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Influence of energy-use scenarios in Life-Cycle Analysis of renovation projects with Building-Integrated Photovoltaics – Investigation through two case studies in Neuchâtel (Switzerland)

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Abstract: Since tomorrow's cities are already largely built, and as many of their buildings – with a low level of energy performance – will still be standing in 2050, urban renewal processes play an essential role towards the sustainable development of European cities. In this context, Building-Integrated Photovoltaic (BIPV) systems can potentially provide a crucial response for achieving long-term carbon targets. Functioning both as envelope material and on-site electricity generator, they can simultaneously reduce the use of fossil fuels and greenhouse gas emissions. Focusing on the architectural design, this paper presents the results of a multi-criteria evaluation in terms of Life-Cycle Assessment (LCA) and Cost (LCC) of different renovation and energy-use scenarios. The goal is to identify which strategies can allow to achieve the ambitious targets for the 2050 horizon by integrating into the design process: **1) Passive strategies**, to improve the envelope through low-embodied energy materials and construction systems; **2) BIPV strategies**, using innovative photovoltaic products as a new material for façades and roofs; and **3) Active strategies**, adapting HVAC systems to improve the efficiency of the BIPV installation and reducing the dependence on the feed-in-tariffs to ensure the profitability of investments. An emphasis is placed on testing the impact of a proposed selection process of BIPV surfaces in order to maximise self-consumption and self-sufficiency, evaluating the effect of electricity storage systems with and without the possibility of injecting the overproduction into the grid. Our methodology and results are presented through the comparison of two real case studies in Neuchâtel (Switzerland). Proposing a new approach to address renovation projects of existing buildings in the urban context towards Low Carbon Buildings, the outcomes provide architects and engineers with advanced BIPV renovation strategies depending on the building typology, the architectural design goals and the level of intervention.

Keywords: Building renovation, Building-Integrated Photovoltaics, integrated design, multi-criteria assessment, Life-Cycle Assessment

Introduction

Many strategies stress the importance of urban renewal processes towards more sustainability (Riera and Rey, 2013) (Aguacil et al, 2017a). Indeed, there are still considerable potential energy savings to be made in European countries in general, and in Switzerland in particular, where most residential buildings were built before 1985 and require large amounts of energy to ensure the minimum indoor thermal comfort (OFS, 2017). In response, one of the objectives of the "*2000 Watt society*" (SIA, 2011) – a concept that promotes an annual limit per person of 1 tonne of CO_2 emissions and 2000 W expressed in mean power – is to drastically reduce greenhouse gas (GHG) emissions taking into account the whole life cycle of buildings. Building-Integrated Photovoltaic (BIPV) systems represent a promising solution to the energy turnaround challenges (SFOE, 2017), as it is estimated that photovoltaics (PV) could cover up to 1/3 of the annual Swiss electricity demand (IEA, 2002).

BIPV is a growing and diverse area of research, as confirmed by the development of new products and their integration on building envelopes (Frontini et al, 2012). Despite this technological progress, only a small part of the available local PV potential is exploited in urban areas. Different types of obstacles limit a large-scale PV integration into urban renewal processes, namely, the limited motivation of architectural designers, a restricted knowledge of the BIPV potential, and an insufficiency of aesthetically-convincing exemplary buildings (Heinstein et al, 2013). To address these challenges, architectural design towards increased integration – and therefore increased acceptance – must be supported. 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” (Aiulfi and Rey, 2010). Prioritizing architectural quality and dialogue with the built environment, it aims at identifying which construction elements can be substituted by PV components, fulfilling the building envelope requirements while producing electricity on-site from a renewable energy source.

This paper is an integral part of an ongoing research project entitled ACTIVE INTERFACES, which aims at studying the technological, spatial, legal and socio-economic parameters related to the development of new adapted BIPV solutions (Rey et al, 2015).

Based on the architectural design strategies already developed in the first step of the project and published in Aguacil et al (2016, 2017b), we here present the impact on the final performance of an optimization process based on an annual irradiation threshold to choose the active surfaces for two case studies in Neuchâtel (Switzerland).

Research methodology

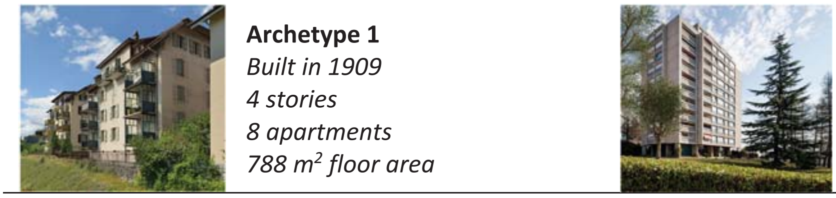
The methodology involves four main phases: 1) selection of archetypal residential buildings; 2) detailed analysis of each building; 3) development, for each archetype, of four architectural renewal scenarios embodying different levels of intervention; 4) multi-criteria assessment of the scenarios. As further details on the methodology and the detailed façade designs to obtain aesthetically convincing examples can be found in Aguacil et al (2016, 2017b), the first three phases are briefly described below in reference to the two presented case studies. The emphasis is more focused on the description of the multi-criteria assessment (phase 4), which is the central purpose of this paper.

Phase 1: Selection of an archetypal building

Considering Neuchâtel as a representative city of the Swiss Plateau (OFS, 2015) and based on its building stock analysis, five residential archetypes have been identified, using selection criteria such as the construction period and heritage protection level. A representative building for each archetype was chosen to carry out a series of real case studies.

Phase 2: Detailed analysis of the buildings

The case studies presented in this paper are two multi-family residential buildings that correspond to residential archetypes 1 and 4. In their current status, to which we will refer as situation **E0**, both buildings, shown in Figure 1, present a low level of energy performance.



Archetype 1
Built in 1909
4 stories
8 apartments
788 m^2 floor area

Archetype 4
Built in 1972
11 stories
52 apartments
5’263 m^2 floor area

Figure 1. Images of the current status of each building along with their main characteristics.

Archetype 1 has an uninsulated envelope; its façades consist of 40 cm thick rubble masonry walls and exterior plaster, windows are single glazing and the sloped roof is finished with ceramic tile (Aguacil et al, 2017b). **Archetype 4** has a poorly insulated envelope; its façades are made of prefabricated concrete elements with 4 cm of expanded polystyrene (EPS) insulation, double-glazed windows and a flat roof with 6 cm of EPS insulation and 5 cm of gravel (Aguacil et al, 2016). In terms of active systems, both buildings have a central oil boiler covering heating and domestic hot water (DHW) needs.

Phase 3: Design of architectural renewal scenarios

Starting from **E0-Current status**, we define four renewal scenarios from an architectural and energy point of view. The **S0-Baseline** scenario aims at achieving at least the current legal requirements defined by SIA 380/1:2016 (SIA, 2016), in accordance with current practices and only through passive strategies to reduce the energy demand (by improving the performance of the envelope using low-cost materials).

The other three design scenarios incorporate BIPV in addition to passive strategies using more ecological materials such as recycled EPS insulation or wooden frames for windows. For **S1-Conservation**, the goals is to maintain the expression of the building while improving its energy performance (at least up to current legal requirements) and respecting the targets to obtain a subsidy of 60 CHF/m^2 from the "programme bâtiment" which promotes energy renovation of existing buildings (EnDK, 2015). For **S2-Renovation**, the general expressive lines of the building are to be maintained while reaching high-energy performance (taking as reference the Swiss Minergie® label (Minergie, 2016)). For **S3-Transformation**, the aim is to achieve the best energy performance and maximum electricity production possible with aesthetic and formal coherence over the whole building (at least "*2000 Watt Society*" (SIA, 2011)).

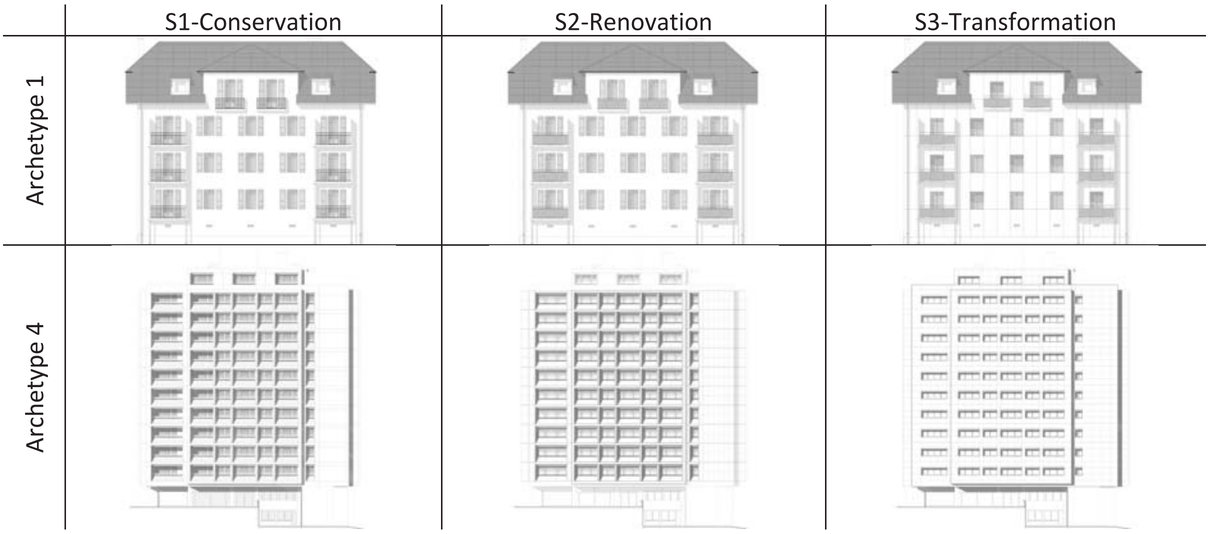


Figure 2. Main façade definition for each BIPV scenario, detailed in Aguacil et al (2016, 2017b).

In combination with the integration of BIPV in S1 to S3 we propose to implement an additional active strategy consisting in the replacement of the existing oil-boiler by an electricity-based system to increase the self-consumption of the electricity produced on-site and reduce the consumption thanks to high-efficiency air-water heat pumps.

The design process consists in an iterative procedure between design at the construction level and energy simulation in order to continuously verify the final performance of each design proposition. Energy simulations are carried out in DesignBuilder v.5 (DB, 2017), based on the EnergyPlus® simulation engine. In an iterative simulation process, we verify the fulfilment of the objectives set for each scenario, adjusting the constructive details of each proposal. From the final design (Figure 2), we obtain the hourly consumption of the building during the entire year for each renewal scenario.

Phase 4: Multi-criteria assessment

One of the main objectives of this research is to define what is the most adequate way to integrate PV elements into the envelope of buildings in renovation projects. To do so, we propose to investigate the influence of three **energy-use scenarios** on the multi-criteria assessment detailed below. Those three scenarios, defined in Figure 3, are: **A**) use 100% of the identified active surfaces; **B**) adjust the amount of active surfaces to the demand of the building by conducting a selection process; and **C**) add batteries given the selected active surfaces obtained in B). A) is obtained following the design phase where we define all potential PV surfaces using standard- or custom-size panels (MB, 2017) with coloured films (CSEM, 2017). Then, for B), a selection process is conducted to define which of these surfaces will finally be covered by BIPV elements versus non-active elements with the same aspect. The selection process begins with a study based on the cumulated annual irradiation threshold. The goal is to identify the annual irradiation threshold which leads to maximizing both the self-sufficiency (energy independence) and self-consumption (level of use of the PV system), two concepts further described in Luthander et al (2015). Surfaces that achieve the optimal irradiation threshold are then considered to be active. For C), in addition to conducting the surface selection of B), batteries (sized for a mean daily demand) are integrated to further increase the self-consumption and self-sufficiency (Swissolar, 2016).

The estimation of the hourly on-site electricity production is done on a detailed 3D model created in the Rhinoceros 3D modelling tool and using the visual programming software Grasshopper with the DIVA plugin (DIVA, 2017).


A) 100% active surfaces **B) Active surfaces selection** **C) With batteries**

Figure 3. Comparative energy-use scenarios

In parallel to the design process and through an iterative cycle, we conduct a multi-criteria evaluation based on Life-Cycle Analysis (LCA) and Cost (LCC) to compare the scenarios and evaluate the impact of the active surfaces selection, using simulation and reference values.

The LCA takes into account energy consumption, GHG emissions, on-site PV generation and environmental impact of materials including BIPV elements for a 60-year lifespan (KBOB, 2016). The environmental impact values for construction materials, PV elements, HVAC systems and batteries are obtained with the ECO-BAT software (ECO-BAT, 2017) and a Swiss eco-building database (KBOB, 2016), with a lifetime of 50, 30, 20 and 10 years respectively.

For the LCC analysis, the renovation cost is obtained using the EPIQR tool (Flourentzou et al, 2000), developed to perform the diagnosis of existing buildings and test different renewal scenarios. Subsidies for both the BIPV installation (Swissgrid, 2017) and energy renovation (EnDK, 2015) are taken into account. We use the existing PV technology based on the single-crystal silicon (sc-Si) cell, with 17% efficiency (Cerón et al, 2013). The expected cost is between 245 and 445 CHF/m^2 for standard-size modules and 780 CHF/m^2 for customized ones, including inverters, wiring and accessories. The estimated cost of batteries is 288 CHF/kWh based on gel technology batteries (Swiss-green, 2017).

The estimation of the global cost-effectiveness is done for a 50-year horizon with a 3% interest rate. The calculation considers energy savings and electricity production, including a 0.8% production decrease per year according to the guaranteed performance of PV elements (MB 2017), and a price of 0.1 CHF/kWh (for heating oil) and 0.2 CHF/kWh (for electricity), tax included. For electricity overproduction injected into the grid, we have considered a cost-covering remuneration (Swissgrid, 2017) between 0.064 and 0.106 CHF/kWh depending on the installation size, scenario, and case study. The payback time is calculated using the DCF (discounted cash flow) methodology by net present value (NPV), considering the real-time self-consumption with no battery systems and the injected electricity overproduction.

Results

Design scenarios implementation for each archetype

As described in Table 1, for **S0** – representing current practice – the insulation is increased for all opaque surfaces and windows are replaced to achieve current legal requirements (SIA, 2016). For scenarios **S1** to **S3**, in addition to the interventions of **S0**, BIPV elements are integrated on roof and façades taking into account the requirements of the design scenarios defined in phase 3 of the methodology and favouring more ecological materials over low-cost materials.

Regarding the façade definition (Figure 2) of the different BIPV scenarios (S1 to S3), we propose for **archetype 1** an external insulation system with synthetic coating cladding for **S1** and **S2**, with PV elements on roof (S1) and balustrades (S2). In **S3**, a ventilated façade system is implemented using PV elements, prefabricated, modular and built with wooden structure. For **archetype 4**, an internal insulation system covering the railing of windows with customized PV elements is proposed for **S1**, and a ventilated façade system incorporating PV panels on the biggest opaque surfaces for **S2**, in order to reproduce the geometry of the existing façade. For **S3**, a ventilated façade system using PV elements, prefabricated, modular and built with a wooden structure is implemented.

Table 1. Summary of design scenarios implementation for each archetype.

Sc.	Arch.	Type (colour) of materials		Insulation	Target U-value [W/m2.K]		Infiltr.
		Roof	**Façades**	**Thickness (type)**	**Opaque**	**Windows**	**[ach]**
E0	1	*Tiles (brown)*	*Synthetic coating*	-	1.33	5.7 (sg-w)	2
	4	*Gravel*	*Concrete*	4 cm (EPS - Int)	1.09	2.6 (dg-a)	
S0	1	*Tiles (brown)*	*Synthetic coating*	14 cm (EPS - Ext)	0.25	1.3 (dg-pvc)	1
	4	*Gravel*	*Concrete*	10 cm (EPS - Int)			
S1	1	SSz (*brown*)	*Synthetic coating*	17 cm (rEPS - Ext)	0.20	1 (tg-w)	0.7
	4	SSz-f (black)	CSz (concrete)	14 cm (rEPS - Int)			
S2	1	SSz (*brown*)	SSz (ochre)	18 cm (rEPS - Ext)	0.19	0.7 (tg-w)	0.5
	4	SSz-f (black)	CSz (concrete)	15 cm (rEPS - Ext)			
S3	1	SSz (*brown*)	SSz (ochre)	20 cm (rEPS - Ext)	0.17	0.7 (tg-w)	0.5
	4	SSz-f (black)	SSz (grey)	17 cm (rEPS - Ext)			

Abbreviations: Custom-size (CSz) or standard-size PV panels (SSz), with frame (-f), standard expanded polystyrene (EPS), 100% recycled expanded polystyrene (rEPS), internal (Int) or external insulation (Ext), single (sg), double (dg) or triple glazing (tg), aluminium (-a), polyvinyl chloride (-pvc) or wooden windows frame (-w).

Active surfaces selection process

To select the active surfaces for the second energy-use scenario (B, see Figure 3), different cumulated annual irradiation thresholds (varying from 0 to 1’200 kWh/m^2.year) are applied on all possible active surfaces identified from the design phase.

Figure 4 highlights the surfaces that do and do not receive enough solar energy to be considered as active (in scenario S3-Transformation). From these results and the derived self-consumption and self-sufficiency, we identify the optimum threshold and the corresponding annual PV production.

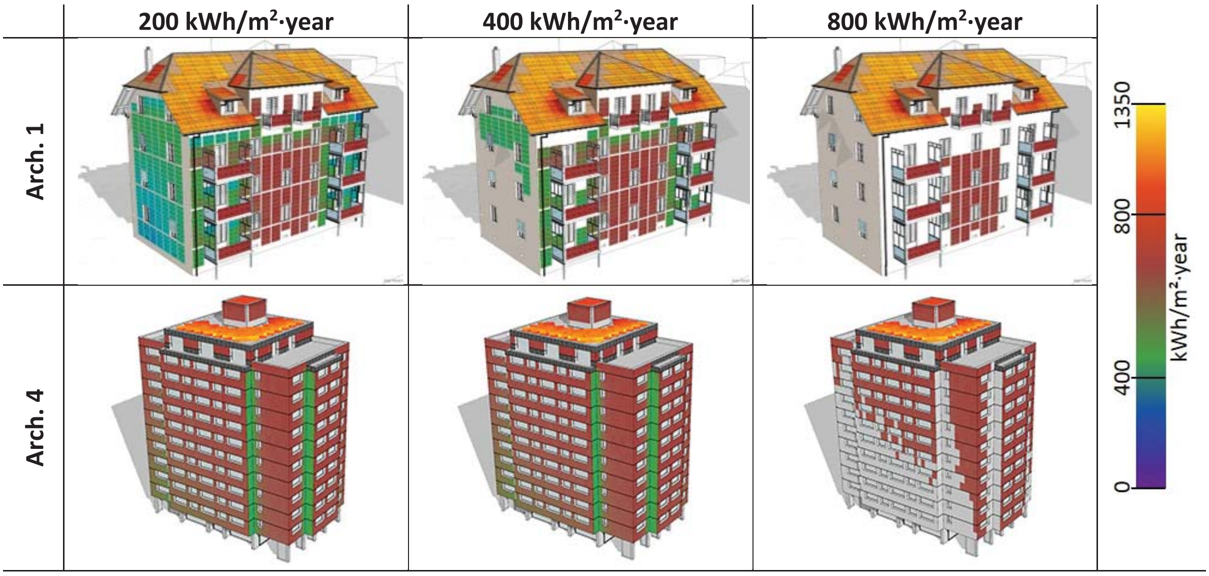


Figure 4. Annual irradiation threshold study for the scenario S3 (SE-SW façades) for archetype 1 (top) and 4 (bottom). Coloured surfaces (according to the scale on the right) reach the threshold values.

For each scenario, two different thresholds are obtained, depending on whether the existing boiler is maintained or replaced. Figure 5 shows an example of optimization results for scenario S3. For **archetype 1**, the threshold is 1’175 kWh/m^2 (oil-boiler) and 800 kWh/m^2 (heat pump), leading to 14 and 28 MWh/year of on-site production respectively, and to 29% of self-consumption and 24.5% of self-sufficiency. For **archetype 4**, the threshold is 800 kWh/m^2 (oil-boiler) and 600 kWh/m^2 (heat pump), for 87 and 139 MWh/year of on-site production respectively, and 32% of self-consumption and 29% of self-sufficiency.

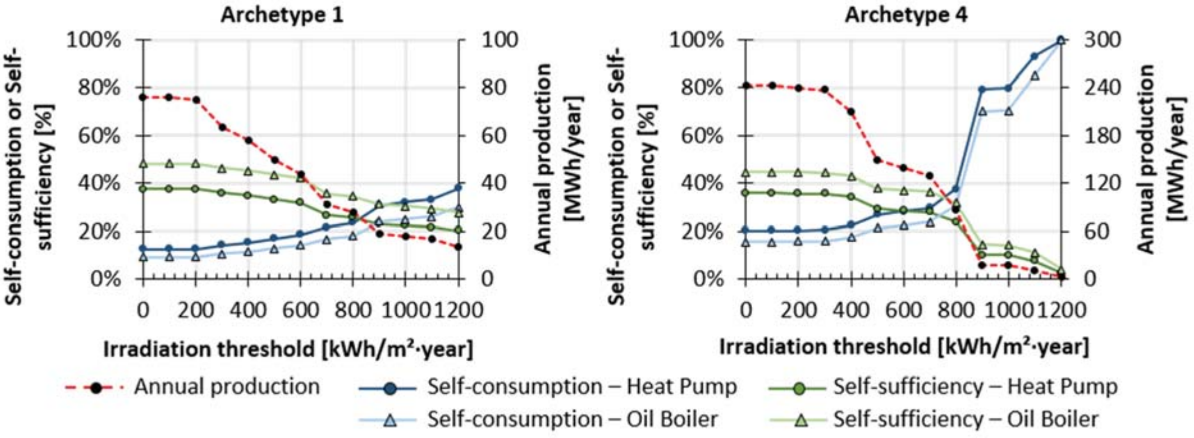


Figure 5. Example of irradiation threshold study based on self-consumption and self-sufficiency for scenario S3.

Energy-use scenarios

We here present an example of the results obtained for the three energy-use scenarios introduced earlier (Figure 3). Figure 6 shows the daily energy balance (15th April) calculated from hourly data for the archetype 1 and for the scenario S3-tranformation. With the selection of active surfaces (scenario B) following the procedure described in the previous section, we observe a better balance between self-sufficiency and self-consumption, leading to a trade-off between the two ratios. When batteries are added (C), both ratios increase while guaranteeing one average day of autonomy. Given that a self-sufficiency of 100% is reached for this example, we can deduce that if we were to integrate batteries with the same storage capacity with 100% of active surfaces (on A), we would obtain the same 100% value for self-sufficiency, but a lower self-consumption as more of the produced electricity could not be stored. Therefore, it seems more rational to integrate batteries after a selection of active surfaces has been done, as is the case here with scenario C).

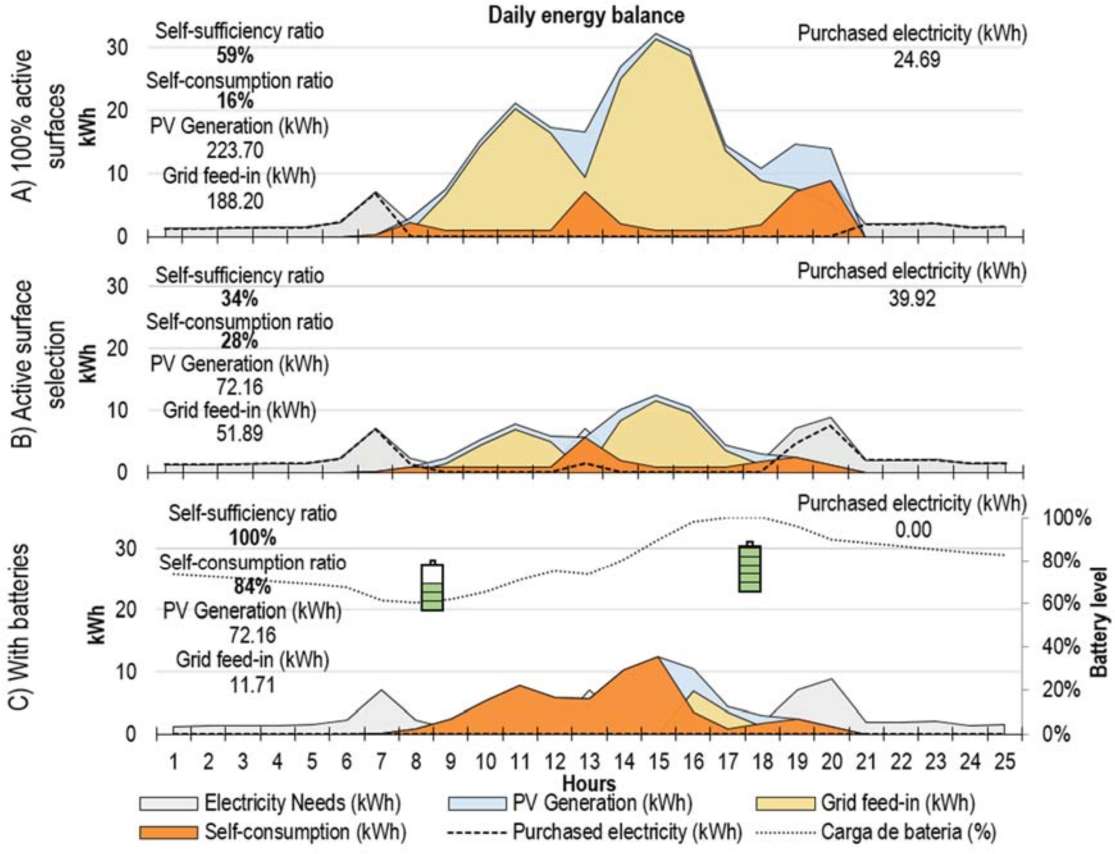
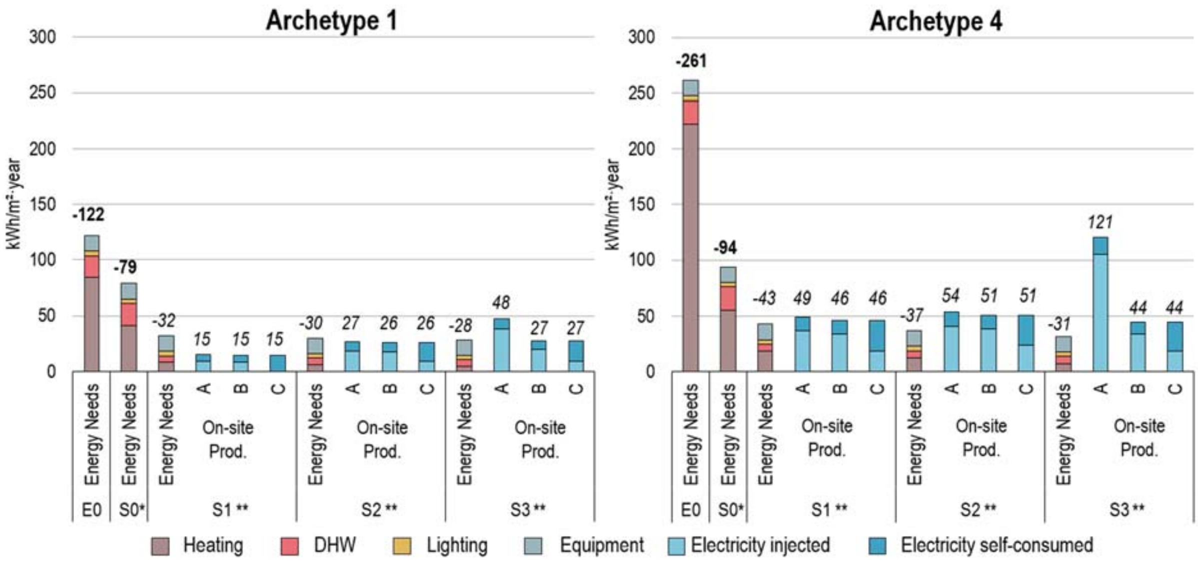


Figure 6. Example of daily energy balance for the three comparative energy-use scenarios (Archetype 1, 15th April, scenario S3-transformation).

Final energy balance

Figure 7 presents the results of the annual final energy balance for all design and energy-use scenarios, including energy needs and electricity produced on-site by the BIPV installation, obtained through hourly simulation. The considerable energy consumption of the current status (E0) highlights the importance of the energy renovation process. In scenario S0, implementing a current practice renovation using the current legal requirements (SIA 380/1:2016) reduces the total energy consumption by 64% and 35% for archetype 1 and 4 respectively. However, the implementation of BIPV scenarios S1 to S3 allows total savings ranging from 77% to 88%.



** Energy model calibration using real consumption data.*
*** The BIPV scenarios include the replacement of the current oil-boiler with an electrical-base system (air-water heat-pump).*

Figure 7. Final energy balance for each renovation scenario and each energy-use option, A) 100% active surfaces, B) active surfaces selection and C) active surfaces selection with batteries.

In addition to the energy savings induced by improving the envelope performance (passive strategies), S1-S3 produce a considerable amount of electricity on-site, in some cases making the building a positive energy building that produces more energy than it needs.

Life Cycle Analysis (LCA)

Figures 8 and 9 show the results of the life-cycle analysis of the whole renovation project (passive and active strategies) for the three comparative energy-use scenarios (Figure 3) based on a feed-in tariff approach, injecting the electricity overproduction into the grid (Figure 8), as well as based on a self-consumption approach, without injection into the grid (Figure 9). A comparison is made with the Swiss "*2000 Watt society*" targets (SIA, 2011) in terms of non-renewable primary energy (CEDnr) and GHG emissions to prevent global warming potential (GWP).

Not included in the figures, and independent from the approach, is the improvement obtained when going from E0 to S0, which is of 60% and 30% in terms of energy consumption and GHG emissions respectively. Observations can first be made regardless of the approach (for both figures). From S0 to S3, as the performance of the buildings increases, the weight of the embodied energy related to the construction materials also becomes more important. Scenarios S1, S2 and S3 respect the Swiss targets. It is also important to highlight the fact that it is only possible to achieve the "*2000 Watt society*" targets by using low-carbon materials and changing the type of energy source (using an electric heat pump instead of an oil-boiler), which increases the self-consumption of the on-site electricity production. These observations represent key elements toward real carbon neutrality. In addition, the selection process of the active surfaces (B) allows achieving the performance objectives in a more rational way, avoiding the excessive injection of electricity into the grid.

In the case, that we are able to inject the overproduction into the grid (Figure 8), for the energy-use option C), the application of the batteries is less efficient than the sole selection of active surfaces, because by injecting the overproduction we are actually using the grid as a storage system. Consequently, the batteries could be useful exclusively for managing the energy, for example in the case where we would like to import electricity from the grid when the content of GHG is lower or when the price of electricity is cheaper. Then, batteries would make it possible to do so and help minimize the CED and GWP (Vuarnoz et al, 2016).

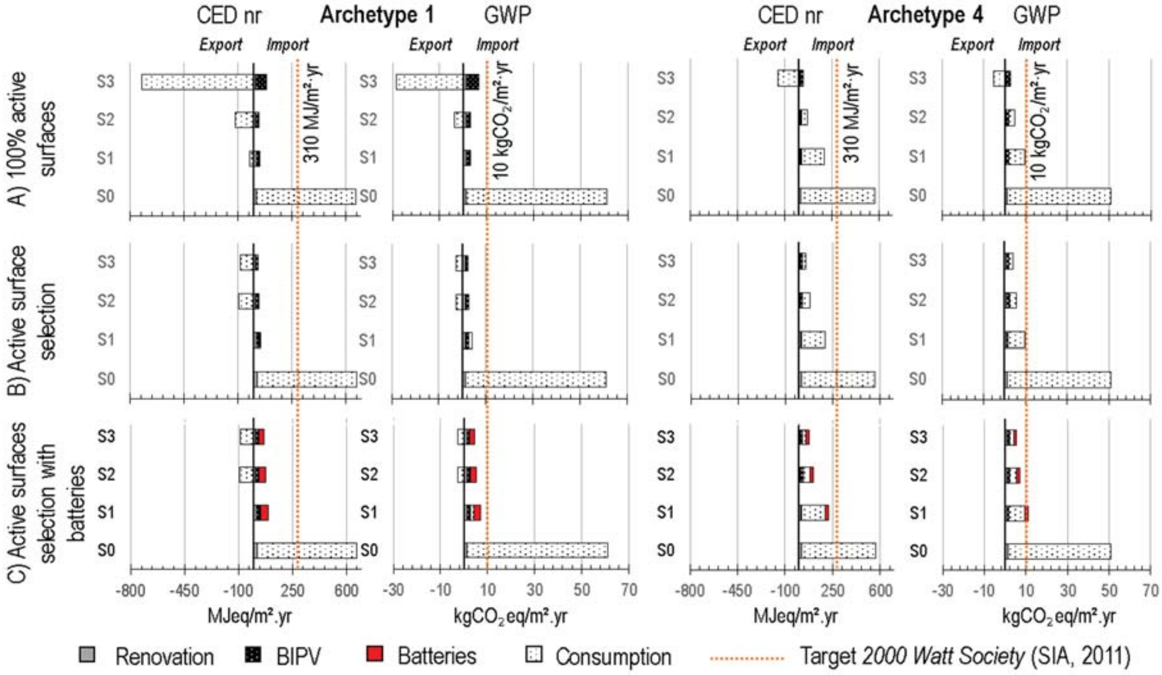


Figure 8. LCA results (**feed-in tariff approach**) in terms of embodied energy, GHG emissions and end-use consumption, taking into account A) 100% of potentially active surfaces, B) selected surfaces and C) batteries.

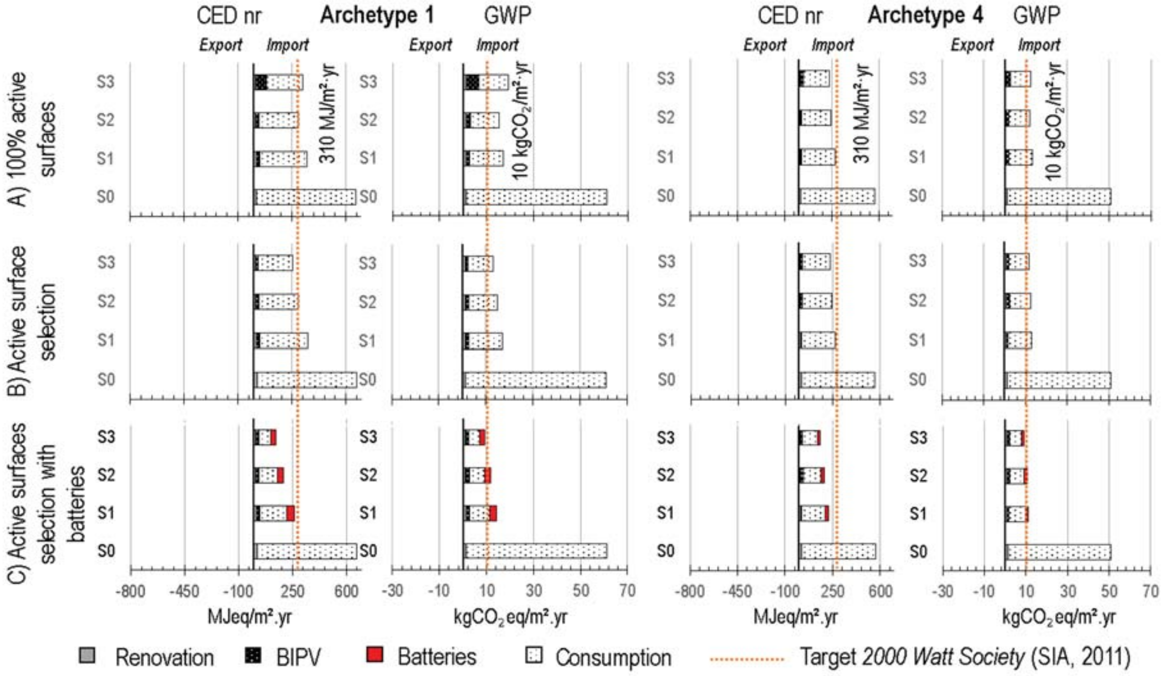


Figure 9. LCA results (**self-consumption approach**) in terms of embodied energy, GHG emissions and end-use consumption, taking into account A) 100% of potentially active surfaces, B) selected surfaces and C) batteries.

In the case that we are not able to inject the overproduction into the grid and must prioritize the self-consumption approach, Figure 9 shows the importance of a reduction of the embodied energy and GHG emission of the BIPV elements via a selection of active surfaces to achieve the Swiss targets. We highlight the important role of the batteries as a system to increase self-consumption and self-sufficiency, to achieve those targets for both, primary energy and CO_2 emission.

Given our objective of achieving the "*2000 Watt society*" targets in the most rational way, at least for the design scenario S3-transformation and taking into account the entire life-cycle analysis, Figures 8 and 9 show that the achievement of these objectives is not easy, but is possible. The results depend on the orientation, type, size and context of the building.

Life Cycle Cost (LCC)

From the study of the two archetypes and the three energy-use scenarios, with and without taking into account the possibility of exporting the electricity overproduction to the grid, Figure 10 shows the difference in terms of payback time of the whole renovation project in function of the energy-use option for both the feed-in-tariff and self-consumption approach.

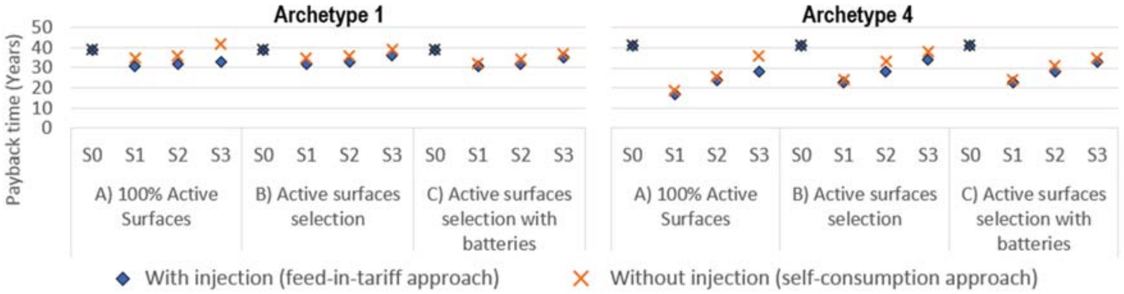


Figure 10. Simple payback time for the two archetypes comparing the three energy-use options with and without taking into account the injection of the electricity overproduction into the grid, substituting the existing oil-boiler by an electric heat-pump for heating and DHW.

Results highlight that, using a feed-in-tariff approach, scenarios S1, S2 and S3, which include BIPV strategies, present in all cases a shorter payback time compared to scenario S0 (standard renovation without BIPV), due to the energy savings and the extra revenue generated by the injected electricity into the grid.

However, when using a self-consumption approach where we are not able to inject the electricity overproduction into the grid, some cases are too close to the payback time of the reference scenario (S0). For archetype 1, the payback time for scenario S3 with 100% of active surfaces exceeds that of the reference scenario (S0) mainly due to the big investment of an oversized BIPV installation with respect to the building's demand, which leads to a too low level of self-consumption (around 9% of the total electricity produced on-site, see Figure 7). Consequently, for this particular scenario, 81% of the electricity produced by the active elements cannot be used by the building or be injected into the grid.

The result of the active surfaces selection process has a more pronounced effect in terms of payback time for archetype 4 due to the larger active surface on façades compared to the active surface on the roof. Above all, in scenario S3 where more PV surfaces are proposed, we observe that the optimization increases payback but avoids excessive electricity injection into the grid. However, S3 continues to be more cost-effective than scenario S0.

After the selection of the active surfaces to maximise self-consumption and self-sufficiency, we tested the introduction of batteries to increase both parameters. Despite the notable increase of the initial investment due to the high price of batteries, the resulting payback time is very interesting to justify the economic viability of batteries in residential renovation projects (Hoppmann et al, 2014). It should be emphasized that, despite not having the possibility of injecting electricity into the grid, the levels of self-consumption and self-sufficiency are so high (between 60-80%) that the results are comparable to the option where all the overproduction could be sold to the grid.

Conclusion

Today, renovation projects improving the building envelope with a high level of thermal energy performance using passive strategies are necessary, but not sufficient. Compensating buildings' energy consumption and embodied energy of the construction materials by producing electricity on-site has become a number one priority. By proposing new adapted BIPV solutions for urban renewal processes, this research contributes to advancing architectural design practices in this direction.

The results presented in this paper highlight the fact that energy renovation projects in the built environment that do not integrate active elements producing electricity from solar energy to cover as much as possible the energy demand of the building are no longer an option if we want to achieve long-term carbon targets.

The analysis of the two case studies highlights the best cost-effectiveness of the BIPV scenarios and the importance of choosing the location of the active surfaces to maximize the self-consumption and self-sufficiency with respect to the building's consumption profile.

Considering that a disconnection from the grid is not an option because of security supply reasons, the role of storage systems using batteries in this kind of renovation projects offers two possibilities depending on the energy-use scenario that we may face. In a feed-in-tariff approach, where the possibility to sell the energy to the grid exists, the main role of batteries could be in terms of energy management, as there are no advantages in terms of non-renewable primary energy and greenhouse gas emissions. However, in a self-consumption approach, where the possibility of injecting the electricity into the grid could be difficult or impossible, the role of batteries is remarkable, because they help increase the self-consumption ratio by decreasing the energy needs from the grid, reaching the Swiss targets.

These are key elements toward real carbon neutrality, allowing us to achieve the performance objectives in a more rational way by optimising the installation to minimise the grid-injected energy. This in turn allows avoiding the intrinsic problem linked to decreasing prices of injected electricity.

The main limitations of this study lie in the fact that available reference values for the LCA are not up-to-date with respect to the proposed products, yet they represent worst-case values given that improvements are expected in terms of embodied energy of materials. Moreover, only one payback value is obtained in the LCC, whereas a range would be preferred since the payback is sensitive to parameters such as the interest rate and the evolution of energy prices.

The next step in our research is to make high quality visualisation of the different design scenarios for each archetype to show that, apart from the energy efficiency of the solutions, it is possible to give an architectural response to different kinds of situations from the urban context and heritage constrains to maintain the quality of the existing buildings. Ultimately, our case studies shall 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.

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