D13. Analysis report for BIPV potential in buildings in Cyprus

ImpAct BiPV

Innovative Design for Improved Application of Glass BIPVs on Buildings

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Deliverable author: Yerasimos Yerasimou

Contributors: All ImpAct-BIPV Partners

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1. Introduction

Buildings account for 40% of global energy consumption and are therefore a large source for CO_2 emissions [1]. The European Union (EU) initiative towards minimization of the dependence on fossil fuels and other conventional energy sources requires that new buildings have very high energy performance. According to Energy Performance of Building Directive (EPBD) and as shown in the timeline for NZEBs implementation in Figure 1, all new public and private buildings become nearly zero–energy buildings (NZEBs) by the end of 2018 and 2020, respectively [3]. Consequently, the energy requirements of each building should be covered by renewable sources, such as photovoltaic (PV) solar energy.

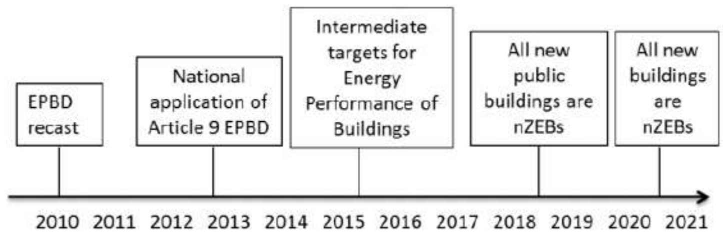

Figure 1: Timeline for NZEBs implementation [3].

Photovoltaic panels are often installed on the roof of the building due to the ease of installation and advantageous positioning toward the sun; both azimuth and elevation angles. Nonetheless, the available area on the rooftop of the building is often restricted by other subsystems and facilities. In addition, the energy demand is increased with respect to the size of the building (height), with the area of the roof remaining constant. Façade areas on the other hand, increase proportionally to the building height and are therefore valuable areas to exploit, by integrating PV cells on them.

Firstly, the aim of this report is to define the problem as to the specific need for building integrated photovoltaics (BIPV)to be implemented in specific building types in Cyprus e.g. to satisfy criteria for NZEBs in Cyprus or to combine energy efficiency and new trends in building envelope aesthetics in retrofitting cases of existing buildings. Following this, the potential for BIPV, including the criteria, conditions, and restrictions that may take place in buildings in Cyprus has been analysed. Different type of buildings existing in Cyprus were reviewed in terms of needs, available space, and envelope (façade, balconies, windows, atria, etc.) retrofitting possibilities together with possible specific applications of BIPV. In this task, the energy yield from BIPV systems in specific applications in buildings has been analysed as well in order to derive the best-case scenarios for BIPV systems in specific building types.

2. BIPV potential in Cyprus

Nowadays in Cyprus, there is an ever–increasing trend in constructing multi–storey (greater than 10 floors) buildings [2]. Currently, there are over 80 pending applications for construction licenses of multi–storey buildings across the country. The integration of BIPV systems to the building envelope is a promising technology for meeting the EU regulations regarding NZEBs thus minimizing the dependence on fossil fuels and other conventional energy sources and increasing the penetration of renewable energy sources in the energy grid. Due to the NZEB directive towards on-site renewable energy sources and the limited available space on rooftops, the implementation of BIPVs becomes an attractive solution for multi-storey buildings. For these reasons, the use of BIPV could lead to the development of a potentially new market, aiming at fulfilling the energy requirements and restrictions.

In general, the minimum requirements and technical characteristics that must be met by NZEBs, as indicated in RAA/2014 are as follows:

1. Energy efficiency class A in the energy performance certificate of a building.
2. Maximum primary energy consumption in residential buildings of 100 kWh/m^2.
3. Maximum primary energy consumption in non-residential buildings of 125 kWh/m^2.
4. Maximum energy demand for heating for residential buildings of 15 kWh/m^2.
5. At least 25% of total primary energy consumption comes from renewable energy sources.
6. Maximum mean U – value for walls and load – carrying elements, which are part of the building envelope of 0.4 W/m^2K.
7. Maximum mean U – value for horizontal building elements and ceilings, which are part of the building envelope of 0.4 W/m^2K.
8. Maximum mean U – value for door and window frames (excluding shop windows), which are part of the building envelope of 2.25 W/m^2K.
9. Maximum mean installed lighting power for office buildings of 10 W/m^2.

Nonetheless, according to the Commission Recommendation with respect to the Guidelines for NZEBs promotion, the recommended values for the Mediterranean region are as follows [4]:

- Single-family house: 0 -15 kWh/m^2 of net primary energy with 50 – 65 kWh/m^2 of primary energy use covered by 50 kWh/m^2 of local renewable sources.
- Office: 20 - 30 kWh/m^2 of net primary energy with 80 – 90 kWh/m^2 of primary energy use covered by 60 kWh/m^2 of local renewable sources.

Therefore, BIPVs have an important role for the integration of on–site renewable energy sources, which is essential for fulfilling the NZEB guidelines. Several considerations should be taken into account for BIPVs integration during the design and implementation stages, including the performance of the BIPV element as a building component, the electrical performance of the BIPV system with respect to the building needs, and the long-term reliability and operation of the BIPV components.

Cyprus relies heavily on fossil fuel and is the first among the EU countries on conventional energy sources dependence [5]. Thus, the integration of BIPV elements should not be limited only to new buildings. Instead, existing buildings should also be candidates for BIPV utilisation. Although some BIPV applications, such as PV skylights, require planning and/or heavily modifying the structure of the building, others, including rainscreen and ventilated façades, could be easily retrofitted to the building envelope. Thus, the building benefits by having local energy generation and by increasing its thermal insulation through the added façades on its surfaces.

Despite that the majority of BIPVs mentioned in the literature are applied to new buildings, about one – third of the study cases focus on retrofit applications [6], as several barriers exist in the adoption of BIPVs for retrofit applications. From the technical perspective, issues such as the need for bespoke PV elements that can installed on the existing structural elements and the architectural integration of the PV elements to the existing building design should be tackled before BIPVs become widely acceptable. Nonetheless, the integration of PV elements on existing buildings in Cyprus and their wider adoption is equally important as on new buildings, since the majority of available buildings and households already exists.

The performance of the BIPV elements as building components covers a wide range of specifications that the BIPVs need to comply with, before they can be installed on the building envelope. Firstly, it is required that the BIPV elements can provide mechanical resistance and stability, and can withstand various loads or impacts. The specifications are subject to the geographical location of the installation, as well as the type of building element it substitutes. Moreover, BIPV components should provide air and water tightness in the case they are utilised as skylights or curtain walls. In addition, they should ensure noise insulation and fire resistance. In addition, the thermal comfort and energy conservation should be achieved through the materials used for the BIPVs. Finally, they should withstand extreme weather conditions.

The building's energy requirements should also be considered during the design phase of the BIPV system. From a financial point of view, the main objective when installing a BIPV system is to cover the building energy demand through the collected energy rather than buying solely from the grid. The dependence on the grid could be further reduced by combining the BIPV system with an energy storage system. The power capacity of the system, should therefore be selected based on the requirements of the building.

Finally, the long-term reliability and optimal operation of the BIPV system is of utmost importance. PV modules used in building – applied photovovoltaic (BAPV) systems are usually expected to have a lifespan of 25 years. For BIPVs, however, the component is expected to fulfil all the requirements both as a building structural element and a power generation device throughout the lifetime of the building. In the case where one of its functions does not operate as expected, the component should be replaced. Another aspect that should be considered is the ease of maintenance for the BIPV components, including dust cleaning and replacement in case of a failure.

Due to the increasing trend in the development of multi-storey buildings in Cyprus, a potentially new market could be developed aiming at fulfilling the energy requirements and restrictions for the integration of BIPV systems to new and existing buildings and meeting the EU regulations regarding NZEBs. Several barriers exist and should be taken into account for the wider adoption of the BIPV elements as building components. The performance of the BIPV systems, the building's energy requirements and the long-term reliability and optimal operation of the BIPV systems cover a wide range of specifications and aspects that the BIPVs need to comply with, before they can be installed on the building envelope.

3. Building types in Cyprus

Buildings can be split in two main categories; residential and non – residential. Figure 2 presents an overview of the building permits share in Cyprus [7]. As shown, the majority of building permits in Cyprus are residential. Buildings that can be classified as residential may include a single-family house, duplex, a flat that is part of an apartment block and terraced family house. Non-residential buildings include office, retail and industrial buildings.

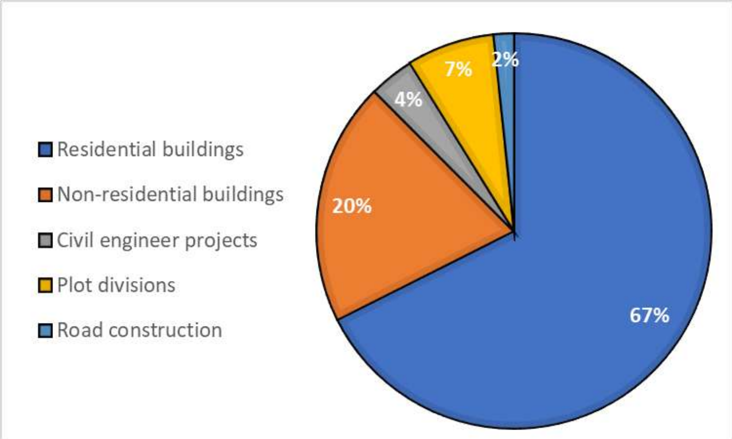

Figure 2: Building permit share in Cyprus [7]

Typical examples of the different types of buildings available in Cyprus are presented in Table I, where their various features, such as the indoor area, window ratio and energy performance are presented for each building type [8]. The parameters for both new and existing buildings are considered in Table I.

Table I: Comparison of building types [8]

Building type	Condition	Surface/ Volume	Window ratio (%)	Area (m^2)	Average energy (kWh/m^2)
1. Single family house	Existing	0.36	8.82	194	666
2. Single family house		0.36	12	195	321
3. Apartment block		0.17	14.83	519	402.5
4. Apartment block		0.11	14.04	826	439
5. Office building		0.33	21.19	1448	537
6. Retail building		0.29	17.81	412	822
7. Single family house	New	0.33	13.6	176	479
8. One bedroom apt		0.34	21.85	46	521/363/664[1]
9. Two bedroom apt		0.34	12.65	88	507/351/635[1]
10. Three bedroom apt		0.35	16.28	103	497/354/617[1]
11. Office building		0.29	27.2	2515	402.7

[1] The values shown in Table I for the average energy performance is for 1st floor, in-between floors, and top floor.

The average energy performance of the buildings depends on many parameters, such as the type of glazing, the efficiency class of the electrical loads installed within the building, and the insulation properties of the building's surfaces. Nonetheless, as shown in Table I, even new buildings that are built using advanced materials that own high thermal insulation properties and are equipped with energy class – A electrical appliances have substantial energy requirements. Therefore, there is a need for on – site renewable energy, in order to reduce the reliance on fossil fuel.

Also observed in Table I, large buildings, such as office and retail buildings, have the largest window ratio. Thus, they offer the greatest opportunity for BIPV integration on the building windows. Moreover, the largest wall surface for all the example office and retail buildings faces the South, which is also important for integrating rainscreen and ventilated façades in the building envelope.

The integration of PV elements on the envelope of the building can have numerous benefits for buildings in Cyprus. Firstly, there is large amount of solar resource available in Cyprus. Hence, its exploitation will result in reduction of the electricity cost. Also, savings in material can be achieved through the use of BIPV elements; especially for new buildings. That is because the BIPV elements can serve both for generating electricity and a substitute to conventional building materials. However, one of the biggest challenges in the BIPV market is their promotion, so that people consider them a viable option. For that reason, a great effort is put into transforming BIPV components to aesthetically pleasing elements that are widely accepted.

In Cyprus the solar irradiation is about 2000 kWh/m^2/year, therefore, the maximum generated energy for monocrystalline is around 400 kWh/m^2/year, whereas for thin – film is around 300 kWh/m^2/year, by assuming cell efficiencies of 20% and 15%, respectively and that the PVs are positioned optimally. Figure 3 shows the percentage of the incident solar radiation for different surfaces. As observed, for south – facing surfaces, the maximum solar irradiation is 70% of the maximum available, whereas for east and west – facing surface the maximum available solar irradiation is 50%. Therefore, installing monocrystalline PV modules on a south – facing vertical wall would yield a total of 280 kWh/m^2/year while on an east and west – facing vertical wall the PV module would yield 200 kWh/m^2/year. Similarly, a thin – film PV module on a south – facing vertical wall would yield a total of 210 kWh/m^2/year while on an east and west – facing vertical wall the PV module would yield 150 kWh/m^2/year. Finally, considering the selection of flat – mounted BIPV roofs, a total energy of 360 kWh/m^2/year for monocrystalline and 270 kWh/m^2/year for thin – film can be achieved. These are the absolute maximum energy values for each building surface for the given cell efficiencies and by assuming that no shading exists.

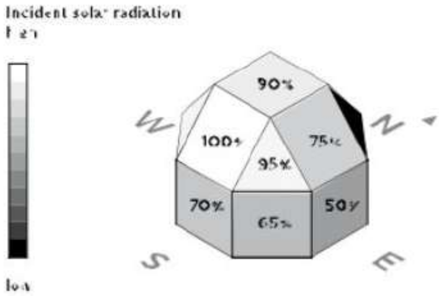

Figure 3: Incident solar radiation on inclined surfaces and positions.

The following reference buildings in Cyprus are considered for BIPV applications:

1. Single family house:
   a. North – facing façade: 52.9
   b. South – facing façade: 52.9
   c. East – facing façade: 56
   d. West – facing façade: 56
2. Office building:
   a. North – facing façade: 280.32
   b. South – facing façade: 280.32
   c. East – facing façade: 216
   d. West – facing façade: 216

Both buildings have large surface areas that can be exploited for installing BIPV elements. Thin – film rainscreen façades can be used to cover the surface walls and windows, thus covering a big portion of the energy demand of the buildings. Considering thin – film BIPV modules from OnyxSolar as an example with peak power (Wp) of the BIPV element of 57.6 Wp for non - transparent, 40 Wp for low - transparent, 34 Wp for medium – transparent, and 26 Wp for high - transparent elements [9]. Thus, considering the reference single-family house as an example, 8.5 kWp can be installed on the south, east and west façades of the building, assuming non – transparent elements will cover the walls and high – transparent elements will substitute the windows. The estimated annual PV production given the irradiance profile and weather data for Cyprus is 7658.7 kWh, which covers about 80% of the energy demand estimated by the EPBD recommendations. It is assumed that no shading is covering the PV modules, however, in a real – case scenario the façades of the building would be affected by adjacent buildings, trees etc. To further increase the PV production, BIPVs can be combined with BAPV elements installed on the roof at optimal positioning towards the sun.

Similarly, for the reference office building 37.1 kWp can be installed by assuming the same conditions as with the reference single house. Therefore, the estimated annual production is 33868 kWh, which only covers about 50% of the office building energy requirements of 60kWh produced by renewable energy sources per m^2. Thus, for the reference office building, other types of BAPVs, such as roof – mounted PVs, or BIPVs, such as a PV skylight, should be utilised in order to cover its energy demand requirements according to the EPBD recommendations.

As shown, buildings in Cyprus can benefit from BIPV applications, as a large portion of their energy demand can be covered by exploiting their façades. Thus, large surface areas that were not utilised earlier, can be used to help in covering the buildings' energy demand and therefore, fulfil their requirements towards NZEBs. Both the single-family house and office reference buildings can fulfil the NZEB requirements with respect to the 25% of energy demand covered from renewable energy sources through BIPV installation, however, additional modules are required to fulfil the EPBD recommendations.

4. Performance of BIPV systems

The PV system can be classified in two types, depending on its mounting structure; BAPVs and BIPVs, as shown in Figure 4 [10]. While the former has several advantages over the latter, such as easy installation on building rooftops, optimal positioning towards sun (both azimuth and elevation angles), BIPV is an alternative technology with many benefits as well. As mentioned earlier, the most important advantage of BIPV elements is their use as a photovoltaic and a building element; thus, increasing the available potential installation area and reducing the cost by substituting conventional building materials.

Kumar et. al. performed a comparison between roof mounted BAPVs and BIPVs for three cell technologies; namely monocrystalline silicon (C-Si), copper indium selenium (CIS) and cadmium telluride (CdTe) [10]. The different systems were evaluated and compared in terms of their annual energy production, yield factor, capacity utilisation factor, and performance ratio.

(a) (b)

Figure 4: Example PV installations: (a) BAPV and (b) BIPV [9]

Yield factor is defined as the ratio of the generated power by the system to the rated installed capacity. Similarly, capacity utilisation factor is the ratio of the power generated by the system to maximum potential generation of the system, without considering factors such as radiation, ambient temperature and angle of incidence. Performance ratio on the other hand, is the ratio of the yield ratio to the available solar radiation resource.

Table II [11] shows the comparative results for the 32.7 kWp system that was analysed for different technologies under BAPV and BIPV mounting configurations. As observed, CdTe technology has better performance for both BAPV and BIPV configurations. In addition, the performance variations between the investigated cell and mounting technologies are insignificant. Therefore, for BIPV applications the most important attributes that should be considered prior implementation are the positioning of the PV elements, as thin – film performs better compared to crystalline in shady environments, and the architectural harmony with the rest of the building.

Table II: Analysis of BAPV and BIPV for different cell technologies [11]

Parameter	BAPV			BIPV		
	C-Si	CIS	CdTe	C-Si	CIS	CdTe
Annual energy production (kWh)	45,400	45,000	46,800	43,700	44,100	46,100
Yield factor	1388,4	1376,1	1431,2	1336,4	1348,6	1409,8
Capacity utilisation factor	15,84	15,7	16,33	15,25	15,39	16,09
Performance ratio	75,04	74,38	77.36	72,23	72,89	76,2

5. Standards compliance

The integration of PV elements to the building envelope should comply with standards that are relevant to the building and PV sectors [12]. Some of the standards are international; however, there are some that are only applicable depending on the installation country or region. Although there is not a BIPV specific standard for Cyprus, a list of international and EU standards that are relevant to BIPVs is presented in Table III. The EN 50583:2016 –" Photovoltaics in Buildings" standard is the most relevant to BIPVs and includes the requirements of the BIPV element as a structure material and possible mounting options. Other standards specific to building and PV elements can be applied as well. However, there is a need for development of a standard to ensure the long–term reliability of PV products as building elements.

Table III: Overview of existing standards related to BIPV

Standard	Title	Component	Sector
EN 1279 (1–6)	Insulated glazing units	Glass	Construction
EN 14449 EN ISO 12543 (1–6)	Laminated glass		
ISO 11485 (1–3)	Curved glass		
EN 13830	Curtain wall	Curtain wall	
ETAG 034	Ventilated façades	Rainscreen façades	
EN 13501–5	Fire classification	Roof elements	
EN 1187	Test methods for fire exposure		
EN 14963	Roof coverings classification		
EN 1873	Prefabricated accessories		
EN 61215	c–Si terrestrial PV modules – Design qualification and type approval	c–Si PV	Photovoltaics

IEC 61646	Thin – film terrestrial PV modules – Design qualification and type approval	Thin–film PV	
EN 61730 (1–2)	PV safety requirements	c–Si and thin–film PV	
EN 50583:2016 (1–2)	PV in buildings: BIPV modules		
IEC 62109	Safety of power converters in PV systems	Inverter	Power conversion
EN 50438	Grid–connection requirements		
IEC 62910	Test procedure for low–voltage measurements		
EN 50530	Overall efficiency of grid–connected PV inverters		

6. Conclusions

This report focused on the penetration of BIPV technologies in new and existing buildings in Cyprus. As shown, the majority of buildings in Cyprus are residential with a large portion of them being apartment blocks or multi – storey buildings. In addition, the current trend in the building sector in Cyprus favours the construction of luxury multi-storey buildings. Thus, to transform them into NZEBs all available surfaces should be utilised including rooftops, façades, balconies etc. Due to the NZEB directive towards on – site renewable energy sources and the limited available space on rooftops, the implementation of BIPVs becomes an attractive solution for new and existing multi – storey buildings. Moreover, it is also an attractive solution for single or duplex family houses that would like to combine PV modules with the architectural elements on their buildings.

7. References

[1] P. Nejat, F. Jomehzadeh, M. M. Taheri, M. Gohari, and M. Z. A. Majid, "A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries)," Renewable and Sustainable Energy Reviews, vol. 43, pp. 843 – 862, 2015.

[2] M. Economidou, P. Zangheri, D. Paci, Long-term strategy for mobilizing investments for renovating Cyprus national building stock, European Commission 2017.

[3] D. D'Agostino, P. Zangheri, D. Paci, Transition towards NZEBs in Cyprus, European

Commission 2017.

[4] 2nd National plan for increasing the number of nearly zero-energy buildings, Cyprus, 2017.

[5] T. Mesimeris et. al, Cyprus' Draft Integrated National Energy and Climate Plan for the period 2021-2030, European Commission 2019.

[6] Martín-Chivelet N, Gutiérrez J, Alonso-Abella M, Chenlo F, Cuenca J. Building retrofit with photovoltaics: Construction and performance of a BIPV ventilated façade. Energies. 2018 Jul;11(7):1719.

[7] Deloitte, Cyprus Real Estate Market Outlook Real Estate Advisory Services June 2016

[8] Calculation for Setting the Minimum Energy Performance Requirements at Cost Optimal Levels According to Article 5 of the Directive 2010/31/EE for the Energy Performance of Buildings (recast), April 2013.

[9] "Onyx Solar," https://www.onyxsolar.com/, accessed: 2019-08-30.

[10] Peng, C., Huang, Y., & Wu, Z. (2011). Building-integrated photovoltaics (BIPV) in architectural design in China. Energy and Buildings, 43(12), 3592-3598.

[11] Kumar, N. M., Sudhakar, K., & Samykano, M. (2019). Performance comparison of BAPV and BIPV systems with c-Si, CIS and CdTe photovoltaic technologies under tropical weather conditions. Case Studies in Thermal Engineering, 13, 100374.

[12] Alim, M. A., Tao, Z., Hassan, M. K., Rahman, A., Wang, B., Zhang, C., & Samali, B. (2019). Is it time to embrace building integrated Photovoltaics? A review with particular focus on Australia. Solar Energy, 188, 1118-1133.

8. Contacts

Project Coordinator

K-ENERGY

Fanos Karantonis, Managing director

6 Pentadaktylou Street, CY-2682 Palaiometocho, Nicosia – CYPRUS

Email: f.karantonis@karantonis.com.cy

Phone: +357 22 311 234

Work Package Leader

Partner Responsible for WP: FOSS Research Centre for Sustainable Energy, University of Cyprus

Name of the contact person: Prof. George E. Georghiou

Address: 1 Panepistimiou Avenue, 2109, Aglantzia, 1678, Nicosia, Cyprus

Email: geg@ucy.ac.cy