SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Conservation compatible energy retrofit technologies

Part V: Documentation and assessment of integrated **solar thermal and photovoltaic systems** with high conservation compatibility

IEA SHC Task 59 | EBC Annex 76
Renovating Historic Buildings Towards Zero Energy

Conservation compatible energy retrofit technologies

Part V: Documentation and assessment of integrated **solar thermal and photovoltaic systems** with high conservation compatibility

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IEA SHC Task 59 | EBC Annex 76: Deep renovation of historic buildings towards lowest possible energy demand and CO_2 emission (NZEB)

Solar Heating and Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives (*"*Implementing Agreements*"*) of the International Energy Agency.

Our mission is *"Through multi-disciplinary international collaborative research and knowledge exchange, as well as market and policy recommendations, the IEA SHC will work to increase the deployment rate of solar heating and cooling systems by breaking down the technical and non-technical barriers."*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

Our focus areas, with the associated Tasks in parenthesis, include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

In addition to our Task work, other activities of the IEA SHC include our:

- SHC Solar Academy
- *Solar Heat Worldwide*, annual statics report
- SHC International Conference

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Energy in Buildings and Communities Technology Collaboration Programme (IEA EBC)

To reach the objectives of SHC Task 59 the IEA SHC implementing Agreement has collaborated with the IEA EBC Implementing Agreement at a "Medium Level Collaboration", and with the IEA PVPS Implementing Agreement at a "Minimum Level Collaboration" as outlined in the SHC Implementing Agreement's Policy on Collaboration.

Contents

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Some of the text presented in this report has been published elsewhere as journal papers and conferences proceedings. All the texts have been written by the authors of these report and as part of the activities developed in the course of Subtask C. All text reproduced here is reference below.

Polo López, C.S., Lucchi, E., Leonardi, E., Durante, A., Schmidt, A. and Curtis, R., 2021. Risk-Benefit Assessment Scheme for Renewable Solar Solutions in Traditional and Historic Buildings. *Sustainability*, *13*(9), p.5246.

1 Introduction

Renewable Energy Sources (RES) implementation, particularly in existing and historic buildings, can contribute significatively to the reduction of the energy requirement for thermal conditioning and electrical needs. The use of renewable solar energy systems in existing buildings is now strongly supported by the legislative European (EU) framework, which introduced specific targets to increase the share of RES, to cut carbon dioxide emissions (CO_2 emissions), and to enhance the energy performances of existing buildings RES play an important role for achieving these goals in energy renovations of existing buildings, as the legislation requires to cover 32.5% of energy produced for domestic hot water, heating, and cooling by RES [1]. The EU 2030 Climate Target Plan consist among other things of an amended proposal on the draft EU Climate Law to incorporate the new 2030 emissions reduction target, considering reducing emissions (GHE) by at least 55% by 2030 as realistic and feasible objective. To put this into perspective, the NextGenerationEU [2] strategy and budget provisions for the next years will help to reboot the economy following the damage inflicted by the coronavirus pandemic, and a minimum of 30% will be spent in support of climate objectives. Examples of specific instruments ensuring a just transition include the European Green Deal Investment Plan [3] and the Just Transition Mechanism, including the Just Transition Fund [4]. Current climate legislation is designed to achieve a reduction of at least 40% GHG gas emissions by 2030, compared to 1990. However, the mechanism recently put in force, as the EU Emissions Trading System (EU ETS) and the Effort Sharing Regulation, combined with the 32% renewable energy target, stated in the recast Renewable Energy Directive [5], and 32.5% energy efficiency target set in the revised Energy Efficiency Directive (EU) 2018/2002 [1] are projected to pursue higher target and if necessary, changing the legislation in force.

The "Renovation wave strategy" [6] aims to double renovation rates in the next ten years lead to higher energy and resource efficiency, enhancing the quality of life and comfort living. The re-use of existing buildings which improve the reuse and recycling of materials will foster contribute to reduce Europe's greenhouse gas emissions. In order to accelerate the use and implementation of energy from RES, particularly solar energy, in new and existing buildings subject to major renovations, it is necessary to establish a sufficient basis for assessing whether the inclusion of minimum levels of RES is technically, functionally and economically feasible. Their implementation in historic buildings, referring both to listed and unlisted buildings with significant elements worthy of preservation and symbol of exceptional cultural significance, has several constraints, mainly related to the aesthetic impact.

In recent or past years, this has been a topic of controversial issues and interest. This could be an optimal solution if combined with a high-efficiency heat pump for heat production system with intelligent building management based on BMS (building management system) in order to best contribute in achieving the RES quota required by EU directives. At the same time, the application of RES in architecturally sensitive areas and buildings is studied by several international and national research Projects [7-12], demonstrating their technical and economic advantages as well as their compatibility with heritage shapes, features, and values. Solar technologies, integrated or not, may be used in historic buildings. New solutions with high-performance levels allow efficient use of solar energy while preserving the character, heritage and architectural quality of historic buildings and sites.

To demonstrate this, many examples of real applications of solar energy in historical buildings have been collected and documented, thanks to the work carried out for the international expert group participating in IEA-SHC Task 59 / IEA-EBC Annex 76 (Sub-Task C4) and documented in the following chapters. Different examples that present real case studies are documented, where solar systems are attached to the building (building attached solar photovoltaic BAPV or solar thermal solutions BAST) or integrated into the building envelope as a more technically and functionally integrated element (BIPV or BAST). Innovative design characteristics of solar technologies nowadays, even already in the market (i.e., solar modules with patterns and colours, easy customizable, geometrically adaptable and economically feasible), can enable new possibilities of integration into old buildings, historical sites, the urban space and landscapes [13-19]. Thus, a bigger acceptance for photovoltaics and solar thermal solutions would lead to a greater expansion of solar technology in the future, helping to improve the energy efficiency of the historic building stock (protected and not).

This report also contains some innovative technical solar solutions still in research development, in this case decontextualized and not applied specifically in historical buildings, which demonstrate the great potential of these technologies to be applied in renovation or existing buildings as well as historical heritage or sensitive contexts in the near future.

In the growing field of “sustainable architecture”, solar energy represents one of the main challenges that are progressively changing the building sector with the tangible revolution of solar architecture. In fact, today solar elements, and specifically photovoltaic solar systems, can be used together with materials that are common in architecture, such as glass or metal, in opaque as well as in semi-transparent surfaces.

Photovoltaic (PV) modules are considered to be BAPV, if the PV modules are mounted on a building envelope. Otherwise, the BIPV acronym defines the specific case of PV products for integration in buildings that have already become construction products and lay down the technical, technological and constructive requirements to be met by these types of products [20]. If the built-in PV module is dismantled, it should be replaced by an appropriate construction component.

BIPV modules may comply with the essential requirements defined in the CPR 305/2011 (European Construction Product Regulation), as well as the applicable electro-technical requirements as stated in the Low Voltage Directive 2006/95/EC/ or CENELEC standards. As building products, in addition to electricity generation, essential requirements of BIPV systems are aspects like mechanical resistance and stability; structural integrity; safety in use and in case of fire; protection against weather (rain, snow, wind, hail); protection against noise; energy economy and heat retention, considering also a sustainable use of natural resources.

The building market today offers a wide range of design possibilities for façades and roofs such as different decorative profiles, materials, fixing and fastening systems, each one with singular features that can be further evolved and customized [21]. Manufacturers of the PV industry today can provide the building sector with different multifunctional PV products, ready to be used, as cladding surfaces, tiles or complete full roof systems, windows and glazing for curtain walls or other accessory elements in buildings, such as shutters, balconies, balustrades, and shading devices (awnings, louvres, brise soleil, etc.). The new standard differentiates five mounting categories, from A to E (Figure 1) as function of the position of the PV system in the building envelope [21]:

- Category A: Sloped and roof integrated, not accessible from within the building. PV modules are mounted at an angle between 0° and 75°;

- Category B: Sloped and roof integrated, but accessible from within the building. PV modules are mounted at an angle between 0° and 75°;

- Category C: Non-sloped (vertically), mounted not accessible from within the building. PV modules are mounted at an angle of between and including both 75° and 90°;

- Category D: Non-sloped (vertically), mounted accessible from within the building. PV modules are mounted at an angle of between and including both 75° and 90°;

- Category E: Externally integrated, accessible or not accessible from within the building.

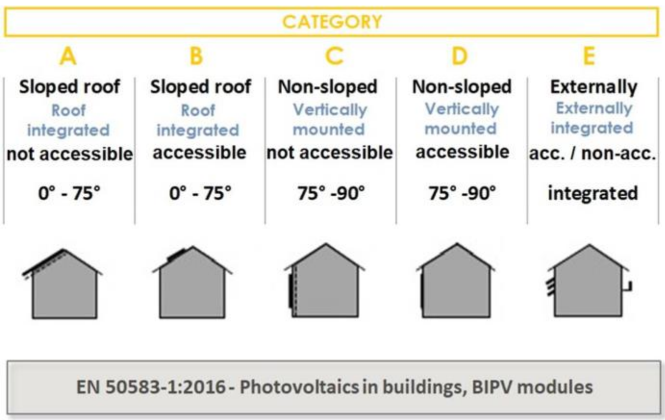

Figure 1: Mounting categories A – E (EN 50583-1:2016 - Photovoltaics in buildings - Part 1: BIPV modules) © Polo López and Bonomo, 2018 [22].

2 Documented solutions

2.1 Overview of documented solutions

Table 1: Summary of all documented solar solutions

Category	Measure	Best Practice Example	Author
Renewables attached to the roof	BAPV Monumental school Innsbruck	-	Pavel Sevela (UIBK)
	BAST Lauriston Place	-	Roger Curtis and Anne Schmidt (HES)
	BAST Magnusstraße	Apartment building Magnusstraße, Zürich	Cristina Polo (SUPSI)
Renewables integrated to the roof	BIPV Technology morpho color	-	Johannes Eisenlohr (Fraunhofer ISE)
	BIPV Solar Silo	Solar Silo, Basel (CH)	Cristina Polo (SUPSI)
	BIPV and BIST Feldbergstraße	Feldbergstraße, Basel (CH)	Cristina Polo (SUPSI)
	BIPV and BIST Doragno Castle	Doragno Castle, Rovio (CH)	Cristina Polo (SUPSI)
	BIPV and BIST Kindergarten Chur	Kindergarten and apartments, Chur (CH)	Cristina Polo (SUPSI)
	BIPV and PVT St. Franziskus Church	St. Franziskus Church, Ebmatingen (CH)	Cristina Polo (SUPSI)
	BIPV Chalet La Pedevilla	Marebbe (IT)	Jennifer Adami (EURAC)
	BIPV Rural Farm Galley	-	Cristina Polo (SUPSI)
	BIPV Wine Shed, Milvignes	-	Cristina Polo (SUPSI)
	BIPV Palazzo Strozzi	-	Giovanna Franco (Unige)
	BIPV Hotel des Associations	-	Cristina Polo (SUPSI)
	BIPV Schlossgut Meggenhorn	-	Cristina Polo (SUPSI)
	BIPV Mehrfamilienhaus Kettner	-	Cristina Polo (SUPSI)
	BIPV Mehrfamilienhaus Stadler Luzern	-	Cristina Polo (SUPSI)
	BIPV Hinter Musegg Farm	-	Cristina Polo (SUPSI)
	BIPV Single Family House Gstaad	Single Family House, Gstaad (CH)	Cristina Polo (SUPSI)
	BIPV Glaserhaus Affoltern in Emmental	Glaserhaus Affoltern, Emmental (CH)	Cristina Polo (SUPSI)
	BIPV House Breuer Tschagguns	-	Tobias Hatt (EIV)
	BIPV Villa Castelli	Villa Castelli, Bellano (IT)	Elena Lucchi (EURAC)
	BIPV, BIST and PVT Single Family House Bern	BIPV Single Family House, Bern (CH)	Cristina Polo (SUPSI)
	BIPV Isola della Certosa Urban Park	-	Antonello Durante (EURAC)

	BIPV La Capanna	-	Antonello Durante (EURAC)
Renewables integrated to the facade	BIPV Solar Silo	Solar Silo, Basel (CH)	Cristina Polo (SUPSI)
	BIPV Romanshorn	-	Cristina Polo (SUPSI)
Free standing PV	Palacinema Locarno	Palacinema, Locarno (CH)	Cristina Polo (SUPSI)
	Crichton Castle	Crichton Castle, Pathhead (UK)	Roger Curtis and Anne Schmidt (HES)
Local sharing of PV	Solar Silo	Solar Silo, Basel (CH)	Cristina Polo (SUPSI)
	Kindergarten Chur	Kindergarten and apartments, Chur (CH)	Cristina Polo (SUPSI)
Model for sharing	Sole per tutti	-	Cristina Polo (SUPSI)
Integration into the landscape	Rural farm Galley, Ecuvillens	-	Cristina Polo (SUPSI)
	Wine shed, Milvignes	-	Cristina Polo (SUPSI)
	Cinque terre: integration in UNESCO context	-	Giovanna Franco (Unige)

2.2 Photovoltaic and solar thermal systems attached to the roof (BAPV and BAST)

Several definitions are considered to define BAPV modules [23]. Photovoltaic modules are considered to be building-attached if the PV modules are mounted on a building envelope and do not fulfil the above criteria for building integration. The integrity of the building functionality is independent of the existence of a BAPV module. PV materials that are not used to replace conventional building materials in parts of the building but simply attached to the building. Usually, photovoltaic modules are placed in parallel to the envelope of the building, in this case, the roof, without the dual function defined in the architectural integration. Horizontal installation is not accepted to favour self-cleaning [24].

2.2.1 Monumental school, Innsbruck (Austria)

Author: Pavel Sevela (UIBK)

What is the solution?

A PV-system with a size of around 10 by 3 meters with a peak power of 5 kW was installed at the south facing roof of the Monumental School (NMS Hötting), Innsbruck, Austria – a historically protected building - in the spring of 2014.
The PV-array is made up of 20 pieces of photovoltaic (PV) modules “SOLARWATT Blue P60 250Wp”, an inverter “KOSTAL Piko 5.5” and “TIGO - Energy control, monitoring and safety system” including sensors for module temperature and global radiation.

Why does it work?

The realization of the mounting was restricted to follow the inclination of the roof surface due to the visibility and architectural reasons. The reduction of the solar energy yield (compared to the ideal inclination) due to the flat inclination of the roof is less than 5 %. Technically the mounting was done with special tin roof fold-clamps. This way, the mounting is reversible without any permanent consequences. The total height of the system is around 12 cm (measured from tin roof surface). The individual electronic MPP-tracking for each module (product name TIGO) makes it possible to utilize the maximum solar energy yield even in case of partial shading of the PV array. If one or several modules are shaded, the TIGO-system is able to choose a different MPP for those modules individually.

This way the energy yield of the unshaded modules is not reduced.
Moreover, this system allows a system shut-down of the DC-grid in emergency case (e.g. fire) to avoid danger due to high voltage (e.g. 480 V in standard PV-arrays).
As the PV-array was set up for research reasons within the 3ENCULT-project, the electrical behaviour and energy yield will be possible to observe and log via online tool. For scientific reasons, the power of each module is logged (in order to see effects of partial shading) as well as the module temperature and the global solar radiation at the level of the module.

The most important issue for decisions on PV-systems on listed buildings is the visibility in terms of format, colour and surface texture. On this school building, the roof covering is a tin roof, hence the frame of the modules was chosen to be an aluminium type in light colour. The chosen module type is SOLARWATT Blue P60 250Wp polycrystalline cells. In total, 20 modules were mounted in two rows at the lower part of the south facing roof. The dimensions of the demonstrator are 10 x 3 meter, which were considered as minimal feasible size for evaluation of the appearance from different viewpoints and for the trustable results of monitoring system considering the shading effects. The surface of the front glazing is specially made of glass with diffuse reflecting finishing to avoid glare (full mirroring) and consequently to minimize its visibility.

Description of the context

A PV-test setup with reversible mounting system was placed on the original roof of the Monument school building NMS Hötting. This design process happened in collaboration with all involved parties (architect, local heritage authority, heritage authority Vienna (BD) and the building owner).

The monument school NMS Hötting is listed as one of the most important examples of early modern architecture in Tyrol (1929-1931).

From an architectural point of view, the architect of the school building (Franz Baumann) intended to realize the imagination of a flat roof. At the time of construction (in 1930) however, the technique for making flat roofs was not state of the art yet. The final solution was an inclined roof with a shallow slope. This way, the inclined roof is visible only from far distance. From the street or from any other close viewpoint, the roof surface appears hidden behind the roof-eaves. As demonstrated by figure 5, the roof with a slope of 13° (lower roof) and 15° (higher roof) is not visible to a person at ground level, from any viewpoint closer than a distance of around 60 m from the building. This was the main argument why, from the heritage point of view, it was permissible to place the PV-array on this roof.

Pros and Cons

Bullet points summarizing pros and cons of so-far-known aspects of this solution:

Pros +	**Cons -**
Protection & reversibility	Not rainproof, do not replace the roofing material
Maintenance	
Energy efficiency	
Scalability of the solution	
Aesthetics	
Educative function for the pupils	

Sources

Life monitoring of the PV-array: http://www.tigoenergy.com/site.php?0c265458-9b59

Energy Efficiency Solutions for Historic Buildings, Troi, Alexandra (EURAC research) / Bastian, Zeno (Passive House Institute), ISBN 978-3-03821-650-6, December 2014

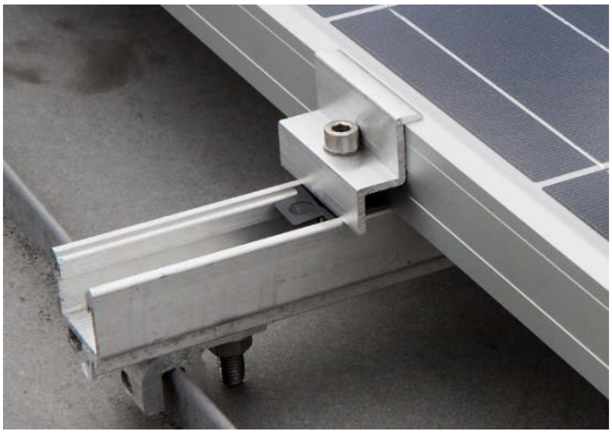

Figure 2 - PV-array on the south-facing roof, reversible mounting by the tin roof fold-clamps, © Pavel Sevela UIBK

Figure 3 - View from the south at a distance of around 65 m, © IIG

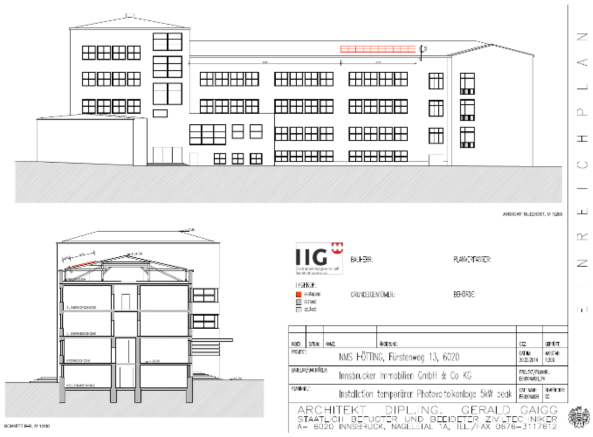

Figure 4 - Location of the PV-array (view from south-west and cross section), © IIG

Figure 5 - PV-array at the tin roof of Monument School NMS Hötting, © Pavel Sevela UIBK

2.2.2 Lauriston Place, Edinburgh (United Kingdom)

Author: Roger Curtis and Anne Schmidt (HES)

What is the solution?

This project was the installation of a series of solar thermal collectors in 2009 on the roof of 10 protected (Category B Listed) blocks of flats, or tenements, in the City of Edinburgh by the owners, Lister Housing Co-Operative. The buildings, dating from 1840, are within the City of Edinburgh World Heritage Site.

Why does it work?

The panels were mounted on to the existing traditional slate roof with special fittings. The piping and other service requirements were routed through the roof voids to the central stair. The central stair in each block was used as the route for the hot water down the building and off the landings into each flat. This followed the routes of other services such as gas and electric and water. The stone plinth of the landing had to be core drilled through. Otherwise, there was minimal impacts on the building fabric.

Description of the context

The shape of the roof in the early 19th C tenement building was an 'M' shape, giving a central valley. The area for the panels was shielded from all sides; there was no impact on the cultural significance of the buildings nor any effect on the World Heritage Site. In addition, the enclosed location allowed safe access for installation and ongoing maintenance of the array.

Pros and Cons

This installation has proved to be successful in assisting tenants with their domestic hot water heating costs. It has proved simple to maintain and long lasting, now being in its 11th year. However, to maximise benefits residents need to plan their hot water use and understand the system; this depends on their engagement, which varies a lot.

Type of Data Available

Simulation provided by the suppliers of the panels.

The Client was Lauriston Housing Co-Operative. The project was supported by Edinburgh World Heritage, City of Edinburgh Council, and managed by Changeworks.

Sources

https://www.hiberatlas.com/smartedit/projects/200/Changeworks Renewable Heritage.pdf

Figure 6: Installation of the solar thermal units, © HES

Figure 7: Electric connection into the house, © HES

Figure 8: Lauriston Place main elevation, © HES

Figure 9: Lauriston Place solar panels, © HES

2.2.3 Magnusstraße Building, Zürich (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The heat energy required to heat the building and provide the domestic hot water is generated by a wood pellet firing system. The combustion gases from the wood pellet boiler are led through a newly created chrome steel chimney over the roof. The fuel storage room is located right next to the heating centre. The heat for the rooms is visibly conducted via new risers and distributed using new radiators. These were placed on the inner walls in the area of the current old oil stoves. Horizontal heating walls were installed in the bathrooms.

Why does it work?

The solar energy thus obtained can be used both for heating the domestic hot water and for supporting the heating.

Description of the context

The two street-side facades are subject to preservation requirements and therefore could not be changed. Otherwise, the attic and the courtyard side. Here the roof with eaves could be broken off and put back in the form of prefabricated wooden elements. In this context, the roof could be raised on the courtyard side.

Pros and Cons

The goal was to create thermally comfortable rooms while being careful with non-renewable energy sources.

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/en/apartment-building-magnusstrasse-zuerich--2-88.html

The project was awarded with the Swiss Solar Prize in 2007. Link: https://www.solaragentur.ch/dokumente//M-07-09-21Magnusstrasse.pdf

Figure 10: *Magnusstraße Building, Zürich. Roof view with solar panels, © V+P (Viridén + Partner AG Architects)*

2.3 Building integration (BIPV and BIST) in historic buildings: roof integration

The standard EN 50583: 2016 lay down the technical, technological and constructive requirements for BIPV systems [21]. In these systems, the balance of the technical and aesthetic aspects of PV technology with those of the building skin becomes a priority, without compromising its functional characteristics, and thus becoming a prerequisite for the integrity of the functionality. If the built-in PV module was dismantled it should be replaced by an appropriate construction component. In addition to electricity generation, photovoltaic systems must be used in the building's envelope to provide, in example [22]:

- Protection against atmospheric agents: separation between indoor and outdoor environments, primary weather impact protection: rain, snow, wind, hail

- Energy economy: such as thermal insulation

- Sun protection and daylighting Modulation: such as shading, daylighting, thermal insulation

- Sound insulation and noise protection

- Security or safety properties

These modules can be divided in two types: roof integrated, and façade integrated. In this section the roof integrated systems are documented.

A pitched/sloped opaque roof is made up of angled and sloped parts divided as “discontinuous” roof due to the presence of small elements (tiles, slates, etc.) or large PV modules covering main surfaces of the roof. The integration of PV modules must consider easiness of install and inclination and orientation towards the sun, and the suitability for PV considering the conservation status of the historical roof and the level of protection. A lot of constructive solutions have been developed over the last years, moving from a first-generation PV systems (the BAPV) towards the most recent watertight solar modules that replace the traditional tiling layer. Categories within this application area include solar glazing, in-roof mounting systems, full roof solutions, large tiles small tiles, and metal panels.

Partially part of the roof or full-integration is possible and could be covered by PV. When the system is based on non-standardized elements the solar plant can be adapted to single roof features such as morphology, pitches size, irregular surfaces, chimneys or other elements. Special parts such as dummies, customizable parts could be made to facilitate the aesthetical integration. When solar systems are integrated in historical buildings by maintaining a part of the original roof, allows that the visibility and aesthetic appearance of the solar system could be minimized, with less impact from the street view and the surrounding environment.

Semi-transparent solar modules could be integrated in the roof, the so-called ‘skylight’. These glazed solar photovoltaic laminates for are often made by crystalline silicon or by thin film modules encapsulated within glazed panes that allow light and heat to penetrate and providing filtered vision. The cell’s pattern and assembly combine glass-glass PV laminates with adjustable light transmission to provide the proper solar and daylighting control. Semi-transparent solar PV modules can be used also in facade elements similarly to a curtain wall. The load-bearing part, usually extruded aluminium frames (but also steel, woods, etc.) is equipped for the electric wirings' passages.

2.3.1 Morpho Color

Author: Johannes Eisenlohr (Fraunhofer ISE)

What is the solution?

Morpho Color is a technology for coloured solar thermal collectors and coloured photovoltaic modules with high efficiencies. To realize a colour impression for the human eye, MorphoColor, which is a combination of surface structure and coating, causes a small bandwidth reflection peak in a tailored spectral range. Thus, efficiency losses due to the additional reflectance can be minimized. Especially for heritage buildings and buildings with high architectural demands, MorphoColor enables integrating of active, solar energy harvesting components in the facade without the aesthetical drawbacks of the typically very technical impression of solar thermal collectors of photovoltaic modules.

Why does it work?

The technology opens possibilities to increase the on-site energy generation for historic buildings. While many building surfaces so far cannot be equipped with solar active components due to the massive change of the buildings character and aesthetic, both on roofs and in facades, such components can help to further close the gap between energy demand and energy supply. From a technical point of view, it is crucial to maintain high technical efficiencies, as available surface areas are usually limited and the components need to pay off with respect to economic and environmental criteria. Therefore, MorphoColor only slightly reduces the efficiency (typically less than 10% relatively, 90% of power of reference product without colour maintained) while adding significant aesthetical design freedom.

Pros and Cons

Pros:

- Large degree of freedom. Many colours possible.
- High efficiencies of solar thermal collectors or PV modules can be kept. •
- More building surfaces can be solarized without too heavy change of the buildings character.
- Colour can be combined with anti-glare surfaces, thus a matt, non-glossy impression can be reached.

Cons:

- Technology still under development. Prototypes available, market introduction on its way but not yet realized.
- Despite the almost free colour choice and the optional glass surface structure for matt/anti-glare properties, it still transports the character of a glass surface.

Type of Data Available

Fraunhofer ISE is working together with industry partners on these solutions. There are detailed simulation models of the coatings and structures themselves and also on the application level, e.g. for the yield calculation for a specific building.

Sources

Bläsi B., Kroyer T., Höhn O., Wiese M., Ferrara C., Eitner U., Kuhn T.E., Morpho butterfly inspired coloured BIPV modules, 33rd European PV Solar Energy Conference and Exhibition, 24-29 September 2017, Amsterdam, available at link https://www.hiberatlas.com/smartedit/projects/196/Blaesi_Coloured-Modules_EUPVSEC2017.pdf

Kroyer T., Eisenohr J., Bläsi B., Höhn O., Heinrich M., Neuhaus H., Kuhn T. E., Pilot installation of highly efficient coloured BIPV modules with anti-glare coating, Conference on advanced building skins 2019, available at link https://www.hiberatlas.com/smartedit/projects/196/Kroyer_Advanced Building Skins 2019_1.pdf

Figure 11: Visualization of a solar thermal collector with a glass cover sheet featuring MorphoColor, © Fraunhofer ISE.

Figure 12: Examples, © Fraunhofer ISE

2.3.2 Solar Silo, Basel (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

Innovative coloured customized photovoltaic modules are used creating a particular visual design integrated in the ventilated roof and façade envelope of an industrial refurbished historic building in Basel, Switzerland. Green, gold, orange, blue and gray PV modules with monocrystalline solar cells and some standard modules in black were used on the roof as well as on the south and north façades. The 159 m2 BIPV plant (23 kWp) installed in the Solar Silo Building is integrated over the entire area and generates 16,400 kWh of solar power annually. It covers around 37% of the building's total energy consumption of 44,400 kWh/year and the building is connected to a district heating supply. The project has finished in 2015 and won the Swiss Solar Prize 2015 in the Category B: Building renovations.

Why does it work?

The aesthetical appearance of the BIPV façades and the BIPV roof arises from the use of innovative coloured PV modules that have been combined with attention to the geometrical aspects and existing constrains of the roof and the façades. The modules technology is characterized by a colour coating on the outer surface of the module's glass that makes the modules a matte panel and the PV cells are hardly recognizable. Besides the technological specific features of the modules, the roof modules have standard dimensions and they have been used as mosaic tiles whereas the façade modules have been customized for keeping the modularity of the existing surface with the smaller number of custom-sized panels. BIPV modules have been installed as cladding elements of the ventilated roof and façades – both southern and northern – although if facing north BIPV produce less amount of electricity, the aim of designers was to have a homogeneous architectural language in the whole building design. To increase the self-consumption of the electricity that is generated on-site and to relieve the public grid, previously used lithium-ion batteries from electric vehicles are used as second life battery energy storage. The PV system and battery storage are being investigated and monitored in detail in a joint research project by the Office for the Environment and Energy of the Canton of Basel-Stadt and the Federal Office of Energy together with the University of Applied Sciences North-western Switzerland (FHNW).

Description of the context

The former building of the heating center and the coal silo of Maschinenfabrik Sulzer and Burckhardt in Basel, has been completely converted into a multipurpose building making way for a cultural district over the past 15 years. The Solar Silo is the result of the refurbishment of an old coal silo tower, where coal was stored to produce heat for an ex-industrial field “Gundeldinger Field”, established in 1844. In the last 15 years, the foundation Kantensprung AG has bought the industrial area to return this site to the local population. The main criteria for site transformation are: neighborhood, ecology, and integration. Therefore, this transformation has been carried out adopting a holistic sustainable approach: re-use of existing materials, rainwater collection, green roofs, photovoltaic systems, and space reconversion for social/work/commercial activities. With regard to the photovoltaics, it has been integrated into the building envelope to provide a visible sign of the shift from the use of fossil fuels for an old manufacturing site to the use of renewable energies for a new cultural and commercial site. The project is part of the "2000-watt society - pilot region Basel".

Various types of photovoltaic modules were installed in the Gundeldingen Feld complex. A photovoltaic system with an output of 50 kWp was also installed on the shed roofs of halls 4 and 5. The electricity produced is fed into the IWB (Industrielle Werke Basel) network. In addition to the PV, a Second Life battery energy storage system (2nd-Life BES) is installed. This maximizes the amount of energy that can be used on site. Especially on summer days and on weekends, the production of the PV system exceeds the local power consumption. This surplus can be stored in the BES and can be consumed at a later point in time.

Pros and Cons

Bullet points summarizing pros and cons of so-far-known aspects of this solution:

- Protection & reversibility
- Aesthetics
- Energy efficiency
- Maintenance, ...
- Synergies for user compared to heaving no renewable energy system
- Scalability of the solution
- Innovative solution

- Customized and tailor-made product to improve the integrability of the architectural solution in the existing building
- Research project to monitor energy performances and to demonstrate innovative BIPV concept
- Socio-cultural revitalization and construction refurbishment of an entire urban area, ex-industrial zone of the city, by adopting renewables energies and a sustainable approach.

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/en/solar-silo-in-gundeldinger-feld-basel--2-51.html

Data monitoring system: https://www.irix.ch/en/references/case-studies/kantensprung-analysis-solar-data-coal-tower

The refurbishment project of Solar Silo building was awarded with the Swiss Solar Prize in 2010. Link: https://www.solaragentur.ch/sites/default/files/g-15-09-02_mehrzweckgebaude_kohlesilo_basel.pdf

Vogel Benedikt, Ein zweites Leben für Batterien, Haustech 12/2015, pp. 34-37. Link: https://www.hiberatlas.com/smartedit/projects/51/1_Beleg_2nd-life-Batteriespeicher_Haustech.pdf

Egger Nina, GEBÄUDEINTEGRIERTE PHOTOVOLTAIK IN DER PRAXIS Überwältigende Vielfalt TEC21 24/2015 - Gebäudeintegrierte Photovoltaik, pp. 27-28: https://www.hiberatlas.com/smartedit/projects/51/tec%2021%2024_2015.pdf

Book: Gundeldinger Feld - A machine factory in transition, Kantensprung AG (ed.), editions denkstatt Basel, ISBN 978-3-9524556-0-9. [Internet]. 2020; Available from: https://www.denkstatt-sarl.ch/app/download/10804542174/Buch_GundeldingerFeld_SCREEN.pdf?t=1586173367

Figure 13: View of the roof and façade, © Martin Zeller

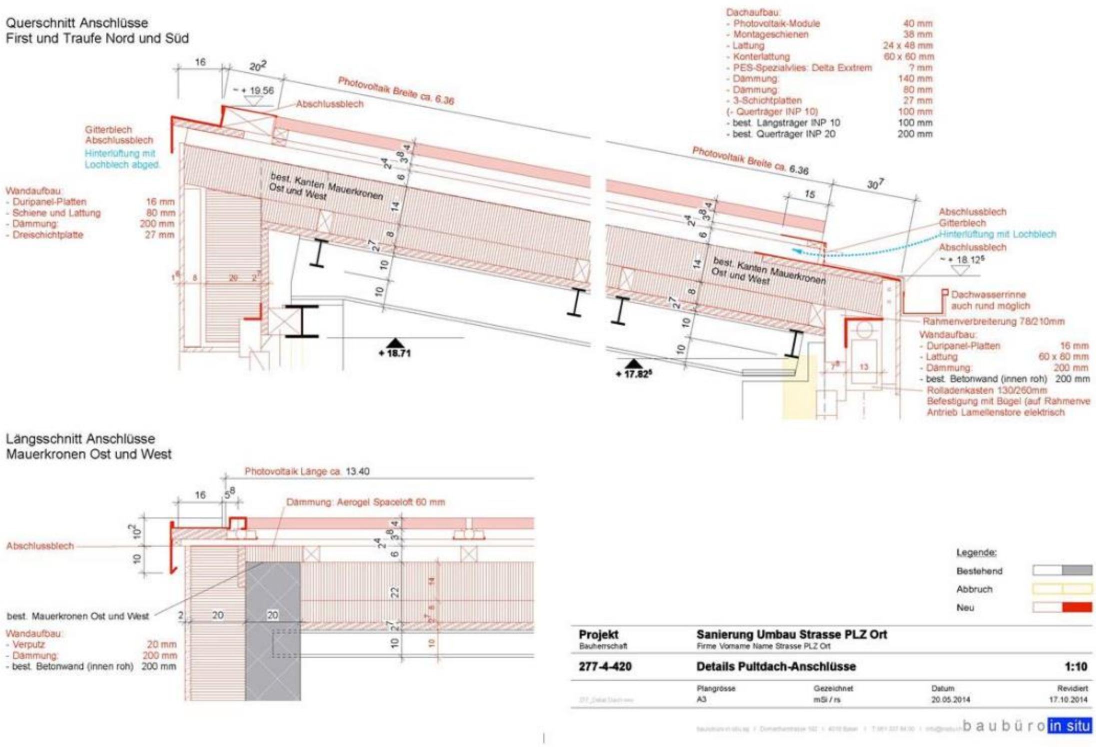

Figure 14: Cross-section detail, © baubüro in situ ag

2.3.3 Feldbergstraße, Basel (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The entire energy requirement for heating, domestic ventilation, hot water and auxiliary energy is covered on the roof of the building. On the one hand, this is achieved through state-of-the-art thermal insulation techniques, on the other hand through passive and active use of solar energy (thermal and photovoltaic).

- PV system pitched roof in-roof system
- Substructure type: montavent in-roof on the dormer roof. Road side mounted on roof
- PV system Total area: 63.7 m^2
- Output: 9.9 kWp,
- Annual yield approx. 9'000.-

Why does it work?

Several requirements of the cityscape commission for façade and roof design had to be met. In this case panels have been integrated into the south pitch which does not have any requirements for protection and on the dormer roofs on the north pitch. This solution has been discussed and accepted by the Commission.

Description of the context

Two more than 100-year-old apartment buildings on Feldbergstrasse are being renovated to produce more energy than they use for heating/hot water, ventilation and auxiliary energy. The 12 apartments did not meet today's comfort requirements. Accordingly, the apartments were poorly rented or stood empty. The need for maintenance was high.

Pros and Cons

Scalability of the solution: if the 1.5 million buildings in Switzerland were renovated on this basis, corresponding to the current technical progress, the total energy needs of our housing stock would decrease from 125 TWh/year, to around 9 TWh/year. The resulting energy substitution of nearly 115 TWh/year corresponds to the annual production of 15 large-scale fossil fuel or nuclear power plants, such as Gösgen with 7.5 TWh/year. This exemplary architectural and energy achievement should be brought to the attention of every parliamentarian.

Additional Information

Three different types of modules and integrated models have been used: -Sanyo HIP 195 with integrating System INDACH (Roof and garret south) -Sanyo HIP 245 (Garret north) -Special execution (Window lintel garret south)

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/en/residential-and-commercial-building-feldbergstrasse-basel--2-67.html

The project was awarded with the Swiss solar prize in 2009. Link: https://www.solaragentur.ch/dokumente//G-09-08-20%20Viriden.pdf

https://www.hiberatlas.com/smartedit/projects/67/Systemkompente Solaranlagen Feldbergstrasse.pdf

Figure 15: Roof with solar thermal and PV, Viridén + Partner AG Architects, © Nina Mann

Figure 16: Roof with solar thermal and PV, Viridén + Partner AG Architects, © Nina Mann

2.3.4 Doragno Castle, Rovio (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The system has been designed and developed specifically to be perfectly integrated.

- BIPV Module Peak power: 16.4 kWp
- Energy production: 16,400 kWh/year
- Building skin application: Solar tiles
- Product: Custom made Manufacturer: ISSOL Switzerland SA
- Architect: deltaZERO / Stefano De Angelis e Maria Mazza
- Photovoltaic installer: Greenkey Sagl – Kim Bernasconi

Why does it work?

The architects have studied and developed this BIPV solar system with a specific mounting system to improve the integration of the solar modules in the roof and to achieve a good integration in the landscape and in the building concept. This has required a specific static verification and the use of BIPV frameless modules (frames) to create a uniform and complete surface of the roof, as well as specific termination elements (ridge line and points where there are ventilation chimneys) specially designed.

Description of the context

The glass is fixed by gluing on cross rails connected to the roof structure in a stable manner. In total, each glass is fixed along three support lines.

Pros and Cons

PRO 1. production of electricity that reduces the overall energy consumption of the building. VERSUS 1. greater difficulty in planning and execution (the plant is perfectly integrated into the roof and does not entail any aesthetic damage even in the case of a historic building) 2. From the financial point of view: in the short term a photovoltaic system represents a higher cost, which, however, by analysing the costs on the 1st life cycle of a building (about 40 years), leads to an important gain.

Type of Data Available

The simulation has been done using the tool PV*SOL premium. Climatic zone Cfb (Warm temperature, fully humid, warm summer).

https://www.hiberatlas.com/smartedit/projects/28/1_simulazione.pdf

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/en/doragno-castle-rovio-ticino-switzerland--2-28.html

Several information is published regarding this project and is available in the in the architect's web page and projects documentation, DeltaZero SA, https://www.deltazero.net/en/what-2/6-icon-projects/doragno-castle/

Maria Mazza & Stefano De Angelis Effrem, deltaZERO Architettura, Il Castello di Doragno, Restauro e sostenibilità energetica, Archi magazine, Rivista svizzera di architettura, ingegneria e urbanistica. August 004, 2020. Pages: 26-29. Publisher: espazium. ISSN 1422-5417, https://www.espazium.ch/it/archi4-20_castello

www.solarchitecture.ch: https://solarchitecture.ch/in-a-nutshell-doragno-castle/S Solar web platform

Figure 17: Doragno Castle, Rovio. PV system © Greenkey

Figure 18: Doragno Castle – Rovio. PV system © Greenkey

Figure 19: Doragno Castle – Rovio. PV system © Greenkey

2.3.5 Kindergarten and apartments, Chur (Switzerland)

Author: Cristina Polo (SUPSI)

Key words: roof integration PV – Local sharing of renewable energies

What is the solution?

With the energetic renovation and an innovative heat network concept with the adjoining apartment building (MFH) with three families, the city of Chur is paving the way for the energy transition. There is a combined PV and thermal system on the roof. It covers its own energy requirements with 28,300 kWh/year to 95%. The solar excess heat of around 9,100 kW /year, which cannot be used in the transition period and in summer, is delivered to the neighbouring MFH. In the winter months, the pellet heating of the neighbouring MFH supplies the kindergartens and penthouses with 8,800 kWh of heat.

Why does it work?

The photovoltaic system on the south and west roof produces approximately 8,800 kWh of electrical energy per year. This corresponds approximately to the electrical energy consumption of 2.5 households. The electrical energy is used directly by the residents (self-consumption). If the consumption is higher than the PV production, the additional energy is obtained from the IBC, if the PV production is higher than the consumption of the residents, the excess is fed into the IBC network.

Description of the context

The complex is divided into two structures. The residential building is characterized by the building height and the facade design as the main volume of the ensemble. The previous commercial building is deeper and due to its L-shaped geometry, forms an inner courtyard which, with its round arches and the widely projecting roof, has a high spatial quality. The specifications of the city of Chur as client were clear. The artistically valuable ensemble was to be preserved in its original expression. The earlier interventions should be dismantled, the change of use of the annex should be visible from the outside as a renewal but should be connected with the original design. And in addition: "Since Chur has been an energy town since 2011, it was necessary to incorporate the latest findings in energy and building physics into the renovation."

Pros and Cons

The PV system complies with many of the geometric and spatial and construction compatibility criteria required by current regulations for the integration of solar systems in historic buildings (grouping, coplanarity with the water table, respect for the eaves lines, joint precision, etc.). The aesthetic, material and colour compatibility with the existing roof is not optimal, but the final result is good and well-integrated with other new elements incorporated in the renovation of the building such as the dormers.

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/en/kindergarten-and-apartments-chur-switzerland--2-148.html

The project manager of the architectural office did his master thesis (sustainable building) on the property. Master thesis - available the complete presentation tables as annex. Additionally, a presentation at one "exchange of experience". Magazine TEC21 (Januar 2016 Nr. 1-2) Magazine Kultchur (November 2016)

Breunig Morris, UMWETL UND ENERGIE, Energiemix auf Parzellenmassstab TEC21 1-2/2016, Publisher: Espazium Schweizerische Bauzeitung, Januar 2016, pp.18-20. Link: https://www.hiberatlas.com/smartedit/projects/148/Tech21_160108.pdf

The project was awarded with the Swiss solar prize in 2016. Swiss solar prize fact-sheet, Solar Agentur Schwei Link: https://www.solaragentur.ch/sites/default/files/g-16-09-22_dwhg_und_doppelkindergarten_chur_def.pdf

Energy concept - Factsheet, Pfleger + Stöckli Architektur GmbH. Link: https://www.hiberatlas.com/smartedit/projects/148/Pagine da KIGA_150916_A3.pdf

Link to energy-cluster.ch data: https://www.energie-cluster.ch/de/deklariert-ch/plusenergiegebaeude/schule-doppelkindergarten-chur-sanierung-(solarpreis-2016)-calandastrasse-50-7000-chur-9-3583.html

Figure 20: Kindergarten and apartments – Chur. Pictures of the building with BIPV, © Ralf Feiner, Malans. [21]

2.3.6 St. Franziskus Church, Ebmatingen (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The Roman Catholic Church of St. Francis Ebmatingen, built in 1989, urgently needed renovation. An old oil heater, an outdated insulation and a partially damage roof ensured a disproportionately high energy requirement of 84,400 kWh/year. In winter 2018/19, the structural and energetic renovation followed with new insulation, geothermal heat pumps, photovoltaics with thermal energy (PVT) and LED lighting. As a result of these measures, the total energy consumption to date has decreased by 35% from 84,400 kWh/year to 54,700 kWh/year. The character of the church was still preserved. The renovation costs amount to CHF 1.2 million. Of the 543 m2 PV system that is optimally integrated into the roof, 161 m2 are equipped with PVT modules. In addition to electricity, they also produce 41,800 kWh/year of heat, which is conducted 300 m deep into the ground in summer which a part is recovered in winter. The installed power of the PV / PVT system is 90 kW. This means that 78,900 kWh/year of CO2-free electricity is generated annually and 41,800 kWh/year of thermal energy is generated with the 161 m2 thermal solar collectors. Both plants generate a total of 120,700 kWh/year. This means that the PEB church has an energy supply of 221%. Church renovation serves as a role model both in terms of energy and ecology. The St. Franziskus Ebmatingen church received the Swiss PlusEnergieBau Solar Prize in 2019.

Why does it work?

St. Francis Church has been transformed into a CO2-neutral PEB building with a 221% energy efficiency. Erected in 1989 and extended in 2008, the 2018 partial refurbishment, including roof, facades and a new heating system with geothermal heat pumps was limited to the original building. Nevertheless, architectural unity is achieved. A solar BIPV system combined with Photovoltaic thermal collectors, (PVT collectors) have been well integrated in the complex surface of the existing roof of the modern renovated Church of St. Francis Ebmatingen. The roof areas are completely covered with photovoltaic modules. It was possible to use the same modules, with only slightly varied connection details, for both the conventional in-roof photovoltaic system and for the PVT system (hybrid). The roof edges and the eaves are identical, resulting in a very uniform architectural design.

Description of the context

Together with the experts involved, the building commission had different variants for the heating replacement have been tested. The building commission and church maintenance unanimously recommended the present project with geothermal probe heat pump heating and combined photovoltaic thermal system (power generation, thermal regeneration of the earth in the probe area, room cooling) and at the same time to carry out the structural renovation. The Windows in the old part of the building received a new, modern, better insulating glazing, as a replacement for the old glazing, which has replaced the end of the had reached the end of its life span. The heat losses through the glass could thus be reduced to about one third, which will have a positive effect on heating costs. It also improves the comfort of the rooms. The renovation and redesign of the lighting in the church interior and the exterior lighting was modernised from halogen downlight technology to energy-saving tuneable white LED lamps. The roof was leaking in places and had to be renovated.

Pros and Cons

The solar photovoltaic integrated system and solar thermal PVT is well integrated in the complex surface of the existing roof. It complies with the geometric and spatial and construction compatibility criteria required by current regulations for the integration of solar systems in historic buildings (grouping, coplanarity with the roof slope, respect for the eaves lines and roof edge, joint precision, etc.). The aesthetic, material and colour compatibility with the existing roof is optimal because it respects the original colour of the roof. The reflection rate is slightly higher with respect to the original roof tile that has been replaced. The final result is very good and well-integrated.

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/en/st-franziskus-church-ebmatingen-switzerland--2-128.html

Römisch-katholische Kirchgemeinde Egg ZH Pfarrvikariat Maur ZH: ENERGETISCHE SANIERUNG KIRCHE ST. FRANZISKUS EBMATINGEN (Festgottesdienst 24.3.2019) St. Franziskus Ebmatingen church renovation project was awarded by the Swiss Solar Prize in 2019 and have won a European Solar Prize the same year, 2019.

Link: https://solaragentur.ch/sites/default/files/g-19-10-02_solarpreispub19_fueradag_v2.p042_43.pdf

European solar prize brochure: https://www.eurosolar.de/en/images/EVENTS/ESP/ESP_2019/Brochure_ESP2019.pdfIs there any related

Service of the Swiss Radio and Television RSI, in Italian language news on Friday 15.11.2019, Published on: 15 November 2019, 21:24, Link: https://www.rsi.ch/news/svizzera/Una-chiesa-a-zero-emissioni-12421722.html

Additional Information

- BIPV module Product: Eternit Integral II
- Manufacturer: Eternit AG / SI Module GmbH
- Cell technology: Mono-crystalline
- Cell colour: Black
- Front glass type/customization: Transmission-optimised solar glass (2×3.2 mm ESG) with anti-reflective coating
- Dimensions: 1300x880x12mm
- Nominal power: 190 Wp
- Specific power: 166 Wp/m²
- Module weight: 11 kg
- Specific weight: 9.62 kg/m²

Figure 22: © Römisch-katholische Kirchgemeinde Egg ZH Pfarrvikariat Maur ZH

Figure 23: © Römisch-katholische Kirchgemeinde Egg ZH Pfarrvikariat Maur ZH

Figure 24: © Römisch-katholische Kirchgemeinde Egg ZH Pfarrvikariat Maur ZH

Figure 25: North front after interventions © *D. Studer, Studer Architekten*

Figure 26: © Römisch-katholische Kirchgemeinde Egg ZH Pfarrvikariat Maur ZH

Figure 27: North front after interventions © *D. Studer, Studer Architekten*

Figure 28*: Roof edges after interventions* © *D. Studer, Studer Architekten*

Figure 29*. PV panels* © *D. Studer, Studer Architekten*

Figure 30: PVT panels, new roof. © *D. Studer, Studer Architekten*

Figure 31: New roof. © *D. Studer, Studer Architekten*

Figure 32*: PVT solar modules.* © *D. Studer, Studer Architekten*

Figure 33: New solar roof. © *D. Studer, Studer Architekten*

2.3.7 Chalet La Pedevilla, Marebbe (Italy)

Author: Jennifer Adami (Eurac)

What is the solution?

The PV system is integrated into the sloped roof of a mountain chalet. It is made of black PV modules replacing the conventional wooden boards. The modules are mounted with aluminium Solrif profile frames and fixed to the substructure with special mounting clamps, used to brace two modules to their frames in the overlapping area.

Why does it work?

The PV system was calculated to reach 6,500 kWh per year. Around an 80% of the produced electricity is self-consumed, covering the electric demand of the ventilation system and the heat recovery. The PV modules are integrated in a new construction that can be seen as a modern interpretation of the old “Paarhof”, the traditional kind of farm building typical for South Tyrol built with local natural materials. Such kind of solution could be applied in a historic context. The PV modules are coplanar with the roof and create a dark matt surface similar to traditional materials used in historic heritage. The reversibility of the solution is guarantee from the supporting structure that allows an easy dismounting of the modules.

Description of the context:

The case study is located in Marebbe (BZ-Italy), surrounded by the scenery of the South Tirol dolomite mountain ridges.

Pros and Cons:

The black PV modules are aesthetically integrated into the building as the dark monocrystalline silicon appearance blends in very well with the building’s dark painted oak exterior and the surroundings. The usage of standard market-available modules allowed to keep the costs relatively low, making the building a great example of photovoltaic integration with high replication potential.

Type of Data Available:

No results from simulation. Just data coming from a rough energy performance estimation, technical data about PV modules features (efficiency, size, ...), overall costs of the PV system.

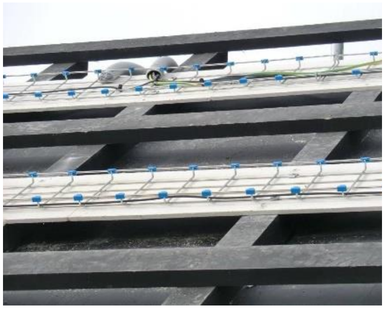

Figure 34: © Leitner Electro Srl

Figure 35: ©Leitner Electro Srl

Figure 36: © Leitner Electro Srl

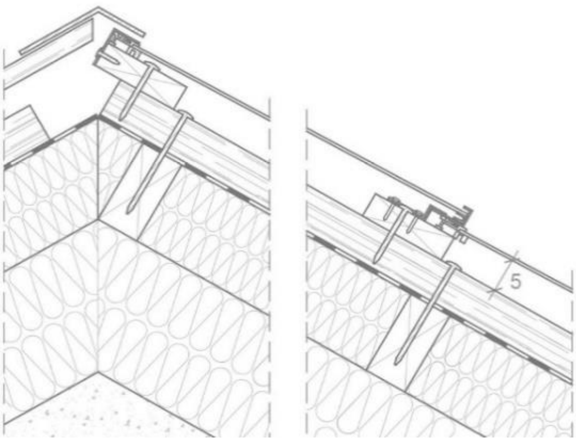

Figure 37: Detail: Leitner Electro Srl, re-drawn by Eurac Research

Figure 38: © Pedevilla Architects

Figure 39: © Pedevilla Architects

Figure 40: © Pedevilla Architects

2.3.8 Rural Farm Galley, Ecuvillens (Switzerland))

Author: Cristina Polo (SUPSI)

What is the solution?

The rural house pilot project in Ecuvillens/FR, dating back to 1859, uses colour modules terracotta developed specifically by the CSEM of Neuchâtel and Issol Switzerland for sites protected at the level of cultural heritage. The 27.2 kWp and 262 m2 PV installation on the roof of the farm. The building generates, with reduced efficiency, 16'500 kWh/year or about 26% of the energy consumption of 62'500 kWh/year. By demonstrating that the energy transition does not take place to the detriment of architectural quality, this project is therefore breaking down the ultimate barriers to the widespread deployment of photovoltaics.

Why does it work?

The farm consumes 2'500 l heating oil or about 27'500 kWh/year fossil energy and emits about 7.5 t CO_2 per year. For the power supply was a 27.2 kW strong Solar system optimally integrated into the roof surface. It supplies about 26% of the total energy demand. The reddish-brown colour reduces the output by approx. 39%* or round 10,800 kWh/year to around 16,500 kWh/year from Total energy requirement covered by the solar system about 39%. With better insulation, the very high energy consumption could be massively reduced.

Description of the context

For the owner of the farm of Ecuvillens - built in 1859 - it would hardly have been possible to produce his own electricity because the strict monument protection regulations of the canton of Fribourg prohibit the installation of terracotta-coloured solar modules in the village of Ecuvillens. Thanks to the research work carried out since 2014 by the CSEM in Neuchâtel in collaboration with Issol Switzerland, it was nevertheless possible to install a solar plant.

Pros and Cons:

After replacing the traditional roof tiles, the new solar modules serve as weather protection, produce renewable energy and ultimately contribute to the preservation of the environment and the local building culture. For this aesthetic innovation, the Galley farmhouse received the Swiss Solar Prize 2018.

Sources

Solaragentur Prix Solaire Suisse, Swiss solar prize 2018, Maison rurale Galley, 1730 Ecuvillens/FR. Link (German and French): https://www.solaragentur.ch/sites/default/files/solarpreispublikation2018_s.82_83.pdf

BIPV module: Product: Solrif® XL as laying system (the PV tile is no longer available) Cell technology: Mono-crystalline Front glass type/customization: Layer of colour applied on the inner side of the textured front glass Cell colour: Terracotta, semi-matt Dimensions: 1530×542 mm Power: 90 Wp Specific power: 120 Wp/m

Figure 41: Rural Farm Galley, (Ecuvillens),©Solaragentur Prix Solaire Suisse 2018.

Figure 42: Rural Farm Galley, (Ecuvillens), © Solaragentur Prix Solaire Suisse 2018.

Figure 43: Rural Farm Galley, (Ecuvillens),© Solaragentur Prix Solaire Suisse 2018.

Figure 44: Rural Farm Galley, (Ecuvillens). Roof detail, © Solaragentur Prix Solaire Suisse 2018.

Figure 45: Rural Farm Galley, (Ecuvillens), © Solaragentur Prix Solaire Suisse 2018.

Figure 46: Rural Farm Galley, (Ecuvillens), © Solaragentur Prix Solaire Suisse 2018.

2.3.9 Wine shed, Milvignes (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

Thierry Grosjean wanted the new wine shed "Le Corbet" built on the Domaine des Caves du Château d'Auvernier (NE) to run on solar energy in all circumstances. Although this wine-growing area is protected, he a permit was obtained to build an installation of integrating coloured solar modules. It produces 14,600 kWh/year, which is a lot of energy, more than the shed consumes. The surplus is used to supply other equipment and winemaking machinery without emitting CO2. It reduces the farm’s need for fossil fuels, the consumption of which is around 114,000 kWh/year. Thierry Grosjean is also planning to use solar energy for his castle.

Why does it work?

It was developed for protected buildings and places by the research institute Centre Suisse d'Electronique et de Microtechnique (CSEM) in Neuchâtel in collaboration with the Swiss company Issol. The colour is printed on the inside of the front glass using a ceramic printing process. According to the Swiss Federal Office of Energy (SFOE), tinted solar modules lose 39% of their output compared to un-tinted, transparent glass-glass modules with monocrystalline solar cells. As long as no official confirmed values for solar power production are available, it is assumed that monocrystalline solar cells without glass colouring could generate about 24,000 kWh/year. The Glass colouring thus leads to a performance loss of 39% or 14,600 kWh/year instead of 24,000 kWh/year.

Description of the context

The newly built wine shelter of Château d'Auvernier/NE was completed in June 2018. Due to the strict building regulations, Thierry Grosjean decided to install a terracotta-coloured PV system.

In terms of architectural integration, we can speak of a success story. Instead of a traditional cladding, the terracotta-coloured, semi-matt PV module with traditional appearance is integrated into the roof and completely replaces the tile covering. The south side of the facade is clad with terracotta photovoltaic tiles while traditional tiles are used to cover the complete the rest of the roof. The tempered safety glass with high light transmission enables a higher production gain compared to common glass. Its mounting system guarantees the same density as a conventional tile roof. The dimensions of the modules can be tailor-made, which is a real advantage. The aluminium Solrif frame 17.5 mm thick terracotta anodized resists saline environment. All these specificities make it possible to create a PV roof close to a traditional tiled roof. The fields of application proposed by the PV terracotta module are countless; it is finally becoming possible to install PV in complete visual discretion, thanks to the state-of-the-art technology developed at the Swiss Centre for Electronics and Microtechnology CSEM of Neuchâtel and meet the most recent standards. The plant produces approximately 23'500 kWh per year, which corresponds to the consumption of about 5 households (4'500 kWh/year excluding heating, average of one household of 4 persons according to Swissolar figures). Producer: ISSOL, Belgium Installations: Gottburg SA

Pros and Cons:

The 24 kW PV system is integrated into the south roof in an exemplary manner over the entire surface. The CO2-free solar power supplies various wine-growing machines, some of which also supply the Château d'Auvernier. Thierry Grosjeans is a convinced advocate of photovoltaics and a stubborn fighter for solar energy. Motivated by his success, he is now planning to expand his to supply historical castle with PV electricity. Thierry Grosjeans has received the Swiss Solar Prize 2019 in in the category of energy installations.

Sources:

Hangar Viticole, Solaragentur Swiss solar award project 2019, Swiss solar award 2019 for the "GOTTBURG SA" company. Link (German and French): https://www.solaragentur.ch/sites/default/files/g-19-10-02_solarpreispub19_fueradag_v2.p084_85.pdf

Figure 47: Wine shed (Milvignes), aerial view, © Atelier d'Architecture de St-Nicolas SA.

Figure 48: Wine shed (Milvignes), © Atelier d'Architecture de St-Nicolas SA.

Figure 49: Wine shed (Milvignes), © Atelier d'Architecture de St-Nicolas SA.

Figure 50: Wine shed (Milvignes), © Atelier d'Architecture de St-Nicolas SA.

Figure 51: Hangar Viticole, © Solaragentur Swiss solar award project 2019.

Figure 52: Hangar Viticole, © Solaragentur Swiss solar award project 2019.

2.3.10 Palazzo Strozzi, Mantova (Italy)

Author: Giovanna Franco (Unige)

What is the solution?

In 1910 the Banca Agricola Mantovana, now Banca Monte dei Paschi di Siena, decided to move its headquarters to Palazzo Strozzi, a prestigious building in the historic centre of Mantua. As happened to other historical buildings in Italy, on the occasion of its transformation into a bank, the courtyard of the palace became the branch hall thanks to the creation of a metal and glass roof that underwent the last modification in 1947, on the occasion of a radical enlargement of the Palace. In the mid-90s of the last century, the roof began to present extensive and worrying phenomena of degradation that worsened exponentially with the passage of time. This situation, together with the poor thermal insulation characteristics, the absolute absence of control of the sunlight penetrating through the glass roof and the poor architectural value of the building, led to the design of a new photovoltaic roof that, although with a formal appearance apparently out of context, would relate to the existing building making it clear the reading of its evolution over time. To achieve these objectives, a new "roofing system" was therefore designed and built, whose geometry derives from the reading and re-proposing, on a different scale, of the orthogonal mesh that characterizes the existing environment. This geometry, in the new roof, can be found from the minimum element, represented by the silicon cell that captures solar energy, square-shaped, to the larger scale identified by the overall structural mesh that supports the glazing.

Why does it work?

A roof capable of both saving and producing energy (15 kWp) has been realized, thanks to a capturing surface equal to about 130 square meters of Energy Glass "glass-glass" photovoltaic panels, with monocrystalline silicon cells. The new roof also makes it possible to reuse rainwater intercepted by all the glass surfaces. The latter is conveyed and collected in special tanks placed in the attic and then used, after a demineralisation and filtering treatment, for washing and automatic cleaning of the glass surfaces, to contribute to the cooling of the salon below, during periods of strong exposure to the sun, and to maintain the efficiency of the photovoltaic panels during the summer season. The roof can create, within the architectural organism, a "chimney" effect through the automatic opening of some vertical windows. It is therefore possible to obtain, at predetermined times of the day and without the aid of mechanical systems, a natural "recirculation" of the air in the rooms, with significant energy savings.

Description of the context

The Palace was built on pre-existing buildings, between the end of XVIII and beginning of XIX century, and from 1872 was the headquarters of the Banca Mutua Popolare di Mantova. A further radical renovation based on a project by architect Giovanni Giachi involved the former Strozzi property between 1910 and 1912 with the use of reinforced concrete, at the time of its new introduction in the building industry. Palazzo Strozzi is an example of eclecticism where elements of the 15th century Tuscany and others of Venetian origin are mixed. The main façade was made entirely of Botticino marble. It stands on the edge of the historical centre of Mantua. The main objective of the project was to create a system characterized by a very limited environmental impact and an extreme flexibility in the integration with the new solutions that technology will provide in the coming years in the field of energy saving and the exploitation of renewable energy. The new structure should not merely fulfil the role of protecting the Bank's salon below from atmospheric agents but should be a real new element capable of producing and saving energy at the same time; it should have connotations that identify it as belonging to the city of Mantua; it should create environmental wellbeing and demonstrate, with its transparency, the Bank's willingness to be transparent to its customers. The latter had to experience the new space no longer as a confined and protected area with respect to the external urban context, but as a sort of covered square, in the style of nineteenth-century city galleries.

Pros and Cons:

Through transparency, light and energy from renewable sources, the bank's showroom has been transformed into a sort of financial centre in close relationship with the surrounding urban fabric. A covered space in the style of nineteenth-century galleries where the passing of the hours and the changing of the seasons is perceived in a natural way by those who operate and frequent the salon, to the benefit of their personal and environmental well-being. The project has been authorized by the protection bodies. Thus, a new page has been written, to some extent, in the "book of history" of the city of Mantua, where the Juvarra dome of the Basilica of St. Andrew soars up towards the sky and creates one inside. The new roof of Palazzo Strozzi reflects the sky with its glass surfaces and creates clean energy. For this reason, it can be seen as a symbol of history and modern technology that, together, summarize the certainty and commitment to a sustainable city and a clean environment.

Type of Data Available:

The load-bearing structure of the new roof, characterized by a strictly orthogonal geometry, is made with tubular steel profiles pre-tensioned by a system of Macalloy stainless steel elements and bars, which allowed the use of profiles with a very small section. In addition, the pre-tensioning was useful to control the operating arrow of the structure once the heavy glazing of the roof has been installed. The secondary structure, made up of light Schüco thermal break aluminium profiles, has the function of containing the selective heat-insulating glazing and photovoltaic panels; moreover, it guarantees a perfect seal against water, wind and air pressure of the entire glass surface and totally eliminates its thermal dispersion.

Credits. Owner: Banca Monte dei Paschi di Siena, Architect: Franco Biondi (Paschi Gestioni Immobiliari S.p.A); Detailed Design: Armando Dalai; Structural design: Davide Vicentini

Figure 53: Different photos of the solution, © Arch. Franco Biondi Monte dei Paschi di Siena

2.3.11 Hotel des Associations, Neuchâtel (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

Located in the protected area of ISOS, the Hotel des Associations is a five-storey building whose socio-cultural identity is based on a foundation created by the City of Neuchâtel. The 27.7 kWp PV installation was commissioned in November 2014. It generates 27,600 kWh/a and thus covers 13% of the 205,400 kWh/a consumed by the building. Based on modules special and blind, it integrates perfectly with the entire roof surface and preserves in addition the historical character of the building. Together with the Hôtel des Associations, the canton of Neuchâtel has a perfect example of how PV systems and historic buildings can coexist.

Why does it work?

The 27.7 kWp PV system is carefully integrated into the upper roof surfaces. It produces 27,600 kWh annually and covers 13% of the total energy demand or 93% of the electricity requirement. The aim was to ensure that the roof and edges were as clean as possible and to make the system as homogeneous as possible. The client therefore installed 110 dummy modules. Because of the vertical orientation and to preserve the character of the building, the bricks were retained in the mansard zone. The 171 m2 facility is oriented to the north, south, east and west and thus achieves good solar power yields all year round. Due to the east-west orientation, the solar yields are relatively constant throughout the day. In winter, production is relatively stable due to the strong 30° inclination of the modules quite high.

Description of the context

The historical building "Hôtel des Associations" in the old town of Neuchâtel belongs to the "Fondation du Home de l'Ermitage & des Rochettes" and is located in the ISOS protection zone. The rooms are available to associations with an ecological and socio-cultural orientation. In just a few years the "Hôtel des Associations" has developed into a central place of urban interaction.

Pros and Cons:

The technologically modern facility takes the traditional, architectural building culture into account in every respect and fits perfectly into the cityscape. Therefore, deserves the "Hôtel des Associations" the Swiss Solar Prize 2015.

Sources:

Solaragentur Swiss Solar Prize 2015; Link (German and French): https://www.solaragentur.ch/sites/default/files/g-15-09-02_hotel_des_associations_neuchatel.pdf

Additional Information:

The roof of the building has been equipped on all four sides with a Meyer Burger Megaslate solar system integrated into the building. To ensure a homogeneous appearance, dummy modules were used as edge seals. Information PV Modules:

- Orientation: East, West;
- Tilt angle: 30°;
- PV surface area: 172 m^2;
- Rated power: 27.7 Wp;
- Energy production: 27,600 kwh/a;
- Final yield: 996.38 KWh/Wp;
- Active solar ratio: 25%-50% (roof);
- Manufacturer: MegaSlate;
- Module technology: monocrystalline;
- Cell colour: Blue;
- Type of glass: tempered glass.

Figure 54: Hotel des Associations, Neuchâtel. Building façade, © Caspar Martig Fotograf GmbH

Figure 55: Hotel des Associations, solar roof, ©Caspar Martig Fotograf GmbH

Figure 56: Hotel des Associations, Neuchâtel, aerial view, © Caspar Martig Fotograf GmbH

Figure 57: Hotel des Associations, aerial view, © Caspar Martig Fotograf GmbH

Figure 58: Hotel des Associations, new roof, © Caspar Martig Fotograf GmbH

2.3.12 Schlossgut Meggenhorn, Meggen (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The complex generates 90,000 kWh annually. It thus covers 190% of the electricity requirements of around 47,400 kWh/a for the Meggenhorn castle and farm. The battery, consisting of 200 cells decentralized 55 kW electricity storage with a capacity of 115 kWh, has a double benefit: On the one hand, it should save an expensive grid expansion, on the other hand it should contribute to the stabilization of the electricity grid.

Why does it work?

The solar-powered 55 kW battery storage system has a capacity of 115 kWh. The plot Schlossgut Meggenhorn with the barn, the castle and the company building are connected with a transformer and forms a distribution network on grid level 7 (230/400V). Thanks to the storage and the regenerative control, a complex network reinforcement with a long cable runs are not necessary. The production peaks are fed into the grid with a time delay. The pilot project will test whether decentralized electricity storage facilities can be used as a replacement for conventional network reinforcements which are technically and economically feasible and suitable for the provision of balancing energy. The project is supported by various representatives of the regional solar industry. Further objectives are the balancing of product peaks, the control of reactive power and grid feedback as well as the grid stabilisation. The perfectly integrated plant, which improves the townscape worthy of protection, has a model character and won the Swiss Solar Prize 2014.

Description of the context

The 580 m2 PV roof system is exemplary fully integrated and flush with the roof and is combined with a decentralised power storage unit. The example shows how a PV system not only respects a site of national importance worthy of protection but upgrades it. As the roof takes up the colours of the castle roof, the Roofscape is more harmonious. In a nearly two-year approval process involving the preservation of historical monuments, finally, the demanding objectives of monument conservation were implemented.

Pros and Cons:

The solar roof system of Schlossgut Meggenhorn is perfectly flush with the roof and fully integrated into the building. The architecture is preserved; the new PV roof matches the colour of the castle roof. The townscape worthy of protection is upgraded and appears modern.

Sources

Winner of the Swiss Solar Prize 2014 "C" category for energy plants. INTERREG case study for protected building's retrofit. Link (German and Franch): https://www.solaragentur.ch/sites/default/files/g-14-10-03_schlossgut_meggenhorn_solpreiskatenergieanl.pdf

Additional information

Information PV Modules: Orientation: South; Tilt angle: 34°; PV surface area: 580 m2; Rated power: 99.8 Wp; Energy production: 90,000 kwh/a; Final yield: 902 kWh/Wp; Active solar ratio: >75% (roof); Manufacturer: BE Netz AG; Module technology: monocrystalline; Cell colour: Blue.

Figure 59: © Caspar Martig Fotograf GmbH

Figure 60: Aerial view, © Caspar Martig Fotograf GmbH

Figure 61: Detail of the solar roof, © Caspar Martig Fotograf GmbH

Figure 62: Side view of the building, © Caspar Martig Fotograf GmbH

2.3.13 Mehrfamilienhaus Kettner, Bremgarten (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The solution on the main roof with large beautifully inserted solar modules generate 9,000 kWh of electricity per year. This inspiring example of solar roof integration generates 30% of the total energy requirement of 30,000 kWh/a. In the future, additional solar collectors will be installed on the south facade.

Why does it work?

Anyone who wants to carefully renovate an old building faces the difficult task of taking into account the latest state of the art technologies while preserving the character of the building. The building, which includes a PV system in operation since July 2012made of unframed solar modules, masters this challenge in a visually appealing way. All recesses were lined with dummy modules. The roof cladding thus obtains a uniform appearance. The modern solar technology blends harmoniously into the time-honoured brick façade. The roof insulation was finished with Rock wool increased to 20 cm. The PV system supplies 50% more electricity than the household use needed 6,000 kWh/a. A wood chip district heating system in Bremgarten supplies the three apartments with 24,000 kWh/a of thermal energy.

Description of the context

During the roof renovation of the 100-year-old first multi-family house (MFH) in Bremgarten, the client integrated an architecturally and aesthetically exemplary full-surface 10 kWp photovoltaic system instead of a conventional roof cladding.

Pros and Cons:

This solar roof renovation shows how modern solar technology can be combined with 100 years of building fabric in an exemplary manner and can be perfectly integrated into the townscape. For this, this plant will receive the Solar Prize Diploma 2013.

Sources:

Winner of the Swiss Solar Prize 2013 "C" category for energy plants. INTERREG case study for protected building's retrofit. Link (German and French): https://www.solaragentur.ch/sites/default/files/g-13-09-17_solarpreispublikation_2013_def_ka_kettner_bremgarten.pdf

Additional Information:

Information PV Modules:

- Orientation: East, West;
- PV surface area: 100 m2;
- Rated power: 10 KWp;
- Energy production: 9,000 kwh/a;
- Final yield: 900 KWh/Wp;
- Active solar ratio: >75% (roof);
- Manufacturer: EOSONO Gmbh;
- Module technology: thin film;
- Cell colour: black;
- Specific power: 110 Wp/m2.

Kategorie C
Energieanlagen
Schweizer Solarpreis-Diplom 2013

PV-Anlage MFH Kettner, 5620 Bremgarten/AG

Bei der Dachsanierung des 100-jährigen Mehrfamilienhauses (MFH) in Bremgarten integrierte der Bauherr statt einer konventionellen Dachhaut eine architektonisch und ästhetisch exemplarische ganzflächige 10 kWp-Photovoltaikanlage. Die auf dem Hauptdach mit grossem Quergiebel schön eingesetzten Solarmodule generieren jährlich 9'000 kWh Strom. Dieses inspirierende Beispiel solarer Dachintegration erzeugt einen Anteil von 30% des gesamten Energiebedarfs von 30'000 kWh/a.

Wer einen Altbau sorgfältig sanieren möchte, steht vor der schwierigen Aufgabe, den neusten Stand der Technik zu berücksichtigen und dabei den Charakter des Gebäudes zu bewahren. Die im Juli 2012 in Betrieb genommene PV-Anlage aus ungerahmten Solarmodulen meistert diese Herausforderung auf optisch ansprechende Art und Weise. Sämtliche Aussparungen wurden mit Blindmodulen ausgekleidet. Die Dachhaut erhält dadurch ein einheitliches Aussehen. Die moderne Solartechnologie fügt sich harmonisch in die altehrwürdige Backsteinfassade ein. Die Dachdämmung wurde mit Steinwolle auf 20 cm erhöht. Die PV-Anlage liefert 50% mehr Strom als die für den Haushaltsgebrauch benötigten 6'000 kWh/a. Eine Holzschnitzel-Fernwärmeheizung in Bremgarten versorgt die drei Wohnungen mit 24'000 kWh/a Wärmeenergie. In Zukunft sollen zusätzlich Sonnenkollektoren an der Südfassade installiert werden.

Diese solare Dachsanierung zeigt, wie sich modernste Solartechnologie beispielhaft mit 100-jähriger Bausubstanz verbinden und sich bestens ins Ortsbild einfügen lässt. Dafür erhält diese Anlage das Solarpreis-Diplom 2013.

Technische Daten

Energiebedarf				
EBF: 324 m²			%	kWh/a
Wärmebedarf:			80	24'000
Elektrizität:			20	6'000
Gesamt EB:			100	**30'000**
Energieversorgung				
Eigen-EV:	kWp	kWh/m²a	%	kWh/a
PV-Dach:	10	100	30	**9'000**
Energiebilanz (Endenergie)			%	kWh/a
Eigenenergieversorgung:			**30**	**9'000**
Gesamtenergiebedarf:			100	**30'000**
Energiezufuhr:			70	21'000

Beteiligte Personen

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1 **Ästhetischer Kontrast zwischen altehrwürdig und modern beim MFH in Bremgarten.**

2 **Die beispielhaft ganzflächig integrierte Photovoltaikanlage Kettner produziert mit 10 kWp jährlich rund 9'000 kWh.**

Schweizer Solarpreis 2013 | Prix Solaire Suisse 2013 | 79

Figure 63: Mehrfamilienhaus Kettner, © Solaragentur Swiss solar prize 2013

Figure 64: Mehrfamilienhaus Kettner, aerial view, © Caspar Martig Fotograf GmbH

Figure 65: Mehrfamilienhaus Kettner, © Caspar Martig Fotograf GmbH

Figure 66: Mehrfamilienhaus Kettner, aerial view© Caspar Martig Fotograf GmbH

Figure 67: Detail of the solar roof, © Caspar Martig Fotograf GmbH

2.3.14 Mehrfamilienhaus Stadler, Luzern (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The first fully integrated PV system in the city of Lucerne presented the client with several challenges, because the building is located in a protected area. In order to meet the high requirements of the monument protection for the Lucerne cityscape, 22 special modules and 36 dummy modules had to be manufactured individually and integrated into the angled roof surface with 26 skylights.

Why does it work?

Architect Alois Stalder realized his exemplary integrated 34 kW PV system in the middle of the protected area B of the city of Lucerne. Stalder used the 200 m2 roof cladding of the newly extended attic to capture the free shining sun rays from all four cardinal points and thus generate 23,100 kWh/year of electricity. The perfectly flush-roof integrated Special modules form a uniform and harmonious roof surface with the filigree roof windows. The sophisticated architecture fulfils the high requirements of the protection of historical monuments and enhances the cityscape. The solar power covers 8% of the total energy demand of 286,800 kWh/a.

Description of the context

On the five-storey apartment building (Multi Family House) in the angular style of the 70s, a wooden extension was built in a very short time. It replaces the existing flat roof with a battlement roof, which is widespread in the neighbourhood. The 34 kW PV system, perfectly integrated on the 200 m2 roof surface, produces 23,100 kWh of electricity per year. It thus covers around 8% of the total energy requirement of 286,800 kWh/a of the More Family House.

Pros and Cons:

The conversion of the flat roof into an extended attic not only allows for a perfectly integrated solar system, which not only significantly enhances Lucerne's cityscape, but also allows greater use of solar energy. This is why it deserved the Swiss Solar Prize Diploma 2015.

Sources:

Winner of the Swiss Solar Prize 2015 "C" category for energy plants. Link (German and French): https://www.solaragentur.ch/sites/default/files/g-15-09-02_solardach_in_ortsbild-schutzzone_luzern.pdf

https://www.hiberatlas.com/smartedit/projects/177/g-15-09-02_solardach_in_ortsbild-schutzzone_luzern.pdf

Additional information:

Information PV Modules:

- Orientation: South, East;
- Tilt angle: 48°;
- PV surface area: 200 m2;
- Rated power: 34 Wp;
- Energy production: 23,085 kwh/a;
- Final yield: 679.411 KWh/Wp;
- Active solar ratio: >75% (roof);
- Manufacturer: BE Netz AG;
- Module technology: monocrystalline;
- Cell colour: Black.

Figure 68: Apartment building Stadler Luzern, © Caspar Martig Fotograf GmbH

Figure 69: Multi-family house Stadler Luzern, detail of the solar roof, © Caspar Martig Fotograf GmbH

Figure 70: Multi-family house Stadler Luzern, aerial view, © Caspar Martig Fotograf GmbH

Figure 71: Multi-family house Stadler Luzern, aerial view, © Caspar Martig Fotograf GmbH

2.3.15 Hinter Musegg Farm, Luzern (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The Musegg Culture and Habitat Foundation has put its commitment to sustainable development into practice by building the old city farm Hinter Musegg in Luzern, formerly a single-family house, converted into a double single-family house with a summer mall. Before the renovation, the EFH, including the farm, consumed 41,000 kWh/a. Thanks to thermal insulation, efficient household appliances and LED lamps, the total energy requirement fell by 47% to 21,900 kWh/a. The exemplary, fully-integrated, 92 kW PV system generates 76,500 kWh/a. Thus, the building has an energy supply of 349%. Since the beginning of 2016, an electric car has been regularly in operation as a temporary storage facility, mainly to balance out power peaks and reduce electricity costs at the same time.

Why does it work?

In accordance with the foundation's purpose, sustainability aspects were consistently taken into account during the conversion of the Hinter Musegg farm. The energy concept is based on the vision of the 2,000-watt society. Geothermal energy, solar power and an electric car enable a significant reduction in dependence on the grid. The electric car also serves as a temporary storage facility for solar power. This is fed back into the building in the evening as required.

Description of the context

In spring 2013, the "Musegg Cultural and Habitat Foundation" was founded to ensure the preservation, protection and care of the Musegg region, of the cultural heritage, the natural environment and the native fauna on the Musegg in Lucerne. In summer, the foundation runs a Hofbeiz and sells farm and regional organic products.

Pros and Cons:

The 2,000-watt concept with production, storage and efficient use of electricity inspires school classes, specialist groups and visitors to the Sommerbeiz. Charging stations for e-bikes and a solar table with USB connections for charging the batteries of mobile phones enables the first-hand experience of functionality of solar power. For the innovative and comprehensive energy concept and the high degree of self-sufficiency, Hof Hinter Musegg achieved 2nd place of the Plus energy building, PlusEnergieBau Solar Prize 2016.

Sources:

Solaragentur Swiss Solar Prize 2016, Category PEB (Plus Energy Buildings). Link (German and French): https://www.solaragentur.ch/sites/default/files/g-16-09-21_peb_sanierung_anliker_affoltern_def_0.pdf

Additional information:

Manufacturer: BE NETZ AG

Figure 72: Hinter Musegg Farm, Luzern (CH), © Solaragentur Swiss Solar Prize 2016

2.3.16 Single Family House, Gstaad (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

On the half-hipped roof is a full-surface homogeneous 32 kW strong PV system integrated in an exemplary manner. It produces over 27,000 kWh CO2-free solar power annually. So, it covers the total energy demand of the single-family house (EFH) of 17,600 kWh/a at 154%. With the solar power surplus of 9,500 kWh/a, six electric vehicles could each ride more than 12,000 km of free emit CO2 per year free ride. The energy index is marked with 84 kWh/m^{2}a relatively high, which indicates suboptimal insulation values. Meanwhile, it corresponded to an all-round balancing of interests, the original walls are not covered by external thermal insulation. This allowed the original character of the building to be maintained.

Why does it work?

The building in Alpine Gstaad, which was originally used for agricultural purposes but later abandoned, was comprehensively renovated in 2018. The total energy requirement of the now spacious detached house (EFH) is 17,600 kWh/a. The exemplary integrated 32 kW PV system generates around 27,000 kWh of CO2-free solar electricity annually. The resulting homogeneous roof surface corresponds to the simple external appearance of the building. This PlusEnergieBau renovation shows how tradition and integrated photovoltaics can be combined aesthetically very well. Overall, the EFH has an energy supply of 154%. A 13 kWh battery storage increases the own consumption.

Description of the context

Every year in Switzerland more than 2,000 agricultural holdings are abandoned. The buildings often remain unused (CVP-Mo 11.3285). A redevelopment or conversion of older buildings into a residential building is due to the federal legal restrictions on the preservation of cultural landscapes not always possible. Every year in Switzerland more than 2,000 agricultural holdings are abandoned. The buildings often remain unused (CVP-Mo 11.3285). A redevelopment or conversion of older buildings into a residential building, due to the federal legal restrictions on the preservation of cultural landscapes, is not always possible. These traditional buildings can be well equipped with the latest technology and come back to life, and Gabriela Matti has tried with the conversion of the unused Mayensäss in Gstaad. The building was in a state of abandonment. The exterior appearance has been preserved in the best possible way to maintain the original character of the building and not to spoil the appearance of the area. A comprehensive renovation transformed the unused and unheated wooden house into a modern PlusEnergyBuilding, that has not lost its "old charm."

Pros and Cons:

It was decided to install the PV system on the roof to take advantage of its favourable position and avoid damaging the green landscape with a ground system. Placing it on the roof takes advantage of an existing element in the panorama. The PlusEnergie-EFH Matti shows in an exemplary way how traditional but unused agricultural buildings can be put to sensible use in order to comply with the Paris Climate Convention without disfiguring the townscape. This intervention is included in the Swiss Solar Prize 2019.

Sources:

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/it/single-family-house-gstaad-switzerland--2-220.html

Solaragentur Swiss Solar Prize 2019: 154%-PlusEnergie-EFH Matti, 3780 Gstaad/BE. Link (German and Frenc): https://www.solaragentur.ch/sites/default/files/g-19-10-02_solarpreispub19_fueradag_v2.p081.pdf

Additional information:

- Orientation NE, SE, NO, SO;
- Tilt angle 44TH NE, 134TH SE;
- Surface PV 178 m2;
- Rated power 31.7 kWp;
- Energy production 27'035 kWh/a;
- Cell colour black.

Figure 73: Single Family House, Gstaad (CH), © Daniel Baggenstos

Figure 74: Single Family House, Gstaad (CH), solar roof, © Daniel Baggenstos

Figure 75: Single Family House, Gstaad (CH), © Daniel Baggenstos

Figure 76: Single Family House, Gstaad (CH), building before intervention, © Gehret Design

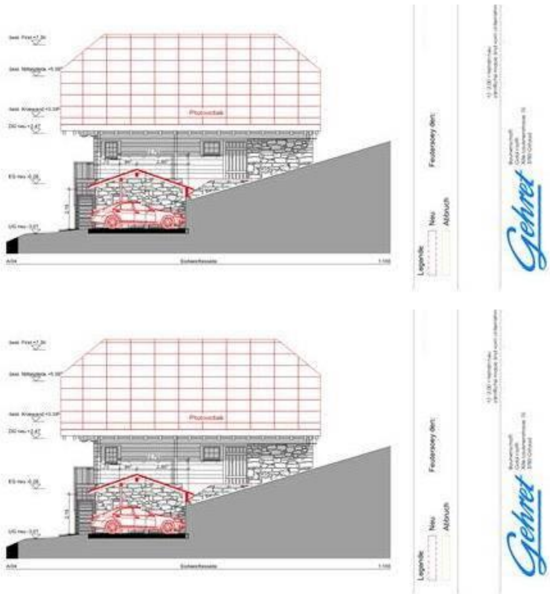

Figure 77: *BIPV plant elevation, © Gehret Design*

2.3.17 Glaserhaus Affoltern im Emmental (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

On the roof of the special craftsmen's house, which is a listed building, a fully integrated photovoltaic system was installed. The modules take over the function of the water-bearing layer, therefore it is an in-roof system. The two large roof pitches facing east and west have been covered, the small one facing south but not the one facing north. The frameless modules of the Swiss company Meyer Burger were used. In order to be able to actively cover the edges of the roof, so-called "Crea modules" from Meyer Burger (made to measure) were also added. In order to maintain a homogenous black appearance of the roof surface, solar-look printed single-pane safety glass was used on the northern mitre sign. The project was awarded with the Swiss solar price 2016.

Why does it work?

From a technical point of view, the building is solidly stabilised and energetically brought up to the latest standards. The building is partially protected. The southern elevation of the building is under protection. The building built in 1965 was completely renovated in 2015 to Minergie-P standards. The only exception is the traditional southern façade which has not been specifically isolated due to the regulation of historical monuments. Insulating glasses were used, inserted in the windows of original size, reusing the glass on the façade for the internal windows, and recovering others valuable elements of the building, such as the "braided" arches and wooden bracing boards. The photovoltaic system in the roof of the building uses selected and highly efficient Meyer Burger MegaSlate ll solar cells, with tailor-made modules to improve integration and adapt to the complex shape of the hipped roof.

Description of the context

Former farmhouse, core of 1765/66, so-called "glazier or doctor house", renovation of 1888. Impressive stand/beam construction under a quarter hipped roof, rising from the vaulted cellar from 1766. The shingle-covered building, whose present appearance is mainly due to the 1888 alteration, has a high, 3-storey, well-windowed front crowned by a roundabout. The eaves-sided upper floor arcades are closed. Contoured woods (braided bows); distinguished grey frame. Gabled building with an extraordinary volumetry. The aim of the project and the associated construction measures is to repair the existing and restore the original condition. The floor plans will be spatially and functionally separated, with the aim of consistently uncovering the core building from 1765 on all floors. This restoration is connected with the aim of preserving the overall appearance of the building, repairing the roof, facades and surroundings and carefully restoring the prestigious south facade.

Pros and Cons:

Integrated BIPV solution that covers the whole complex pitched roof, with careful reflection materials, colour and panel shape, along with the way they are positioned, aligned and anchored. Maximum surface extension of the BIPV plant to improve overall energy efficiency of the building. The arrangement of solar panels on triangular pitched roofs approaches solves the critical points with tailored solar modules with attention to detail and fixing systems. Consequently, panel-laying may be compatible, if geometrically adaptable shaped panels are employed, as “laser cut” or "dummies" solar modules. Selected and highly efficient solar cells were used.

Sources:

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/it/glaserhaus-affoltern-im-emmental-switzerland--2-234.html

The project PlusEnergieBau renovation Anliker, Affoltern iE was awarded with the Swiss Solar and the European Solar Prize in 2016. Solaragentur Swiss solar prize 2016 PlusEnergieBauten, Minergie-P Standard. Link: German and French): https://www.solaragentur.ch/sites/default/files/g-16-09-21_peb_sanierung_anliker_affoltern_def.pdf

Article: 250-jähriger Plus-Energiebau: So geht's!, Nachhaltig Bauen 2-2016 (German), pp. 54-55; Publisher: clevergie gmbh Wyssachen; Link: https://www.hiberatlas.com/smartedit/projects/234/clevergie_Affoltern_MegaSlate_3.pdf

Additional information:

Climatic zone Cfb (Warm temperature, fully humid, warm summer).

Monitoring data: https://www.energie-cluster.ch/de/deklariert-ch/plusenergiegebaeude/efh-anliker-sanierung-eggerdingen-7-3416-affoltern-im-emmental-9-3495.html

Figure 78: Glaserhaus Affoltern im Emmental (CH), before interventions, © C. Anliker

Figure 79: Glaserhaus Affoltern im Emmental (CH). Photovoltaic roof, © C. Heilig

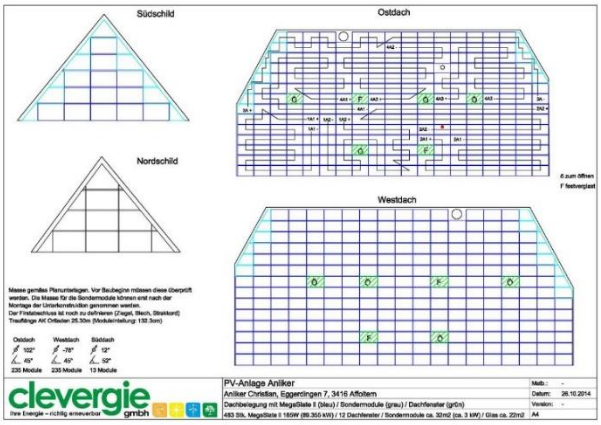

Figure 80: Glaserhaus Affoltern im Emmental (CH). Photovoltaic roof plan, © Clevergie

Figure 81: Glaserhaus Affoltern im Emmental (CH). Detail new roof, © C. Martig

2.3.18 House Breuer Tschagguns, Montafon (Austria)

Author: Tobias Hatt (EIV)

What is the solution?

The full-surface arrangement of the integrated PV and solar thermal modules gives the roof a uniform appearance, which is additionally supported by choosing non-reflecting modules with a dark background and metal frame.

Why does it work?

The solar thermal panels provide the hot water heat demand in the summer months and a part of the room heating demand in spring and autumn. The logwood heating system is thus relieved. The electricity produced by the PV panels cover a part of the domestic electricity, especially in the summer months. The installation of full surface, integrated PV and solar thermal modules is not compatible with the conservation approach because the modules replace the existing roof covering completely to achieve the uniform appearance of the new roof.

Description of the context

Part of a best practice – Project Breuer, Montafon

Pros and Cons:

By installing solar thermal panels, the end energy demand of the heat generator, in this case the logwood heating system is reduced, because the panels cover the hot water demand in the summer months and a part of the room heating demand in spring and autumn. Furthermore, less electricity has to be taken from the grid, because the produced electricity of the PV panels covers part of the domestic electricity, especially in the summer months. The existing roof covering is completely replaced by the full surface, integrated PV and solar thermal modules, which is a disadvantage from the conservation point of view. Nevertheless, it is possible to remove the panels without damaging the original roof structure and replace them by a roof covering similar to the original one.

Type of Data Available:

Detailed drawings of the roof structure with the integrated PV panels. Pictures of the completed building.

Sources:

https://www.hiberatlas.com/smartedit/projects/109/Dach I Solaranlagen.pdf

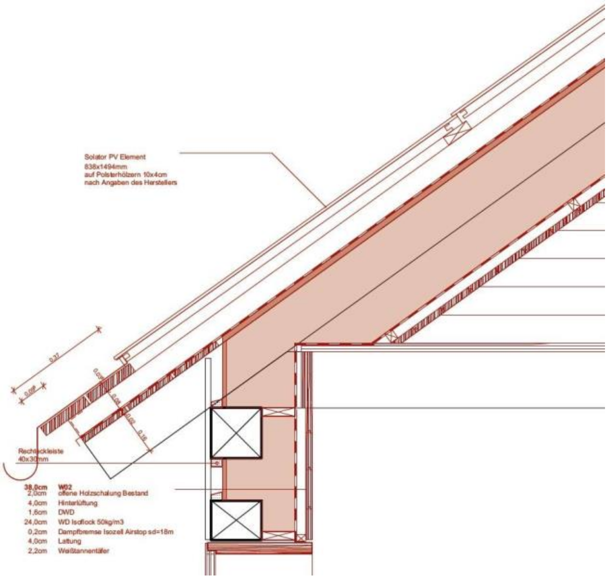

Figure 82: Roof structure with the integrated PV panels, eaves, © Bernhard Breuer Produktentwicklung Architektur Städztebau

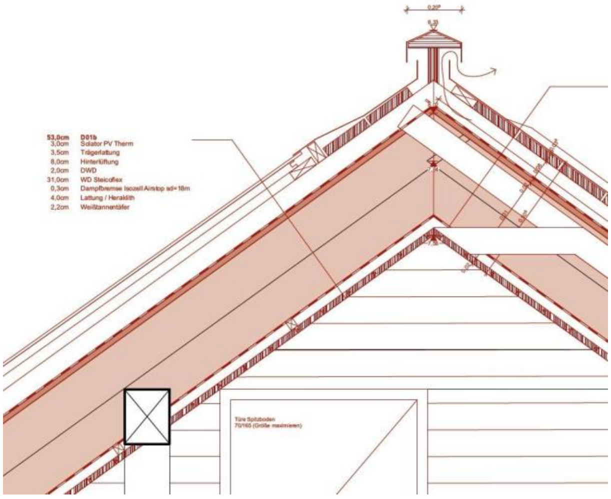

Figure 83: Roof structure with the integrated PV panels, ridge, © Bernhard Breuer Produktentwicklung Architektur Städtebau

Figure 84: side view of the building, © FG Marcello Girardelli

2.3.19 Villa Castelli, Bellano (Italy)

Author: Elena Lucchi (Eurac)

What is the solution?

The BIPV roof was designed with several working table among designers (architects and engineers), manufacturers, and heritage Authority. The panels, in fact, were already in production and were used almost exclusively for sailing boats and small flexible products. The roof is made of anthracite grey BIPV panels, directly glued on the aluminium roof with a specific structural double-sided tape with a similar thermal expansion coefficient of the roof. This technology was developed with a cooperation with the Italian National Research Centre (CNR). It is based on an innovative lamination process of monocrystalline cells with special and selected technopolymers as encapsulants.

Why does it work?

Electrical energy is produced with a PV-system, integrated in the roofing. The captive surface is 10 kWp, as a balance between the optimization of production and the aesthetical visual impact. During the design phase, managed directly by the Solbian company, a solar diagram was used to simulate the daily and annual trend of shading, allowing the estimation of the average monthly losses. The choice to install a 10 kWp system is based on the estimation of some possible future consumption and on the need to maximize the electricity production.

Description of the context

The building is located in Bellano, on Lake Como (Lecco, Italy). The area is listed from a natural point of view. The building itself is not listed.

Pros and Cons:

The architectural integration project considered the visual impact of colours and shapes in the PV integration on the roof. The heritage office in charge of the project has evaluated as fundamental criteria: (i) the aesthetic characteristics of the panels (colour and surface finish); (ii) their geometric arrangement in relation to the shape of the roof surface and the orientation of the building (shape of the plant, modularity); (iii) the adherence and coplanarity to the roofing; (iv) the non-reflective surfaces; (v) the perceptibility from around, with particular reference to the road, lake and circus-standing landscape level. Before the heritage authorities approved the PV system, several prototypes were developed for a roof-integrated and preferably invisible installation. The selected prototype was developed in a technical working table was created with Solbian and Prefa, with walkable, thin, efficient panels perfectly camouflaged within the roof. The system was integrated in the roof, following its symmetry made by different pitches with a varied orientation. Then, it considered the important shading produced by some secular plants of the historic garden over large areas of the same. The heritage authorities opted for the double-curled aluminium sheet covering of the roof - which is quite common for buildings of this age in a similar way - with integrated mono-crystalline PV modules, folded plates with integrated photovoltaic cells, of about 11 kWp.

Type of Data Available:

The system of Villa Castelli consists of inverters, a monitoring system, a measuring system for production and consumption, and a series of radio sockets for the direct management of the loads. The monitoring system receives continuously the PV production data, the input data, and the data of the energy grid. In addition, through the available meteorological data, it determines a production forecast and automatically rationalizes the loads.

Three prototypes were developed. First, colored cells panels have been chosen to privilege the aesthetic impact of traditional materials and landscape. The roof also has to solve the problems caused by the presence of a large Deodara Cedar above the house that causes several maintenance problems due to its continuous fall of needles. Three prototypes have been developed. Initially, a roof in Valmalenco Stone (serpentine) was chosen. This material is frequently used on historic buildings throughout Lake Como . Two prototypes were produced. The first was created on a transparent support by combining two glass panel and interposing the classic polycrystalline PV cells. The integration was based on the transparency of the support. The second prototype was based on chromatic integration. A special panel has been created using gray-green cells from Germany with a size perfectly adapted to the Valmalenco stones. In collaboration with Brandoni, an Italian manufacturer of PV panels, a 1: 1 prototype has been created to verify the installation problems. The result was aesthetically pleasing, but impractical due to the panels not being walkable and the complex maintenance. In a second step, a technical working table was created with Solbian and Prefa and a third prototype has been defined. For publications: see the general publication list of the case study "Villa Castelli"

Sources

·V. Carì, O. Stuffer, E. Lucchi, Risanamento conservativo sulle sponde del lago, Cas&Clima 51 (2016) 44-52.
·E. Lucchi, M. Tabak, V. Carì, M. Perna, BiPV ed edifici storici: l'integrazione è possibile?, AICARR Conference, 2016.

Figure 85: The roof before the intervention,© Valentina Carì Progetto Serr@

Figure 86: The BIPV roof, ©Valentina Carì Progetto Serr@

Figure 87: Study of the visual impact with Heritage Authorities, © Valentina Carì Progetto Serr@

Figure 88: Study of the visual impact with Heritage Authorities, © Valentina Carì

Figure 89: Study of the visual impact with Heritage Authorities, ©:Valentina Carì. ProgettoSerr@)

Figure 90: Detail of the roof, ©Valentina Carì, Progetto Serr@

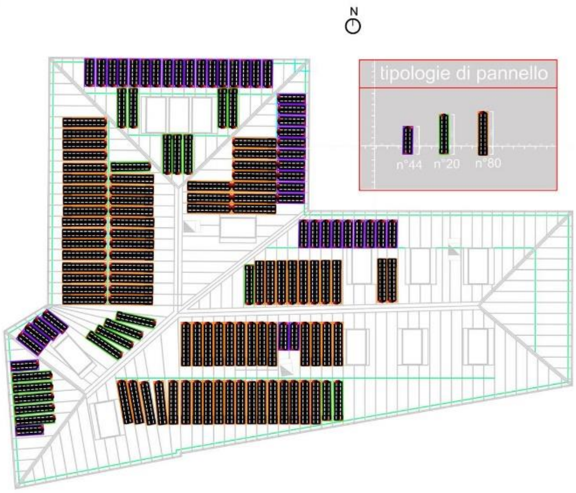

Figure 91: BIPV roof, © Myriam Perna

Figure 92: Detail of the roof,© Valentina Carì, Progetto Serr@

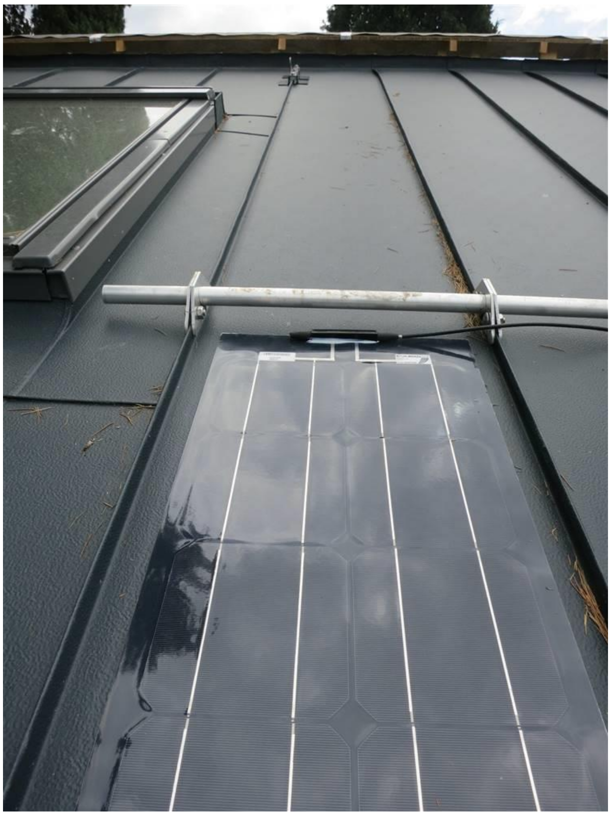

Figure 93: Detail of the roof, © Photo: Valentina Carì, Progetto Serr@

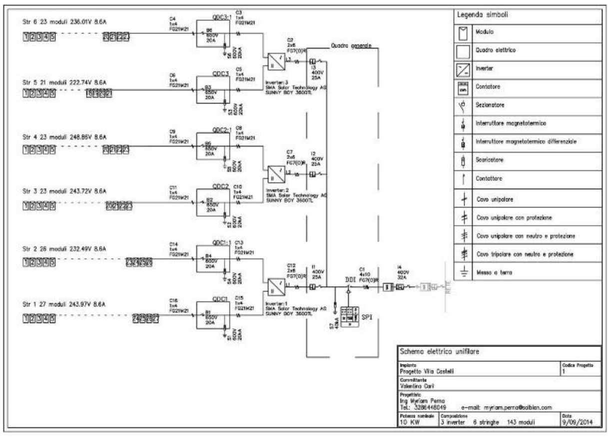

Figure 94: Electrical scheme, © Design: Myriam Perna

Figure 95: BIPV roof construction, ©Valentina Carì, Progetto Serr@

Figure 96: BIPV roof construction, ©Valentina Carì, Progetto Serr@

2.3.20 Single family House, Bern (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The listed neo-baroque house in Bern/BE by 1898 was extensively renovated and thermally refurbished. Thanks to the renovation, the total energy requirement fell by 76% from 46,900 kWh per year to 11,100 kWh/a. On the upper roof surface, a PV+PVT (solar thermophotovoltaic) system with an electrical output of 2.7 kWp supplies around 3,200 kWh/a of electricity.

Thus, 13m^2 of Solar thermal, STh natural slate collectors were installed, which corresponds to an output of about ~5kWp.

The thermal systems generate about 10'000 kWh/a of solar heat. The single-family house with its carefully integrated solar system has a self-energy supply of about 29%.

Why does it work?

During the refurbishment, the requirements of the preservation of historic monuments were somewhat softened, so that the PVT system was possible on the flat (upper) part of the roof.

The PVT and natural slate collector systems are also used to regenerate the geothermal probes/ground temperatures with excess heat available from the PVT and the slate collectors on multi-day to seasonal time scale (on diurnal time scale the solar tank is the heat storage). This regeneration is a win-win(-win) situation: By cooling the PVT panels and transferring the excess heat (up to 12 kW) into the ground. For example, in summer, the PVT panels produce significantly more electricity (up to 500 W) than the pump required to transfer the heat into the ground (~50W). The regeneration thus increases the net solar electricity production and at the same time prevents the ground to cool down over time, assuring a constantly high COP over the lifetime of the geothermal probes. In addition, the cooled roof helps the rooms of the top floor to remain cooler in summer.

The project shows which energy and emission reductions are possible even at listed buildings. For this reason, the house has been awarded with the Swiss Solar Prize 2014.

Description of the context

The neo-Baroque house is among the cantonal inventories with a high degree of protection. Any changes must obtain the approval of the Department of Historic Monuments, which initially opposed the integration of solar systems. For this reason, natural slate has been selected, which conceals the collectors in the roof and allows an integration of the context. By maintaining a part of the original roof, the visibility and aesthetic appearance of the solar system is minimized.

Pros and Cons:

The Bernese House is listed in the cantonal building inventory with the highest protection level. For this reason, the building project had to be accompanied by the monument preservation authorities. Originally, the officials of the monument preservation department did not want to allow a solar installation. Therefore, the solar collectors were hidden on the pitched roof of the natural slate roofing. In the case of covering the entire roof, be it triangular or rectangular, a fringe band of traditional roof covering could opportunely be left intact. The arrangement of solar panels on triangular pitched roofs approaches solves the critical points with tailored solar modules with attention to detail and fixing systems. Due to the high level of protection, solar panels are slightly visible from the street, leaving part of the original slate roof intact.

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/it/single-family-house-bern-switzerland--2-174.html

Winner of the Swiss Solar Prize 2014, "B" category for building's retrofit. Link: https://www.solaragentur.ch/sites/default/files/g-14-10-03_hutterli_roethlisberger_solpreiskatsan.pdfAdditional information

Article: Architecture report: Energy-producing roof despite a listed building, Hausinfo, Architecture reports conversions; Publisher: GVB Services AG and the Homeowners Association Switzerland. Link: https://www.hausinfo.ch/de/home/gebaeude/architekturreportagen/hutterli-bern.html

Additional information

Information PV Modules:

- Orientation: South;
- Tilt angle: 28°;
- PV surface area: 21 m2;
- Rated power: 2.7 Wp;
- Energy production: 3,207 kwh/a;
- Final yield: 1.187.77 KWh/Wp;
- Active solar ratio: >75% (roof);
- Manufacturer: Meyer Berger AG;
- Module technology: monocrystalline;
- Cell color: Black.


1

2

1 Durch die energetische Sanierung konnte der Gesamtenergiebedarf von 46'900 kWh/a um 76% auf 11'100 kWh/a gesenkt werden.

2 Eine hybride 2.7 kWp-PV-Anlage erzeugt 3'210 kWh/a Strom und liefert zusammen mit den Naturschieferkollektoren (Bild 1) rund 10'000 kWh/a Wärme.

Schweizer Solarpreis 2014 | Prix Solaire Suisse 2014 | 69

Figure 97: Single family House, Bern. Roof top view, © Caspar Martig

Figure 98: Single family House, Bern. Roof top view, © Caspar Martig

Figure 99: Single family House, Bern. Installation of PVT+PV panels, © M. Hutterli

Figure 100: Single family House, Bern. Installation of PVT+PV panels, © M. Hutterli

ROOF

Orientation	170° S
Tilt angle	28°
Surface	
24 m^2	24 m^2

Degree of suitability

EXCELLENT VERY GOOD GOOD MEDIUM LOW

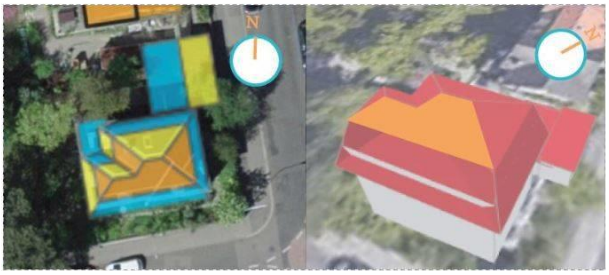

Figure 101: Single family House, Bern. Data and degree of suitability, © SUPSI

2.3.21 Isola della Certosa Urban Park, Venice (Italy)

Author: Antonello Durante (Eurac)

What is the solution?

The solution deals with the integration of PV systems in buildings included in a protected area in the Venetian Lagune. Three innovative photovoltaic systems integrated into the roof were built, transforming over 1110 square meters of opaque surfaces into an active roof using the BIPV system with coloured photovoltaic tiles.

Overall, 184 kWp of power were installed, along with a storage system. The unique photovoltaic tiles were of double laminated glassmaking them more resistant than single glass panels. Visual continuity was obtained by adding some tiles of the same colour and material as the others where PV modules were not needed. Thanks to the colouring of the front glass of the tails that simulates the terracotta effect, and the usage of custom tales, the roof refurbishment resulted in a valuable example of PV integration.

Why does it work?

The solution works because the historical values of the protected area are not violated. The integrated PV system is built according to aesthetic integration, energy integration and technological integration aspects.

The photovoltaic panels used are equipped with double laminated glass. Thanks to the particular colouring of the front glass, a chromatic effect similar to terracotta is obtained. The terracotta colour is typical of the traditional roofing used in the lagoon area and in most of the regions of northern and central Italy. This solution offered the possibility of obtaining a recovery of the well-exposed roof pitches that resulted in complete chromatic assonance with the other pitches, with the surrounding buildings and the rest of the lagoon.

The photovoltaic roof installed was built with standard modules and custom modules. Not all inserted items are actively producing energy. Where necessary, filling modules with identical characteristics to the active modules have been installed to guarantee a homogeneous view of the roofs.

The system has an installed power of 184 kWp producing about 211 MWh per year of clean energy. This energy is used for the needs of the buildings and partly accumulated in storage.

The PV panels installed are equipped with fixing systems, drainage channels at the back and watertight systems that allowed their use to replace the tiles.

Description of the context

The Isola della Certosa Park is located on the Certosa Island in the northern Venetian lagoon. The Certosa Island is the largest of the small lagoon islands.

The island is currently part of the Venetian Lagoon Areas of Public and Cultural Interest as per Legislative Decree 42/04 art.128 and DM 1 December 1961 and Article 128 of Legislative Decree 42 / 04 of the Italian law. It is also included within the UNESCO sites and the Natura 2000 sites.

During the Middle Ages, La Certosa was the seat of a prestigious monastery. The area was demolished during the Napoleonic era, except a portion of the Chiostro Minore dei Conversi, whose fragments are still visible today. From the Nineteenth Century until the Second World War, the area was used as a military warehouse and industrial plant for armaments production. The closure of the war industry left the island abandoned until the end of the Nineteen Century. Recently, the Municipality of Venice started a refurbishment of the area aiming at transforming it into a park. Currently, this project is close to completion.

The Certosa Island acts as a laboratory and showcase hub for energy production from renewable sources projects in historic areas.

Pros and Cons:

The use of terracotta-coloured panels makes the solution aesthetically integrated as the terracotta colour is commonly used in Italy for roof covers. For the latter and because PV systems are more conveniently applicable on roofs than on other building surfaces, this solution results highly replicable in other contexts.

Due to the high degree of technological integration, the solution results not easily reversible.

Type of Data Available:

The solution described above was drawn from areal project that was awarded as PV integration best practice in the Solar Architecture in heritage award 2020.

Figure 102: Isola della Certosa – overview, © VdV

Figure 103: Building 1, © GruppoSTG

Figure 104: Building 2, © GruppoSTG

La Capanna

Author: Antonello Durante (Eurac)

What is the solution?

The solution deals with photovoltaic and solar-thermal systems that were applied on the roof of a pavilion structure close to the main building and part of the historic complex. The photovoltaic elements installed have a nominal power of 0.15 kWp/m^2. The photovoltaic system, which has a total power of 6 kWp, fulfils the whole building's energy needs.

Why does it work?

The solution works because the historical value of the building is preserved due to what is called decentralised production of power; the panels are integrated into a building near the main historic building.

The PV system is integrated according to aesthetic integration, energy integration and technological integration aspects.

A pavilion attached to the main building houses on its roof the photovoltaic and solar thermal panels. The pavilion structure overlooks a basement of a pre-existing and more recently built volume than the main building. This system power the house and relates to it through an open-air living area. The basement houses a living area and service areas for the house and the pool.

The hut integrates the photovoltaic and hybrid modules (solar thermal and solar photovoltaic) flat with polycrystalline silicon cells in a coplanar surface composed of the reflective score of the dark-coloured panels, bounded by the perforated sheet of the eaves and the ridge also of the same colour dark, with the function of ventilating the underlying part and collecting rainwater.

The photovoltaic system project pursues two integration criteria:

(i) landscape integration, which is found in the choice of the shape of the building that respects the morphology of the vernacular architectures typical of the place, in the spatial relationship that is established between the new and pre-existing building, as well as in the chromatic, morphological and reflectance choice of the panels towards of the surrounding landscape; (ii) aesthetic integration with respect to the new building, which is found in the coplanarity of the panels, in the coverage of 100% of the surface, in the type of panels chosen, in the selection of monochromatic cells, as well as in the study of the construction detail of the junction between the panels and sheet metal and rainwater drainage system. The photovoltaic panels perform the function of tiles.

Description of the context

La Capanna is a building in the province of Lucca (IT). Initially, it was used for tobacco production and re-adapted to residential use in 2017. It is a typical 18th century building common in the northeast of the Tuscany region. It looks like a compact volume with large symmetrical openings.

Pros and Cons:

The historical value of the building is preserved due to decentralised power production. The system is more manageable for maintenance because it is mounted on a single-story building. Due to the attention to design and colours that were chosen, it is aesthetically pleasing. The system is connected to an integrated webserver.

Due to the high level of technological integration, the reversibility of the system is, in some way, limited.

Type of Data Available:

The solution described above was drawn from a real project that was presented as a PV integration best practice to an award for Solar Architecture in heritage context 2020.

Figure 105: Main building with annex building, © Beatrice Speranza

Figure 106: Detail, © Beatrice Speranza

Figure 107: © Beatrice Speranza

2.4 Building integration (BIPV) in historic buildings: wall integration

The common introduction to Building integrated Photovoltaics Modules can be found in paragraph 2.3.

Increasing requirements regarding energy efficiency in buildings has resulted in the use of PV in the façade envelope as a substitute of traditional materials in most common façade systems (e.g. cold façade or curtain walls), both opaque and transparent. Opaque photovoltaic cold façades have an air gap between the building surface and the photovoltaic module allowing ventilation bringing a cooling effect for the wall and improves the efficiency of the modules [25]. The solar modules can be integrated as the outer building cladding like a conventional cladding element. Transparent or semi-transparent solar photovoltaic façades have a key role with respect to the comfort of the indoor microclimate (for reducing overheating in summer and allowing solar gains in winter). Besides, it enhances the comfort due to an increase of natural lighting. Glazed curtain walls, the energy parameters related to solar gain control such as thermal and visual comfort are strictly related to the PV design (e.g. cell's arrangement, distance, etc.). Similarly to skylights, the transparent functional layer (glass) is replaced with an active glazed pane including PV (e.g. a laminated glass), whilst the load-bearing part, represented by the frame, is equipped for the electric wirings' passages [25]. . The common introduction to Building integrated Photovoltaics Modules can be found in paragraph 2.3.

In this section the cases with wall integrated systems are documented.

2.4.1 Solar Silo, Basel (Switzerland)

Author: Cristina Polo (SUPSI)

The description of this example is in the paragraph 2.3 in page 11 since this an example also for roof integration.

The specific part relative to the photovoltaic façade is included in the "walls" part.

2.4.2 Romanshorn, Multi-family House (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

The south and west façade of the PEB-MFH in Romanshorn with the optimally integrated 295 m2 PV modules generate with 53 kWp a good 25,650 kWh/a. The flat roof mounted 26.3 kWp PV system and the 69 m2 solar collectors produce 64,050 kWh. The almost 7 m high 60,000 litre storage tank in the former lift shaft stores thermal solar energy, which covers the heating and hot water requirements together with an air-to-water heat pump. Unfortunately, the outside space is lacking a more efficient ground source heat pump. Viridén's PEB falls below the 2000 watt specifications by 120% (with a total energy requirement of 84,100 kWh) and is a trendsetting building in every respect with exemplary character. It proves that practically every municipal building can be PEB, or as the magazine "Hochparterre" aptly puts it: "Both in terms of greenhouse gas and energy indicators, [the] building allows the 2000 Watt society and Minergie-A old look."

Why does it work?

The office Viridén+Partner is implementing the "dense building" required by the new spatial planning law (RPG) in an exemplary manner also in the city centre of Romanshorn. Viridén expanded the multi-family house (MFH), built in 1962 with 3 shops, from 6 to 22 exemplary renovated apartments at socially acceptable rents. Energy consumption to date has fallen thanks to the Minergie-P building envelope from 296,120 kWh/a by more than 70% to 84,100 kWh/a. The 53 kWp monocrystalline PV system is optimally integrated into the facades and balconies of the MFH. Another PV plant with 26.3 kWp is mounted on the roof next to the 69 m2 solar panels. Together the solar systems generate a good 89,700 kWh/a. In an average year, this flagship PlusEnergieBau (PEB) with 56% more living space has an energy supply of 107% (EEV) on. Enough to power three electric cars with zero emissions.

Description of the context

Viridén+Partner's PlusEnergie Building shows integrated PV facades in an exemplary manner, the perfect combination of technology, aesthetics and functionality. The renovated MFH convincingly demonstrates how today's solar architecture can also be used in urban area and can significantly enhance street appearance. Built in 1962, the residential and commercial building is the most important first exemplary energy PEB refurbishment with more than five storeys. The number of apartments rose from 6 to 22; also, the 3 shops were renovated.

Pros and Cons:

The completely successful densification from 1,517 to 2,361 m2 (+56%) shows in perfection how the new RPG can also be implemented in cities: massively more living space - without building over 1 m2 of cultivated land - with excess electricity for emission-free traffic. This ingenious solar architecture deserves the 1st Norman Foster Solar Award 2013.

Sources:

Solargentur Swiss Solar Prize 2013: 107%-PEB-Sanierung Viridén, 8590 Romanshorn/TG. Link (German and French): https://www.solaragentur.ch/sites/default/files/g-13-09-17_solarpreispublikation_2013_def_ka_viriden_romanshorn.pdf

Additional information

- Orientation: East, North, South, West;
- Tilt angle: 144°East, 0°North, 170°South, 260°;
- PV surface: 144 m^2 PV roof, 295 m^2 facade, 69 m^2 solar thermal collectors;
- Rated power: 26.3 kWp PV roof, 53 kWp facades;
- Energy production: 89,700 kWh/a; Final yield: 1'131 kWh/Wp;
- Producer: HOLINGER SOLAR AG - PV, Ernst Schweizer AG - Solar collectors-,
- PV module: Monocrystalline and thin film;
- Type glass: Satiny; Cell color: black;
- Dimensions: 1'600 x 860 mm;
- Specific power (system): 176.60 kWh/m^2.

Figure 108: Viridén + Partner AG Architects, © Solargentur Swiss Solar Prize 2013: 107%-PEB-Sanierung Viuridén, 8590 Romanshorn/TG

Figure 109: 8590 Romanshorn/TG_Before the renovation, © Solargentur Swiss Solar Prize 2013: 107%-PEB-Sanierung Viridén,

2.5 Free standing PV

Usually, free-standing PV and non-integrated systems could be installed laying on flat roof surfaces. This could be a good solution in historical buildings because less visible and with lower aesthetical impact.

Furthermore, it is possible to put solar panels on a flat roof with flat solar racking. This is not yet very common. Flat roof solar panel systems can actually be more flexible in their design than sloped rooftop installations, making its installation easier. In this case, the angle of inclination, orientation and location (horizontal or vertical) of the solar panels can be better used to adjust to the surface of the roof and optimize production power supply and in some cases even place the modules in opposite orientations (e.g. east-west) to better match demand peaks.

Labour and installation costs typically are less expensive with the benefit that there is a rear ventilation of the solar modules increasing efficiency in final yield output with a shorter payback period.

2.5.1 Palacinema Locarno, Locarno (Switzerland)

Author: Cristina Polo (SUPSI)

What is the solution?

A photovoltaic system has been installed on the roof. With a nominal power of 135.7 kWp, the production is about 130'000 kWh/y. The total cost is 178'000 CHF.

Why does it work?

The preliminary analysis showed an open horizon on the roof, with good sunshine throughout the year. For this reason, it was decided to work with modules inclined at 15° with a bidirectional east-west system that allows energy production to be better distributed throughout the day. The lower inclination results in lower profitability, but the covered surface area can be increased in the absence of shading, thus compensating for this factor.

Description of the context

In the aftermath of the 2007 global financial crisis and rampant global warming –and perhaps the demise of “starchitecture” as a default procedure to build urban identity–, the Palazzo del Cinema Locarno project is guided by principles of economy, trying to capitalise in the existing structure and the public affection for the Palazzo Scolastico –which used to host the local schools and now hosts a variety of NGOs and community associations, to provide an architectural identity for the new cinema complex in Piazza Remo Rossi in Locarno, in the shores of Maggiore Lake. At a time when energy resources are dwindling and climate change has become a crucial problem for our cities, it would have been irresponsible to simply discard the existing building in order to build an entirely new one, with the corresponding expenditure of vital resources. Urban Recycling is a more adequate strategy for this intervention. Three levels of action to reduce the emissions have been considered: demand reduction, improved energy efficiency of systems and improved building management.

Pros and Cons:

The intention is to guarantee the best possible integration from an aesthetic and architectural point of view. For this reason, the system has been inserted on the roof. Initially the intent was to install an integrated PV system, but after a cost comparison it was decided to continue with a standard black/blue monocrystalline cell system. The inverter is installed in the technical room on the top floor. The bidirectional east-west orientation of the PV system allows energy production to be better distributed throughout the day.

Sources

Case study - Historic Building Energy Retrofit Atlas (HiBERatlas): https://www.hiberatlas.com/en/palacinema-locarno-locarno-switzerland--2-254.html

Knüsel Paul, PALACINEMA, LOCARNO Wie ein Palast aus der Asche, Real estate and energy. Nr. 1/N° 1 2018 (Special issue - Editions for the culture of construction), p. 35-37. ; Publisher:espazium, Switzerland, 2018. Attachment to TEC21 n. 46/2018, TRACÉS n. 23–24 / 2018 and Archi n. 6/2018. Link:

https://espazium.s3.eu-central-1.amazonaws.com/files/migration/documents/5bf7a9347396d.pdf

Luoghi e architetture del cinema, In Archi n. 4/2018; Espazium: Zurich, Switzerland, 2018; ISSN 1422-5417 Articles in Archi n. 4/2018(Italian):

· Neri Gabriele, Le architetture per il Festival del Film di Locarno 1946-2018 Gabriele Neri, p. 29-38

· Interview with Speziali Carla, PalaCinema: ieri, oggi, domani. Interview with Carla Speziali, p. 46-47

· Fumagalli Paolo, Un commento sul concorso per il Palazzo del Cinema a Locarno,, p. 48-49

· AZPML Architects, PalaCinema, Locarno, p. 50-57

Palazzo del Cinema a Locarno, in Archi n. 4/2018 (Digital) https://www.espazium.ch/it/attualita/palacinema-locarno

Additional information

Photovoltaic system: Monocrystalline Total nominal power: 135.7 kWp Elevation angle: 15° Orientation: Est - West Overall yearly production: 130'000 kWh/y Cost: 178'000 CHF

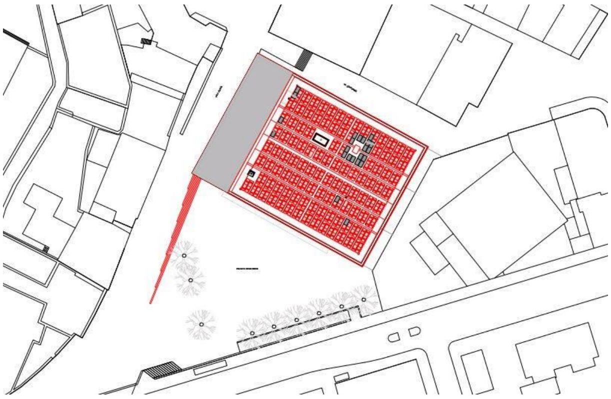

Figure 110: Palacinema Locarno. Planimetry with PV system, © Greenkey Sagl

Figure 111: Palacinema Locarno. Roof view, © Greenkey Sagl

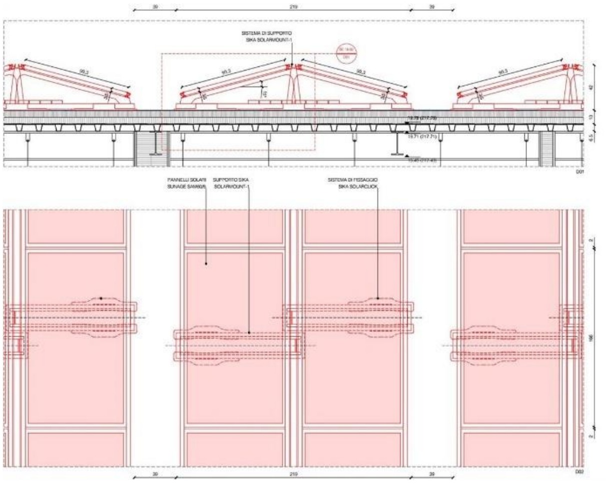

Figure 112: Palacinema Locarno. Connection system, © Greenkey Sagl

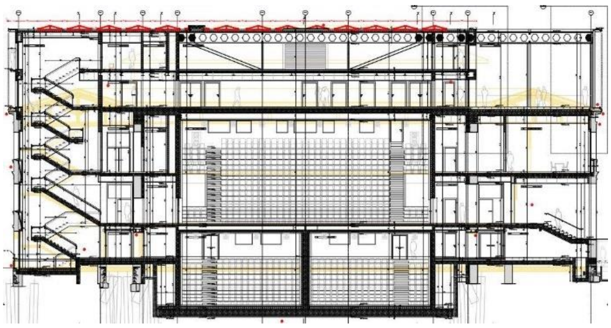

Figure 113: Palacinema Locarno. Section of the building with PV systems, © Greenkey Sagl

Figure 114: Palacinema Locarno. Section of the building with PV systems, © Greenkey Sagl

Figure 115: Palacinema Locarno. View of the building with installed PV system, © LaRegione.ch

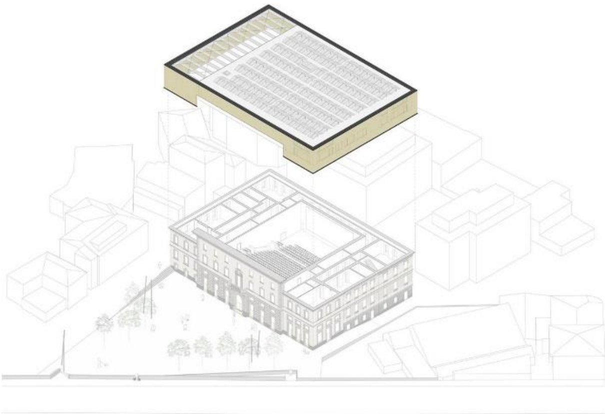

Figure 116: Palacinema Locarno. 3D of the building, © AZPML

Figure 117: Palacinema Locarno. View of the PV system, © Greenkey Sagl

Figure 118: Palacinema Locarno. View of the PV system, © Greenkey Sagl

2.5.2 Crichton Castle, Pathhead (United Kingdom)

Author: Anne Schmidt and Roger Curtis (HES)

What is the solution?

This project involved the installation of solar PV units on the upper part of a 16th C ruined castle in 2005, and subsequent upgrade with new panels in 2019. The array is 5 square metres, monocrystalline, installed in 2019. Power generated 1800 W. The angle of the array is 25 degrees, orientation 220 degrees. The heating load in the custodian's office is 2000 W, and lighting 330W. The array charges a battery bank which can give a normal usage time of 26 hours; this is more than adequate as the building is only open 6 hours a day.

Why does it work?

The panels were mounted on the roof of the castle, mechanically fastened to a modern flat roof. Due to the parapet of the ruin still being quite high, the panels could not be seen from the ground. Historic fabric was not affected by the installation. Scheduled Monument Consent was required for this installation, but as it had no effect on the historic fabric that was granted back in 2005, and again for the new panels in 2019.

Description of the context

The building is a ruin, but open to the public at ground floor level. The power demand was modest, but not being met by the PV panels put up in 2005, and a generator was occasionally required. Upgrading was needed. The cabling required from the roof down to the ticket office was low power. The cables were surface mounted via existing routes within the ruin and were reused for the new units.

Pros and Cons

The new panels replaced ones first installed in 2005. This has proved to be reasonably simple to do, although crane access was needed to get the panels up. Existing power cabling was used, o no disruption inside the monument, and similar fixing points on the roof were used. The new batteries have given additional running time for the custodians in the event of low solar incidence.

Type of Data Available

Estimated power generated was provided by the panel supplier - see attached data sheet.

Sources

https://www.hiberatlas.com/smartedit/projects/194/Crichton Castle PV Additional Notes.pdf

https://www.hiberatlas.com/smartedit/projects/194/KC125g-2 Datasheet.pdf

Figure 119: Installation of the PV panels, © HES

Figure 120: Crichton Castle and the surrounding landscape, © HES

Figure 121: View of the panels on one of the towers, © HES

2.6 Local sharing of PV

Energy sharing concepts could lead to improved energy resource use. Interactions and energy exchanges are often used to maximize energy surplus and benefit and cost-saving, as well as the potential for environmental benefits. The use of a combination of renewable resources (e.g. solar energy plus geothermal) could allow the energy storage, balancing the energy surplus during the different seasons of the year, resulting in a more efficient system. The final aim will be to achieve an annual balance between exports and imports. For example, solar collectors and PV systems could be used to support the heat pump by increasing the water temperature into the heat pump improving the COP. At the same time could be also used to regenerate the geothermal probes/ground temperatures with excess heat available on multi-day to seasonal time scale. The regeneration thus increases the net solar electricity production and at the same time prevents the ground to cool down over time, assuring a constantly high COP over the lifetime of the geothermal probes.

In other cases, the energy surplus is transferred to the grid, or is linked to a global district heating system.

2.6.1 Solar Silo, Basel (Switzerland)

Author: Cristina Polo (SUPSI)

Key words: roof integration – façade integration – local sharing of renewable energies

The description of this example is in the paragraph 2.3 at page 11 since this is also an example of roof and façade integration.

2.6.2 Kindergarten and apartments, Chur (Switzerland)

Author: Cristina Polo (SUPSI)

Key words: roof integration PV – Local sharing of renewable energies

The description of this example is in the paragraph 2.3 in page 22 since this is also an example of roof integration.

2.7 Model for the sharing of renewable energies via power/network

To encourage the installation of solar installations, there are techno-economic models available nowadays. These models are divided into different categories, those which are applicable to collective projects and those which are also strategic and thus make it possible to promote solar technology itself.

In some cases, owners and tenants have the option of buying shares in PV installations located in their constituency. Facilities are located and not directly linked to the perimeter. The purchase of shares should be reserved for those who cannot install a photovoltaic system (tenants, buildings with unfavourable conditions). In other cases, a group of owners can establish a solar purchase group to act together to make their solar plants so as to benefit from conditions (i.e. price, quality, transparency). Other grid providers are offering an "all-inclusive" offers from a third-party investor who invests, maintains and operates the solar installation. In this way, it is possible take advantage all or part of the solar plant's production at a competitive price.

There are other models like the acquisition of a stake in a company specifically set up for the development of a solar power plant or when the energy supplier is responsible for the development of the solar power plant and then the panels are sold to citizens.

These are excellent solutions when it is not possible to install the solar system in the building, as it could be in the case of a historic building with a high level of protection where the installation of solar systems is not possible, and it is forbidden.

2.7.1 "Sole per tutti" Sun for all: clean energy project in Ticino

Author: Cristina Polo (SUPSI)

What is the solution?

Thanks to the "Sun for All" product, homeowners and tenants have the possibility to buy shares in photovoltaic installations located in their areas. Everyone can use solar energy immediately and without the costs generated by individual installations. Each share is equivalent to 1,000 kWh/year of energy produced exclusively by photovoltaic panels installed in the area. Depending on availability, there are no limits on the number of shares that can be purchased. Achievements:

- Installed power 445 kWp;

Why does it work?

Each shareholding is equivalent to ,000 kWh per year of energy produced exclusively by photovoltaic systems installed in the area of reference. The customer is offered the opportunity to buy whole shares and / or half shares. 500 kWh per year of electricity. The cost for each share depends on the duration of the subscription (5, 10 or 20 years) and the total number of shares purchased.

Description of the context

The " Sun for All" project has existed since 2011 and is promoted jointly by Aziende Industriali di Lugano (AIL) SA, Aziende Municipalizzate di Bellinzona (AMB) and Aziende Industriali di Mendrisio. (AIM), Aziende Municipalizzate di Stabio (AMS) and Società Elettrica Sopracenerina (SES). The initiative offers anyone who is a customer of these distribution companies the possibility to purchase shares in photovoltaic installations located in the corresponding area. It does not matter if you are the owner of a house or tenant or if you live in an area that is not favourable from the point of view of sunshine: everyone can become a self-producer of solar energy.

Pros and Cons:

Citizens can contribute personally to the development of renewable energy in Ticino while reducing the price of their electricity bill. With "Sole per tutti" in fact, the value of the participation fee is paid only once at the time of subscription and therefore the cost of electricity is fixed for the next 5, 10 or 20 years (depending on what was decided at the time of subscription) against an upward trend in market prices expected in the coming years. You also save up to 30% of costs compared to building your own photovoltaic system and do not have to worry about maintenance.

Sources:

Brochure sole per tutti privati https://www.ail.ch/privati/elettricita/prodotti/sole-per-tutti.html

The plant in Barbengo, an example recently built: 7'000 thousand square meters of surface covered with panels will provide energy to over 200 families. An initiative project of the Companies industrialists of Lugano, who support the work, in return from this roof will yield 1,000 megawatt hours per year, that is. energy for 220 families, as part of the "Sun" project for all"

Swiss Radio Television Service, Il Quotidiano, Published on: June 20 2018, 18:15: Link: https://www.rsi.ch/news/ticino-e-grigioni-e-insubria/Fotovoltaico...-monumentale-10606329.html

-Global Energy Prize 2003, Eurosolar 2002 (citation) and Photovoltaic Architecture Prize Baden-Württemberg (2nd prize)

Figure 122: The plant in Barbengo, an example recently built: 7'000 thousand square meters of surface covered with panels will provide energy to over 200 families. An initiative project of the Companies industrialists of Lugano, who support the work, in return from this roof will yield 1,000 megawatt hours per year, that is. energy for 220 families, as part of the "Sun" project for all", © RSI 2018

2.8 Solar integration into the landscape and study of integration of PV in an UNESCO context

In the section 'integration into the landscape', specific solar solutions that have had a special consideration to improve the level of integration of the technical solution in the landscape and in the surrounding environment (e.g., historical settlements, historical city cores and rural areas with specific environmental and cultural value) have been considered. Specific solar products were used in these projects.

The replacement of an existing material with a new one in architecture, is usually accompanied by the permanence of old traditions looking both at architectural design and building systems technology. The process of innovation is related also to building morphology, architectural image, technological behaviour and so on. Unfortunately, there are not many examples of real applications in historic buildings so far. However, new and innovative solar technologies are being developed to achieve new options of integrability in building envelopes and here some examples are presented. Coloured PV cells, PV tiles, PV curved tiles, solar copper and innovative solutions where solar cells are not visible were developed with the aim to better integrated in historical buildings and heritage protected contexts.

2.8.1 Rural Farm Galley, Ecuvillens (Switzerland)

The description of this example is in the paragraph 2.3.8 in page 29 since this an example also for roof and façade integration.

2.8.2 Wine shed, Milvignes (Switzerland)

The description of this example is in the paragraph 2.3.9 in page 31 since this an example also for roof and façade integration.

2.8.3 Cinque Terre: integration of PV in UNESCO context

Author: Giovanna Franco (Unige)

What is the solution?

This experience refers to a particularly sensitive site, placed under the protection of the state and interested international agencies: The National Park and UNESCO site of the Cinque Terre, Porto Venere and the archipelago of the islands Palmaria, Tino and Tinetto in the extreme east of Region Liguria. In such context, renovation projects designed for residence or agricultural facility are more and more frequently making provisions for the installation of solar energy devices for autonomous energy consumption. These new requests have opened up new questions as to how technologies can be integrated into fragile and sensitive landscapes. The installation of photovoltaic and thermal devices, even if of limited dimensions, entails undoubted modification to the characteristics of buildings and places, the impact of which must be carefully assessed. Such assessment should include details in the form of analysis of the connotative elements of the landscape: the created environment, the presence of panoramic points and routes, the significant visual rapport between site of hypothetical intervention and context and the perception of landscape identity as determined by the European Convention of Landscape. The work herein presented, which constitutes the summary of research aimed at defining criteria and strategies to improve the eco-efficiency of the rural settlements strewn throughout the UNESCO site, has been ordered by the Regional Secretary (a branch of the Ministry for Cultural Heritage and Related Activities and Tourism). It is one of the first case studies preceding the compiling of guidelines for improvement in the energy efficiency of the cultural heritage. Particular in-depth study is dedicated to 1) identification of criteria to better integrate solar technologies for energy production in rural buildings, for end consumer utilization (owners and technicians), as well as 2) local government and safeguarding agencies called upon to evaluate acceptability.

Why does it work?

The application of PV solar panels in sensitive landscapes and contexts is a very controversial problem, especially in Italy, in the absence of specific legislation or shared criteria at national or local level. After some medium-sized installations in prestigious territories, favoured by government economic incentives, a lively debate has taken place, leading to consider this technology as one of the least appropriate for architectural and landscape protection. The option to install solar technologies in sensitive landscapes neither win unanimous approval in scientific circles. Alongside evaluations of a technical-economic nature and considerations relevant to effectiveness and efficiency (duration in time, maintenance and discarding costs all contributing factors), the installation of solar-supplied devices clearly contrasts with the “slippery” project to safeguard cultural and material values, juxtaposing different weights unlikely to find common ground This study is focused on the identification of technical operations for improvement of energy performance in scattered and rural buildings and architectural and landscape compatibility criteria in the application of solar technologies for heating and electricity supply, which is in effect the most delicate and controversial issue. Compatibility criteria for architecture and landscape safeguarding, consider factors affecting the visibility and impacts on nature: a) localizing (focusing on territorial vocations, panoramas, building and morphological characteristics of the network but also on the real conditions of minor building preservation); b) quantitative (depending on whether it is a question of isolated systems or repeatable/groupings, considering, hence, the question of scale, with implications for the so-called cumulative factor); c) qualitative (relating to the morphology of the device, its colour, the possibility to mitigate on the visual impact).

Description of the context

The UNESCO site Cinque Terre, Porto Venere and the islands Palmaria, Tino and Tinetto, in the extreme east of Region Liguria stands as one of the foremost examples of safeguarded landscapes. Given its particular morphology, its relative difficulty of access and a protection policy dating back to even before the Second World War, the territory has managed, in part, to save itself from twentieth-century transformations pursuant to industrialized society. The crucial issue of the UNESCO site is, in fact, its conscious management of the questionable balance between the preservation of its constituent features and renewal - often in conflict rather than in harmony with each other. Just think of the problems arising out of tourist over-crowding on the country paths and the difficult recovery of isolated rural settlements or very small groups of buildings which persist in those parts of the area distant from route networks - still devoid of connections for electricity, gas and water installations, not to mention liquid disposal. Historically this has not prevented the creation of temporary, agriculture-based facility forms satisfying comfort expectations and conditions - contrasting starkly with those of contemporary demands. However, on the UNESCO site still now many rural buildings are isolated from any energy supply system and their recovery, as an essential form of protection and reuse, must contemplate the possibility of using electricity. Especially in the most isolated contexts, the insertion of PV cells can be considered a valid intervention, provided it is made according to criteria of architectural and landscape compatibility and protection (objective of the work here presented).

Pros and Cons:

Pros: This study, based on principles of maximum material preservation of traditional buildings, aspires to fruitful dialogue between technical innovation and architectural evaluation and conservation, counting on creativity of project invention, going beyond the threshold of pure camouflage. The material conservation, the minimization of impacts, the protection of the territory and landscape are in fact the indispensable objectives of any new intervention within the Park boundaries. Some important methodological criteria lie at the basis of this specific work: 1) to ensure the maximum material preservation it is preferable to intervene on traditional buildings if quite degraded or in state of collapse, where completely new roofing is required; 2) to minimize the alterations to a landscape it is desirable to intervene on shelters, harbours, service access volumes annexed to the rural building and leased by the country estate rather than on buildings which fully embody traditional rural characteristics; 3) in the grouped nuclei, it is preferable to intervene on buildings already compromised by blatant, modifying stages of intervention or on recent/ twentieth-century buildings, in which materials and building techniques often employed already differed from traditional architectural regulations.

Cons: The compatibility criteria consider eligible some technologies less efficient than others (for example coloured PV modules or integrated shingles), with minor impact on the landscape, even considering that the rural buildings have very limited consumption. These technologies may also have major costs in relation to their efficacy.

Type of Data Available:

The installation of photovoltaic and thermal devices, even if of limited dimensions, entails undoubted modification to the characteristics of buildings and places, the impact of which must be carefully assessed. Such assessment should include details in the form of analysis of the connotative elements of the landscape: the created environment, the presence of panoramic points and routes, the significant visual rapport between site of hypothetical intervention and context and the perception of landscape identity as determined by the European Convention of Landscape. Identification of criticality connected to impacts on historical, landscape and environmental context, is substantially summed up below: - visible intrusion, given recipient chromatic characteristics, their shape, reflecting surface (generally contrasting with morphological surfaces, matter and already existing colours); - modification of soil structure, minute territorial soil formation, vegetation etc.; - replacing of existing materials and loss of matter characteristics in traditional architectural presence; - alteration of social perception of the places. The definition of some landscape and architectural compatibility criteria, in full respect of the safeguarding of the characteristics of traditional constructions is based on:

1. Intervention on roof: Quantity and quality factors
    a. Maximum extension and surface rapport for panels
    b. Shape
    c. Materials and colour
    d. Slope and anchoring/aligning
    e. Tile and slab textures (elements of small dimensions)
2. Land solutions: related quantity and quality factors
    a. Maximum height
    b. Maximum width
    c. Linear development and alignment.

Sources:

This work has been published in: Franco G., Solar powered energy and eco-efficiency in a UNESCO site. Criteria and recommendations for the National Park of Cinque Terre, Italy, in "Energy and Buildings" Volume 174, 1 September 2018, Pages 168-178, ISSN: 0378-7788, https://doi.org/10.1016/j.enbuild.2018.05.059

Figure 123: UNESCO site of Cinque Terre, typical terraced landscape, the settlement so called "Fossola",

Figure 124: UNESCO site of Cinque Terre, typical terraced landscape, the settlement so called "Monestiroli"

Figure 125: Monestiroli, photo-simulation of a compatible intervention. On the left, current state, on the right, the use of transparent PV cells

Figure 126: Fossola, simulation of use of different products (left: current state): solar copper, PV curved tiles coloured PV cells.

Figure 127: Fossola, simulation of use of different products: coloured PV cells, PV tiles, PV curved tiles, solar copper.

Figure 128: Simulation of a new coloured PV roof (almost integral) on slate or on tiles. A) the current state, b) the new roof inserted on slates, c) the new roof inserted on tiles (FAI).

Figure 129: Palmaria Island, simulation of a new solar copper roof on a ruined building (on the left).

Figure 130: Schiara, study of the different impact of two thermal solar panels on a roof changing their position and alignment

Figure 131: Palmaria Island, study on possible texture of PV curved tiles on a ruined roof

Figure 132: UNESCO terraced landscape, study of possible position and alignment of coloured PV panels on the terraces

3 Assessment of solutions according EN 16883:2017

3.1 Methodology of assessment

The assessment criteria of the standard EN-16883:2017 have been reviewed and tailored to better suit solar implementation evaluation in heritage contexts by experts in technical and conservation fields in the IEA SHC Task 59. Based on the collection of case studies with solar PV and ST systems in historic buildings, the assessment scheme has been checked and validated to verify their correspondence to the adapted new criteria proposed. In the case studies investigated (all of them are listed buildings, not protected, or placed in conservation areas or city centres), different solar renewable solutions (e.g. PV, ST and solar hybrid photovoltaic-thermal) were implemented. According to the standard, to verify the applicability of the criteria two different levels of assessment have been defined. First, nineteen solutions for solar systems applied or applicable to historic buildings are analysed by the quick assessment. The solutions include systems attached to the roof or façade, as well as integrated in the roof or façade. Furthermore, free-standing systems and systems integrated into the landscape are assessed, as well as models of local sharing or sharing via a network. This analysis highlights the main trends, strengths, and weakness of the solar solutions effectively implemented in historic buildings. In a second step, a more accurate detailed assessment of a selection of three case studies has been completed. This analysis allows an in-depth evaluation of the aspects that were highlighted in the quick assessment as critical points, to show the weaknesses and the strengths of the application of the standard procedure. It permits also to verify the ease of interpretation, the future exploitability, the usefulness, and the convenience of use of the new tailored criteria to solar technologies. [26]

3.1.1 Assessment criteria catalogue for Solar Systems

3.1.1.1 Technical compatibility

3.1.1.1.1.1 Hygrothermal risks (STANDARD)

The likelihood of moisture accumulation on the backside of the Photovoltaic/Solar thermal panels (RES) will be evaluated, considering the indoor and outdoor moisture sources in relation to the level of integration of the system. This can be a vapor or a dew, for example. Excessive accumulation of moisture can lead to other risks, see below.

3.1.1.1.1.2 Structural risks (STANDARD)

The structural requirements for the lead support structure should be evaluated. In addition, the maximum distance between the support points of the RES panels for the climatic loads (wind, snow, etc.) and for the possibility of walkability should also be considered. Structural and mechanical characterization is necessary related the fixing systems considering safe adequate operational condition and enough mechanical resistance to prevent excessive deflections and in the case of solar modules with special dimensions (e.g. XL and custom-made solar modules) there is a need for specific testing procedures before its installation in the building.

Structural risks due to the moisture risk will be considered if RES is applied on roof / walls with structural elements that are vulnerable to moisture (e.g. timber, iron).

3.1.1.1.1.3 Waterproof function

The RES will be evaluated to verify whether it can fulfil the rain and hail impact protection function and thus replace the function of standard roof/façade components. What are then the minimum requirements such as minimum inclination, need for secondary roof folds or membranes, etc.?

3.1.1.1.1.4 Risk reduction efficiency *

The likelihood of reduction of energy-generation efficiency will be assessed. The influence of external environment (e.g. dust, snow, shadows, high temperature levels during operation and depending on mounting system, mismatch effects in solar modules and PV arrays when solar cells or modules do not have identical properties, etc.) and the installation of the RES itself (inclination, temperature rise, reduced air-cooling effect and natural decrease of efficiency over time) will be considered.

3.1.1.1.1.5 Fire safety

Combustibility of the cabling and the panel's materials, short circuit risks and hot spots of PV systems, or stagnation risks by the solar thermal systems are potentials risks for causing damages on the health and properties. The aspect of fire safety and the extinguishing procedure of RES system fire will be evaluated.

Electrical connection needs to be optimized and easily accessible to prevent hot spots in the electronics as a result of, e.g., a faulty connection, reducing the possibility of electrical arcs and to prevent fire risks. It would be important to verify the accuracy of the PV installation at each stage, verifying the wiring connections, checking for the presence of debris accumulation under the panels and the ignition risks of the mounting structure. Fire prevention regulations must be taken into account also at the design level and during construction.

3.1.1.1.1.6 Robustness/Buildability/design/Application

The ability of a system to deal with uncertainty and variability of weather conditions, to protect against the falling risks, installation mistakes and other imperfections will be evaluated. The solar RES system must comply with current standards and certifications and as a building product it is necessary to observe the Construction Products Regulation CPR 305/2011, and accordingly all building products should carry the CE-mark to indicate conformity with essential health and safety requirements set out in the European harmonized standards.

3.1.1.1.1.7 Thermal bridges/Connection

Ease of installation from the perspective of invisibility, time of assembly, need for maintenance of connection over time, extensibility of installation, thermal bridges, etc. will be evaluated.

3.1.1.1.1.8 Reversibility * (STANDARD)

It will be evaluated if the RES system is intended to provide ease reversibility, considering the use of hard materials for bonding and the use of mechanical fixings.

Also, visual change to the existing exterior finish due to RES systems will be evaluated. In some cases, specific solar systems could be selected for better integration in the existing envelope, considering similar colors, textures or finishes in order to imitate or hide the solar solution and minimize the visual impacts.

3.1.1.2 Heritage significance of the building and its settings

3.1.1.2.1.1 Risk of material, constructional, structural impact (STANDARD)

Any refurbishment of a historical building should aim at achieving the optimal protection of the existing building structure while providing state of the art technologies at that time. In the field of preservation of historic monuments, however, there is a need for preservation beyond the purely structural demands, including the preservation of certain building attributes and the values they convey. This can be a specific construction technique, definable construction phases expressed by the use of different materials, wooden parts allowing the dating of a construction, etc.

When applying RES systems, a distinction must be made in particular between RES systems with different levels of building integration and free-standing RES systems. The load of an addition construction on the roof or wall can, for example, demand reinforcement of the roof structure or drilling into even original plaster layers for the fixtures. Reversibility; a complete restoration previous state; is not by 100% possible in this case.

Furthermore, the condensation (for example on the back side of the panels) or high temperatures reached by the solar modules in operation can bear risk to the historical truss and lead to damage (see aspect Hygrothermal risks).

3.1.1.2.1.2 Risk of architectural, aesthetic, visual impact * (STANDARD)

A visual impact caused by interventions on the external walls and roof for example, concerns two main aspects: A) the visual change and aesthetic of the historic surface (colors and textures) and B) the change of geometrical relationships, when the surface. The former is particularly relevant when historic roof tiles, wall finishes, window shatters are still present and are covered by the application of new layers with different visual properties and shapes. The geometric relationships of a building might be changed when applying RES as shading elements, e.g. roof overhangs, window shutters, balcony railing.

In conclusion, the evaluation is therefore always carried out as an impact assessment of the renovation measures on existing attributes in collaboration with the monument protection office, if applies. Which roof and wall surfaces are changed and to what extent? How much it is possible to imitate the original surface, is it more aesthetic to cover continuous surfaces completely or partially? Where does the geometry changes by applying additional layers or components? What influence does this have on perceiving the historical value of the building (overhangs, shadowing elements, freestanding systems)? Is it possible to customize the solar elements to preserve the historical significance of the building paying particular attention to the geometrical and visual aspects, and considering existing constrains?

3.1.1.2.1.3 Risk of spatial impact (STANDARD)

For the installation of the RES, the spatial impact partly affects the same points already mentioned above regarding the change of geometrical relationships. Another point of view is to consider the approach chosen for renovations of the surrounding buildings, with the option to become a pioneer of an aesthetically accepted method with the possibility of scaling-up such a solution in the near vicinity. The city special architect office and the monument protection office might be the best assist in this issue.

3.1.1.3 Economic viability

3.1.1.3.1.1 Capital costs (STANDARD)

The direct cost of installing the RES solution and the economic savings due to its operation will be evaluated (prior to installation). If the installation is done in combination with other measures, not referring to RES, then only the additional costs caused by installation of RES on the roof/ wall is to be included, to evaluate whether the installation is economic viable, based on estimates of installation cost, savings by delivered less energy from the grid and profit by injecting energy into the grid (this may vary strongly from region to region – should be considered if should be considered), and expected service life (example: if renovation of roof is needed to avoid moisture damage of the house and the RES overtake the rain-protection function, the cost is to be reduced by price of the standard roofing e.g. roof tiles). Considering specific custom-made or innovative solar solutions to improve aesthetic could imply an increase in costs, in this case the benefit ratio must be assessed and considered previously.

3.1.1.3.1.2 Operating costs, including maintenance costs (STANDARD)

Economic viability can also be evaluated including the operation/maintenance costs (life cycle economy). This may influence which specific solution to choose, in the case more than one solution is considered. The RES size, system location and orientation and selected technology type and possibility of energy storage strongly influences the annual yield and so the economics. The target is to evaluate that particular system at its location and suggest how it could be optimized to reach better economics.

3.1.1.3.1.3 Economical return (STANDARD)

The calculation of the economical return should be based on the overall levelized cost. It begins with the capital cost as defined in the capital cost section plus the cost of the credit if needed. Then the discounted cost of the expected operating and maintenance cost on a fixed period (usually 30 years) are added. The economy on the energy bill has to be calculate considering a scenario of an increase in the purchase price. This scenario has to be stated. The economical return has to be compared with the expected service life. Two kinds of calculation could be performed: with or without public subsidies (Reference ISO 15686-5)

3.1.1.3.1.4 Economic savings (STANDARD)

To assess the economic savings, it should be compared the energy costs before and after the retrofitting. The result in energy consumption difference must be converted in money considering a scenario of increase in the energy purchase price year after year. It is also possible to consider the increase of the value of the retrofitted building in some cases.

The RES size, system location and orientation and selected technology type and possibility of energy storage strongly influences the annual yield and so the economics. The target is to evaluate that particular system at its location and suggest how it could be optimized to reach better economics.

3.1.1.4 Energy

3.1.1.4.1.1 Energy performance and operational energy demand in terms of primary energy rating (total), primary energy rating (non-renewable), primary energy rating (renewable) * (STANDARD)

Regarding the solutions for RES systems, the annual yield in relation to annual energy consumption (energy autarky if possible) will be evaluated. How the energy concept is solved (technology, installed power, active area, MPPT, monitoring, energy storage, etc.) will also have a role in the evaluation.

3.1.1.4.1.2 Life cycle energy demand in terms of use of renewable primary energy and non-renewable primary energy (STANDARD)

The LCA analysis' result (if available) is evaluated. In the LCA calculation are considered all the stages of the life of the product: from the raw material extraction, through the material manufacture, to the disposal or recycling.

3.1.1.5 Indoor environmental quality

3.1.1.5.1.1 Indoor environmental conditions suitable for achieving good occupant comfort levels (STANDARD)

The ability to contribute to the improvement of internal heat and light conditions (for example by shading and thus by limiting summer overheating) will be evaluated. Impact on the outdoor environment

3.1.1.6 Impact on the outdoor environment

3.1.1.6.1.1 Life cycle energy demand in terms of greenhouse gas emissions and emissions of harmful substances

The LCA analysis' result (if available) is evaluated. In the LCA calculation are considered all the stages of the life of the product: from the raw material extraction, through the material manufacture, to the disposal or recycling. Relevant information for LCA is how much fewer emissions will be released due to energy generated by the RES with respect to the region's energy mix. The LCA should focus on the ecological impact of the material's life, with the focus on greenhouse emissions and emission of harmful substances.

3.1.1.6.1.2 Natural resources use (STANDARD)

It is worthwhile to evaluate the demand of raw metals and minerals (such as cobalt, lithium) to manufacture the RES technologies. Technologies that handle these raw materials economically (on an example of PV, the thinner films and advanced light trapping technologies) and technologies with better recyclability will be preferred.

3.1.1.7 Aspects of use

3.1.1.7.1.1 Influence on the use and the users of the building & Consequences of the change of use (STANDARD)

The positive and negative effects on the user will be listed (e.g. change in habits required, changes in use / control of HVAC home systems, reduced operating costs, system maintenance, etc.)

Maintenance: Soil and dust accumulation on solar plants can provoke malfunction, hot spots and energy losses, in the long time it could affect durability and the energy performance. In many cases, rain can be sufficient to wash away dirt. However, in cases of heavy soiling or in areas with little precipitation, additional cleaning of the roof/façade elements is necessary. If this is required, the cost of cleaning must be weighed against the earnings from the additional energy yield.

3.1.1.7.1.2 Ability of building users to manage and operate control systems (STANDARD)

Indication of how the user is informed about the production of renewable energy (e.g. monitoring with home-display, monitoring data accessible via mobile phones, etc.) and the impact of this information on the ability to adapt the energy consumption to the current energy generation by the RES will be evaluated. Predominantly systems that allow increased consumption of own renewable energy are less burdensome for the electricity transmission network and offer more user-friendly operating costs.

3.1.2 Assessment scale

Building upon what the standard suggests, the assessment consists of an evaluation of a RES solar system according to the criteria and sub-criteria identified in Paragraph 3.1.1 , through a five-points Likert scale (Table

2). To accelerate the rating process, make comparisons easier and visually emphasize results, the same color-coding of the standard was applied to the Likert scale. This method, following the standard, should not be seen as a mechanical tool that provides an answer; rather it is meant to allow for a transparent assessment and the interdisciplinary dialogue that is needed to identify the interventions that best meet the requirements of the building in question. An overview of the scale with colours, definitions, and examples for a few meaningful assessment categories and criteria are provided in Table 2. A similar approach can be applied to the other assessment categories and criteria. Thanks to this assessment procedure, by analysing the ratings of each category and for each individual sub-criterion, a comparison between different types of buildings (e.g. listed and protected buildings) or different type of solar integration (e.g. façade or roof integration) can be readily made.

In this section, a risk-benefit assessment scheme tailored to solar solutions has been described. A five-level assessment scale from *High Risk* to *High Benefit* has been proposed.

Technical compatibility, Heritage significance of the building and its settings, Economic viability, Energy, Indoor environmental quality, Impact on the outdoor environment and Aspects of use criteria have been described in detail. The assessment scale proposed offers an alternative way to evaluate RES systems. The color-coding allows for rapid comparison between the solutions. The results of this assessment are intended as a means for discussion between the members of the multidisciplinary team assessing RES solutions, so as to take into consideration aspects from different perspectives and with similar aims. [26]

Table 2: Assessment scale: definitions for each step of the scale and examples for some meaningful assessment categories and criteria[1]. Source: elaboration of the authors.

Scale Grade and Colours	**Rationale**	**Example 1[1]**	**Example 2[1]**	**Example 3[1]**
		***Assessment category.* Technical compatibility**	***Assessment category:* Heritage significance of the building and its settings**	***Assessment category:* Economic viability**
		***Assessment criteria:* Reversibility**	***Assessment criteria:* Risk of visual impact**	***Assessment criteria:* Capital cost**
High benefit (deep green)	The installation results highly successful / provides high benefits / cost-benefit approach / effective	The installation is fully reversible as all fixing and cabling can be removed	High positive impact	The solution capital cost is 50% below the average
Low benefit (light green)	The installation results sufficiently successful / provides medium-low benefits / average cost-benefit approach	The installation is fully reversible, fixing and cabling can be removed even if some alteration to the ancient fabric remains	Low positive impact	The installation capital cost is 25% below the average
Neutral (white)	The installation results neither a success nor a failure or it do not directly impact the historic building	No direct installation of PV system on the historic building is made	No impact	The installation capital cost is on average
Low risk (yellow)	The installation results almost not successful / of medium risk impact	The installation is partly reversible, only some components can be removed without altering the historic building	Low negative impact	The installation capital cost is 50% above the average
High risk (red)	The installation results not successful / of high-risk impact / expensive / ineffective	The installation is not reversible, components cannot be removed without damaging the historic building and its appearance	High negative impact	The installation capital cost is 100% above the average
[1] Examples are not supposed to be conclusive; a similar approach is intended to be applied to the remaining criteria listed above.				

3.2 Quick assessment

The quick assessment, as the standard highlights, has been based on the criteria defined in 3.1.1 using experience rather than thorough analysis. The different criteria should be seen as a checklist to consider all important aspects in connection with the renovation of historic buildings.

With the aim of validating the adapted criteria of the standard and to find strengths and weaknesses of the different systems, a quick assessment of nineteen solutions implemented in traditional and historic buildings has been done. The solutions analysed represent different countries, building ages, refurbishment ages, types of building, use, protection levels, types of solar technology, and solar application in roofs or facades Table 3. The heritage and traditional buildings analysed were grouped by typology, mainly dividing them based on their usage pattern (continuous/discontinuous) and on their occupancy– (residential/non-residential), as well as on their relationship with the surrounding environment (e.g. urban or rural buildings, mainly residential buildings, single family houses SFH and multi-family houses MFH). The buildings' relationships with the surroundings and landscapes can have an impact on the aesthetic, visual and material dimensions of the intervention. It also implies a direct relationship with aspects of the evaluation related to heritage significance of the buildings and their settings and technical compatibility. The different levels of occupancy (e.g. public buildings, museums, schools, etc.) represent different using-loads, electricity needs or HVAC and ventilation requirements, as factors that affect the solar plant size. This aspect is directly related to the economic viability, energy, indoor environmental quality and aspect of use criteria. Another important aspect highlighted in this research is related to the type of solar system used (i.e. mostly roof solutions whilst façade solutions or accessory elements were found to a lesser extent). Likewise, the level of protection of the building (i.e. listed buildings with a higher level of protection or not protected) can also determine significant differences in the evaluated criteria. In this way, a rational analysis of the results has been possible thanks to a comparison between the risks and benefits of each intervention.

The tabular risk-benefit assessment scheme (paragraph 3.1.2)developed in the present research that follows the standard EN-16883:2017 qualitative approach has been applied to the case studies (see Table 4 and Table 5)., in order to validate the adapted criteria of the standard. With the aim of identifying strengths and weaknesses of solar solutions, the results of the assessment of the single solutions were averaged, dividing solutions into listed and unlisted buildings; roof attached and roof integrated systems (

Table 6 and

Table 7).

In the overall evaluation, all examples have been taken into consideration (roof attached, roof integrated solutions, and façade integrated or attached solar systems) evidencing the differences between protected and listed buildings or unprotected or unlisted buildings studied (

Table 6) . Since the number of analysed examples of facade solutions are a minority (5% of the total), only the roof solutions were averaged in

Table 7(solar integrated 63% and attached 11%). [26]

Table 3: Summary of the solutions that are assessed

Name		Country	Building age	Intervention age	Protection level	Building type	Building use	Solar integration	Solar Technology
NON-RESIDENTIAL BUILDINGS (discontinuous use)	Kindergarten, Chur	CH	1914	2015	listed	School	Nursery school	Roof integrated	BIPV-BIST
	Kindergarten, Chur	CH	1914	2015	listed	School	Nursery school	Local sharing	BIPV-BIST
	Monument School, Innsbruck	AT	1929	2014	listed	School	School	Roof attached	BAPV
	Crichton Castle, Scotland	UK	1500	2019	listed	Castle	Monument	Free standing	PV
	Fondazione Pino Pascali, Puglia	IT	1800	2016	not listed	Public	Museum	Roof integrated	BIPV
	St. Franziskus Church, Ebmatingen	CH	1989	2018	not listed	Church	Church	Roof integrated	BIPV
	Kohlesilo Solar Silo, Basel	CH	1844	2015	not listed	Public	Multiple uses	Roof integrated	BIPV
	Kohlesilo Solar Silo, Basel	CH	1844	2015	not listed	Public	Multiple uses	Façade integrated	BIPV
	Parco Isola della Certosa, Venezia	IT	1900	2020	not listed	Industrial	Multiple uses	Roof integrated	BIPV
	Giardino Pensile Hotel Luna, Capri	IT	-	2020	not listed	Third sector	Hotel	Landscape	free-stand PV
	Wine shed Milvignes	CH	2018	2018	listed	Rural	Wine shed	Roof integrated	BIPV
RESIDENTIAL (continuous use)	Rural farm Galley, Ecuvillens	CH	1859	2018	listed	Rural	Farmhouse	Roof integrated	BIPV
	Doragno Castle, Rovio	CH	< 1600	2017	not listed	Castle	SFH	Roof integrated	BIPV
	La Capanna, Capannori, Lucca	IT	1700	2017	not listed	Rural	MFH	Annex building	BIPV
	Glaserhaus, Affoltern im Emmental	CH	1765	2015	listed	Residential	SFH	Roof integrated	BIPV
	Lauriston Housing, Edinburgh	UK	1840	2009	listed	Urban city	MFH	Roof attached	BAST
	Villa Castelli, Como	IT	1850-1900	2013	not listed	Villa	SFH	Roof integrated	BIPV
	Feldbergstraße, Basel	CH	1986	2009	listed	Urban city	MFH	Roof integrated	BIPV
	Chalet La Pedevilla, South Tyrol	IT	2013	-	not listed	Mountain	SFH	Roof integrated	BIPV

Note: SFH (Single Family House), MFH (Multi Family House), BIPV (Building-integrated photovoltaic); BAPV (Building applied photovoltaic); BIST (Building-integrated solar thermal).

Table 4: Quick Assessment of the single solutions – part 1

	Type of Solution	La Capanna, Capannori	Monument School Innsbruck	Integration of different PV panels - Kohlesilo Solar Silo Basel	Intergration of PV and solar thermal Feldbergstraße	Intergration of PV and solar thermal Doragno Castle	Intergration of PV and solar thermal Kindergarten Chur	Integration of PV panels Church Ebmatingen	Chalet La Pedevilla	Villa Castelli	PV panels «Kohlesilo», Solar Silo Basel
	Institution	EURAC	UIBK	SUPSI	SUPSI	SUPSI	SUPSI	SUPSI	EURAC	EURAC	SUPSI
	Category	roof integrated	roof attached	facade integrated	roof integrated	roof integrated	roof integrated	roof integrated	roof integrated	roof integrated	roof integrated
	Listed building?	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO
Technical Compatibility	Hygrothermal risk	3	5	5	5	5	5	5	5	5	5
	Structural risk	3	5	5	4	5	5	5	5	5	5
	Water Proof	3	1	4	5	5	5	5	5	5	4
	Risk Reduction Efficiency	3	4	4	4	5	4	5	5	5	4
	Fire Safety	3	4	no data	4	4	4	4	5	5	no data
	Robustness/Buildability/design/Application	3	5	4	3	5	4	5	5	5	4
	Thermal Bridges/Connection	3	5	4	3	5	4	5	5	5	4
	Reversibility	3	5	4	1	1	2	1	5	5	4
Heritage significance	Risk of material, constructional, structural impact	3	2	3	2	3	4	2	5	5	3
	Risk of architectural, aesthetic, visual impact	2	5	4	2	3	4	3	5	5	4
	Risk of spatial impact	2	5	4	3	4	4	3	5	5	4
Economy Viability	Capital costs	no data	4	1	1	No data	4	4	5	5	1
	Operating costs, including maintenance costs	no data	4	no data	4	No data	No data	5	no data	no data	no data
	Economical return	no data	5	2	5	No data	No data	5	3	3	2
	Economic savings	no data	5	no data	5	No data	4	5	3	3	no data
Energy	Energy performance and operational energy demand in terms of primary energy rating (total), primary energy rating (non-renewable), primary energy rating (renewable) *	4	5	4	5	5	5	5	5	5	4
	Life cycle energy demand in terms of use of renewable primary energy and non-renewable primary energy	no data	4	No data	No data	No data	No data	No data	3	3	no data
Indoor Environmental Control	Indoor environmental conditions suitable for achieving good occupant comfort levels	4	5	4	5	4	5	4	3	3	4
Impact on the outdoor environment	Life cycle energy demand in terms of greenhouse gas emissions and emission of harmful substances	no data	no data	no data	5	No data	5	5	no data	no data	no data
	Natural resources use	no data	1	2	No data	No data	No data	No data	no data	no data	2
Aspects of use	Influence on the use and the users of the building & Consequences of the change of use	5	5	5	4	5	5	4	3	3	5
	Ability of building users to manage and operate control systems	No data	5	No data	No data	No data	No data	No data	no data	no data	No data

Table 5: Quick Assessment of the single solutions – part 2

Type of Solution		Rural farm	Wine shed Milvignes	Change with neighbourbuilding (STh out, pellets in) Kindergarten Chur	Glaserhaus - Affoltern im Emmental, Switzerland	Solar panels on roof of Crichton Castle, Scotland	Solar thermal collectors, Lauriston Housing Cooperation, Edinburgh	Fondazione Museo Pino Pascali	Parco Urbano Isola della Certosa, Venezia	Giardino Pensile Hotel Luna, Capri
Institution		SUPSI	SUPSI	SUPSI	SUPSI	HES	HES	EURAC	EURAC	EURAC
Category		roof integrated	roof integrated	local sharing	roof integrated	free standing & integrated into landscape	roof attached	roof integrated	roof integrated	free standing & integrated into landscape
Listed building?		YES	YES	YES	YES	YES	YES	NO	NO	NO
Technical Compatibility	Hygrothermal risk	4	4	5	5	5	5	5	5	5
	Structural risk	5	5	5	5	5	5	5	5	5
	Water Proof	5	5	5	5	5	5	5	5	5
	Risk Reduction Efficiency	1	1	4	5	2	5	4	5	5
	Fire Safety	4	4	4	4	5	5	5	5	5
	Robustness/Buildability/design/Application	5	5	4	5	5	5	5	5	5
	Thermal Bridges/Connection	4	4	4	5	4	4	5	5	2
	Reversibility	2	2	2	1	5	4	4	5	5
Heritage significance	Risk of material, constructional, structural impact	5	5	4	2	5	2	4	2	5
	Risk of architectural, aesthetic, visual impact	5	5	4	2	5	5	4	5	5
	Risk of spatial impact	5	5	4	3	5	5	5	5	4
Economy Viability	Capital costs	2	2	4	No data	4	5	no data	1	no data
	Operating costs, including maintenance costs	No data	No data	No data	No data	No data	No data	no data	no data	no data
	Economical return	No data	No data	No data	No data	No data	No data	no data	no data	no data
	Economic savings	No data	No data	4	5	4	5	no data	no data	no data
Energy	Energy performance and operational energy demand in terms of primary energy rating (total), primary energy rating (non-renewable), primary energy rating (renewable) *	2	5	5	5	4	3	4	4	4
	Life cycle energy demand in terms of use of renewable primary energy and non-renewable primary energy	No data	No data	No data	No data	No data	No data	no data	no data	no data
Indoor Environmental Control	Indoor environmental conditions suitable for achieving good occupant comfort levels	No data	No data	5	5	3	3	3	3	4
Impact on the Outdoor Environment	Life cycle energy demand in terms of greenhouse gas emissions and emission of harmful substances	3	No data	5	5	4	4	no data	no data	no data
	Natural resources use	2	2	No data	No data	3	3	no data	no data	no data
Aspects of use	Influence on the use and the users of the building & Consequences of the change of use	No data	No data	5	5	5	5	3	3	5
	Ability of building users to manage and operate control systems	No data	No data	No data	No data	No data	2	4	no data	no data

Starting from the results obtained in

Table 6 and

Table 7, an analysis was carried over from the group of experts. The technical compatibility criteria of solar systems do not represent a critical aspect, whether it is protected or unprotected buildings. The risk of reduction of efficiency is higher for listed buildings (as the weighted value is lower). The analysed examples showed that PV or BIPV systems, for the selected case studies and in listed buildings, are used mainly on less visible surfaces (e.g. in internal courtyard such as in the Feldbergstrasse building or using only the surfaces best exposed to solar radiation or as in the case of Villa Castelli not visible by the lake). In some solutions, for example, it is preferable to use solar technologies with improved aesthetic integration which minimize the impact of the system, even if this can compromise the efficiency of the solar system (e.g. Terracotta colour modules in the rural farm Galley or no visible solar cells in the Solar Silo building). In a BAPV system, the waterproofness does not depend on the solar solution. Thermal bridges and poor connections are avoided in all cases analysed. As the greater number of cases analysed correspond to BIPV or BIST, the reversibility value turns out to be a critical point (lower value than others).

Heritage significance criteria is better in roof attached than in roof integrated systems. This is evidenced by the fact that lower risks (higher values) are found by the architectural, aesthetic, and visual also as well as the spatial impact criteria considered. It could be the result, as previously mentioned, of less visible and more reversible solutions implemented.

Economic viability criteria are a critical issue in most of the case studies analysed, especially capital costs which is not usually publicly known and is difficult to obtain. Data on the operational and maintenance costs or economic return is missing in most cases, and for a quick evaluation there is no value that can really be taken into account. Energy criteria is good, considering the energy performance and operational energy demand in terms of coverage of the building's energy needs.

Few differences are shown between listed and unlisted buildings and the value is also better in the case of integrated systems compared to non-integrated ones. Data on life cycle analysis (LCA) was found in only three cases analysed and for this reason is not a factor that can be considered of weight in a quick study. This means LCA is not widely used yet, not even in the field of research. Indoor environmental quality criteria indicating the conditions to achieve good comfort levels for occupants were achieved mainly when the solar systems are complemented with other technical solutions for the energy retrofit of the building. In this case, the improvement of the overall energy performance compared to the previous situation is given in most of the cases studied and therefore generally the value found is good, with a lower value for roof-integrated solutions. Impact on the outdoor environment criteria considers two main aspects, firstly the carbon emissions and harmful substances emissions reduction, which is generally good or very good with an always-positive impact considering the use of solar renewable sources. On the other hand, it takes into account the factor of the natural resources used, which is evidenced by the experts as a critical aspect (neutral or bad although there are fewer examples with information in regard to the total number of cases analysed). Aspects of use criteria are based mostly on the ability of building users to manage information about the solar plant. It manifests itself as a positive factor when there is the possibility for users to be able to supervise and monitor the solar installation (e.g., having a display with data or a home automation control system to evaluate if the system is working properly) which is not usual or is not well understood. The analysed examples show that there is no influence on the use or on the users due to the change of use of the building after the intervention. [26]

Table 6: Results of the quick assessment averaged grouping solutions on listed and not listed buildings (Note: in brackets are the number of solutions averaged over)

Assessment category	Listed buildings		Not listed buildings	
	Strengths	**Weakness**	**Strengths**	**Weakness**
Technical compatibility	Hygrothermal risk (9)	Reversibility (9)	Hygrothermal risk (10)	Reversibility (10)
	Structural risk (9)		Structural risk (10)	
	Waterproof (9)		Waterproof (10)	
	Fire safety (9)	Reduction efficiency risk (9)	Reduction efficiency risk (10)	
	Design and installation (9)		Fire safety (8)	
	Thermal bridges (9)		Design and installation (10)	
			Thermal bridges (10)	
Heritage significance	Risks of visual impact (9)	Risk of material impact (9)	Risks of visual impact (10)	Risk of material impact (10)
	Risk of spatial impact (9)		Risk of spatial impact (10)	
Economic viability	Operating costs (2)	Capital costs (8)	Operating costs (1)	Capital costs (6)
	Economical return (2)			
	Economic savings (7)		Economic savings (3)	Economical return (5)
Energy	Energy performance (9)		Energy performance (10)	Life cycle energy demand (2)
	LCE demand (1)			
IE quality	IE conditions suitable (7)		IE conditions suitable (10)	
Impact on the outdoor environment	Greenhouse gas emission (7)	Natural resources (5)	Greenhouse gas emission (1)	Natural resources (2)
Aspects of use	Effects of RES on users (7)	Easy to manage and operate (3)	Effects of RES on users (10)	
	Effects of change of use (7)		Effects of change of use (10)	
			Easy to manage and operate (4)	

Table 7: Results of the quick assessment averaged grouping roof attached and roof integrated solar solutions (Note: in brackets are the number of solutions averaged over).

Assessment category	ROOF ATTACHED BAPV-BAST		ROOF INTEGRATED BIPV-BIST	
	Strengths	**Weakness**	**Strengths**	**Weakness**
Technical compatibility	Hygrothermal risk (2)		Hygrothermal risk (12)	
	Structural risk (2)		Structural risk (12)	
		Waterproof (2)	Waterproof (12)	
	Reduction efficiency risk (2)			Reduction efficiency risk (12)
	Fire safety (2)			Fire safety (12)
	Design and installation (2)		Design and installation (12)	
	Connections (2)		Connections (12)	
	Reversibility (2)			Reversibility (12)
Heritage significance	Risks of visual impact (2)			Risks of visual impact (12)
	Risk of spatial impact (2)			Risk of spatial impact (12)
		Risk of material impact (2)		Risk of material impact (12)
Economic viability	Operating costs (1)		Operating costs (2)	
	Economical return (1)		Economical return (5)	
	Capital costs (2)			Capital costs (9)
	Economic savings (2)		Economic savings (6)	
Energy	Energy performance (2)		Energy performance (12)	
	Life cycle energy demand (1)			Life cycle energy demand (2)
IE quality	IE conditions suitable (2)		IE conditions suitable (10)	
Impact on the outdoor environment	Greenhouse gas emission (1)	Natural resources (2)	Greenhouse gas emission (5)	Natural resources (3)
Aspects of use	Effects of RES on users (2)			Effects of RES on users (10)
	Effects of change of use (2)			Effects of change of use (10)
	Easy to manage and operate (2)			Easy to manage and operate (4)

3.3 Detailed assessment examples for Solar Systems

A more in-depth study of the risk-benefit scheme has been carried out in a detailed assessment of different case studies. Three projects have been selected, from the case studies analysed, for which there is enough information (technical, economic and functional) to carry out this analysis. Furthermore, the selected buildings have different protection levels (a listed building and unlisted-buildings in conservation areas), building typology (castle, industrial building, villa), function (museum, multipurpose, residential), solar technology type (BAPV, BIPV), and solar application (roof, façade). These case studies have been selected, both from technological and conservation points of view as representative projects which use renewable energy and in particular solar energy in combination with other energy retrofit measures to achieve a rational use of energy and low CO_2 emissions. [26]

The three selected solutions are part of the best practice cases documented in Subtask A and in the HiBERatlas.

The selected buildings are:

- Crichton Castle, a listed castle in Scotland (United Kingdom);
- Solar Silo, an unlisted industrial building in a protected area of Basel (Switzerland);
- Villa Castelli, an unlisted villa in a protected landscape on Lake Como (Italy).

3.3.1 Free standing Photovoltaic system for Crichton Castle, Scotland (UK) – Anne Schmidt (Historic Environment Scotland)

3.3.1.1 Technical compatibility

Hygrothermal risks

There is no hygrothermal risk associated with the installation of the panels. The panels themselves are attached with an incline above a clear space. This allows any condensation to run off and evaporate freely.

Figure 133: The installed solar panels with ventilation space and incline, © Historic Environment Scotland

Structural risks

The structure used for this purpose a non-historic 20th century concrete roof, into which the original 2005 panels were bolted to this structure. Due to the nature of the roof and the minimal size of the panels, this was considered acceptable and did not present a higher structural risk. As the adjacent materials are not vulnerable to it, there is also no additional risk of humidity.

The solar panels installed in 2019 are composed of monocrystalline solar cells as well as high-transmission tempered anti-reflective glass of high standards. They are designed according to the standards IEC 61252 in terms of the longevity of the panels as well as IEC 61730 for electrical and mechanical safety. As the dimensions and weight are comparable to those installed in 2005, the fixings and structural calculations did not need to be changed. They were attached sloped, in accordance with the manufacturer's guidance.

Figure 134: *The fixings into the concrete roof, © Historic Environment Scotland*

Moisture safety

The panels have been installed according to manufacturer's guidelines in order to facilitate the self-cleaning function. The fixing mechanism within the concrete roof is designed in such a way as to present no entry point for water into the space underneath. As the panels are installed as part of a ruined building, almost the whole site would be considered an outdoor space and has water management systems in place accordingly. The glass has an impact resistance of 25mm diameter hail at 23m/s which ensures hail and weather protection.

Figure 135: *Incline of the panels to facilitate runoff and self-cleaning, © Historic Environment Scotland*

Risk reduction efficiency

There is limited risk to reduction of efficiency. The solar panels are installed in such a way as to enable free ventilation and thereby a reduced risk of decreased efficiency due to high temperatures. Being the tallest building in the landscape and virtually no nearby high vegetation, there is no risk of shadows or vegetation covering the panels. While snow might be present during parts of the year, the incline will be sufficient to shed this in a timely manner. While dust could accumulate, the high precipitation experienced in this area, together with the inclined installation, minimises the risk of reduced efficiency.

Since there is no scheduled maintenance regime in place due to the remote location and difficult to access panels. This means that even if the risk itself is very low, the potential reduction of efficiency could remain unknown for some time.

Figure 136: Crichton Castle and surrounding area, © Historic Environment Scotland

Fire safety

The panels themselves are designed based on the UL1703 Type 2 Fire Rating. The cable management and battery storage are furthermore subject to the normal fire safety regulations. Since this building is also only occupied during the day for part of the year, and most of the surrounding material is not flammable, the risk of fire is low.

Robustness/Buildability/Design/Application

The design and installation are fully compliant with the current standards.

Thermal bridges/Connection

Since the area of the building underneath the panels is not heated, thermal bridging is not a concern in this example. Additionally, the bolts were drilled into, but not through the concrete roof, providing no direct connection between the material.

Reversibility

The installation of the panels is fully reversible, as the panels, fixings and cabling can be removed, and the fixing holes backfilled with appropriate materials. The cabling is fixed into the mortar joins, which can be replaced as part of a normal maintenance routine. The batteries and other infrastructure are stored in free-standing cabinets and therefore have no direct fixings into any of the historic fabric.

Figure 137: The associated infrastructure in a free-standing setup, © Historic Environment ScotlandHeritage significance of the building and its settings

3.3.1.2 Heritage significance of the building and its settings

Risk of material, constructional, structural impact

Since the panels are attached to a modern flat roof, there is minimal impact to the historic structure. All service cables were routed through existing routes along the exterior of the stone wall. Possible fixings were drilled into the sacrificial layer of mortar between stones.

Risk of architectural, aesthetic, visual impact

Crichton Castle is a protected ruin of a former aristocratic seat within a largely uninhabited landscape. The vistas towards the castle on all sides are an important feature of the building. In order to minimise the visual and aesthetic impact, the panels were installed behind the historic parapet of one of the towers and are not visible from the ground level. The cables are initially run through an old chimney and along existing routes on the interior of the ruin. As all access points are temporary, there are no additional services visible either. As such, the architectural, aesthetic and visual impact of the installation has been kept to an absolute minimum.

The solar panels have replaced the formerly used petrol generator, which used to produce a significant amount of noise in an otherwise tranquil and picturesque site. As such, these solutions have added significant benefits to the overall aspect of the heritage site by removing a source of auditory disturbance.

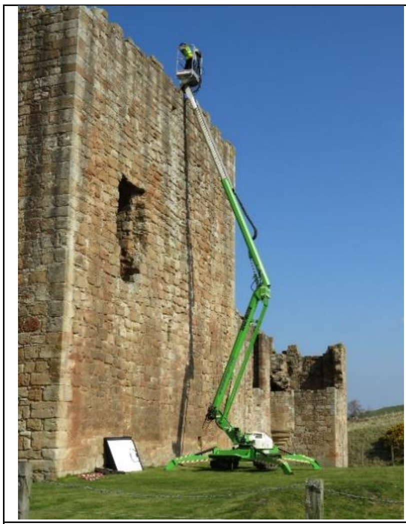

Figure 138: The temporary access and the façade after completed installation. Panels and cables are not visible even from the elevated position, © Historic Environment Scotland

Risk of spatial impact

As mentioned, Crichton Castle is situated in an isolated location without nearby buildings. Due to the location, there is no mains electricity, so the solar panels supply all the energy required in the building. As the building is only used seasonally and as a visitor attraction only open during the day, the energy use is comparatively low. As such, this is a solution most likely suitable to other similarly isolated buildings, however any higher energy consumption might require different setup or other backup.

3.3.1.3 Economic viability

Capital costs

The investment comes from within the organisation, with a view to create a greener and more sustainable estate. The total cost of the 2019 installation £8580 for the new batteries, new panels, their installation as well as the charge controllers. The cables, battery housings, fixings and inverter were retained from the 2005 installation. The old panels were retained and are currently in holding for future installation, as there is still a significant portion of the 25 year lifespan left. The reason for the replacement was the desire to obtain 100% of the energy required from the panels and only keep the oil generator as a backup.

Operating costs, including maintenance costs

The running and maintenance costs are difficult to calculate, as all the maintenance is done on an ad-hoc basis by the in-house staff. During the winter period when the building is not in regular use, the staff members perform routine maintenance such as charging the batteries to maintain their efficiency. This is done in conjunction with other tasks around the monument related to the conservation of the historic fabric.

Economical return

There is no information about the economic return. As the site is not connected to the mains electricity, the surplus electricity is not fed back into the grid.

Economic savings

The economic savings associated with this upgrade have to be compared to the previously used oil generator. This was used for 100% of the electricity and heating prior to the 2005 installation and was also used to supplement the energy produced by the old 1kW solar panels during the colder months between 2005 and 2019. The new solar panels are now able to supply 100% of the electricity necessary for the running of the site and heating requirements of the site. The oil generator is now only a backup for the winter months, when the site is not operational, if the solar panels are not providing enough energy to charge the batteries.

The direct savings are for the oil which is not bought anymore. In addition, the deliveries of oil are also no longer necessary as frequently as they were before, saving the economic equivalent of the time and fuel needed for these.

3.3.1.4 Energy

Energy performance and operational energy demand in terms of primary energy rating (total), primary energy rating (non-renewable), primary energy rating (renewable)

The panels have a 1.8kW peak production. It has a MPPT built into the system. The energy is stored in six deep cycle batteries. While the exact amount of energy used per year is highly variable, and not available at this point, 100% of the energy during normal operation is produced by the solar panels. The energy used is metered at the batteries. Any surplus energy collected but not stored and any energy leaking out from the batteries is not measured and is wasted.

Life cycle energy demand in terms of use of renewable primary energy and non-renewable primary energy

Life cycle analysis of the energy use is not available.

The product is Cradle to Cradle Certified$_{TM}$ Silver, a certification awarded if the materials and methods are safe and enable a circular economy.

3.3.1.5 Indoor environmental quality

Indoor environmental conditions suitable for achieving good occupant comfort levels

There has been no change to the indoor environment as a result of the installation.

3.3.1.6 Impact on the outdoor environment

Life cycle energy demand in terms of greenhouse gas emissions and emissions of harmful substances

There is no additional information about the emission of greenhouse gases during the production of the solar panels.

The solar panels are replacing an oil generator and are now producing 100% of the energy used during the time the monument is open to visitors. As such, there is a great reduction of the total use of oil and emission of greenhouse gases during the normal operation of the panels.

Natural resources use

There is no additional information about the use of raw materials of the panel. The Cradle to Cradle Certification$_{TM}$ does imply that considerations for the use of natural resources were made.

3.3.1.7 Aspects of use

Influence on the use and the users of the building & Consequences of the change of use

There is a reduced risk of the users such as the maintenance staff and visitors to be exposed to the fuel during delivery (staff only) as well as the fumes produced by the generator (staff and visitors). The considerable reduction in noise can also be considered a positive effect on the users.

In addition, the connection of the generator to produce electricity required staff to climb a ladder and run a cable through a small window. As such, not running the generator avoids the inconvenience and potential risk associated with this task.

Figure 139: *The generator, which requires cables to be run through one of the small windows, © Historic Environment Scotland.*

Ability of building users to manage and operate control systems

There is no direct user control and monitoring of the solar panels. There is an electricity meter measuring the electricity used from the batteries, which is checked periodically. No remote access to this data is available.

3.3.2 Roof and façade integrated Photovoltaic system for “Kohlesilo”, Solar Silo Basel (SWITZERLAND). Cristina Polo López, (SUPSI)

3.3.2.1 Technical compatibility

Hygrothermal risks

The external cladding consists of coloured frameless photovoltaic modules and fibre cement panels. The new façade consists of a layer of PV, a ventilating air space, and a layer of insulation, held by a wooden and aluminium substructure. The width of the air space behind the facade-integrated PV is 80 mm. This allows for the heat that is generated behind the modules to dissipate, which has a positive effect on their efficiency and output, also to allow effective ventilation of the roof and façade solution. As external thermal insulation, 200 mm mineral wool with a thermal conductivity of 0.035 W/(m2K) is used, whereby a U-value of 0.16 W/(m2K) has been reached.

The BIPV modules are ventilated and serve as the water-bearing stratum. Moisture accumulation on the back-side of the Photovoltaic module in this case in not probable as the solution is a ventilated façade. The existing reinforced concrete wall structure thanks to the use of external insulation is placed in stationary thermal and hygrometric conditions, despite the possible large differences in temperature and / or humidity between the exterior and the interior.

Besides, the external insulation placed over the original concrete surface of the building allows plus water repellence, identified as low capillary water absorption and diffusivity, which means low resistance to the diffusion of water vapor.

Wall

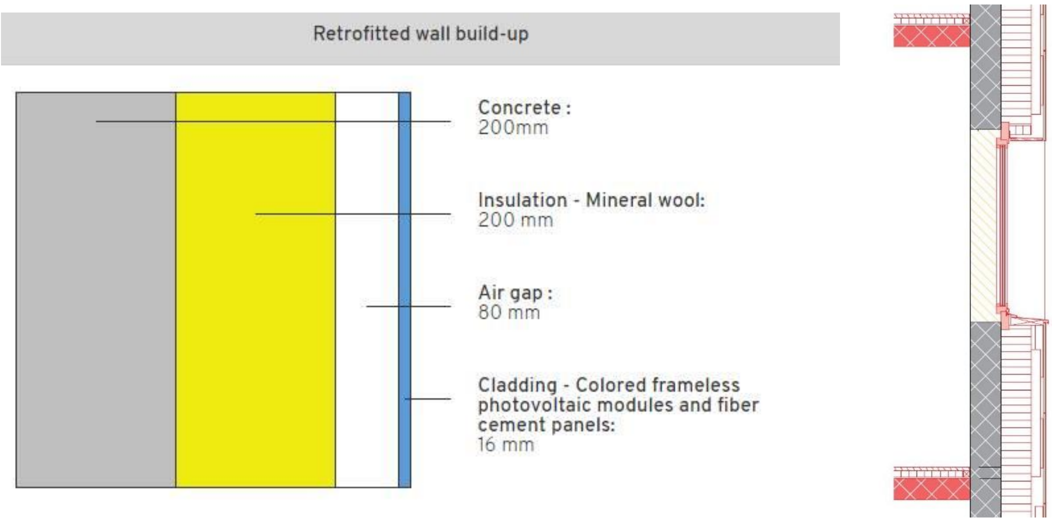

Figure 136: Cross section façade north. Source: © Baubüro in situ

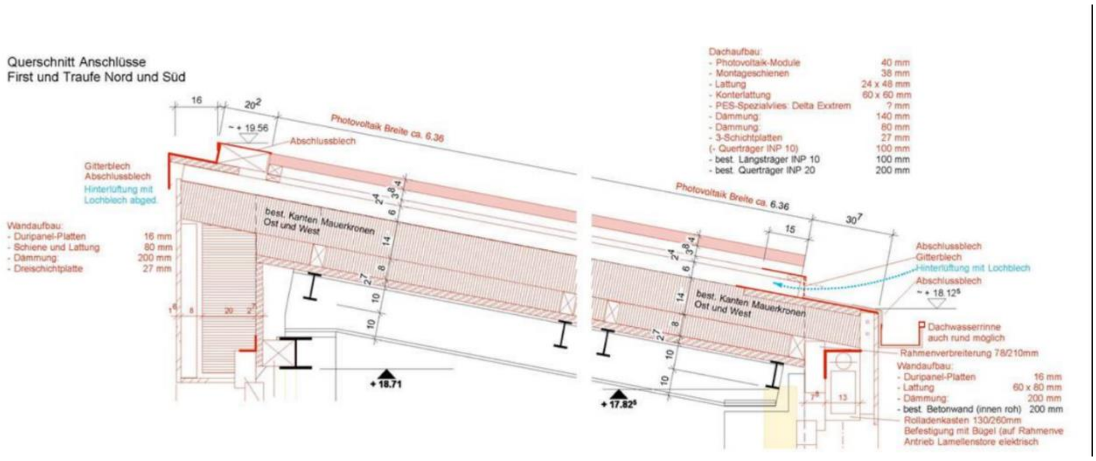

Figure 137: Cross section roof detail, © baubüro in situ

Structural risks

The BIPV modules (both for facade and roof installation) have not large or special dimensions. The BIPV system is made by innovative cutting edge photovoltaic coloured modules: Mono-crystalline solar cells, glass/glass (4 + 4mm) VSG laminated safety glass, both framed-standard sizes are integrated in the roof and custom-sized frameless glass-glass modules are integrated in the south and north façades. BIPV modules are subject to tests for the qualification of the design of a photovoltaic module according to the IEC standards, IEC 61730 (specific to safety and mechanical resistance). Standard IEC 61730 addresses requirements to ensure that PV modules provide electrical and mechanical operating safety during their entire expected service life. The laminated solar photovoltaic glass is defined as laminated glass that integrates the function of photovoltaic power generation and need to comply with ISO 12543 (Glass in building — Laminated glass and laminated safety glass) for application in buildings. New specific standards as ISO/TS 18178: Glass in building - Laminated solar photovoltaic glass for use in buildings and pr IEC 62980: Photovoltaic modules for building curtain wall applications are still under development and discussion within IEA-PVPS T15 activities. Structural and mechanical characterization for the climatic loads (wind, snow, etc.) related fixing systems, to safeguard adequate operational condition are considered in the standards test qualification. Besides to produce electrical energy, the solution will assure to protect against the falling risks.

The structural risks due to the risk of humidity in this case are not present since the PV system has been applied on the roof or in the ventilated wall with structural elements that are not vulnerable to humidity (aluminum substructure). However, the second wooden substructure could pose a slight risk for this reason, if not adequately protected.

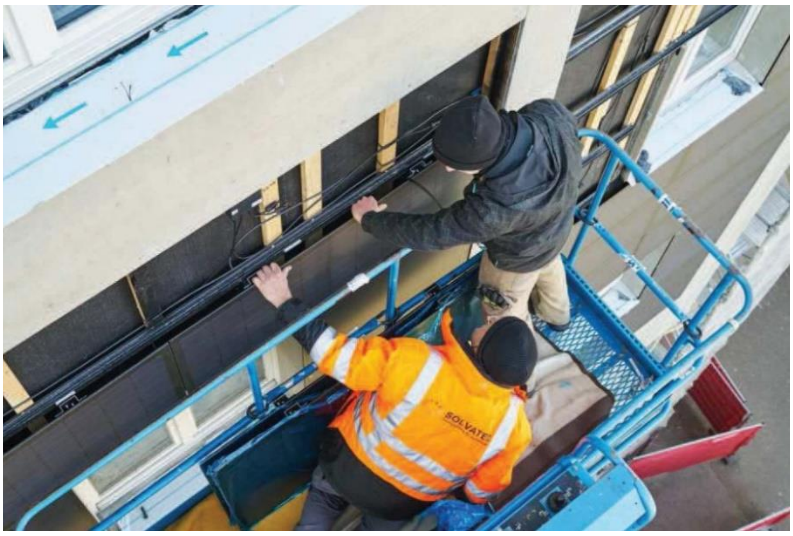

Figure 138: Installation of PV modules on back rails, . Picture: © Martin Zeller

Source: Kerstin Müller, Transformation of a historical coal bunker into a solar power station using multi-coloured BIPV, Proceedings of 10th Conference on Advanced Building Skins 2015, Bern, Switzerland.

Figure 139: Installation of PV and BIPV modules on the Roof, © Martin Zeller

Moisture safety

PV systems considered to be building-integrated (BIPV), only if the PV modules replace a building component providing a function as defined in the European Construction Product Regulation CPR 305/2011. Thus, the multi-functionality of the BIPV is a prerequisite for the integrity of the building's functionality and must be able to satisfy the same technological requirements of other similar construction cladding material (e.g. water-tightness, mechanical resistance, etc.). The solution fulfils with EC qualification standards to ensure the weather or thermal protection. VSG laminated safety BIPV glasses assure hail and weather protection and high resistance against mechanical influences and weather conditions.

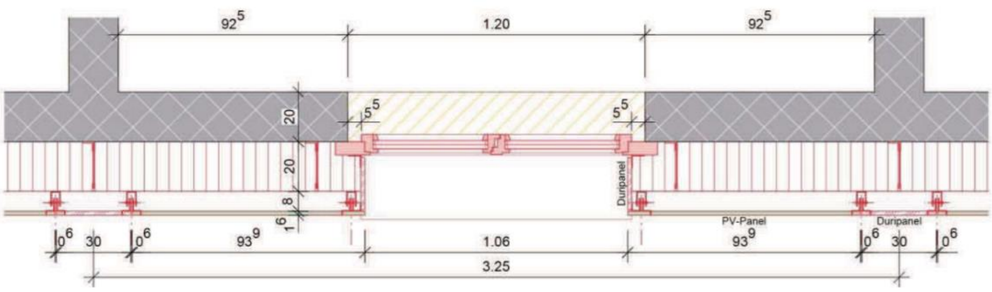

Figure 140: Cross section facade north, ©. Source: Baubüro in situ

Risk reduction efficiency

Ventilated BIPV solution (roof or façade mounting solution) reduce the risk of efficiency drop due to high thermal operating conditions in PV modules. The heat generated behind the modules can be properly dissipated, which has a positive effect on their efficiency and power yield output. The BIPV modules are frameless which allows to limit and even eliminate the possible accumulation of snow, dust or dirt, and at the same way there are not projected shadows on the solar cells which could limit the proper functioning of the PV plant facility.

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. In this pilot research project, coloured and innovative BIPV modules have been installed. Colours are black, green, blue, grey and gold. A special glass-cover to make invisible the solar cells that combines effects of diffuse surface and interference filters (Kromatix™ panels, https://www.swissinso.com/kohlensilo) were have been specially developed to integrate solar energy smoothly into the built environment with a minimal loss of efficiency. Tempering is usually mad after the coating, providing the high resistance of the coloured coating.

BIPV modules could be affected by external elements (such nearby trees or buildings, protruding elements, chimneys, dormers, etc.) which can affect seriously the performance. In this building, solar modules are perfectly integrated into the façade and the roof, so that they are completely in line with the other construction elements, avoiding possible shadows and hotspots, which cause system malfunctions and decrease efficiency over time.

Figure 141: South front, © P. Bonomo SUPSI

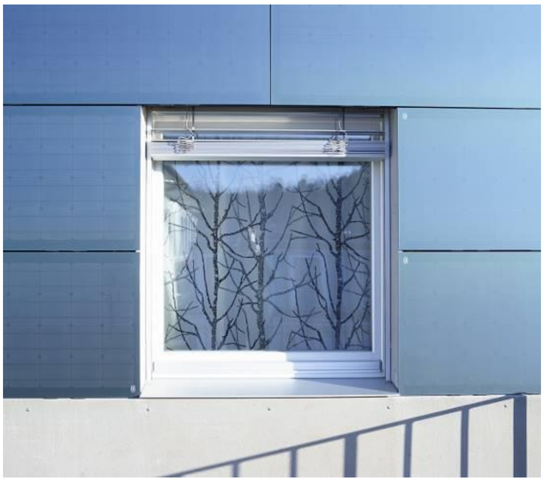

Figure 142: New window, © Martin Zeller

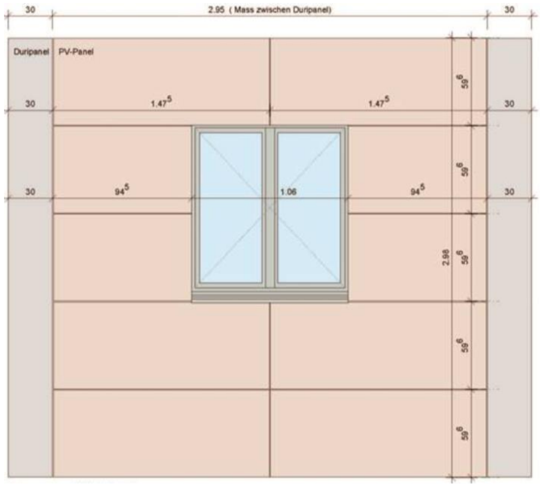

Figure 143: Detail window first floor, © baubüro in situ

Figure 144: Solar roof, © Martin Zeller

Fire safety

Fire prevention regulations has been taken into account at the design level and during construction; and it would be important to verify the accuracy of the installation at each stage, verifying the wiring connections, checking for the presence of debris accumulation under the panels and the ignition risks of the mounting structure. Particular electric connections in a PV or BIPV module, could be important to protect the DC-wiring of PV-systems against safety hazards due to electric arcing. Besides, defects in junction boxes, cold solder joints, loose screws, imprecisely bent connections and badly built cell connectors within the panels, could provoke electrical arcs in a very small area trigger to invisible hotspots. Despite the fact that low voltages at the inverter could reduce the risk of electrical arcs, in larger systems where several modules are connected in series and in parallel, the problem occurs that wiring faults can lead to an arc which can keep burning for a long time with risk on fire safety. In solar facades, for example, suitable solutions for the electrical connection need to be optimized for low-light conditions. Moreover, the connection technology needs to be easily accessible, i.e. not be mounted to the panels themselves or directly behind the facade. That would have fire-safety repercussions, in case of a hot spot in the electronics as a result of, e.g., a faulty connection.

In this case masking the busbars connections of solar cells with colour coating surfaces does not add hotspot but reduces the efficiency of cells by 7% of losses (Jolissaint et al., 2017)

Reference: Jolissaint N., Hanbali R., Hadorn J-C., Shüler A., Coloured solar facades for buildings, Energy Procedia 2017, 122, (2017) pp. 175-180.

Robustness/Buildability/design/Application

Currently, the performance capabilities of innovative technologies (e.g. coloured coating solar modules) are tested on in standard testing conditions (STC), according to IEC standard procedures. Nonetheless most projects require IEC and/or UL certification to ensure a minimum level of module robustness. Notwithstanding, it is widely accepted that these certification standards are not sufficient enough to demonstrate new BIPV module reliability and performances as this approach does not consider real operation conditions, while if integrated in buildings. This project is a pilot research project, which is being monitored to understand better the BIPV performances under real installation conditions. The measurements serve to optimize the PV system and to investigate the effects of the different colours on the PV performance.

Thermal bridges/Connection

The building envelope was thermally insulated without thermal bridges. As external thermal insulation, 200 mm mineral wool with a thermal conductivity of 0.035 W/(m2K) is used, whereby a U-value of 0.16 W/(m2K) has been reached.

The northern and southern facade (as well as the roof) are equipped with coloured PV modules, the east and west facades are plastered. The cladding ventilated facade consists of coloured frameless photovoltaic modules and fibre-cement panels. The building envelope has been made airtight according to the SIA 180 standard, in particular since the premises that were previously not heated and consequently not even airtight, are now perfectly habitable. The SIA standard requires that all the connections between the construction elements, for example between the window frame and the masonry, are carefully executed. However, no tightness tests were performed.

Reversibility

The solar system is easily removable like other ventilated roof or facades. Nevertheless, the entire envelope of the building has been energetically upgraded by using new insulating layer with external thermal insulation of 200 mm mineral wool attached to the original concrete wall.

A visual change in the exterior finish has occur with respect to original status. However, 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.

Figure 145: Roof image, © Martin Zeller

3.3.2.2 Heritage significance of the building and its settings

Risk of material, constructional, structural impact

The internal structure of the four coal silos was kept in the interiors, only internal doors were cut out of the concrete shafts. On the outside, the four shafts can be read by looking at the façade (four vertical sections in the façade). Risk of material, constructional, structural impact has been explained in detail under technical compatibility.

Risk of architectural, aesthetic, visual impact

As "Gundeldinger Feld" ensemble is under heritage protection, the remodelled building was required to match the style and colour scheme of the site. In 1999 the industrial production abandoned the area. The industrial coal silo has been modernized and was completely converted into an energy efficiency multi-purpose building. The building is remodelled from coal silo into office spaces.

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. There is no protection on the building but the cooperation with the department for building conservation went well.

Figure 146: Building after intervention (north and south elevation), © Martin Zeller

Risk of spatial impact

The former site of the Sulzer Burckhardt AG in the “Gundeldingen“ neighbourhood in Basel has changed in the last 16 years from an industrial area into a vibrant place with a variety of uses. This transformation process of the “Gundeldinger Feld“ was accompanied by the establishment of cultural, social and commercial uses and has had a positive impact on the immediate environment and the neighbourhood. The project is part of the "2000-Watt society - pilot region Basel" and Solar Silo project that was rewarded in the "renovation" category with the 2015 Swiss Solar Prize, as model best practice example of refurbishment project.

The changes do not influence any conservation aspects. The handling of the existing building fabric, the design quality of the solar systems, the embedding of the energy concept in an entire area and the checking of the energetic quality in operation justify the Swiss Solar Prize 2015 for the coal silo in Basel.

Furthermore, as BIPV is integrated in the roof and the facades of the solar silo building, the solar field take up 80 m2 and produces the same amount of electricity as the flat roof of the closest building in the area, fully covered with standard modules but using three times the floor surface rate (Jolissaint et al., 2017).

Figure 147: Building and surrounding area after intervention., © Martin Zeller

Reference: Jolissaint N., Hanbali R., Hadorn J-C., Shüler A., Coloured solar facades for buildings, Energy Procedia 2017, 122, pp. 175-180.

3.3.2.3 Economic viability

Capital costs

The “Amt für Umwelt und Energie Kanton Basel-Stadt“ (Office of Environment and Energy canton Basel-Stadt) and the “Bundesamt für Energie“ (Federal Office of Energy) gave financial support for the coloured BIPV, BES and monitoring. The building, which kept the old name “coal silo”, is being funded as a pilot project by the Office for Environment and Energy of the Canton of Basel City and the Federal Office for Energy and is supported by the University of Applied Sciences Northwestern Switzerland (FHNW).

The project is part of the "2000-watt society - pilot region Basel".

Operating costs, including maintenance costs

There is no information about running and operating cost

Economical return

There is no information about economical return cost. However, the innovation in the solar system used and the big renovation project of a complete neighbourhood, as model for testing and demonstration site within the "2000-Watt society - pilot region Basel" in order to promote uptake of sustainability urban development in Switzerland, justify the major investment cost and the necessity of public subsidies.

Economic savings

Color BIPV modules were used on the roof as well as on the south and north façades. The 159 m2 solar plant is fully integrated and generates 16,400 kWh of solar power annually. It covers around 37% of the building's total energy requirement of 44,400 kWh / a.

The possibility to use energy storage is being assessment. In order to increase self-consumption on the site, storage is used on second-hand accumulators, made up of used Li-ion batteries, obtained from electro-mobility.

3.3.2.4 Energy

Energy performance and operational energy demand in terms of primary energy rating (total), primary energy rating (non-renewable), primary energy rating (renewable)

In order to optimize the self-consumption of electricity in the area, a “second-life battery storage” made of used lithium-ion batteries from electromobility were installed. Monitoring records the performance data of each BIPV module. The measurements serve to optimize the 24 kW PV system and to investigate the effects of the different colours on the PV performance.

Life cycle energy demand in terms of use of renewable primary energy and non-renewable primary energy

LCA analysis is not available.

3.3.2.5 Indoor environmental quality

Indoor environmental conditions suitable for achieving good occupant comfort levels

The building is connected since many years at the district heating net from the waste disposal plant IWB Basel (Industrielle Werke Basel).

The completely new windows offer optimal thermal and sound protection but in particular they allow to illuminate and aerate the internal spaces in a natural way, which house completely different uses from the original ones. The floor area is rather small, so the day light is sufficient. Ventilation occurs naturally. The interior of the individual floors has been individually adapted by the users and internal temperature is adjusted by the tenants. They use thermostats for the regulation. In the biggest rooms, which are not permanently occupied, some decentral gas heaters are occasionally used to warm up.

The building envelope was thermally insulated. The northern and southern facade (as well as the roof) are equipped with coloured PV modules, the east and west facades are plastered. The cladding ventilated facade consists of coloured frameless photovoltaic modules and fibre cement panels. The ventilated and well insulated BIPV solar roof and façade contribute to avoid overheating the indoor spaces and to increase energy efficiency of the building.

Figure 148: Interior view of the building (spaces under the roof solar plant), © Martin Zeller

3.3.2.6 Impact on the outdoor environment

Life cycle energy demand in terms of greenhouse gas emissions and emissions of harmful substances

There is no information.

Natural resources use

There is no information.

Many of the core components of solar panels can be recycled on their own. Metal, glass, and wiring can all be recycled and reused. Silicon cells and silicon wafers are not recyclable like glass and plastic are, some specialty recycling companies are able to reuse silicon cells by melting them down and reclaiming the silicon and various metals. The non-profit PV Cycle Association in Europe to collect and recycle solar panels

3.3.2.7 Aspects of use

Influence on the use and the users of the building & Consequences of the change of use

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.

No information about additional maintenance cost due the singularities of the BIPV solar systems, as the same to other standard PV plants

.Ability of building users to manage and operate control systems

There is no information regarding the control of the solar plant production (RES plant). The solar plant is being monitored to optimize the final energy yield and to investigate the effects of the different colours on the PV performance.

3.3.3 Roof integrated Photovoltaic system for Villa Castelli (ITALY) – Antonello Durante (Eurac Research)

3.3.3.1 Technical compatibility

Hygrothermal risks

There is minimal or no hygrothermal risk associated with the installation of the panels. The panels are glued to the roof surface.

Structural risks

The structure used for this purpose was a newly refurbished metal roof. Panels were attached directly to the roof using special glue. Due to the nature of the roof and the nature of the panels, the latter was considered acceptable and did not present any structural risk or additional risk of humidity for the adjacent materials to the panels.

Figure 140*: The PV panel applied on the metal roof,© Valentina Carì Progetto Serr@*

The photovoltaic panels are composed of monocrystalline solar cells incorporated in plastic. They are designed according to the standards IEC 61252 in terms of the longevity of the panels and IEC 61730 for electrical and mechanical safety.

Moisture safety

The panels were integrated into the roof and did not replace any roof components. They were installed according to standards and manufacturer's guidelines.

Risk reduction efficiency

During the design phase, a solar diagram was used for simulating the shading trend over the day and the year; that allowed an estimate of the average monthly losses of the system and helped its correct dimensioning.

Fire safety

Given this unique technology of the PV cells which are encapsulated in plastic, there are limited fire risks.

Robustness/Buildability/Design/Application

The design and installation are fully compliant with the current standards.

Thermal bridges/Connection

The panels are encapsulated in plastic and glued to the roof, so they are not subject to thermal bridges. The panels are lightweight, so they do not impact the roof and are walkable, facilitating the maintenance of both the panels and the roof.

Figure 141: The PV panel applied on the metal roof and connection cables, © Valentina Carì Progetto serr@

Reversibility

The panels are glued to the roof. The glue's thermal expansion coefficient is similar to that of the metal cover where PV panels are fixed. Given this unique technology, the system has a sufficiently high reversibility degree. The colour of the metal roof is very similar to that of the PV panels, so easy reversibility might be provided with minor variation in colour and shapes.

3.3.3.2 Heritage significance of the building and its settings

Risk of material, constructional, structural impact

Since the panels are attached to a renovated metal pitched roof, there is no impact on the historic structure. All service cables were routed through routes built on purpose. Possible fixings were drilled into specific points without consistent damage to the historic fabric.

Risk of architectural, aesthetic, visual impact

The aesthetic impact of the roof-integrated PV panels was based on the following criteria: (i) coplanarity; (ii) compliance with the lines; (iii) consistency with the roof pitch shape and dimensions; (iv) grouping of panels; (v) attention to detail and (vi) colour and reflectivity. The panels and the new roof were almost on the same plane due to the thin-film panels. The panels were installed according to the original roof symmetry lines. The panels were designed to conceal the triangular or trapezoidal shape of the pitches. A homogeneous coating surface could be perceived from the surroundings.

They are of the same colour as the metallic roof cover, are ultra-thin and glued to the roof with special glue. Also, the dark-greyish colour of the metal roof is similar to the colour of the area's traditional stone roofs. For these reasons, the panels are not visible from a long distance (e.g. from the lake) because their reflectance value is similar to the roof aluminium finish. Due to these features, the aesthetic impact of the BIPV system is limited. Therefore the historical value of the villa is not affected.

Figure 151: Aesthetic integration of the PV system, © Valentina Carì Progetto Serr@

Risk of spatial impact

The PV architectural integration in Villa Castelli followed a complex design process. As a result, three prototypes have been developed: (i) classic polycrystalline photovoltaic cells with transparent support made combining two glass sheets; (ii) panel made by greyish and greenish small cells of a size similar to stone-made local roof tiles; (iii) thin-film BIPV modules applied on a metal cover. The first solution resulted poorly integrated, while the second, although aesthetically integrated, was not walkable and required complex maintenance. For these reasons, the third solution was chosen.


(ii)


(iii)

Figure 142: Different PV system approached tested, © Valentina Carì Progetto Serr@

3.3.3.3 Economic viability

Capital costs

The BIPV system for Villa Castelli costed 490 euros/m2 approximately. Given that an innovative technology made by flexible PV panels was used, capital costs are higher than traditional systems. On the contrary, the installation has led to economic savings because the panels were applied through a particular glue; no other fixing components were needed. Furthermore, due to their ultra-lightweight, the modules were more manageable than traditional walkable modules: this overall reduced installation time and costs.

Operating costs, including maintenance costs

The maintenance of the PV system is similar to that of a system with ordinary walkable panels. The plastic film used as an encapsulant for the silicon cells, even if with a long lifetime, as guaranteed by the manufacturers, could deteriorate more quickly than traditional systems using glass supports. This would affect operating costs when considering an extended life cycle of the system or would limit the reuse of the panels in other contexts if that foreseen.

Economical return

Given the reduced productivity of the flexible plastic components compared to traditional systems, the total surface of the modules needed to obtain the desired production had to be considerably greater than an ordinary system, and this might postpone the economic return. There is no further information available about the economic return.

Economic savings

The economic savings associated with the installation of the PV system is remarkable. The new solar panels are now able to supply 100% of the electricity necessary for the house. The insolation procedures and the adoption of other appropriate energy-saving systems and appliances during the refurbishment of the villa made it possible. The ten kWp photovoltaic system produces more than the power needed. This decision is based on the estimate for possible future consumption and the need to maximise electricity production compared to the available surface.

3.3.3.4 Energy

Energy performance and operational energy demand in terms of primary energy rating (total), primary energy rating (non-renewable), primary energy rating (renewable)

Villa Castelli's PV system consists of inverters, a system for monitoring and measuring production and consumption and a series of radio sockets that allow direct management of the system's loads. The monitoring system continuously receives PV production data and the data for entering and withdrawing energy from the grid. Furthermore, through the available meteorological data, the monitoring system determines a producibility forecast and based on the latter, it rationalises the automatic activation of controlled loads. This process optimises the system's use by superimposing the production and consumption data and allows, especially in the case of excess energy produced, to increase self-consumption dynamically through the activation of the controlled loads. The absorbing surface, which is equal to 10 kWp, uses the extension of the coverage and ensures a low visual impact. During the design phase, a solar diagram was used. By simulating the shading trend over the day and a year, an estimate of the average monthly losses was made possible. The choice for installing a 10 kWp photovoltaic system is based on the estimate of possible future consumption and on the need for maximising electricity production in relation to the available surface.

Life cycle energy demand in terms of use of renewable primary energy and non-renewable primary energy

Life cycle energy demand data are not available.

3.3.3.5 Indoor environmental quality

There has been no change to the indoor environment as a result of the installation.

3.3.3.6 Impact on the outdoor

Life cycle energy demand in terms of greenhouse gas emissions and emissions of harmful substances Capital costs

There is no additional information about the emission of greenhouse gases during the production of the solar panels. In compliance with The Restriction of Hazardous Substances Directive 2002/95/EC, the RoHS certification does imply that considerations for the use of greenhouse gas emissions and emission of harmful substances were made.

Natural resources use

There is no additional information about the use of raw materials of the panel. The RoHS certification does imply that considerations for the use of natural resources were made.

3.3.3.7 Aspect of Use

Influence of the use and the users of the building & Consequences of the change of use

Due to the PV system installation and a complete refurbishment of the villa, the energy consumption is reduced by 90%. Villa Castelli is surrounded by a historic garden so that the roof-mounted panels need some extra maintenance for cleaning in addition to the rain that might be not sufficient to wash the dirt away.

Ability of building users to manage and operate control systems

A control and monitoring system of the roof-mounted solar panels was installed.

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