# '15 PLEA

**Architecture in (R)Evolution**

Bologna, 9-11 September

the 31° International **PLEA** Conference

**P**assive **L**ow **E**nergy **A**rchitecture

www.plea2015.it

# TOWARDS INTEGRATED DESIGN STRATEGIES FOR IMPLEMENTING BIPV SYSTEMS INTO URBAN RENEWAL PROCESSES: PRELIMINARY CASE STUDY IN NEUCHÂTEL (SWITZERLAND)


| | | |
|---|---|---|
| Sergi Aguacil | Laboratory of Architecture and Sustainable Technologies (LAST) École polytechnique fédérale de Lausanne (EPFL) | sergi.aguacil@epfl.ch |
| Sophie Lufkin | LAST-EPFL | sophie.lufkin@epfl.ch |
| Emmanuel Rey | LAST-EPFL | emmanuel.rey@epfl.ch |


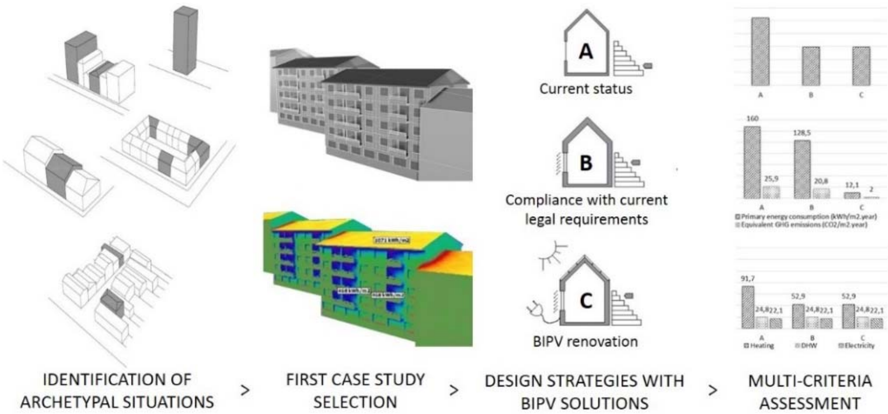


Fig 1: Diagram of the proposed research methodology

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?


**Research summary**

European energy directives define highly-demanding performance standards, from zero-energy buildings to positive-energy buildings. In Switzerland, one of the specific objectives of the new "Energy strategy 2050" is to install PV systems on existing building surfaces in order to cover 1/3 of the annual Swiss demand for electricity. In view of the considerable importance of urban renewal processes, building-integrated photovoltaic (BIPV) systems therefore provide a crucial response to the challenges of the energy turnaround. However, in spite of technologic progress and economic evolution, diverse types of obstacles limit a large-scale advanced PV integration into urban renewal processes.

In this context, urban and architectural design towards increased integration – and therefore increased acceptance – provides an essential solution to overcome these barriers. It represents a key element towards establishing a systematic link between BIPV and the necessary renewal of the considerable existing building stock. Towards this aim, the present paper proposes a first approach to define a holistic multi-criteria assessment methodology for BIPV-adapted solutions in urban renewal design processes in the Swiss context. This document presents the first steps towards the validation of the proposed methodology through a preliminary case study in Neuchâtel (Switzerland).



**Keywords**: building-integrated photovoltaics, energy efficiency, renewable energy, sustainable architectural design, urban renewal, renovation strategy, multi-criteria assessment.

## 1. Introduction

One of the top priorities of European countries is to reduce energy consumption and greenhouse effect in the built environment. Towards this aim, since the city of tomorrow is largely already built, many strategies stress the importance of urban renewal processes towards more sustainability in terms of economic, social and environmental impacts.
Indeed, there are still huge potential energy savings to be made in European countries in general, and in Switzerland in particular. Most residential buildings were built before 1985 and require large amounts of energy to ensure the minimum indoor thermal comfort (OFS, 2014). In response, recent research works have started considering the large existing building stock, bringing to light the considerable importance of urban renewal strategies for the sustainability of the built environment in the next decades (Riera, Rey, 2013).
In parallel, one of the objectives of the “Energy strategy 2050” is to install PV systems on approximately 30% of existing building surfaces in order to cover 1/3 of the annual Swiss demand for electricity (IEA, 2002). Building-integrated photovoltaic (BIPV) systems therefore provide a crucial response to the challenges of the energy turnaround (SFOE, 2014).
BIPV is a growing and diverse area of research. In particular, it includes research on the development of new products, modelling, simulation, assessment of their integration, electrical and thermal performances of mounted modules (Frontini et al., 2012).

## 2. Research objectives

Despite all this technological progress, only a small part of the available local potential for BIPV is valorised in urban areas (integration into roof and façades elements). Diverse types of obstacles limit a large-scale advanced PV integration into urban renewal processes. Most barriers are related to the limited motivation of architectural designers, a restricted knowledge of the BIPV potential and an insufficiency of aesthetically-convincing exemplary buildings (Heinstein, Ballif, Perret-Aebi, 2013).
To address this challenge, urban and architectural design towards increased integration – and therefore increased acceptance – could potentially provide a decisive solution. Although it remains largely disconnected from solar renewable energy issues (Nault, Andersen, Rey, 2013), it represents a key element towards establishing a systematic link between BIPV and the necessary renewal of the considerable existing building stock.
Therefore, instead of considering BIPV as a technical constraint for designers, we propose a new approach based on the integration of BIPV solutions as a new “raw material” for architectural renewal projects (Aiulfi, Rey, 2010; Rey, 2014). By prioritizing architectural quality and dialogue with the built environment, it aims at identifying which construction elements can be substituted by the most appropriate PV components. The latter will not only provide answers to the same requirements as other parts of the building envelope (water and air tightness, mechanical resistance, etc.), but also generate electricity on site from a renewable energy source.
Towards this aim, an ambitious research project entitled ACTIVE INTERFACES is currently being developed in order to study in a structured and in-depth manner the technological, spatial, legal and socio-economic parameters related to the development of new adapted solutions, taking into account diverse criteria (energy, comfort, LCA, costs, aesthetics, costs of

electricity and grid connection). Crossing over the limits of current practices, this ongoing project aims at designing and assessing BIPV-adapted scenarios embodying different urban renewal strategies in the Swiss context through a multi-criteria assessment methodology.
The present paper is the first milestone on the road towards these integrated design strategies for implementing BIPV systems into urban renewal design processes. It presents the results from the preliminary case study in Neuchâtel (Switzerland), based on the simplified analysis and comparison of different urban renewal scenarios. The intermediary objective is to test, validate and find ways to improve the proposed methodology.

## 3. Proposed methodology

The methodology involves four main phases: 1) preselection of an archetypal building; 2) study of the current state of the building and of the thermal envelope's construction details; 3) development of three architectural renewal scenarios embodying different levels of intervention; 4) multi-criteria assessment of the design scenarios.

### *3.1 Preselection of an archetypal building*

The process of identification of the first case study starts with an analysis of the city at urban scale. Firstly based on a typological study including parameters such as the construction period and type, it uses different sources such as the current master plan, aerial images, information from registration of the propriety and statistical data from the construction sector.
Subsequently, to select a representative building within each archetypal type, five selection criteria are defined, related to the opportunity to implement BIPV elements. They are listed below on a priority basis:

1. Context and urban morphology
2. Solar access (roof / façades)
3. Average heritage protection
4. Stakeholders in the renovation process (type of ownership)
5. Access to information on the building

### *3.2 Description of the case study*

The building chosen for the first test of the methodology is an urban residential building typical of the 70's: a four-storey communal property, consisting of 18 apartments and 1,287 m$^2$ of living floor area. This building has been recently renovated without considering the integration of BIPV (Bauer  et al., 2013), being a public property building, the energy saving data have been published and it will be used to validate ours results using the proposed methodology.
In terms of active systems, the building is connected to the district heat2ing (DH) of the city to cover heating and domestic hot water (DHW) needs (Fig 2).


Fig 2: Building image before renovation (Google)

According to the architectural approach based on a renovation design process, a study of the thermal envelope's construction details is crucial to identify opportunities to implement photovoltaic elements. The existing building presents a concrete sandwich panel façade, composed by an interior plaster, concrete, insulation and external concrete facing. The double slope roof is composed by reinforced concrete, insulation wooden plate and ceramic tile (Fig 3).

*3.3 Description of the renewal scenarios*

For the purpose of this paper, three simplified architectural renewal scenarios embodying different levels of intervention are proposed: A) **Current state** (reference case): represents the current situation of the building without any renovation strategy; B) **Current legal requirements**: group of measures that ensure compliance with the minimum level of performance according to SIA 380/1:2009 (current Swiss building performance standard). C) **BIPV renovation**: group of strategies that ensure compliance with the level of performance according to SIA 380/1:2009 (current Swiss building performance standard) with the integration of PV elements into the roof renovation process (Table 1). In order to focus on the development of the methodology, BIPV on facades is being deliberately overlooked.

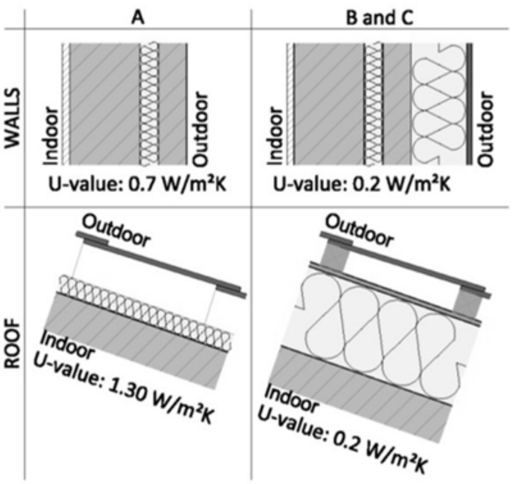


Fig 3: Envelope details for insulation strategy

| Elements | A | B | C |
|---|---|---|---|
| Facades | - | ΔInsulation | |
| Roof | - | ΔInsulation | ΔInsulation +BIPV |
| Windows | - | Replacement + shading system | |

Table 1: Improvement strategies for each scenario

*3.4 Definition of assessment indicators*

To carry out a multi-criteria evaluation of the design scenarios, seven indicators are defined. They assess and compare their performances in terms of energy, economic and environmental aspects (Table 2). This preliminary definition will provide the basis for the more in-depth assessment in the future steps of the research project.

| | |
|---|---|
| Energy consumption | |
| - Primary energy consumption | $kWh_{PE}/m^2.year$ |
| - Equivalent GHG emissions | $CO_{2EQ}/m^2.year$ |
| Photovoltaic installation | |
| - Annual production | $kWh_{FE}/m^2.year$ |
| - Ratio electricity covered | *%* |
| Costs and payback | |
| - Renovation cost | *CHF* |
| - Payback | *years* |
| - Impact on rent | $CHF/ m^2.year$ |

Table 2: Assessment indicators

## 4. Simulation

The tool used to estimate the assessment criteria related to energy consumption, emissions and photovoltaic production is DesignBuilder v.4 (based on the EnergyPlus simulation engine. www.designbuilder.co.uk).

For economic criteria, the calculation has been done with the EPIQR tool (F. Flourentzou et al., 2000), developed for testing different renewal scenarios and identifying the most performing one(s).

*4.1 Input data for energy consumption*

The mean values for the corresponding construction period (1960-1970) in the Swiss context are used to define the input data of the current status (A) (Giebeler et al., 2011). For scenarios B and C, the U-values correspond to SIA 380/1:2009 requirements (Table 3).

| Scenario | | A | B | C |
|---|---|---|---|---|
| Exterior walls | $W/m^2K$ | 0.7 | 0.2 | 0.2 |
| Roof | $W/m^2K$ | 1.3 | 0.2 | 0.2 |
| Internal floor | $W/m^2K$ | 1.1 | 0.2 | 0.2 |
| Window | $W/m^2K$ | 2.6 | 1.3 | 1.3 |
| Glazing | $W/m^2K$ | 2.8 | 1.0 | 1.0 |
| Windows frame | $W/m^2K$ | 1.6 | 1.3 | 1.3 |
| Vent. + Infiltr. | r/h | 1.0 | 0.5 | 0.5 |

Table 3: Input data for the different scenarios

*4.2 Input data for photovoltaic installation*

The choice of the BIPV component to be used in scenario C responds to the will of carrying out a rehabilitation which preserves the architectural quality of the building, while compromising as little as possible the level of electricity produced (Swisspearl, 2015). The Swisspearl INTEGRAL2® PV module (Fig. 4) was chosen to substitute the existing tiles in the retrofitting process of the roof insulation. Based on the monocrystalline (sc-Si) technology of PV cells, an efficiency of 14% is estimated (Cerón, Caamaño-Martín, Neila, 2013).

Fig 4: Roof BIPV component (www.swisspearls.ch)

According to the technical specifications, the installed power can be estimated at 1kWp=7m$^2$ of PV. Price is around 3,000 CHF/kWp, including inverters, wiring, accessories and connectors. We propose to cover the entire roof of the building (360m$^2$) using BIPV elements, substituting the actual tiles during the improvement process of the roof insulation.

*4.3 Input data for costs and payback*

One of the main concerns about BIPV installations is related to the economic and financial aspects. Therefore, the precise evaluation of the costs is an essential aspect of the proposed methodology. The estimation of the payback period for each situation is calculated by counting the number of years it will take to recover the cash invested in a project, using energy cost savings and extra revenues from the sale of PV energy produced. This method is recommended by the cost-optimal methodology applied to renewal processes (BPIE, 2011), considering medium- or long-term investment scenarios. For this case, a horizon of 40 years (3% of interest rate) has been considered. Apart from energy savings, we also took into account the repercussion of the investment cost on price of the monthly rent; 3 different thresholds are analysed: 3% for minimum profitability, 4.5% for average profitability and 6% for significant profitability (Table 6).

**5. Results**

*5.1 Energy consumption*

The target set by the SIA 380/1:2009 for housing, considering Ath=1,764 m$^2$ and AE=1,587m$^2$ is 45 kWh/m$^2$ per year (renovations). The target is achieved for scenarios B and C (Fig 5), corresponding to 56% savings on heating energy demand. In terms of final energy consumption, scenarios B and C achieve 58% savings (according to the HOLISTIC report), related directly to consumption costs. With the aim of analysing the influence of an architectural renovation based on passive strategies to reduce energy demand, no active improvement strategies are proposed to reduce energy consumption of DHW and electricity (Fig 6).

The values obtained for the current situation (scenario A) far exceed the target values set by SIA 380/1. They show the changes needed to achieve the goals set by the "Energy Strategy 2050" and highlight the importance of strategies to promote urban renewal processes.

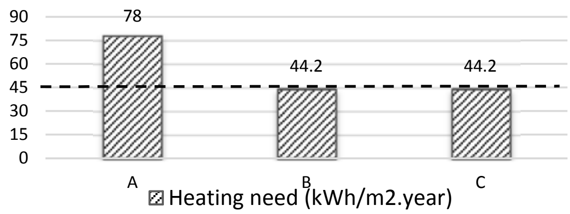


Fig 5: Heating needs (kWh/m$^2$.year)

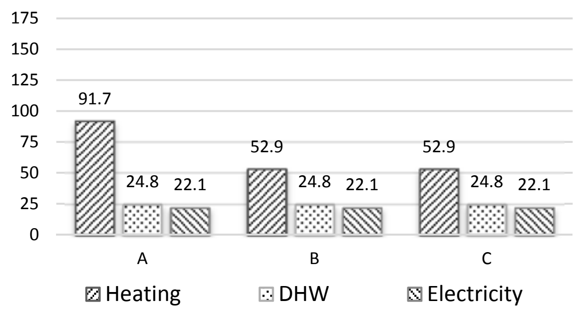


Fig 6: Final energy consumption (kWh/m$^2$.year)

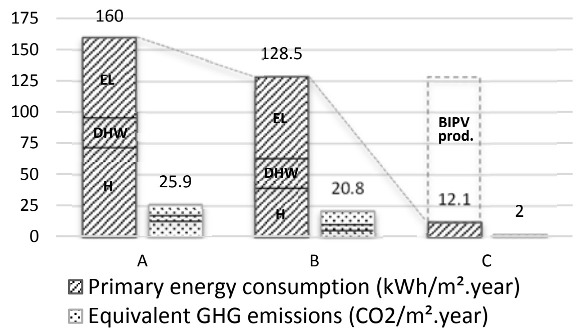


Fig 7: Net energy consumption and emissions

Comparing the results in terms of primary energy is essential to take into account the origin of each energy source. In this case, we have not proposed any change of energy source (DH) to highlight the influence of the photovoltaic installation (Fig 8).

To obtain the results of the net primary energy consumption and CO2 equivalent emissions, it is necessary to use coefficients to convert from final to primary energy. In the Swiss context, these coefficients are provided by SIA 380/1 (Table 4).

| | Electricity | DH |
|---|---|---|
| kg$CO_2$eq/kWh | 0.162 | 0.162 |
| kWhEP/kWhEF | 2.970 | 0.810 |

Table 4: Conversion coefficients

*5.2 Photovoltaic installation*

Concerning the BIPV strategy implemented in scenario C, the estimated production of the installation is 49,262 kWh per year (50 kWp), corresponding to 39.2 kWh/m$^2$ per year (116.4 kWh/m$^2$ per year in terms of primary energy savings) (Fig. 7), or 177% of domestic electricity consumption. The cost of the installation is approximately 150,000 CHF.

*5.3 Costs and payback*

The global costs of renewal scenarios B and C correspond to 236,400 CHF and 386,400 CHF respectively. The difference lies in the BIPV installation, which represents an additional cost of 63% compared to scenario B.

| Profitability threshold | Rent increase (CHF/m$^2$ per year) A | B | C |
|---|---|---|---|
| 3.0% | - | +5.5 | +9.0 |
| 4.5% | - | +8.3 | +13.5 |
| 6.0% | - | +11.0 | +18.0 |

Table 5: Rent increase for each scenario

In this case we have chosen 3% of profitability thresholds to take into account the repercussion of the investment cost on the rent

(Table 5), as compared with the average value of the rent in the region of Neuchâtel, estimated at 220 CHF/m$^2$ per year (OFS, 2015).

In this regard, it is important to jointly represent the three different scenarios to compare their performances and highlight the effectiveness of each strategy (Fig 9).

In the Swiss context, the sale and purchase price of electricity is approx. 0.2 CHF/kWh, tax included. Financial aid to tackle the investment cost (corresponding to around 1,000 CHF per kWp installed) are obtained only if the installation is less than 30 kWp (Swissgrid, 2015). Using these data, the payback is 24 years for scenario B and 16 years for scenario C. The BIPV strategy thus represents a payback time 30% shorter thanks to the extra revenue generated by the sale of the energy produced.

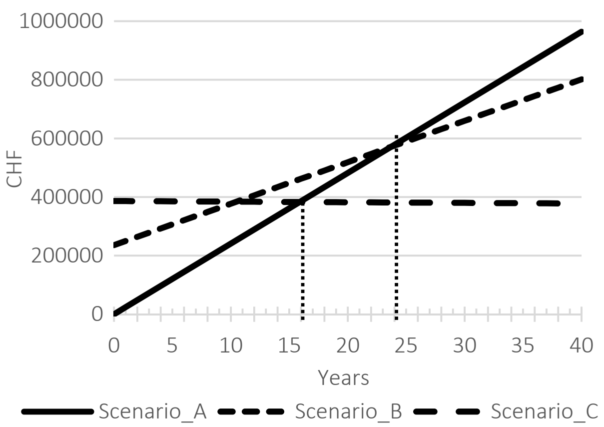


Fig 8: Cost evolution of energy consumption and payback estimation

## 6. Conclusions

Based on the results of the evaluation, it seems clear that energy renovation projects without integration of renewal energy in general and BIPV in particular are no longer an option if we want to achieve the objectives of the "Energy strategy 2050". Today, renovation projects improving the building envelope with a very high level of thermal energy performance are necessary, but not sufficient. Compensating buildings' energy consumption by producing electricity on-site has become number one priority. In this sense, by proposing new adapted BIPV solutions for urban renewal processes, the research contributes to advancing architectural and construction design practices in this direction.

At an early stage of the research, the results of this preliminary application case study highlight several interesting elements, such as the shorter payback period of the BIPV scenario, just taking into account a simplest passive strategy (insulation) 40% saving of heating are achieved. It seems easily arrive to 80% of total savings with introducing of mix strategies (passive, active and renewal energy systems). Economic aspects, in particular, appear as key elements to understand obstacles and find ways of getting around them. In this sense, the type of financing is an essential issue and will require specific attention in the future phases of the project. The distribution of economic benefits generated by the BIPV electricity production among the involved stakeholders (owner and tenant) is another key aspect.

This preliminary study also allows a first validation of the proposed methodology and opens up perspectives for the upcoming process of finalisation and refinement.

First, in order to support a more holistic approach, implicit in the concept of sustainable development, it is essential to increase the number of indicators. The multi-criteria assessment needs not only to take into consideration quantitative and qualitative parameters, but also to include criteria from all three pillars of sustainability (i.e. not only environmental and economic indicators, but also sociocultural ones). Among others, we will include indoor comfort and LCA assessment of the entire renovation project. The integration of these additional indicators will require using new simulation tools specifically designed assess retrofitting projects with BIPV.

Furthermore, the amount of scenarios will also need to be increased in order to define and evaluate a broader number of BIPV retrofitting options. BIPV products will be introduced to substitute not only roof elements, but also façade components. Different levels of intervention will thus be distinguished with more subtlety, from basic sanitation to substitution, including renovation and transformation strategies. Finally, after these various refinements will have been carried out, further phases of the research will consist in applying the methodology to other archetypal buildings. These upcoming case studies will ensure the validation of the finalised methodology and enable the extrapolation of the most performing BIPV renovation strategies at urban scale. Moreover, these case studies will provide architects, installers and public authorities with a catalogue of innovative and adapted "best practice" solutions for a large-scale advanced BIPV integration into urban renewal processes.

## 7. Acknowledgments

This work was supported by the Swiss National Science Foundation (SNSF) – National Research Program NRP 70 "Energy Turnaround" and the Ecole Polytechnique Fédérale de Lausanne (EPFL).

## 8. References

Aiulfi D., Rey E. (2010). *Les technologies vertes, matières premières pour la créativité des architectes*. Neuchâtel: MICRO 10, specialized lectures.

BPIE (2013). *Implementing the cost-optimal methodology in EU Countries*. Brussels: BPIE.

Cerón I., Caamaño-Martín E., Neila F.J. (2013) 'State-of-the-art' of building integrated photovoltaic products. *Renewable Energy*, 58(0)127-133.

Flourentzou F., Droutsa K., Wittchen K.B. (2000), EPIQR software. *Energy & Buildings*, 31(2000), 129-136.

Frontini, F. et al. (2012). A case study of solar technologies adoption: criteria for BIPV integration in sensitive built environment. *Energy Procedia*, 30(2000), 1006-1015.

Giebeler G. et al. (2011). *Rénover le bâti. Maintenance, reconversion, extension*. Lausanne: Presses Polytechniques et universitaires romandes.

Heinstein P., Ballif C., Perret-Aebi L.E. (2013). Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths. *Green*, 3(2), 125-156.

Bauer F., Oswald D., Trachsel C., Rey E. (2013) *HOLISTIC: Retour d'expériences.* Public Final Report. Neuchâtel: CONCERTO Program.

IEA (International energy agency). (2002). Pote*ntial for Building Integrated Photovoltaics, Report PVPS T7-4*. Switzerland: IEA

Nault E., Andersen M., Rey E. (2013). *Solar Potential and Interactive Design in the Urban Context*. Munich: sb13, April 24-26.

Office fédéral de la statistique. (2015). Neuchâtel.

Rey E. (2014) *From Spatial Development to Detail*. Collection Notatio. Lucerne: Quart Publishers

Rey E. et al. (2015), Building integrated photovoltaics. ACTIVE INTERFACES, NRP 70(Energy Turnaround) and NRP 71 (Managing Energy Consumption), Kick-off Meeting Luzern, 24 April

Riera Pérez M, Rey E (2013). A multi-criteria approach to compare urban renewal scenarios for an existing neighbourhood. Case study in Lausanne (Switzerland). *Building and Environment*, 65(2013), 58-70.

SFOE. (2014) Energy Strategy 2050.

SIA (2009). *SIA 380/1:2009 L'énergie thermique dans le bâtiment*. Zurich.

Swissgrid. (2015). Retrieved April 23, 2015, from http://www.swissgrid.ch