Life" batteries to be used later by the residents of the area. As "Gundeldinger Feld" ensemble is under heritage protection, the remodelled building was required to match the style and colour scheme of the site and all the old industrial area has been reconverted in a new model energy district. The project is part of the "2000 Watt society - pilot region Basel". Solar Silo project that was rewarded in the "renovation" category with the 2015 Swiss Solar Prize.

"There are always problems which we must not neglect; for example, energy, resources, costs, social aspects. You should always be careful about all these aspects. For me, architecture is a global issue. There is no ecological architecture, intelligent architecture, sustainable architecture. There is only good architecture…"
Souto de Moura

Analysis of the case studies

Within this section the aim is to analyse the best practices realized during 40 years of the BIPV history. The timeline at page 34 and 35, shows the most representative events and case studies that influenced the BIPV evolution.

The 97 case studies collected and analysed are grouped by:

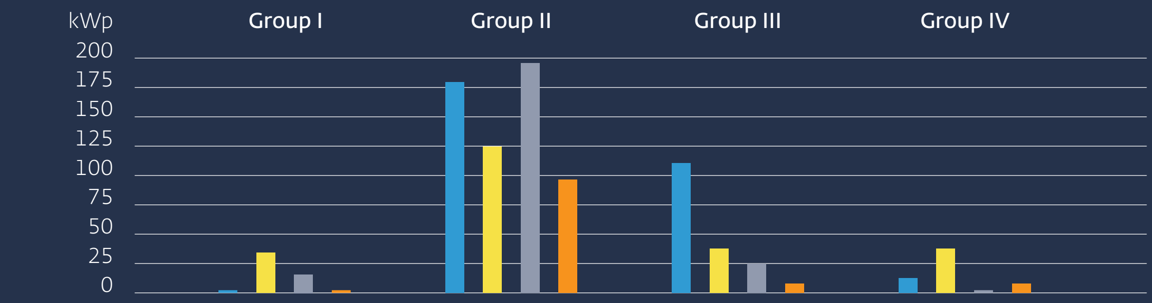
- Technological system (opaque and semi-transparent building envelope);
- Characterizing clusters ((BI)PV as experimentation; Architecture of standard PV; Energy integration: BIPV as a building's skin material; BIPV in dialogue with history);
- Values (nominal power, final yield, solar ratio and efficiency).

Nominal power
High values of nominal power emerged during the period of the "boom" of the photovoltaic. This is explained by the "feed-in tariff" policy to encourage the solar installations. Nowadays, the building envelope of administrative and industrial typologies is often exploited for small installations of experimental solar modules, new technologies and semi-transparent solutions. BIPV systems are used to increase the value and the image of administrative buildings. In addition, today, it is common to cover the whole building envelope with solar solutions regardless the orientation, preferring a homogeneous architectonic language to the maximization of the energy production. This concept is represented by the high installed photovoltaic nominal power of cold façades. For historical building, BIPV used as cladding material (cold façade) in the analysed cases is mostly used in private buildings were high level of appreciation of BIPV are reached where acceptability of flagship or showcases pilot project to demonstrate the innovation of solar technologies are important.

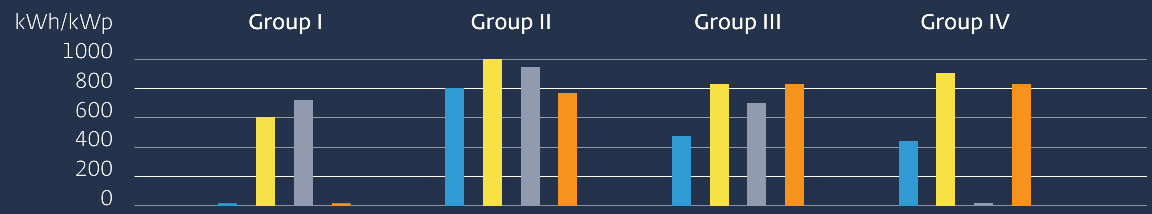
Final yield
High values of final yield mean that photovoltaic solutions are oriented and tilted to maximize the energy production on a yearly basis. This usually happens for roof solutions both opaque and semi-transparent. The shape and the tilt of the roof offer an optimal surface to optimize the design of solar systems. It explains the high values for residential and industrial building typologies, where the roof represents the most common application area for solar systems. Today, it is common to have solar solutions integrated to the building envelope rather than applied on it, preferring an architectonic language homogeneous instead of high solar irradiation. For this reason, the final yield of BIPV solutions can be lower than that of BAPV solutions. Nevertheless, from the analysed case studies, it seems that solutions are still often installed with the objective to maximize the energy production.

Solar ratio
The shape of a traditional roof often permits to fully cover its available surface maximizing the energy production. This is visible within the first three groups. For semi-transparent solutions, including transparent façades and skylights, the architectonic component is often partially covered by PV, this justifies the low value of solar ratio for these categories. The solar ratio value for opaque solutions (rainscreen systems and discontinuous roofs) is increased during the last years from an average value of 65% during the period "Architecture of standard PV" up to 90% in the period "Energy integration: BIPV as building's skin material". It shows that a high ratio of the building envelope is covered by solar integrated solutions. Semi-transparent solutions, often integrated in administrative and industrial buildings, still cover a small portion of the building skin.

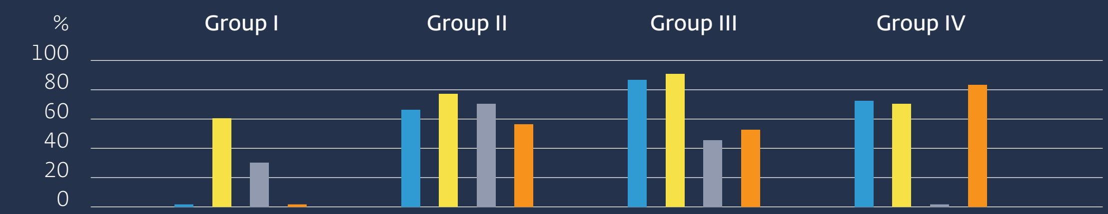
System power density
Good technical performances, even for transparent solutions, are shown within the characterizing clusters "Architecture of standard PV". It expresses a massive use of standard (or almost standard) PV solutions. Low customization, no colourful coatings and crystalline solar modules are exploited as BIPV. The efficiency of solar solutions integrated in façades remained the same as in the previous period but the installed solar modules are customized in size, shape and colour and in most cases the solar cells are not visible. This result highlights the development of the solar industry and technology during the last years.



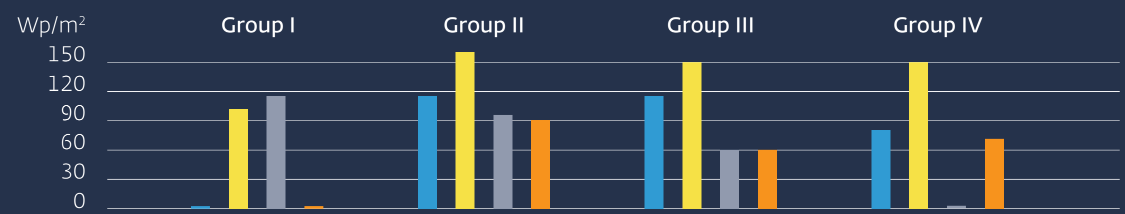
Nominal power



Final yield



Solar ratio



System power density

Rainscreen   Discontinuous roof   Curtain wall   Skylight

Group I: (BI)PV as experimentation;
Group II: Architecture of standard PV;
Group III: Energy integration: BIPV as building's skin material;
Group IV: BIPV in dialogue with history.

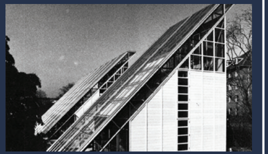
BIPV timeline

1970's

First PV solutions for buildings

Wohnanlage Richter (1)

Credits: BDA



1982

First integrated solar installation on a glass surface

1990's

BIPV systems commercially available, concept of multifunctional construction material

Pompeu Fabra Library (7)

Credits: Roberts S., Guariento N.

1998

Experimental semi-transparent curtain wall

1999

"Architects encounter several problems when designing PV buildings. One of the main problems is that PV systems do not correspond with building sizes. [...] the colours and sizes of PV panels are too limited." Task 7 IEA PVPS.

2000

Renewable Energy Sources Act, principles of feed-in-tariff

Tourism Office (16)

Credits: objectifgard.com

2001

Example of BIPV renovation of cultural heritage

BedZed (17)

Credits: ZEDFactory

2002

The first example of Plus Energy District

Monte Rosa Hut (29)

Credits: ETH Zurich

2009

A BIPV plant at 2,883 meters above the sea level

Market Bejar (36)

Credits: Onyx Solar

2011

Refurbishment: coloured and semi-transparent modules

Omicron Headquarters (55)

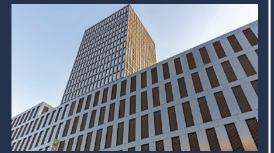
Credits: Sunovation

2014

BIPV façade and LED glass elements in CI colours

Grosspeter Tower (83)

Credits: NICE Solar Energy



2017

The solar skyscraper in Switzerland

2018

"Nobody can know that it is a solar-powered house."
Architect Erika Fries,
HUGGENBERGERFRIES Architects

Rural House Galley (86)

Credits: CSEM

2018

Coloured terracotta modules in a refurbishment

2018

BIPVBOOST.
Bringing down the cost of multifunctional building-integrated photovoltaic (BIPV) systems

Definition of BIPV.
IEA-PVPS T15-04
International definitions of "BIPV"

CP Pregassona (97)

Credits: Alsolis

2021

The largest BIPV façade in Ticino (CH)

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