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Building Integrated Photovoltaics (BIPV) in Line with Historic Buildings and Their Heritage Protection

Building Integrated Photovoltaics (BIPV) in Line with Historic Buildings and Their Heritage Protection

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Abstract. Historic buildings are often classified as highly energy-intensive buildings with low energy efficiency. Thanks to their overall percentage share in the European real estate market, it is important to focus on these dwellings with an innovative approach and functional, sensitive aesthetic solutions, thus significantly reducing their energy intensity, increasing their energy efficiency and improving the indoor living conditions. At the same time, it will greatly increase the chance to meet the new energy and emission targets currently proposed by the European Commission.

1. Introduction

Historic buildings are often very energy intensive in terms of their operation. More, they are usually lacking high energy efficiency and quality of indoor living conditions, which is often generally perceived as paying the price to maintain the level of heritage preservation and protection. Yet the share percentage of the historic building stock in the European market is quite large.

Energy Performance of Buildings Directive and Energy Efficiency Directive as a main legislative instrument used for the improvement of the energy performance of buildings were updated on 30 November 2016, as part of the Clean Energy for All Europeans package.[1].

These measures will then substantially increase the pressure on existing building stock in terms of their energy efficiency, performance and bigger renewable energy uptake in buildings.

Thus focusing on historic buildings due to their market share and energy inefficiencies has the great potential to contribute to significant energy savings, reducing the EU's total energy consumption, lowering CO_2 emissions and comply with newly updated energy targets for the year 2020, 2030 with the transition to a decarbonized economy and building stock by 2050 [2].

Yet trying to integrate renewable energy into the historic building structure on the bigger scale would also intensify mutual conflicts between environmental protection on the one hand and the cultural heritage on the other.

This paper shows how these seemingly contradictory views and requirements could be solved by the integration of new types of Building Integrated photovoltaic technology (BIPV) which are able to fulfil strict architectural and functional requirements. Some examples of good practice from different European countries will be presented followed by new PV materials more suitable for integration into historic buildings.

2. New legislation aspects in relation to the market´s share of historic dwellings, integration of renewable energy sources in terms of heritage preservation and environmental protection implications

2.1. Legislative aspects

The original climate and energy targets 2020 (2020 climate & energy package) has recently been updated. The new targets are based on three key objectives for 2030 (2030 climate and energy framework) and the long-term objectives for the transition to a low carbon economy for the year 2050 (2050 low-carbon economy) [3], [4].

This applies, in particular, to further reduce the greenhouse gas emissions, energy and transport, and maintain global warming at 2 °C (temperature increase of the Earth compared to pre-industrial levels). The plan includes even more ambitious goals, the recent proposals by the Intergovernmental Panel on Climate Change (IPCC), which stated that introduction of more strict measures would keep the global warming levels of 1.5 °C [5], [6].

- At least a 40 % reduction in the greenhouse gas emissions (from 1990 levels).
- At least 27 % share of renewable energy
- At least 27 % improvement in energy efficiency
- Reduction of emissions at 80–95 % by 2050 (From 1990 levels)

Currently, in Brussels, so-called "Clean Energy for all Europeans" is being finalized based on the schedule of the European Commission. The package contains proposals for updating energy directives (electricity and consumers markets, energy efficiency and energy efficiency for buildings together with the percentage of renewable sources used) and other documents. As part of its admission, the EU should achieve a 27 % to 35 % share of the renewable sources in gross energy consumption [7] [8]. Figure 1 is a timeline of the energy package; the original European Commission proposal is divided into eight legislative proposals.

Subsequently, these changes will be reflected in the new Energy Act. This should comprehensively address energy storage, renewable energy sources (RES) and lead to a so-called "New energy codex", which will contain all new parts discussed [8].

On 19 June 2018 Directive (2018/844/EU) amending the Energy Performance of Buildings Directive as part of Clean Energy for all Europeans package was published. Europe Union Member States will have 20 months to transpose its provisions into their national law [9].

	European Commission Proposal	EU Inter-institutional Negotiations	European Parliament Adoption	Council Adoption	Offical Journal Publication
Energy Performance in Buildings	30/11/2016	Political Agreement	17/04/2018	14/05/2018	19/06/2018 - Directive (EU) 2018/844
Renewable Energy	30/11/2016	Political Agreement	13/11/2018	-	-
Energy Efficiency	30/11/2016	Political Agreement	13/11/2018	-	-
Governance	30/11/2016	Political Agreement	13/11/2018	-	-
Electricity Regulation	30/11/2016	Ongoing	-	-	-
Electricity Directive	30/11/2016	Ongoing	-	-	-
Risk Preparedness	30/11/2016	Ongoing	-	-	-
ACER	30/11/2016	Ongoing	-	-	-

Figure 1. Clean Energy for All Europeans package – state of play (November 2018) Implementation Schedule of the 8 legislative acts [1].

2.2. Market share of dwellings in the Czech Republic and other EU countries

Buildings are responsible for approximately 40 % of energy consumption and 36 % of CO_2 emissions in the EU. Currently, about 35 % of the EU's buildings are over 50 years old and almost 75 % of the building stock is energy inefficient, while only 0.4 % to 1.2 % (depending on the country) of the building stock is renovated each year [2].

In the Czech Republic, there are 600 protected urban units of which 296 are towns (256 urban heritage zones, 40 urban heritage reservations) and 276 villages (61 village heritage reservations and 211 village heritage zones) [10].

The share of historic dwellings built before 1945 varies between EU countries (figure 2). According to the EU building database, 21.87 % of all dwellings in the Czech Republic were built before 1945 compared to Austria (26.55 % in 2014), Germany (25.24 % in 2014). For EU 28 countries 22.69 % of all dwellings were built before 1945 [11].

In four European countries, the share exceeds 1/3 of the building stock: UK (39.4 %), Spain (38.9 %), Denmark (38.6 %) and France (34.9 %) [12].

In European countries including the Czech Republic, the protected stock is less than 50 % of the .3historic building stock. Thus, particularly the energy refurbishment of the historic buildings (due to their building stock market share) can significantly contribute to the new energy and climate change goals in the terms of reducing their energy demand, increasing energy efficiency, lowering CO_2 emissions and improving their living conditions [2].

Troi and other authors estimate an average demand for historic building´s energy consumption of 170 kWh/m². The number of the historic dwellings in EU is 55 million (14.3 % prior to 1919, 12.1 % 1919–1945) and their total energy demand is of 855 TWh/year. The renovation of historic buildings could significantly reduce the EU's total energy consumption by 5–6 % and lower CO_2 emissions by about 5 % [2]. Furthermore, Troi assumes savings of 180 Mt/year within 2050 (3.6 % of 1990's EU-27-emissions) by refurbishments [12].

Thus, all the aspects mentioned in this section will also have direct implications on historic dwellings and their energy performance requirements.

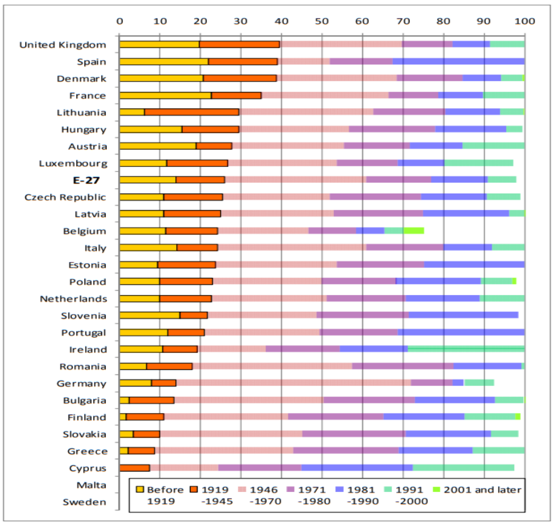

Figure 2. The share of dwellings in classes for periods of construction for EU-27, the reference year 2001, Dwellings built before 1919, between 1919 and 1945 for EU-27 [12].

2.3. Heritage preservation and environmental protection implications

Trying to integrate various energy conservation measures into historic buildings is a complex task and will inevitably lead to heightened conflicts between representatives of heritage preservation, architects, urban planners, conservationists and investors. Yet in the current situation, it is no longer sufficient to merely try at all costs affect the thermal insulation properties of the building envelope [10].

There are many examples of good practice, based on meticulous planning and research at the early stages of the projects together with innovative use of the latest technologies together with the use of renewable energy sources (RES) available on the market.

Some of the European initiatives (NEW4OLD, EFFESUS, 3ENCULT, RENERPATH, RESSEEPE, LIFE-INSU-SHELL, PIME's) towards improving energy efficiency with special attention to historic buildings demonstrates the immense potential for their better energy performance and efficiency [13].

3. Review of present and future integration of PV in heritage zones and historic buildings

Reviewing some cases in the Czech Republic and in other European countries can provide fruitful information about how the issues of BIPV integration into the historic buildings, the challenges, main obstacles and solutions were successfully resolved.

In this paper were reviewed three cases in the Czech Republic dealing with protection of the roof landscape character. This is the area which almost always leads to considerable differences of opinions between stakeholders to find a meaningful consensus.

3.1. The cases in the Czech Republic

Three projects already completed in the Czech Republic are listed below. The first one is the Archbishop's Grammar School in Prague 2 situated on Peace Square, where the large solar thermal system was installed (figure 3a), [14].The second project is the installation of a photovoltaic system with an output of 40 kW at the Faculty of Education Masaryk University (MU) in Brno (figure 3b), [15].

The last project described in this section is the PV system placed on the roofs of the National Theatre building (figure 3c), [16].

These projects were preceded by an extensive confrontational discussion about their indisputable contribution to the reduction of energy consumption and the environment. Yet it was also pointed out the considerable disruptive effect of these installations on historical heritage.

In the case of Archbishop Gymnasium project, it was argued the impact on so-called „Character of Roofing landscape ". Even though the building itself is not a heritage protected site and the installation is not visible except the aerial view. Yet, the bird's eye view is not in accordance with the protected monumental zone [10], which is in close proximity to the object.

Figure 3. a) Archbishop grammar school, b) Faculty of Education Masaryk University (MU), c) National Theatre, Source: Google Maps.

The second project is a photovoltaic system with an output of 40 kWp on the roof of the Faculty of Education Masaryk University, located on the vertical strip at the top of the facade of the building facing south. Because the building is located on the edge of the conservation area it was necessary to reduce the angle of inclination of the photovoltaic panels from originally planned 45º to new angle of 30º based on a request from the National Monuments Protection body, so that the frame structure with photovoltaic (PV) panels attached, would be less intrusive [14].

The last project is a PV system placed on the roofs of the National Theatre building (figure 3c). Due to aesthetic requirements and location, there were flexible photovoltaic panels installed based on thin film technology with three-layer amorphous cells without using a fixed tilted frame. The PV flexible panels were integrated directly into the roof membrane Evalon. The nominal power plant located on the roof of the operations building is 22.01 kWp and power plant on the roof of the New Stage is 24.48 kWp [16].

Due to the strict conservation protection rules of the historical centre of Prague, the negotiations and the preparatory phase of the project were quite complex and time-consuming, which took more than two years. One of the key issues was again an impact on the roof landscape character from the bird's-eye view.

Given the overall energy savings achieved throughout the Energy Performance Contracting (EPC) method, higher by almost 10% compared to guaranteed savings, the project can be considered in terms of energy saved as very successful. Yet in the terms of aesthetics and integration of PV, the project is still causing contradictions between some experts.

3.2. Roof landscape character issues

In terms of legislation, we understand the heritage protected area as the territory declared under §5 and §6 of Act no. 20/1987 Coll., on state monument care, as amended, for the conservation zones and conservation areas [17].Roof landscape character is understood as "characteristic appearance of roofs, contributing to a sense of identity, positive and irreplaceable value in terms of preservation of whole and preserving the beauty of Czech and Moravian cities and villages, and last but not least, the place that traditional roofs occupy in the image of the cultural landscape“ [18].

Yet in many areas, there is the substantial aesthetic damage of the roof landscape character by highly disparate elements as television antennas, satellite receivers, different dormer disparate shapes and colours, ventilation ducts, air conditioning units, various skylights in a chaotic arrangement etc.

They are also important aspects of the heritage building itself. In cases of the refurbishment of the existing building, it is often required to use original materials including roofing.

The PV systems intended for historical buildings should be fully aesthetically integrated directly into the building envelope as Building Integrated Photovoltaics (BIPV). There are already many examples of good practice of BIPV elsewhere in Europe.

For example, a publicly well-known project of listed building of Reichstag in Germany (Figure 4a) where they were photovoltaic systems of various technologies on the total area of 3600 m² installed [19].

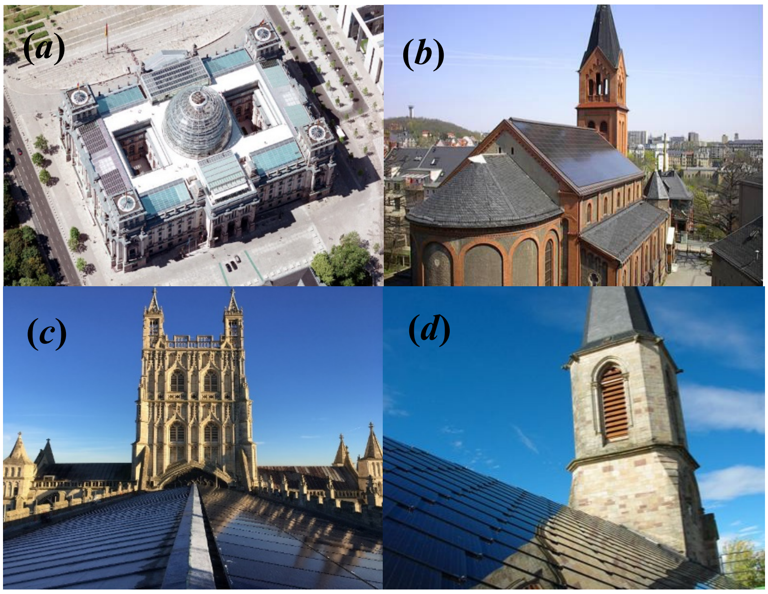

Figure 4. a) Reichstag building, b) Herz-Jesu-religious building in Plauen, c) Gloucester Cathedral and d) Church Eglise Saint Leger Manspach

Another project is the Church Herz-Jezu in Plauen Germany (Figure 4b) with fully integrated 24 kWp BIPV system [20]. All-black monocrystalline modules from SOLARWATT were integrated as part of the programme “parishes for the solar energy” supported by The Deutsche Bundesstiftung Umwelt DBU (German Federal Environmental Foundation) [21].

Cathedral in Gloucester, England (Figure 4c) is the installation of a photovoltaic system on one of the oldest buildings of its kind, the 1000-year-old church. BIPV system of 150 all-black solar panels (REC Peak Energy BLK2) with a total output of 38 kWp were fully integrated [22].

Figure 4d depicts the BIPV system consisting of 462 solar tiles SG Solar Sunstyle firm Saint-Gobain Solar. It is a religious building Eglise Saint Leger Manspachu, France [23].

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Church buildings in Germany, France and England can be considered as very successful projects passing strict requirements of monument protection and aesthetically and technically meets both goals of heritage and environmental protection.

4. Review of solutions for the adequate integration of PV in historic buildings

Intense innovation in the field BIPV in the form of various types of roofing materials, such as solar tiles, shingles or metal roofing sheets is currently coming on the market.

In terms of aesthetics and function, they can meet even the stringent requirements of heritage conservation where the use of the standard Building Applied Photovoltaics (BAPV) systems would prohibit.

The presented products have been chosen based not only on the successful demonstration of new innovative BIPV materials used on the heritage buildings but also where the heritage protection authorities were actively engaged in the whole project together with the support of the other relevant government agencies.

Figure 5a shows a rural farm dwelling situated in a heritage protected site, Ecuvillens village in the Swiss canton of Friborg. BIPV roof tiles Solar -Terra produced by Issol Suisse were fully integrated into the roof structure with a total area of 230 m² expected 28 MWh of electricity produced per year. The project is a collaboration of experts from Swiss government agencies for the protection of cultural heritage, the Swiss Federal Office of Energy, Swiss Centre for Electronics and Microtechnology CSEM.

These tiles allow full customization and flexibility thanks to its unique design with the possibility of cutting different shapes according to the diagram (figure 5b) [24].

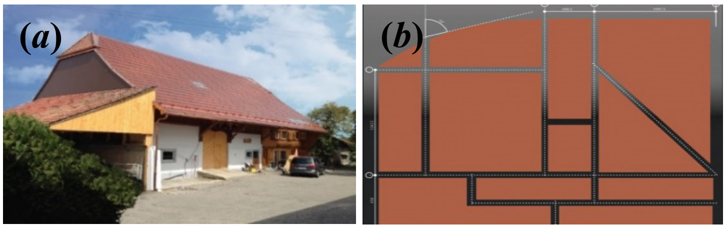

Figure 5. a) Ecuvillens Village, the rural Swiss farmhouse, b) Diagram of cutting in case of custom-made execution

Figure 6a depicts the Farmhouse in Priesnitzhoeve, heritage protected village of Laag Soeren located on the edge of National Park Veluwezoom in Holland.

The fully integrated BIPV system into the roof structure of the farmhouse consists of solar tiles produced by Dutch company ZEP BV (figure 6b). The roof tiles ZEP Blackline (all-black tile including black busbars, 2 variants matt/glaze) have the indicated output of 90 Wp/m², efficiency of one monocrystalline module is 20.22 %, dimensions are 487 x 296 mm and weight of weight 4.8 kg/tile, and recommended roof slope is 15–80°. 30 pcs of tiles are connected per one power optimizer allowing detailed monitoring and high fire safety protection [25].

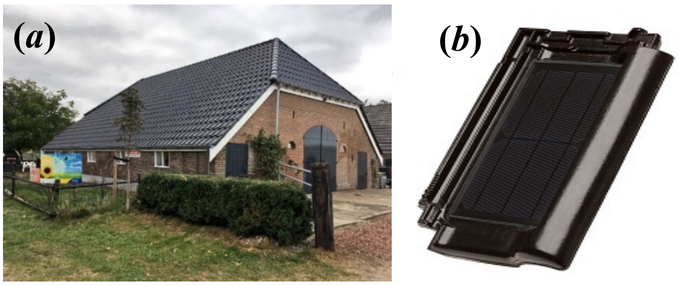

Figure 6. a) Farmhouse in Priesnitzhoeve, b) Detail of solar roofing tile ZEB Blackline.

Figure 7 is a slate roofing material with integrated photovoltaic technology. Colour matte shades of blue-grey, black or terracotta. Optically one panel looks like three traditional slate tiles (ie. Duchess Slate) dimensions of 600x300 mm.

The size of one roof panel is 980 mm x 410 mm x 4.5 mm, the weight of 3.5 kg, the minimum roof pitch required is 22°. Performance of PV slate modules based on type is 35–40 Wp, the roof area of 7 m² is approx. needed for the output of 1 kWp [26].

Another innovative product is well suitable for historic buildings solar tile and shingle from Solteq GmbH available in a wide range of colours including grey, black and terracotta, in various sizes and templates. All-black version of Solteq Quad Premium Black + 40 tile has an estimated output of 44 Wp with the efficiency of 20.2%,173 to 212 Wp / m², weight 3.3 kg, 14 kg / m². Tiles can be assembled into different patterns (templates) and also in different densities (Figures 8) [27].

Figure 7. BIPV slate roof.

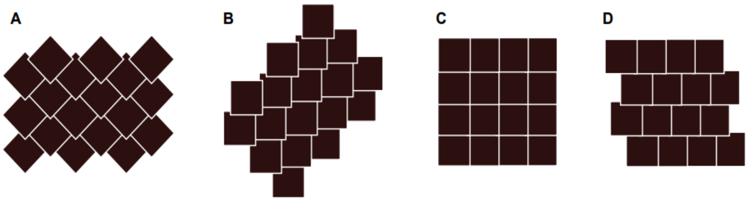

Figure 8. Different designs: diamond look (A), skew angled (B), horizontal nested (C) or horizontal composite (D).

Dyaqua Invisible Solar Company in Italy recently introduced a range of new innovative solar products with a realistic surface that could be integrated into the heritage-listed dwellings and protected sites. The main product represents a very traditional Italian roof tile known as Coppo tile. One tile has dimensions of 45 cm x 19 cm x 13 cm, the weight of 1.5 kg and a power output of 4.5 Wp, 67 Wp / m².

The company also preparing other PV products in the realistic appearance of stone, concrete and wood in various colour combinations for other construction applications (figure 9). It should be noted that the drawback of excellent aesthetics is the lower electrical output, 1.15–3 Wp for the stone, concrete and wood module. The company stated that Coppo tile was also recognized by the Italian Ministry for Cultural Heritage and Tourism (MiBACT) as the appropriate technical solution for improving the energy efficiency of cultural and historic buildings [28].

Figure 9. PV Coppo tile, imitation of wood, stone and concrete with integrated photovoltaic technology

5. Conclusions

Recently updated EU legal dispositions entered into the force related to energy efficiency and performance of the buildings with the focus on increasing the percentage of renewable energies used and further decrease CO_2 emissions will also have large implications on historic dwellings.

Heritage dwellings have proportionally quite a large market share of whole European building stock plus they are often very energy intensive in terms of their operation. Thus, not focusing on their refurbishment in the context of the legal requirements of 2020, 2030 and 2050 EU directives for climate protection and energy efficiency could make it extremely difficult to reach these targets.

Yet the refurbishment of historic dwellings is a complex task which requires implementation of highly aesthetical and functional techniques to comply with heritage protection law requirements. Renewable energy and particularly photovoltaic technology seem indeed controversial in terms of integration into the historic building envelope.

This paper presents some successful projects in the Czech Republic and other EU countries. More it reviews recent innovative BIPV photovoltaic systems especially related to roof cladding which could fully comply with strict heritage protection rules and at the same time make the heritage dwellings more energy efficient, lower their CO_2 footprint and retain their architectural elegance for future generations.

Acknowledgements
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