bFAST: a methodology for assessing the solar potential of façades in existing building stocks

Pierluigi Bonomo[1], Cristina S. Polo López[1], Erika Saretta[1,2], Paolo Corti[1], Francesco Frontini[1]

1 ISAAC-SUPSI, Campus Trevano, CH 6952, Canobbio, Lugano (Switzerland)

2 Department of Architecture, Built environment and Construction Engineering, Politecnico di Milano, Italy

Abstract

The research presented in this paper proposes a new approach to assess the solar potential for photovoltaic (PV) integration in façades of existing buildings, by evaluating both energy and building features of the built environment. Since the feasibility of a BIPV plant, especially in façade, is strictly related to the construction compatibility and not only to the energy exploitability of surfaces, a key-part of the project focuses on the definition of a methodology to move the assessment from a "theoretical solar potential", actually provided by solar mapping tools, to a "more realistic" estimation considering the building with its typological and technical/constructive constraints together with urban morphology. The implementation of the main project results, developed within the project bFAST co-financed by Fondo Energie Rinnovabili (FER) of the Canton of Ticino, can be replicated in order to create the impact to support the transfer and implementation of integrated PV (BIPV) in the renovation of the built environment in the next years. The article provides an overview of this research by presenting the main motivations, methodological aspects and discussion on results.

Keywords: building integrated photovoltaics- BIPV, solar potential, solar mapping, energy retrofit, façade

1. Introduction

The Swiss Federal Energy Strategy 2050, implemented at local level in the building sector (MuKEn/MoPEC, 2014), emphasizes the key role of combining energy efficiency and integration of renewable solar energy (RES) for a sustainable refurbishment of the existing building stock. At cantonal level, the expected potential for the coming years, as targeted on the Cantonal Energy Plan (PEC), is to achieve a production of 280 GWh per year of electricity through PV, representing the 7% of electricity production expected (Cereghetti and Pampuri, 2013). Even though the goal to reach 99 MW by 2035 is already achieved at 45% (Impianti fotovoltaici in Ticino, 2017), there is a great potential not yet exploited in the façades of existing buildings, mostly of which will require an energy retrofit in the coming years. According to the policy to use the built environment as a strategic priority for solar integration, this topic calls into considerations greater complexity than PV roofs, opening up also the role of façades in the solar exploitation as well as the need of an integrated assessment of energy, architectural and technological-constructive aspects of the built environment. As solar map of Canton of Ticino (www.oasi.ti.ch) is already implemented as a decision making tool for supporting the preliminary estimation of solar potential in roofs, Sonnenfassade for Swiss buildings (www.uvek-gis.admin.ch/BFE/sonnenfassade/) represents one of the unique examples of solar maps for building vertical surfaces. However, such an existing solar mapping platforms quantify the potential of the building surfaces by mainly considering the gross area and the incident solar radiation. Their purpose is not to quantify the "real" solar potential in an urban context as it would be required in a project phase (Mavromatidis et al. 2015; Peronato G. et al. 2016), but rather to provide an indicative scenario by displaying the expected suitability degree based on the available irradiation of the building surfaces (Kanters, et al. 2014). It emerges as typological elements such as windows, balconies, volumes or eaves, which typically have a strong impact and create barriers reducing the solar potential of the building skin, are not taken into consideration. Within the research we introduced building criteria in the procedure of evaluation of the solar potential for building façades, developing a new methodology for the identification of solar PV/BIPV potential on façades in the Canton of Ticino.

2. Method

As explained in Figure 1, a first phase of the work concerned an analysis of the cantonal building stock with the goal to define the main potentials for solar integration at urban level (e.g. most relevant categories according to building uses, year of construction, energy and refurbishment needs, etc.) and to define alternatives representing the most frequent façade archetypes (1, in Fig.1). Afterwards, reference parameters conditioning PV integration have been identified, by including both quantitative and qualitative typological “indicators”. For each façade type, the relative ranges of variability (e.g. reduction factors due to overhang or balconies projection or length, window surfaces, etc.) have been analyzed and synthetized with reference to relevant scenarios (2, in Fig.1); these "indicators", considered as positive or negative aspects affecting PV integration, have been adopted as the basic input for the methodology to calculate the final value closer to the real solar potential through the equation of solar potential introduced in the project (3, in Fig.1) and then validated through real case studies (4, in Fig.1).

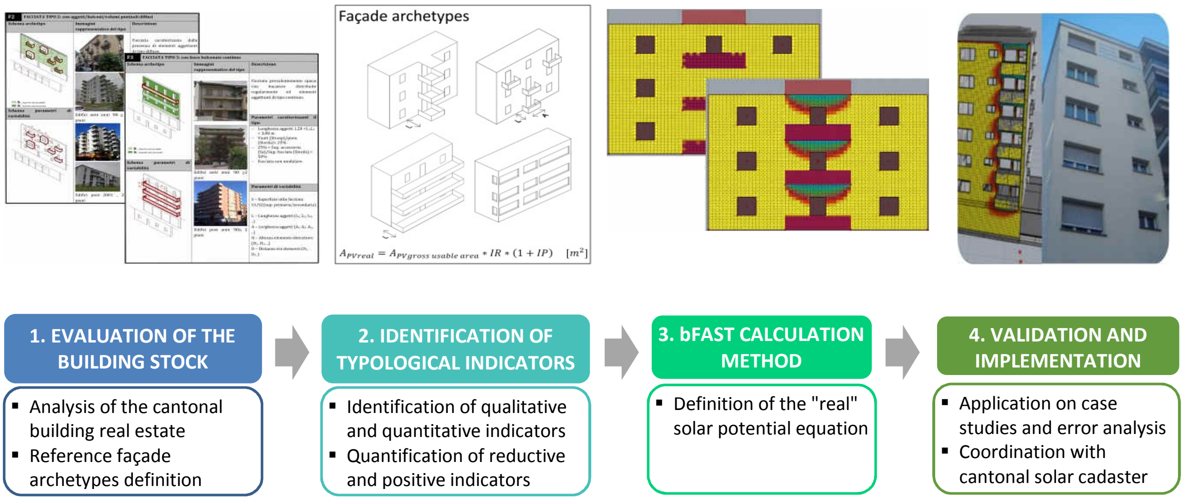


Fig. 1: Methodological process of bFAST research project

The evaluation and statistical analysis of the buildings in Ticino has also been useful to characterize the building stock and to select different façade archetypes as representative of architectural and typological parameters affecting solar potential. BIPV technological solutions were collected and a technical-economic estimation of the BIPV façade systems corresponding to significant types were carried out as case studies.

2.1 Evaluation of the building stock

The first analysis, on the basis of statistical evaluations made on different available datasets, such as the federal Register of Buildings and Dwellings RBD, the Building Programme data (2010-2016) for energy retrofit of buildings and the Cantonal Energy Certificate of Buildings (CECE®) data since 2009, the Canton Ticino building stock consists mainly of **residential buildings** (96.28 % that’s account for 108’817 of a total of 113'023 buildings analyzed), as seen in Figure 2.a and Figure 2.b. The most relevant part (up to 70%) was built **before 1980** thus figuring out the need for an energetic retrofit in the coming years (e.g. 45.2% with low thermal insulation, on a sample of 1'520 buildings, see Figure 3.a). However, from the data processed in the annual reports of the Building Incentives Program, it appears that only a small percentage of buildings (2.9% if we consider the analyzed Ticino real estate) have requested financing for the **renovation**. Of the former (see Figure 3.b), only 8.9% refers to the request for financing for the rehabilitation of façades, while the highest percentage of applications was for the rehabilitation of roofs and windows. Most of the buildings (78% in residential, 52% in commercial / service buildings and 49% in industrial buildings) are between two and three storeys; In multi-family buildings a high percentage is represented by buildings with heights of more than four and five floors (see Figure 3.c). On the other hand, if we consider only multi-family residential buildings,the requests made so far (for energy renovation represent only 3.5%. This means that 96.5% of the multi-family buildings are yet to be rehabilitated and can benefit from a combined intervention including both facade energy retrofit and the use of active solar systems. This is relevant also considering that multi-family buildings (category I) are characterized by a high energy consumption rate, essentially twice the energy consumed by single-family houses (category II), as showed in Figure 4.a).

The study also confirms a significant potential for the use of solar systems in façades at the cantonal/regional level: considering only residential buildings, the total estimated gross usable façade area is about 41.67 km^2 as presented in Figure 4.b. If only the 5% of all theoretical gross façade area available was used to integrate solar systems (which corresponds to 2.24 km^2 for the total of buildings and 0.99 km^2 only for multi-family houses), considering a

PV exploitation factor of 1 kWp/10 m^2 and an average energy yield of 500 kWh/kWp, this could generate about 112 GWh/year at Cantonal level, namely configuring a realistic contribution of facades for about 43% to the Cantonal Energy Plan. The total estimated economic value for the construction of these photovoltaic façades could be around CHF 1.43 billion (Table 1).

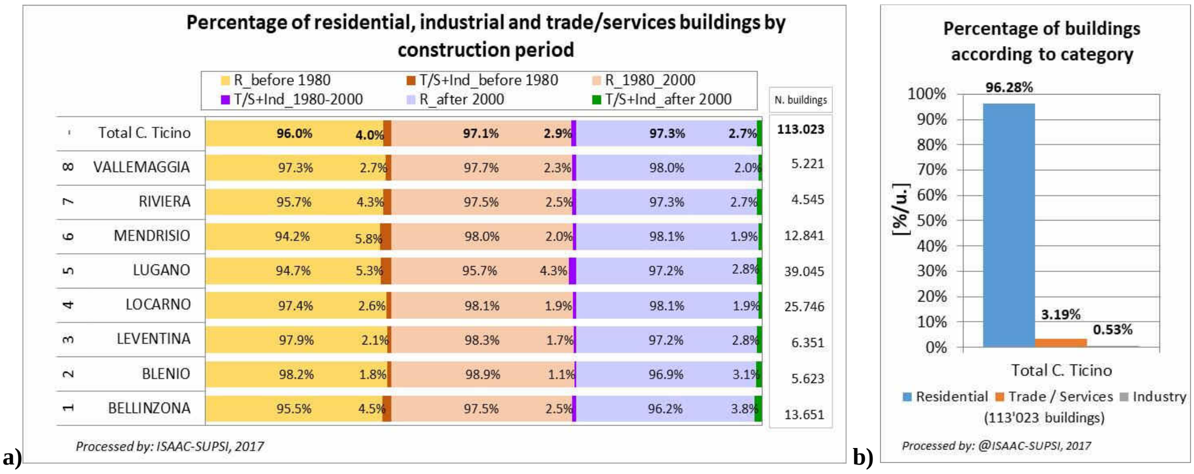


Fig. 2: Share of buildings [%] residential, industrial and trade / services by construction period (total percentage of the number of buildings in each district. Source: RDB, processed by SUPSI).

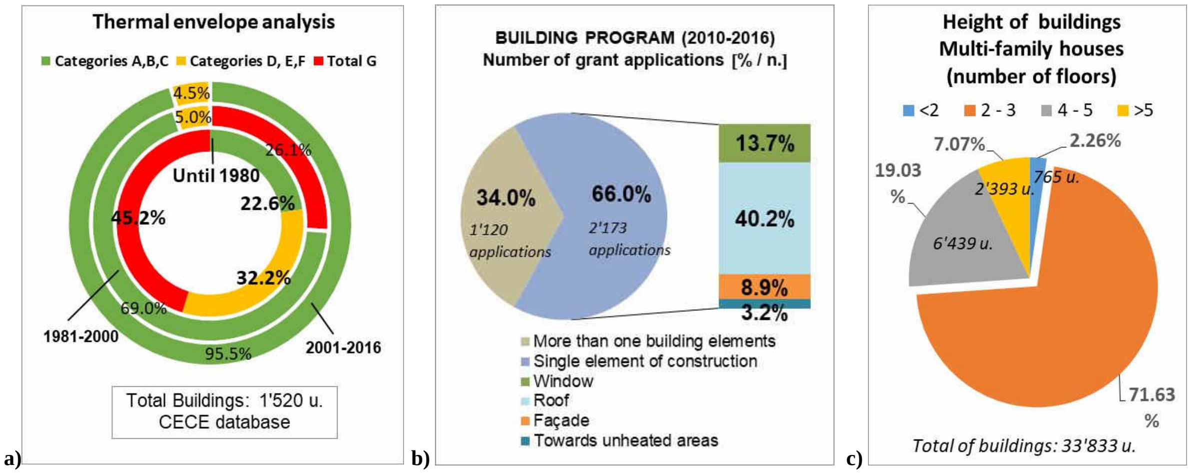


Fig. 3: Statistical data processed for Ticino: a) Evaluation of the thermal envelope, in the different building construction periods (before 1880, from 1 981 to 2000 and from 2001 to 2016) and distribution for efficiency classes (Categories A, B, C and D, E, F and G). Source: CECE®, processed by SUPSI; b) Buildings Program, number of requests for funding [% / n.] carried out in the Canton of Ticino, in the period 2010-2016 and percentage distribution for individual elements of construction refurbished; c) Height of buildings in Ticino [num. plans], in residential buildings (multi -family houses). Source: Building Program, processed by SUPSI

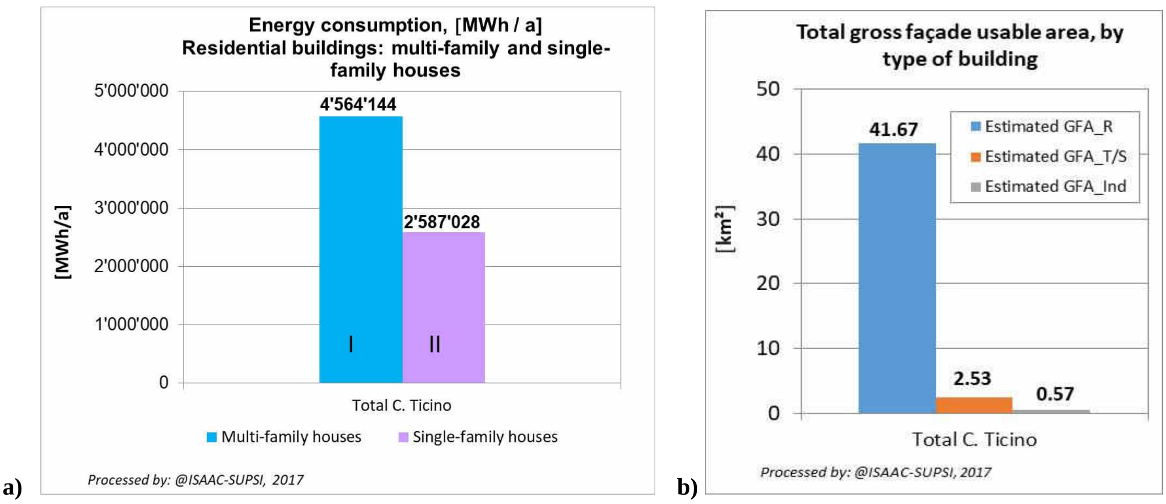


Fig. 4: a) Energy consumption [MWh / year] of residential buildings: multi-family (I) and single-family (II) houses; b) Estimated gross façade usable area by typologies (R, Residential buildings; T/S, trade and services; Ind, Industry buildings). Source: RDB, processed by SUPSI

Tab. 1: Estimated gross area available on façades, calculated active PV power [MWp], annual energy production [MWh] and estimated economic value of the installation [CHF]

Canton of Ticino Building Stock	Estimated Gross Façade Area (GFA)	Estimated active PV area on façades[2]	Estimated active PV power[3]	Estimated annual energy produced by façades	Estimated economic value
	(GFA)	[Km^2]	[MWp]	[GWh]	[CHF millions]
Total Buildings[1]	44.77	2.24	224	112	1’456
Residential buildings	41.67	2.08	208	104	1’352
- Multi-family houses	19.79	0.99	99	50	643.5

[1] *Residential, Trade/Services and Industry buildings*
[2] *Corrective factor: 5% of GFA*
[3]*Assumptions: PV exploitation factor of 1 kWp/10 m^2 and an equivalent average energy yield of 500 kWh/kWp*

2.2 Identification of typological indicators

The analysis and evaluation of reference typological archetypes, representing the local settlements, was used to define a catalog of main facade types. Reference typological **façade archetypes** were identified among all residential real estate of Ticino (see Figure 5 and Figure 6), in order to define quantitative and qualitative typological “indicators” by determining their relative ranges of variability (e.g. overhang or balconies projection or length, window surfaces, etc.), as positive or negative aspects for solar PV integration.

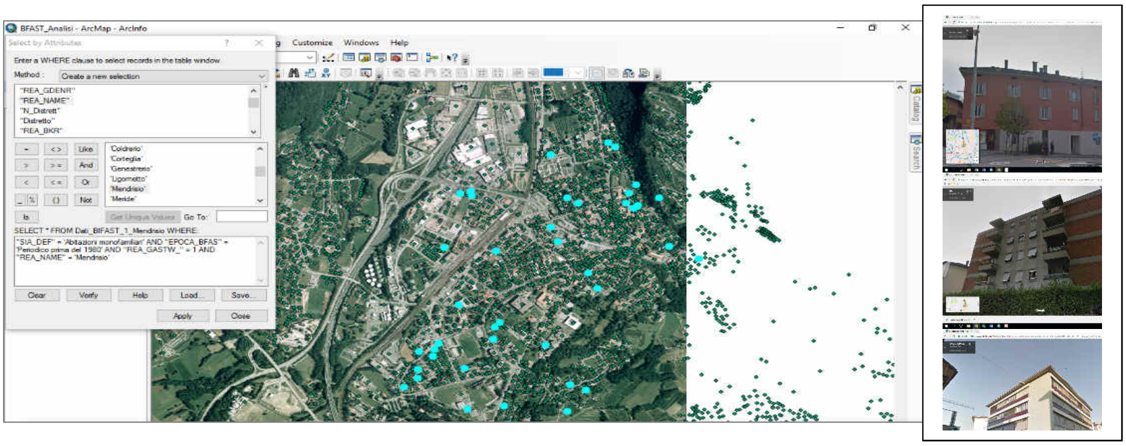


Fig. 5: GIS platform used for research on the cantonal territory of the typological classes to be further analyzed.

The method adopted, therefore, as a consequence of a systematic analysis of the Ticino real estate, is based on the definition of a typological abacus of the facades which characterize the type of building analyzed. Ten different types of façades were identified and then analyzed, with particular reference to the multi-family residential category, identified as a strategic intervention areas.

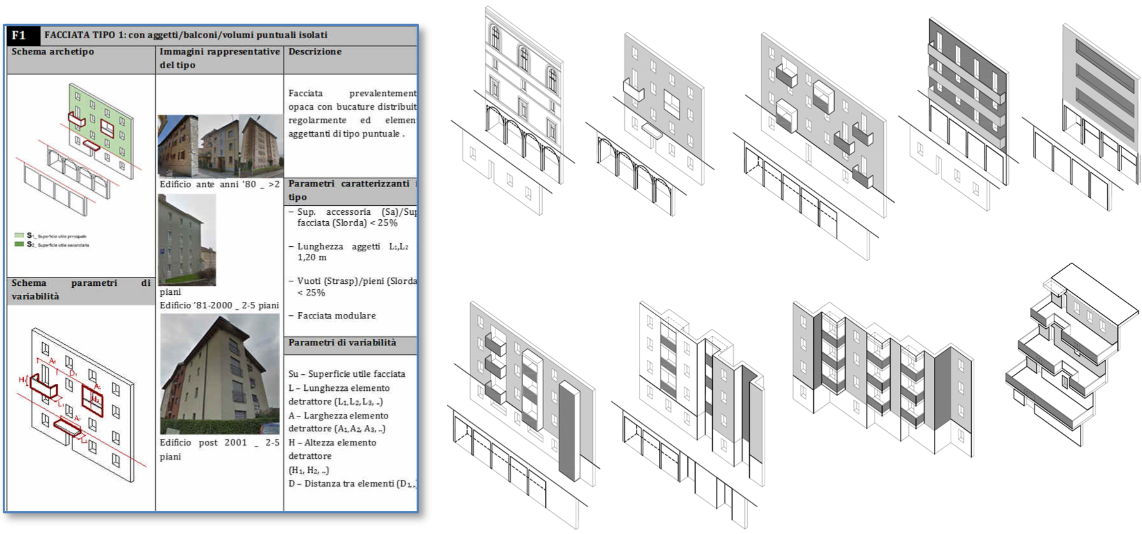


Fig. 6: Façade archetypes defined (source: ISAAC-SUPSI).

Each type of façade is therefore distinguished and evaluated on the basis of some parameters defined as "**indicators**" useful for estimating the solar potential (*quantitative parameters*), such as the relationship between opaque and transparent surface, the reduction due to protruding elements, technological systems in facade, accessory elements). Other criteria, in relation to the greater / less ease of integration of solar systems, defined in the study as *qualitative parameters* (e.g. construction type, modularity of the façade, surface finishing envelope), have not been evaluated but only indicated since they were not the main aim of the research.

The set of parameters considered for each type of façade will result in a global indicator with the aim of expressing, through a synthesis quantity (e.g. a numerical coefficient through which to reduce the available gross surface of the façade), the largest or lower applicability of a solar system, for each type of façade assessed.

2.3 bFAST calculation method

The calculation method presented in this study has been developed starting from the existing solar cadaster of facades for Swiss buildings, named Sonnenfassade (Figure 7).

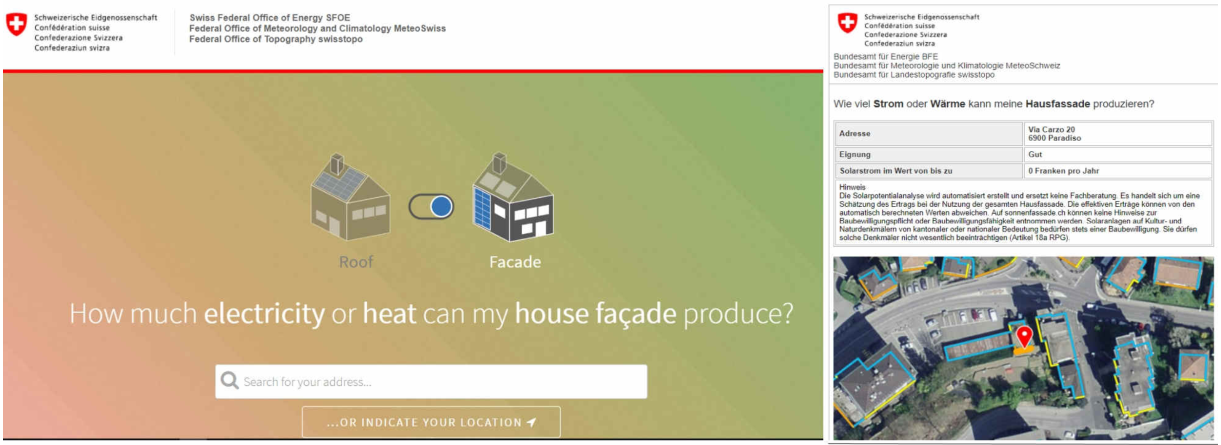


Fig. 7: Swiss Sonnenfassade Web platform for calculating solar façades potential throughout the country (www.uvek-gis.admin.ch/BFE/sonnenfassade).

In the current Web platform (Figure 7), it is possible to obtain, for individual geometric sub-sections in which the façade is discretized according to the geometric survey, the solar potential of the selected surface. In detail, this solar cadaster provides the annual solar potential for every façade of each building, as described in the following Eq. 1.

$$Solar\ Potential\ [kWh\ /\ y] = S_{gr}\ [m^2] \cdot IRR_{avg}\ [\ kWh/m^2y\ ] \qquad \text{(eq. 1)}$$

Where "S_{gr}" and "IRR_{avg}" represent respectively the gross surface of a façade as reported by swissBUILDING3D 2.0 and the average yearly irradiation value, calculated in the middle point of the façade (SFOE, 2016).

Even though this solar cadaster is one of the more advanced, it approximates the façade area considering the gross surface, thus not including the presence of architectural elements (e.g. openings, balconies…), which significantly affect the solar potential. Hence, the calculation method developed by authors aims at taking into account typical façade elements of archetypes by means of reduction/ additional indicators (Equation 2), which are multiplied to the gross surface of the façade to obtain the "real" opaque area suitable for BIPV (Equation 3). Therefore, the equations for the calculation of the BIPV potential of facades are the following ones:

$$BIPV\ Potential\ [kWh\ /\ y] = S_{BIPV}\ [m^2] \cdot IRR_{avg}\ [\ kWh/m^2y\ ] \qquad \text{(eq. 2)}$$

$$S_{BIPV}\ [m^2] = S_{gr}\ [m^2] \cdot IR\ \cdot (1 + IP) \qquad \text{(eq. 3)}$$

Where "S_{BIPV}" represents the real opaque area suitable for BIPV with irradiation values greater than 600 kWh/m2y and IR and IP indicate respectively reduction indicators (e.g. due to openings) and additional indicators (e.g. presence of balcony parapets), which are calculated for each façade archetypes, previously indicated.

Specifically, real opaque area suitable for BIPV can be also described as Equation 4, by means of indicators described in Table 2.

$$S_{BIPV}\ [m^2] = S_{gr}\ [m^2] \cdot IR_{ACC} \cdot IR_1 \cdot IR_2 \cdot IR_3 \cdot IR_3 \cdot (1 + IP_{ACC}) \qquad \text{(eq. 4)}$$

Tab. 2: Reduction and additional indicators

Indicators	Description	Equation
IR_{ACC}	Reduction indicator due to the presence of extra architectural elements such as balconies and/or protruding volumes	$IR_{ACC} = \frac{S_{gr} - S_{ACC}}{S_{gr}}$
IR_1	Reduction indicator due to the presence openings	$IR_1 = \frac{S_{gr} - S_{open}}{S_{gr}}$
IR_2	Reduction indicator due to the shadows of balconies	$IR_2 = \frac{S_{gr} - S_{shadow,balc}}{S_{gr}}$
IR_3	Reduction indicator due to the shadow of the roof overhang	$IR_3 = \frac{S_{gr} - S_{shadow,roof}}{S_{gr}}$
IR_4	Reduction indicator due to the presence of technological elements (e.g. lifts, air conditioner devices…)	$IR_4 = \frac{S_{gr} - S_{techn}}{S_{gr}}$
IP_{ACC}	Additional indicator due to the presence of extra architectural elements such as balconies and/or protruding volumes that can be totally or partially used for BIPV	$IP_{ACC} = 1 - \frac{S_{ACC}}{S_{gr}}$

In particular, indicators have been calculated using an experimental method for each façade archetype. As shown in Figure 8, the method is based on the setting-up of a Rhino-Grasshopper® model capable to combine the parametric geometric façade archetype and the simulation of solar radiation by means of the tool DIVA (McNeil & Lee, 2012). In such a way, for each parameter variation, the incident solar radiation on the façade has been evaluated and the portion with annual irradiation greater than 600 kWh/m^2 y (in accordance with the threshold set in the solar cadaster) has been detected to calculate reduction and/or additional factors.

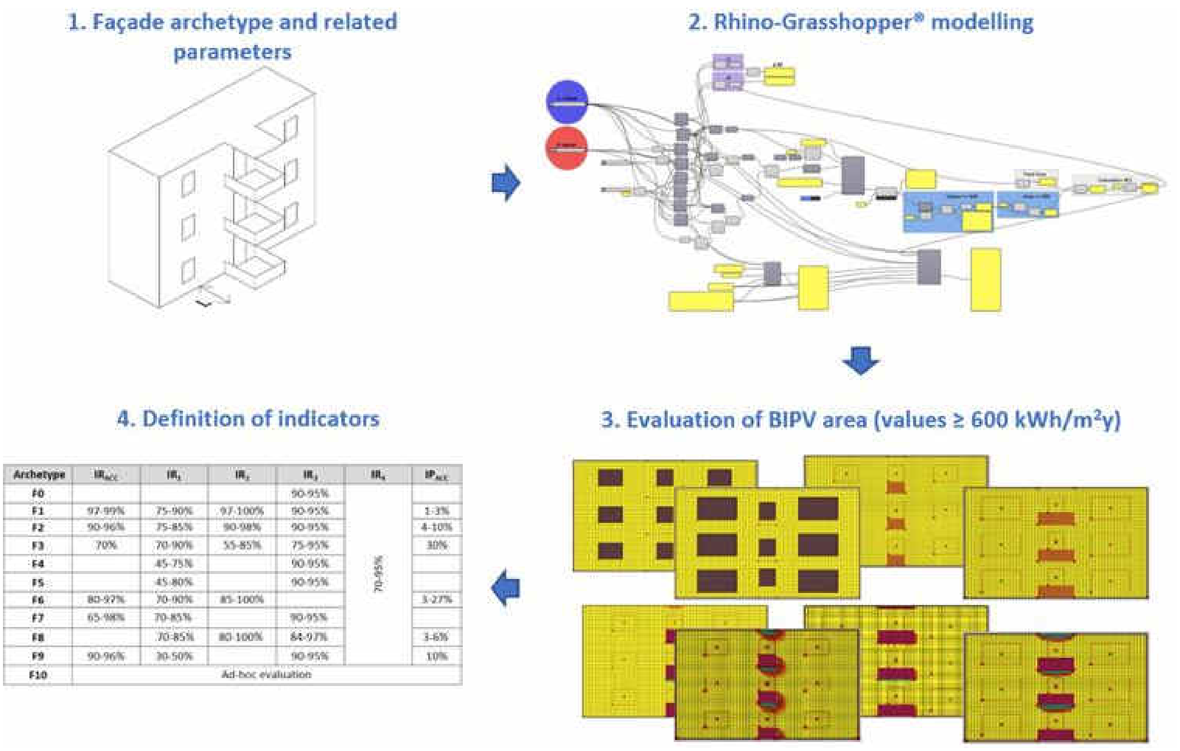


Fig. 8: Phases of the bFAST method to calculate the suitable facade area for BIPV.

2.4 Validation and implementation

It is important to note that this calculation method has been developed in accordance with an archetypal approach that allows dealing with the complexity and the heterogeneity of the building facades by identifying the main recursive characteristics. As a consequence, through the application of indicators, it is possible to estimate the BIPV potential even though it can be not accurate as a professional analysis on a real case study. For this reason, the method has been validated through real case studies for which the following values have been compared: area provided by Sonnenfassade (S_{gr}), area useful for BIPV calculated using the bFAST method (S_{BIPV}), through the application of the corrective factors associated with the type of façade corresponding and useful area obtained through an accurate "design" simulation of the real building (S_{PVSIM}).

Specifically, the error of the area supplied by Sonnenfassade with respect to the accurate area from simulation (ε1) and the error of the area calculated with the bFAST method with respect to t the real area from simulation (ε2) have been calculated and compared. Therefore, when ε1 results lower than ε2, the method is validated. In particular, the validation is carried out by the evaluation of three real case studies of multi-family buildings for which the geometric data are available and, in this case, the method is always verified with ε1 in the range 8-151% and ε2 in the range 2-27%. One case study is shown in Figure 9.

Real Simulation	Sonnenfassade	Archetype F5
		
$S = 198\ m^2$	$S_{GR} = 449\ m^2$	$S_{BIPV} = S_{GR} \cdot IR_1 \cdot IR_3 \cdot IR_4 = 220\ m^2$
	$\varepsilon_1 = +127\%$	$\varepsilon_2 = +11\%$

Fig. 9: Example of the calculation of errors for the method validation.

3. Technical solutions, analysis and assessment of case-studies and scenarios

As part of analysis on real case-studies, we analyzed some reference real scenarios for the PV integration in the building envelope by assessing architectural, technological and economical features of the technical solutions. The first step permitted to identify different technical possibilities related to the construction of an active building skin. Reference examples related to the defined scenarios were identified. The second step identified design examples and reference products. In particular, different PV applications on façade have been evaluated and analyzed for each related technological solutions through the use of real case-studies. In the Table 3 the map of the BIPV technical solutions for the vertical envelope is shown.

Tab. 3: Classification of technical solutions for the BIPV envelope

1) Building integration
(F) <u>Façade system</u> **(F.a)** *Warm Façade /Curtain Wall* – **F.a.1** Stick system – **F.a.2** Unitized curtain wall – **F.a.3** Structural / semi-structural glass façades – **F.a.4** Point-fixed or suspended façade **(F.b)** *Opaque Cold Façade* – **F.b.1** Added/Attached solutions (BAPV/BAST) – **F.b.2** Ventilated facade (BIPV/BIST)

(F.c) *Multifunctional façade and innovative* – **F.c.1** Double skin semi-transparent façade – **F.c.2** Interactive and dynamic façade **(F.d)** *Ready-made system* – **F.d.1** Prefab and multifunctional systems **(F.e)** *Accessory elements* – **F.e.1** Shading and solar protection **F.e.2** Balconies and railings
2) Technology
(Ac) Active (Pa) Passive (Ib) Hybrid (In) Innovative
3) Purpose of the BIPV system
(E) Electric production (T) Hybrid electrical and thermal production (C) Constructive and multifunctional: thermal insulation, soundproofing, ventilation, protection (wind/rains), solar control, safety and structural function.
4) Application / Integration
(Pu) Punctual - Specific or regular application (Pa) Partial - Non complete or partial/linear surface (To) Total - Complete façade/roof surface (Mi) Mixed

Thanks to this analysis it was possible to identify five different façade systems, the related reference techniques of BIPV integration and design solutions. From the case-study analysis the effectiveness, in term of energy and cost, was shown for a vertical BIPV system, despite the yield losses due to non-optimal exposition and shading of facades thanks to the self-sufficiency, self-consumption, final yield and limited extra-cost of the BIPV system compared with a traditional cladding. Particular attention was given to the economical assessment of BIPV systems, where the active cladding replaces an equivalent non-active system whose economic value is expressed in term of extra-cost compared with the similar traditional system (SUPSI-SEAC report 2017, available on the website www.bipv.ch – Bonomo, 2017). Figures 10 and 11 show a cost comparison in CHF/m^2 between the traditional envelope claddings and the PV claddings[1]. Figure 10 shows the cost variation of different claddings, including two PV typologies (horizontal and vertical black lines) while Figure 11 shows the cost of different PV modules compared with a traditional cladding. If the BIPV cost is higher than the traditional system is identified with the colour red, if is lower with a green texture. Further analyses were carried out on case-studies with an in-depth analysis on the design, energy, technology and economy aspects. In the Table 4 an example of case-study referred to a BIPV cold façade for a retrofit on a residential building in Chiasso (Ticino, Switzerland).

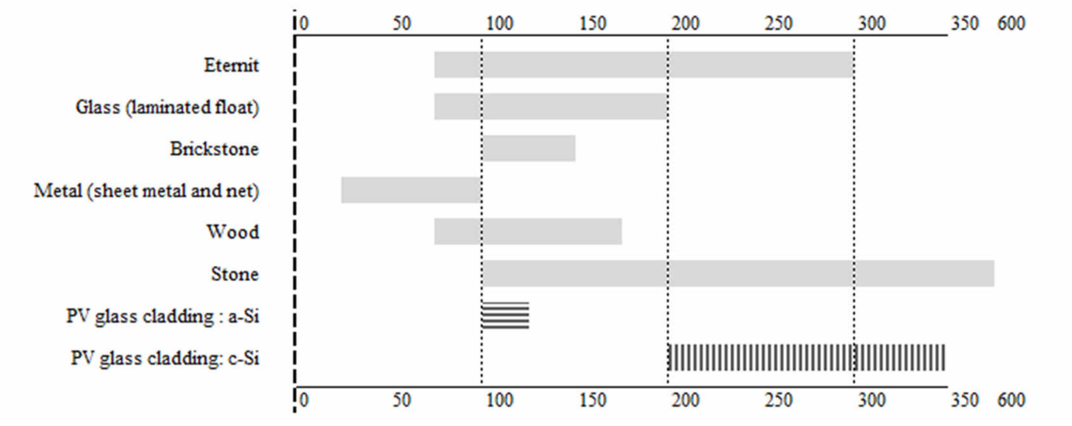


Fig. 10: Cost of material (CHF/m^2)

[1] Values are evaluated on a not complete record; they should be considered just as an example. Values do not assume design binding value. A specific offer should be request before the project starts. Substructures and insulation are not considered.

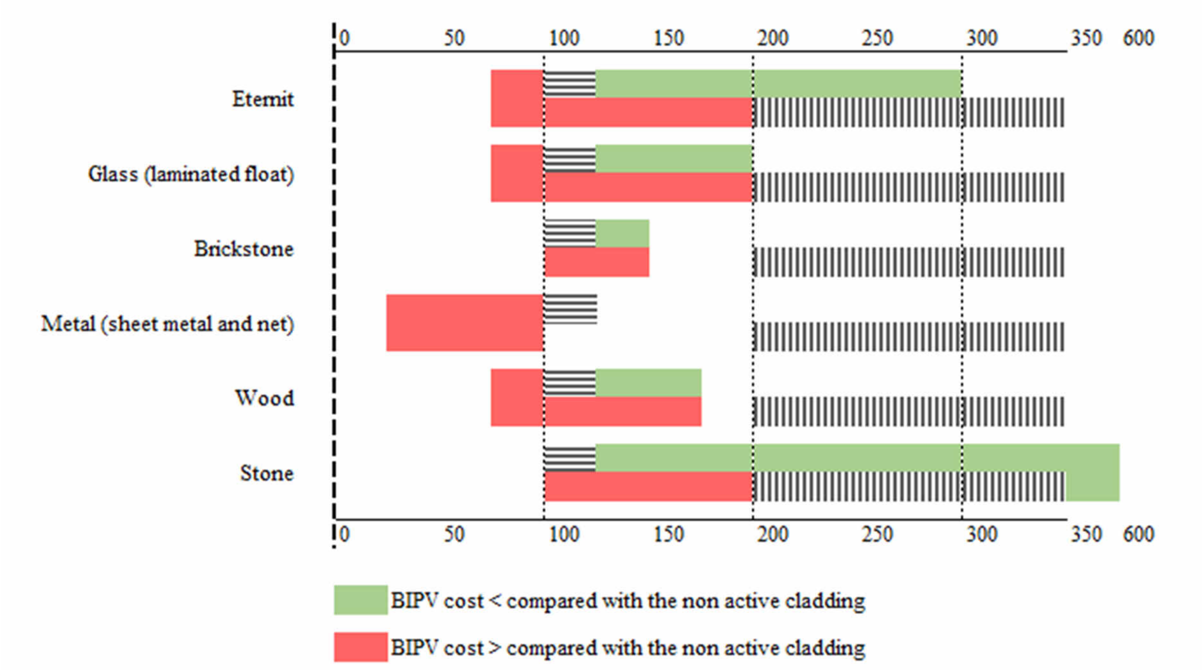


Fig. 11: Extra-cost BIPV compared with the material (CHF/m^2)

4. Conclusions, scientific innovation and relevance

Energy policies at local emphasize the importance of increasing the supply of energy from renewable sources, by also reducing energy demand with new solutions for the sustainable refurbishment of the existing building stock. The bFAST provided a methodology to define the information base to integrate data into the energy mapping, with more detailed indications on the typological-building features of the facades. Through the research, the critical definition of information was prepared, to be made available and functional for implementation within existing spatial information models and those in preparation for the coming years.

The solar potential of the facades is very promising in Ticino for the next few years, evaluating the characteristics and nature of the existing building heritage and its high attractiveness to rehabilitation and redevelopment. A multidisciplinary approach such as that of the bFAST project is essential to grasp the features and building factors that are essential for estimating the potential for real integration of solar systems in the built environment.

The percentage of residential buildings is significantly higher than other types of buildings (industry and trade / services) and in multi-family buildings a high percentage is represented by buildings with heights greater than four and five floors. In all the districts the buildings built before 1980 are predominant, which in the case of housing is more than 65% in all districts. The buildings that have so far required a financial contribution for rehabilitation within the Buildings Program represent only 2.9% of the canton's building stock, for which a potentially important market emerges for the coming years. According to the hypotheses mentioned above and to case studies and simulations, the overall assessment of the report estimates that the total photovoltaic façade surfaces potentially available at the cantonal level are over 2 km^2, which, although deriving from exploitation of only 5% of the total (taking into account the potential impact of the different typological, geometric, technical and local climatic factors) could contribute about 43% to the Cantonal Energy Plan (about 208 MWp installable on the facades for approx. 104GWh/year).

The defined methodology and the information developed through the project (such as the building indicators in the definition of the "realistic" solar potential of the facades for multi-family buildings) can be replicated on the remaining part of the building stock (e.g. in other contexts or on other typologies). In this sense, the methodology set in this project could lead to the improvement of the current digital territorial systems for the evaluation of urban solar potential, through the implementation of data in the Swiss solar cadaster, with the perspective to encourage an optimal management of the building stock for production of solar renewable energy.

Tab. 3: Analysis of the case study Palazzo Positivo

Palazzo Positivo Chiasso (CH) – Case study

Description

The project concerns a complete refurbishment of a MFH with the aim to reach the passive house standard. The main feature of this intervention is the installation of a PV system as re-cladding of the building envelope for each orientation. In this case study are evaluated the PV elements installed on the facades (no balconies and roof).

Imagines




Fonte: SUPSI

BIPV system

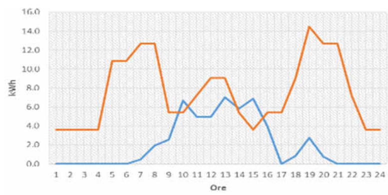
Typology	MFH
Year of construction	2013
Modules	a-Si, polycrystalline
Façade typology	Ventilated

Electric production

Nominal power	45.9 kWp
Active surface	583 m²
Annual production	14'268 kWh
Cladding cost unit	100 CHF/m² a-Si 200 CHF/m² c-Si
Cladding cost total	65'480 CHF

Economic assessment

Location	**Chiasso**
Orientation	S/E/O/N
Tilt	90 °
Nominal power	78.73 Wp/m²
Electric production	24'473 Wh/m²/y
Final yield (average for facade)	311 Wh/Wp/y
Electric production in 20 years	489 kWh/m²
Interest rate	1 %
Annual energetic demand	66'022 kWh/y
Self-consumption rate	88 %
Self-sufficiency rate	19 %
Extra-cost BIPV compared with a cotto tile ventilated facade	0 CHF/m²

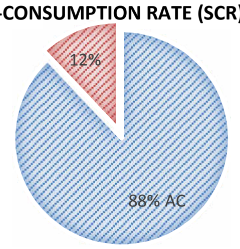


The energy demand of the 29 th of June 2017 is shown by the orange profile. The blue profile represents the BIPV energy production during the same day. The area subtended both profiles represents the self-consumed energy.

Analysis of consumption

Self-consumption rate	**88 %**
Energy injected into the grid	2'976 Wh/m²/y
Self-consumption	21'497 Wh/m²/y
Yearly revenues [1]	4.29 CHF/m²/y
ROI extra-cost of facade	0 years

[1] The energy withdrawn from the grid has a price of 0,19 CHF/kWh, the energy injected into the grid has a price of 0,07 CHF/kWh. **In this analysis are not considered subsidies and the yearly increase of the energy price.**



Comments

BIPV Modules on the façade of Palazzo Positivo are in a-Si or in monocrystalline silizium. The orientation of PV modules is not optimal, however, considering that the cost of the PV cladding in a-Si in this specific case is comparable with a traditional cladding similar for typology, it is possible to notice the economic feasibility of the system and the economic gain given by the PV production and enhanced by the possible self-consumption.

Disclaimer: the economic/energetic assessment within own research activities using available data from the monitoring of the PV system and assuming results from real hourly profiles of the energy demand and real costs. The values do not represent the real data of the building and they will be analysed hereafter.

5. Acknowledgments

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6. References

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