From Nearly Zero Energy Buildings (NZEB) to Positive Energy Buildings (PEB): the next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example

Anna Magrini, Giorgia Lentini, Sara Cuman, Alberto Bodrato, Ludovica Marenco

PII: S2666-1659(20)30015-6

DOI: https://doi.org/10.1016/j.dibe.2020.100019

Reference: DIBE 100019

To appear in: *Developments in the Built Environment*

Received Date: 17 March 2020

Revised Date: 22 May 2020

Accepted Date: 13 June 2020

Please cite this article as: Magrini, A., Lentini, G., Cuman, S., Bodrato, A., Marenco, L., From Nearly Zero Energy Buildings (NZEB) to Positive Energy Buildings (PEB): the next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example, *Developments in the Built Environment*, https://doi.org/10.1016/j.dibe.2020.100019.

Title

From Nearly Zero Energy Buildings (NZEB) to Positive Energy Buildings (PEB): the next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example

Authors

Anna Magrini, Department of Civil Engineering and Architecture, University of Pavia, Pavia, Italy

Giorgia Lentini, Department of Civil Engineering and Architecture, University of Pavia, Pavia, Italy

Sara Cuman, Department of Civil Engineering and Architecture, University of Pavia, Pavia, Italy

Alberto Bodrato, Stecher Srl, Engineering Services, Ovada, Italy

Ludovica Marenco, IRE SpA (Regional Infrastructure for Energy Recovery), Genova, Italy

Corresponding Author

Anna Magrini, Department of Civil Engineering and Architecture, University of Pavia, via Ferrata 3, 27100 Pavia, Italy, magrini@unipv.it

Title

From Nearly Zero Energy Buildings (NZEB) to Positive Energy Buildings (PEB): the next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example

Abstract

The European energy policies introduced the Nearly Zero Energy Building (NZEB) objective (Directive 2010/31/EU and 2018/844/UE) to stimulate the energy transition of the construction sector. EU programs, specifically "Horizon 2020", promote the NZEB design and also its evolution, namely the Positive Energy Building (PEB) model.

Based on the most recent developments, a critical review of the main actions of the European Union towards the development of the NZEB and PEB design models has been conducted. Some considerations on advanced materials and technologies (PCM, VIP, smart glass, integrated photovoltaic systems) have also been added. Finally, a case study is presented (single-family residential NZEB) to show how a careful and integrated design of the building envelope and systems not only allows to obtain an almost total coverage of the energy consumption by renewable sources, but also to generate an energy surplus that could be shared with urban grids (PEB potential).

Keywords

Energy efficiency policy, Nearly zero energy building (NZEB), Positive energy building (PEB), Energy performance of buildings, Renewable Energy Sources (RES).

1. Introduction

The European Union is focusing on the NZEB target, trying to respond effectively to the problems that, particularly in the last decades, are affecting the environment: pollution, resource depletion, global warming. The climate change perceived by society today is nothing more than the result of past political, economic and technical choices, no longer in conformity with the present needs.

The construction sector, in particular, is one of the main causes of pollution, due to the excessive emissions released into the environment as a result of the processes of heating and cooling systems in buildings.

Therefore, a turnaround is required, entrusted to the design of new buildings with a reduced annual energy requirement, supported by the inclusion of systems powered by Renewable Energy Sources (RES). The challenge, however, is not limited to new buildings. In fact, according to the EU Building Stock Observatory - the observatory that monitors the energy performance of buildings across the Member States - the building stock is inexorably aging, as confirmed by the alarming figures, composed of 75% buildings built before 1990 [1] with a renewal rate around 1.2% [2].

A probable, and already outlined, further step is represented by the possibility of connecting the individual NZEBs to an intelligent energy distribution network, also called smart grids. Positive Energy Buildings (PEBs) could be a new target, through their contribution to the energy support of other buildings connected to them, producing more energy than necessary to their needs. A system of units connected together at the neighbourhood level, aiming of achieving neutrality or, in extreme cases, energy positivity is the next challenge. The buildings will thus become collectors and energy storage structures.

The following aspects will be addressed below:

- European regulatory situation;
- Some of the most recent results provided by the European Construction Sector Observatory (ECSO);
- Some design features (building envelope, systems) of the current European NZEB model;
- The PEB model: definition and diffusion;
- An example of NZEB with the potential to achieve the PEB status.

The aim of this review is to consider some of the most recent developments promoted by European directives to increase the energy performance of buildings, rather than to present a thorough review of materials and techniques.

The development of the work lies in outlining the tools and practical application of the indications of the European Union for the resolution of environmental problems, which involve air pollution, the depletion of natural resources and climate change. In order to mitigate these problems, the EU has offered several tools to its Member States: energy policies, observers, action programs to finance NZEB and PEB projects and research into promising materials and technologies.

Considering the current target for NZEBs as a base reference, the evolutionary model PEB will be outlined, which represents the possibility of further improvement in a long-term perspective.

Energy consumption and production will be analyzed for a case study, represented by a building built with the utmost attention to energy aspects, located in areas outside densely populated urban centres. Its location and energy potential allow it to be considered an exemplary case and a starting point for guidelines on an intelligent planning of the realization of energy-independent diffused building areas.

The creation of positive energy districts (PED) or entire urban neighbourhoods would allow to achieve neutrality or, in extreme cases, even energy positivity.

2. Energy efficiency policies for the European Construction Sector

2.1 European regulatory framework

The international regulatory situation allows stating that the continuous attention on building energy consumption [3] has led to the drafting of increasingly stringent laws, which aim at the energy efficiency of both new and existing buildings and at the reduction of polluting emissions. In fact, recently the premises of the EU Commission Recommendation on building renovation [4] reaffirms: “Buildings are central to the Union's energy efficiency policy as they account for nearly 40% of final energy consumption”, of which 27% is attributable to the residential sector.

A first indication about NZEB was introduced in the EU Directive in the year 2010 ([5], art.2): “a building that has a very high energy performance, … The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”.

The application of the NZEB model in Europe became mandatory starting from 31 December 2018 for new public buildings and it will be the same for all new buildings at the end of this year (31 December 2020) [5].

Moreover, in order to achieve the Union’s own targets for decarbonisation and energy efficiency in a cost-effective manner, the non-ETS (Emissions Trading Scheme) sectors - such as buildings and transport - must deliver on their potential. The goal is the reduction of greenhouse gas emissions by 80 to 95% by 2050, as compared with 1990, to increase the proportion of used renewable energy [6].

Finally, the most recent Directive (EU) 2018/844 [7], entered into force on 9 July 2018, amended the EPBD introducing (Art.2a) the target of NZEB also for existing buildings in the long-term renovation strategies.

These strategies are implemented through the use of building automation and control technologies, as well as the introduction of smart grids for energy sharing.

The NZEB model, already applied for new buildings in several European Countries, is representing the target for the energy performance improvement also for the renovation of existing buildings, even if it is possible only for a part of the building stock, depending on a cost optimal analysis. Despite this, there is another model that could be considered, by overtaking the NZEB target towards the so called Positive (or Plus) Energy Building (PEB). This one can be considered different from a net-ZEB that in some periods produces excess energy that uses in other times, because the PEB should produce excess energy all over the year.

Therefore, the PEB model could be considered as a mean to make zero-energy-consumption one building and contemporarily to cover, even partially, the needs of some other existing buildings, leading perhaps to reach the energy independence of whole building stocks, when the mix of existing buildings and PEB can balance the energy needs. Several studies are already developed on this building model, and its potentialities (ref. 4.2 par.), even if a common definition and features have not yet been indicated.

In the following parts, a review of several examples of the development of the NZEB model in Europe is synthetized, also referring to EU projects on NZEB pilot cases. Finally, the near future on PEB is outlined: by means an overview on the main objectives and expected results of some EU projects. Furthermore, an example of a particular NZEB is described and some energy consumption data are discussed. This building, designed before EU indications on NZEB, falls within the current requirements for NZEB and could be adequate to be considered as a PEB. This project demonstrates that a smart integrated approach between building envelope and systems, right from the design phase, allows to obtain results that can go well beyond a NZEB.

2.2 Monitoring the policies application

The energy transition is a process essential to raise the construction sector, following the economic recession caused by the debt crisis in Europe. Some notes on the EU energy policies are here considered.

Since 2010, with the publication of the “Europe 2020” strategy proposal, the European Commission has shown growing interest in supporting “smart, sustainable and inclusive growth” among its Member States.

The construction sector in particular is an important economic engine for Europe, to such an extent that in many countries the strength or weakness of the construction sector is the main indicator of the economic and development situation.

Subsequently, in 2012, the “Strategy for the sustainable competitiveness of the construction sector and its companies” and the “Construction 2020” action plan were presented, which aim to support the construction sector in its adaptation to the main upcoming challenges.

However, what stimulated the pursuit of the energy transition in Europe was the “Clean energy for all Europeans” package [8]. The development of a “sustainable, competitive, safe and decarbonised” energy system should be achieved through the following main themes:

- energy efficiency in first place: the new Energy Efficiency Directive (2018/2002 / EU - EED), in fact, sets a new energy efficiency target of 32.5% in 2030;
- more renewable sources: target of at least 32% of energy production from renewable sources by 2030;
- governance of the Energy Union: strengthened through the Integrated National Plans for Energy and Climate for the period 2021-2030;
- consumer rights: improvement of rules to guide consumer decisions on how to produce, store, sell or share one's energy;
- electricity market: introduction of new laws that ensure supply, also through the integration of renewable energies in the network.

2.2.1 European Construction Sector Observatory

Following the publication of strategies and packages aimed at setting the objectives to be pursued, European observatories have been activated to monitor the progress of the construction sector.

The European Construction Sector Observatory (ECSO) [9] worked in this direction, presenting in November 2018 analyses, statistics and comparative assessments between the 28 EU countries, with the aim of raising awareness among policy makers and stakeholders about market conditions, staff skills and energy efficiency.

The economic recession caused by the debt crisis in Europe has affected many southern European countries (e.g. Greece, Cyprus, Portugal, Spain, Italy and Bulgaria), immediately leading to cuts in national budgets and thus affecting the share of GDP dedicated to public and private investments in the construction sector.

The slow economic recovery has been facilitated by the disbursement of national and EU funds in the 2014-2020 programming period and by the implementation of around 120 smart specialization strategies, which involve aid of over 60 billion euros, promoting the competitiveness and interregional cooperation [9].

Another aspect that struck the attention of ECSO are the conditions of human capital in the construction sector [10]. Energy efficiency and sustainable construction will offer significant market potential, as only the renewable energy sector is expected to employ up to 2 million people by 2020, with most new jobs created in the energy sector. Therefore, an increase in the level of education, specialization of staff and skills in the field of energy efficiency must be initiated.

It is known that EU policies aim at encouraging Member States (MS) to reduce the energy consumption of their national building stock and to stimulate their conversion from energy consumers to energy producers through retrofit measures and integration of renewable energy sources [1].

This transition is made possible by improving resource efficiency, environmental performance and commercial opportunities. In fact, buildings are goods with a long life and a natural tendency to low replacement and renovation rates. At the current rate of renovation (around 1% per year depending on each MS), it will take more than 100 years to renovate the EU building stock [11]. Therefore, in addition to the new construction of NZEBs, it will be necessary to focus above all on the redevelopment of the existing one.

Finally, the good news is that there is a positive change of trends in building energy performance: new buildings today consume only half of the typical buildings of the 1980s. This was facilitated by the introduction of the EPBD and subsequent transpositions into national codes, which allowed consumers to make informed choices to save energy and money.

2.2.2 EU action programmes for the NZEB promotion

In addition to the policies, strategic measures and financial instruments implemented by more than two thirds of the Member States to facilitate the spread of energy efficient homes [12], the 8th European Framework Programme for Research and Innovation "Horizon 2020" [13] (2014-2020) has been launched by EU in order to promote “smart, sustainable and inclusive” economic growth for the sectors of science, industry and society.

Thanks to nearly €80 billion of funding available - in addition to the private investments - some projects have been activated with the aim of improving the knowledge and skills of the designers in the construction field and pursuing the ultimate goal of creating new buildings or energetically renovating existing ones, according to NZEB standards.

Some of the most recent “Horizon 2020”-funded projects are summarised below, with their objectives:

- CoNZEBs [14]: identify technological solutions to reduce the construction costs of multi-family buildings.
- CRAVEzero [15]: identify and eliminate extra costs, promoting innovative business models.
- A-ZEB [16]: reduce the construction and life cycle costs, optimizing the process in all design phases.
- ABRACADABRA [17]: increase the real estate value of existing buildings through an architectural and energy transformation.
- FIT-TO-NZEB [18]: improve worker training on energy efficiency in buildings.

Finally, the next Research and Innovation Framework Programme “Horizon Europe” (2021-2027) [19] will contribute to the goals of sustainable development by focusing on three pillars:

- Excellent Science
- Global Challenges and European Industrial Competitiveness
- Innovative Europe

3. The today’s NZEB model in EU: some features and developments

Some main objectives and characteristics of the NZEB model are here resumed, through an excursus among design features, recent developments on materials that optimize the building envelope, and systems that support the coverage of energy needs.

3.1 Design features and objectives

In the EPBD, numeric thresholds or ranges are not clearly defined to identify the NZEB characteristics, therefore several interpretations both for the NZEB definition and limits are available in the EU Countries.

The different choices could be justified by specific climate conditions, local targets, or building traditions, that allow different national targets.

Some general criteria, usually adopted also in the bioclimatic architecture, have contributed to define the NZEB target:

- the building position and orientation help to control the solar radiation contributions on the opaque and transparent envelope and the wind exposition;
- the building thermal mass allows to reduce the temperature variations due to the outdoor climatic conditions;
- the thermal regulation is finalised to maintain the design indoor conditions, with the aim both to guarantee the internal comfort and to limit energy consumption;
- the solar shading is fundamental to avoid overheating in summer.

The main targets of the NZEB model regard the energy needs reduction and the energy efficiency improving.

An important role is played by the heating and cooling systems that should be used to cover the extremely low energy needs and should be driven mainly by renewable energy.

With the application of the EU Directives on new and existing building, a decrease of heating needs can be expected in the next future, due to higher attention to thermal insulation and higher systems efficiency.

Also the constantly increasing demand (3.14% per year) of air conditioning in summer, mainly in Central and Southern European countries (68% of total EU demand) [20], due to climate change [21] must be considered.

The introduction of the NZEB target in the building design will encourage a decrease in the amount of energy required, thus abandoning fossil fuels: a graphical interpretation of the NZEB energy balance is indicated in the scheme of fig.1 [22].

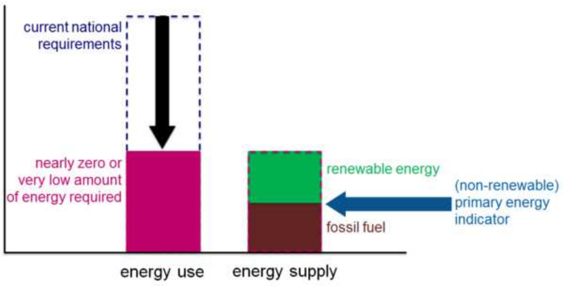

Figure 1 – The NZEB model according to EPBD indications.

3.2 Promising Technologies: advanced material solutions and sustainable energy generation

To reduce the energy demand, considering the boundary conditions of the building system and the constrains affecting the building performance, innovative materials (PCM, VIP, aerogel, etc.) can be used in combinations with traditional solutions, active and passive technologies for space heating and cooling, supported by RESs depending on the source availability in the project site [23].

Starting from an integrated design approach, which involves both a careful selection of materials and components and a complete set of installations, it is possible to realize very high-performance buildings. Moreover, thermal insulation of the building envelope, optimized glazing, high air tightness, reduction of thermal bridges and a high-efficiency ventilation system are means that would allow to achieve, not only energy efficiency, but also a high degree of thermo-hygrometric comfort.

3.2.1 Advanced material solutions: thermal insulation and glazing

Researches on new materials and on technologies widely investigated in the past can be considered both, also taking inspiration from studies carried out by the European Construction Technology Platform (ECTP). Through the Energy Efficient Buildings Project (E2B) [24], the Platform focused attention on materials to optimize the building envelope, such as advanced materials and nanotechnologies (including aerogel, VIP - Vacuum Insulation Panel, PCM - Phase Change Material, electrochromic glazing).

Thermal insulation: aerogel, PCM, VIP

Recent researches have investigated the use of nanomaterials, such as aerogel or vacuum insulation panels, characterised by high thermal insulating properties and small thickness [25].

On the other side, Phase Change Materials (PCMs) represent one of the passive technological solutions that has already been extensively studied. They allow to store the energy supply of solar radiation, when located in the external layers of walls. In the form of mixtures of salts or paraffins, they are able to retain thermal energy under form of latent heat, to pass it successively in correspondence with a phase change (from solid to liquid and vice versa), in a temperature range compatible with human comfort (between 20°C and 30°C). The integration of these materials in the building envelope involves a series of advantages, including the reduction and the phase shift of the summer and winter thermal load peaks, the reduction of energy requirements (thanks to the use of more dynamic energy), and the potential improvement of the thermal comfort of the environment.

For the above-mentioned advantages, researchers have extensively studied a new approach to develop a building envelope with high energy efficiency by increasing the ability of latent heat storage of the buildings through the macro-encapsulation technique [26]. This method improves the internal thermal behaviour of buildings and it has various advantages: high strength, durability, and thermal stability, and prevention of PCM losses during phase transformation. To prevent losses, maintain the density of thermal energy storage and increase the thermal conductivity of PCM through the use of porous materials based on carbon as support materials; a research was carried out on an aerosol based on porous carbon [27].

Moreover, PCMs could help to improve the thermal inertia of light structures [28]. Recent study has been carried out on a hybrid type cladding panel, consisting of three types of PCM with different phase change temperatures, which can be used efficiently depending on the season (29°C for summer, 18°C for the mid-season and 12°C for the winter) [29].

The application of PCMs is quite wide, ranging from building materials (brick, plaster, concrete) to opaque and transparent components up to systems. Despite the advantages and applied research set out, PCMs would need further research to find solutions to still open problems, including the high cost of encapsulation production, the possible variation of thermal storage capacity after several cycles of use and the absence of real and practical reliable results.

Vacuum Insulation Panels (VIP) have been recently considered, thanks to their ability to improve the thermal performance of buildings with reduced thickness. Together with aerogel, VIP belongs to the promising family of Super-Insulation Materials (SIM). The thermal insulation is obtained by means of a gas-tight enclosure surrounding a rigid core, from which the air has been evacuated. Thanks to their high thermal resistance, VIPs would allow to reach ZEB standards with a reduced thickness when compared with traditional insulation (rock wool or EPS) and are declared to reach a thermal transmittance of 0.18 $W/(m^2 \cdot K)$ [30]. Their application in buildings energy retrofit could be interesting. In fact, if an internal insulation is used - preferable in the case of historic or listed buildings - a larger usable floor area is saved, compared to the installation of traditional insulators, resulting in an economic advantage for the building owner [31].

In this direction, E2PBEER (Affordable and Adaptable Public Buildings through Energy Efficient Retrofitting) - a four-year research project partially financed by “Horizon 2020” - has developed a cost effective, “energy efficient retrofitting” methodology for public buildings, drawing on the expertise of over 21 partners from 11 European countries. A practical example is the application of very thin (3 cm) VIP rationally pre-dimensioned to an external insulated façade [32]. The total finished ventilated façade, including VIP, anchoring, air chamber and the covering is 10 cm thickness only, achieving a heat transmittance (U-value) of 0.276 $W/(m^2 \cdot K)$.

Nevertheless, the current barriers to the wide application of this technology are: the risk of damage during installation; the lack of knowledge about their durability and useful service life; the thermal bridging effects between the panels which, if not properly mitigated, may compromise the final performance; and the high initial cost compared to common insulating materials [31].

Glazing

Since the design phase, a great deal of attention must be paid to glazing, as they determine comfort or discomfort, increase in the annual heat demand, possibly lowering the use of electricity for lighting using daylight supplies, depending on their quality. In fact, they are considered the weakest link in the building envelope, in terms of thermal insulation; heat loss through windows is responsible for almost 30% of a building's energy consumption [33].

In order to improve their thermal performance, on an experimental level, numerous researches have been carried out which concern multiple glazing with gap where the vacuum is realized (reducing the heat transfer by conduction and convection), and “smart” glazing, i.e. photochromic, thermo-chromatic, electrochromic and electro-thermal glazing.

A study [34] on the different orientations of the windows, through the impact of the windows-to-wall ratio (WWR) on the energy performance of buildings in three Italian climatic zones, by means of a dynamic simulation model show the advantages of a reduced WWR. In order to reach the NZEB objective, it is not a good design practice to increase the WWR, since, in general, for all locations and orientations, the use of large glass surfaces increases both the heating and cooling energy demand and the peak power. Therefore, to balance the increasing energy consumption in summer, it is recommended to design high-performance shielding devices.

Among the “smart” glazing mentioned above, the electrochromic glazing allows to increase the WWR and to improve the building openings without a negative impact on the energy performance of the building, thus offering designers greater flexibility [35].

In the last decade, numerous methods have been proposed to improve the thermal resistance of transparent components, such as the optimization of the spacing between the glass sheets, the filling of the gap between the slabs with a participating gas or aerogel, the application of multilayer glass and coating of glass surfaces with low-emissivity materials. The incorporation of PCM in the glass structure seems promising as allows to increase the thermal storage capacity. In fact, this type of technology is able to absorb part of the solar radiation for the storage of thermal energy, letting the visible radiation enter the internal environment for daylighting. Thanks to their potential, PCMs can be used in various types of glazing, such as conventional windows, facades and roofs [36].

3.2.2 Sustainable energy generation

Renewable Energy Systems (RES) are decisive to achieving NZEB goals. The European directive 2018/844 encourages Member States to increase the share of energy consumption from renewable sources, depending on the territorial and climatic conditions. Renewable energies on site, such as solar thermal and photovoltaic systems, are more convenient in Mediterranean climates (e.g. Spain, Italy, Greece) characterized by greater solar radiation. Biomass products used in heating systems and heat pumps (geothermal energy) are particularly common in cold climate countries in northern Europe (e.g. Finland, Sweden, Latvia). A study [37], in 12 European capitals, demonstrated the importance of the role played by renewable energy sources in reaching the nZEB target. Compared to the basic building, the NZEB configuration, optimized by the combination of insulation, air tightness, class A++ appliances, and home energy management systems together with photovoltaics, is characterized by 90% energy savings.

Once all the building envelope optimization measures, feasible from a technical-economic point of view, have been implemented to reduce the energy demand, RES must intervene to balance the demand for residual energy. They can be integrated during the initial design process as part of the structure or could be added as a retrofit. In Italy, heat pumps, supported by photovoltaic panels, are largely diffused.

In order to achieve the goal set by the directive of a completely decarbonised stock of buildings by 2050, the contribution of integrated photovoltaic systems (BIPV) in existing buildings is a good mean. As an alternative to the common integration in coverage or ground installation, research has been developed on the integration of innovative semi-transparent photovoltaic systems on the façade. The main difficulty of this type of integration is to allow sufficient penetration of daylighting, which can also be guaranteed by the recent appearance of perovskite-based solar cells, characterized by an increase in photovoltaic conversion efficiency [38]. The manifesto of this technology, patented by Professor Michael Grätzel, was the Austrian Pavilion of Expo 2015.

Recent studies have proved the advantages of the application of the PCM in the photovoltaic system, for a passive cooling technique. The connection of a PCM panel on the back of the photovoltaic panel guarantees the maintenance of a lower temperature of the photovoltaic cells, thus obtaining a higher conversion efficiency and a lower need for maintenance compared to the more traditional photovoltaic / thermal technologies [39].

4. The next future: the Positive Energy Building (PEB) model

After citing some of the most recent design elements that can support the NZEB targets, a review of the model evolution is now outlined: definition, design features and deployment methods.

4.1 Definition and design features

One possible further step is represented by Positive Energy Buildings (PEB) that could be considered as a sort of NZEB, but so efficient as to produce more energy than they consume, leaving users with extra energy to employ in other ways, such as powering mobile devices, electric tools or even the electric car.

These would represent therefore an evolution of the NZEB model, since, by producing more energy than necessary to their needs, they could contribute to the energy support of other buildings connected to them, creating a system of units connected together at the neighbourhood level, with the aim to obtain neutrality or, in extreme cases, energy positivity.

Some characteristics of the PEB model are resumed in Table 1, which highlight the distinctions with the NZEB model.

Table 1 – Comparison between the main features of the NZEB and PEB models [40].

NZEB model	PEB model
A bidirectional exchange of energy between a single building and the network	A more complex set of exchanges and energy partnerships
A one-year period of balance between demand and energy generation	A time span of an entire life cycle
Power generation is based on individual buildings for export	Energy performance is maximized in a system-based approach.

A PEB does not only aim to generate more energy, but upstream there must be attention to the purpose and distribution of excess resources [40]. Therefore, rather than considering individual and isolated PEB, it is interesting to develop the concept of a Positive Energy District (PED), composed of several buildings connected each other at the neighbourhood level to contribute to the energy support of the whole through a “smart” distribution of energy networks.

4.2 The prosumer concept

Before some notes on the PEB model and its application at the district level, a brief discussion focuses on the dual energy role that a PEB is able to play. In recent decades there has been a progressive evolution of the energy market. The traditional production-consumption model, operating according to a static distribution system (Distribution Network Operator - DNO) and focused on the supply of one-way electricity, threatens to be replaced by a more fluid distribution system: the Distribution System Operator (DSO), based on more active and decentralized energy management. This is made possible by the introduction of innovative technologies: production of energy from renewable sources, data management systems, smart grids and energy storage systems.

The birth of this new model of the energy market involves the creation of “prosumers” (PRO-ducers + conSUMERS of energy, simultaneously), term indicating buildings that not only use the energy produced on site from renewable energy sources for self-consumption, but which also share the excess of energy produced with their neighbours through the connection to a smart grid. A bi-directional flow of energy and information is therefore triggered between users and the public network [41].

Among the possible interpretations of the “prosumer” concept existing in the literature, the following can be mentioned:

- buildings equipped with smart technologies in order to stimulate active management of energy consumption and production by proactive energy customers [42];
- units connected to a smart grid to encourage energy sharing at the district level [43];
- economically active and motivated entities that consume, produce and store electricity, playing a key role in energy optimization [44].

The spread of prosumers would have positive implications for the three spheres of sustainability:

- environment, reduction of CO_2 emissions thanks to the use of clean energy from RES;
- society, creation of a community based on solidarity that works together for the common purpose of energy support;
- economy, compared to the initial investment in smart grids and integration of RES in buildings, users can count on economic savings in energy costs.

The concept of prosumer can be a solution to the increase in energy demand from buildings, due to the introduction of energy-efficient electronic equipment, introduced by users to improve their lifestyle [45]. In order to maximize the share of energy destined for self-consumption, a prosumer must be equipped with a mix of efficient technologies, such as photovoltaic system, heat pump, energy and thermal storage systems and electric vehicles [46]. However, the most pressing problem now is the adaptation of existing urban networks to this small-scale proliferation of resources [47].

In this regard, it is necessary to conduct studies and comparisons between the energy regulatory frameworks of European countries and to highlight the main challenges and opportunities for the diffusion of smart grids and prosumers. It should be emphasized that the EU promotes the integration of entire prosumer communities in each Member State, through increasingly stringent energy policies, such as the EU Clean Energy Package [48].

Hence, the theory of individual prosumer that cooperate for the energy needs of entire communities perfectly aligns with the concept of PED.

4.3 EU promotion of multifunctional elements and smart energy management systems

The Energy Positive Neighbourhoods were investigated in a FP7 project regarding the ICT infrastructures working on possible uses of the surplus energy and on managing the connection to the electric urban grid.

In general, the surplus energy produced by a PEB is electric energy, more commonly coming from the photovoltaic systems, rather than from wind turbines or another sources. It could be used to supply buildings and infrastructures in the vicinity (public lighting, etc.), contributing to distribute sustainable energy in urban areas.

In some European countries (Germany, Denmark and Belgium) attention is focused on a better use of on-site generation to partially satisfy local consumption and contribute to the evolution of smart grids by means of more efficient control of electrical flows between the photovoltaic system, loads and the electricity grid. Buying and selling the electric energy by the grid could be a solution, even if the grid itself must be ready to accept the contribution because it could have problems of stability due to the variation of production and needs [49, 50, 51]. In these researches, PEB has been considered as a building that with its renewable energy production could positively contribute to the optimization and safety of the urban electricity grid, and contemporarily satisfying quite completely its very small needs.

Therefore, to achieve the performance of a PEB, both of these aspects are fundamental:

- A careful design of the building envelope, with the possibility of introducing multifunctional elements;
- An accurate design, control and management of the systems, through Building Control Systems (BCS) and Building Management Systems (BMS).

As regards the first aspect, multifunctional elements, i.e. elements that can perform multiple functions simultaneously (e.g. providing energy and resisting structural loads), are sometimes used to increase the performance of a building, reducing thickness and therefore loads. Contrary to the traditional sequential design, in which each construction element performs its function, the performance of these elements is defined at assembly level 52] and requires an innovative approach that gives priority to the use of renewable energy sources and to the reduction of the use of standard building materials [53].

One of the application cases that can be cited to exemplify this concept is HiLo (High performance, Low energy) 54], the first research and innovation unit launched by the NEST (Next Evolution in Sustainable Building Technologies) project, promoted by Empa (Swiss Federal Laboratories for Materials Science and Technology). This building, which houses both research offices and duplex housing modules, has three types of multifunctional elements: a lightweight shell roof, a funicular floor and an adaptive solar facade. Thanks to a design based on structural lightness, material saving, TABS (Thermo-Active Building Systems) and BIPV (Building Integrated Photo Voltaics), the experimental building in Zurich boasts a PEB classification, with an annual energy requirement of around 38 kWh/m^2 and a surplus of generated energy of 45%.

The second concept deals with the continuous monitoring of the internal and external conditions, which aims to maintain indoor comfort and optimal energy production and consumption. These needs are supported by wide analyses on the indoor environmental quality and energy efficiency of building systems to be optimised by means of Building Management Systems (BMS) application [55]. The use of interoperable and low-cost wireless communication systems is indicated as a priority, even if studies should be developed to use low power solution and wireless real-time connection of all elements that must work together.

Nevertheless, at the moment, there are a few indications about a possible PEB target by the European Commission, perhaps because they still represent the evolution of a small part of the new building construction.

4.4 Two ways of spreading of the PEB model: PED and Horizon 2020 Programmes

The PEB model has been widely addressed over the years, especially at a theoretical level, as evidenced by the ninth edition (2014) of the European Sustainable Energy Week (EUSEW), the largest event organized by the European Commission, dedicated to renewable energy and to its efficient use in Europe.

The Buildings Performance Institute Europe (BPIE) together with Fraunhofer IBP discussed the role that the PEBs could play in achieving the next EU objectives for 2030, through the presentation of some pilot projects in France (BEPOS) and Germany (Energy Positive House / Plus Energy House), countries where these innovative building practices are fully integrated into national legislation, unlike the other European countries. The goal of this event was to understand whether positive energy buildings could represent a viable option for future European standards or were rather “an exotic niche technology” [56].

4.4.1 The PED Programme

In 2017, in order to achieve the ambitious energy objectives, the EU launched the “Positive Energy Districts and Neighbourhoods for Sustainable Urban Development” programme as part of the SET Plan Action 3.2 “Smart Cities and Communities”, which aims to support the planning, deployment and replication of 100 PEDs by 2025 with the support of 20 Member States [57].

The PED programme is entrusted to JPI Urban Europe [58], a Joint Programming Initiative created in 2010 to address current global urban challenges. Its vision is to become the European research and innovation platform, able to create and to make available knowledge and concrete evidence for sustainable urban development. Furthermore, during the last edition of EUSEW (2019) [59], JPI Urban Europe studied the topic of “Policies and models for the energy transition: from barriers to breakthroughs” by introducing the concept of PED through:

- **Meaning**: A positive energy district with an annual net import of zero energy and zero net CO_2 emissions, which produce a surplus of renewable energy to integrate it into an urban energy system.
- **Target:** The transition from individual PEBs to positive energy blocks towards entire neighbourhoods could activate a new level of impact on sustainable urban development.
- **Transition**: Innovative ideas and solutions transmitted in the form of apps, products, services, platforms, networks or political change are needed to engage the community [60]. Indeed, the PED Programme is a tool for involving stakeholders, such as cities, industry, research and innovation organizations and citizens' organizations. Thanks to the participation of 20 countries (fig.2), over 70 projects have been funded with around € 100 million of public investment.

Figure 2 – Countries involved in the PED Programme [58].

4.4.2 Horizon 2020 Programme

Some of the most recent projects funded by “Horizon 2020” for the diffusion of the PEB model are summarised in Table 2. It was not possible to report for the moment the results for each project, as many of the following are still in progress; however, for the most recent ones, an estimate of the expected impacts is indicated.

Table 2 – Selection of the most recent projects funded by the EU's Horizon 2020 research and innovation programme.

Project	Objectives (O) and Results (R)	Participants	n. Case studies
ZERO-PLUS 2015-2020 [61]	**O**: Development of innovative solutions both for the design of new high-performance buildings and for the housing district. **R**: Examples of technologies (solar and ventilation) for the feasibility of zero / positive energy buildings.	Italy, France, Germany, United Kingdom, Greece, Cyprus, Israel	n.4: (UK), (IT), (CY), (FR)
RESPOND 2017-2020 [62]	**O**: Implementation of cooperative energy automation from the building unit to the entire building up to the district. **R**: Applications of home automation devices in 3 pilot projects to sensitize end users and their behaviour towards energy saving.	Spain, Denmark, Ireland, Serbia, Czech Republic	n.3: (ES), (DK), (IE)
Pro-GET-OnE 2017-2021 [63]	**O**: Indications on new solutions to renovate buildings by drastically reducing energy consumption. **R**: Definition, development and feedback of strategies for prefabrication, the flexibility of the envelope and the integration of RES, with feedback in 4 case studies.	Italy, Germany, Greece, Netherlands, Romania, Spain, Belgium, Switzerland	n.4: (IT), (NL), (GR), (RO)
IRIS 2017-2022 [64]	**O**: Improvement of urban life through integrated sustainable solutions that can be replicated at European level. **R**: The main technologies for excess energy production concern envelope, ventilation, RES and storage systems.	Holland, France, Sweden, Spain, Romania	n.2: (FR), (SE)
MAKING-CITY 2018-2023 [65]	**O**: Development of new long-term strategies to transform the urban energy system towards PED. **R**: The expected impacts will concern the transformation of the local economy of 8 pilot cities, where a positive annual energy balance is expected.	Spain, Netherlands, Finland, Italy, Turkey, Slovakia, Bulgaria, Poland, France	n.8: (NL), (FI), (ES), (IT), (TR), (SK), (BG), (PL)
+CityxChange 2018-2023 [66]	**O**: Development and distribution of positive energy blocks and districts across Europe by 2050. **R**: The 11 demonstration projects are expected to increase efficiency, share and accumulate energy and improve air quality.	Ireland, Norway, Romania, Czech Republic, Spain, Bulgaria, Estonia, Italy, Netherlands, Germany	n.7: (IE), (NO), (RO), (ES), (CZ), (BG), (EE)
EXCESS 2019-2023 [67]	**O**: Demonstration that near zero energy buildings can be transformed into positive energy buildings **R**: Study of innovative materials and technological systems to optimize generation, storage and energy consumption at the district level.	Finland, Spain, Belgium, Cyprus, Germany, Greece, Austria, France	n.3: (ES), (BE), (AT)
POCITYF 2019-2024 [68]	**O**: Transformation of the cultural and historical urban environments through blocks and districts with positive energy.	Portugal, Spain, Italy, Germany, Greece, Netherlands,	n.8: (PT), (NL), (ES), (IT), (SI), (HU), (GR),

	R: The research fields focus on RES, energy storage and management, smart grids and digitalization.	Slovenia, Hungary, Denmark, Finland, Austria, Switzerland	(DK)
CULTURAL-E 2019-2024 [69]	**O**: Definition of modular and replicable solutions for Plus Energy Homes, considering climatic and cultural differences.	Italy, Spain, Germany, United Kingdom, Belgium, France, Norway	n.4: (IT), (FR), (DE), (NO)
	R: The expected results integrate design tools (climate atlas) with intelligent technologies (ventilation systems and home automation management).		
ATELIER 2019-2024 [70]	**O**: Development of PED through innovative solutions that integrate efficient buildings and technologies.	Netherlands, Spain, Switzerland, Germany, Hungary, Poland, Latvia, Denmark, Slovakia, Portugal, Italy	n.8: (NL), (ES), (SK), (HU), (DK), (PL), (PT), (LV)
	R: Establishment of long-term roadmaps (2050) for the expansion of positive energy solutions.		

To conclude this overview of PEB and PED, the references of the latest European project buildings, belonging to different countries, are summarised in Table 3, indicating if they refer to new building or retrofit.

Table 3 – Selection of the most recent PEB and PED projects located in Europe, sorted in chronological order and divided between new building (N) and retrofit (R).

Country	Hungary [71]	France [72]	Italy [73]	Denmark [74]	Norway [75]	Spain [76]	Finland [77]	Czech Republic [78]
(N) / (R)	R	N	N	N	N	N	R	N
Country	Ireland [79]	Estonia [80]	Netherlands [81]	Turkey [82]	Austria [83]	United Kingdom [84]	Romania [85]	Germany [86]
(N) / (R)	R	R	R	N	N	N	N	N

5. An exemplary building

An example of good design regarding a building realised when the NZEB model was not widespread, and therefore largely before the PEB, is presented here. This helps to testify that the technology is already mature and that the constructions can be made according to this model, without great difficulties, if not those, perhaps, mainly due to a certain resistance opposed by designers and builders.

The building is intentionally characterized by a traditional and uniform architectural shape, typical of the hilly context in which it is inserted (fig. 3). In fact, although it is a high efficiency building, this does not imply that it must necessarily have modern lines, which may cause a great visual impact on the urban and landscape context.

This single-family residential building was built in northern Italy in 2013, so before the publication of the national Minimum Requirements Decree [87], which indicates the national NZEB requirements, and came into force on 1st October 2015. Despite this, the building design features correspond to the current NZEB requirements and, for this reason, in 2011, the project won a regional tender that promoted the construction of NZEB following the EPBD recast indications [5].

Figure 3 – Investigated building: overview (left); lateral view (right).

5.1 Description of the case study

The building is distributed over three levels (usable area of 322.4 m^2): basement, which houses cellars, garages, a bathroom and the thermal power plant; ground floor, with the living area and a part of the mezzanine which houses two bathrooms and two bedrooms; first floor, where the master bedroom with its bathroom and vestibule is located, and a loft with the function of a study. The private residence has the capacity to accommodate 4/6 people.

From a constructive point of view, its opaque envelope (52 cm thick, of which 35 cm of half-filled blocks of brick and 14 cm of insulation in fiberglass) has a thermal transmittance $U = 0.19\ W/(m^2K)$, while triple glazed wooden window frames characterized by $U = 1.30\ W/(m^2K)$.

As for the technical systems, the “brain” of the house resides in the thermal power plant in the basement. It is composed of:

- the electrically powered air-water heat pump, with a useful heat output of 13.1 kW and ON-OFF operation, which is responsible for both winter air conditioning with coupling to the radiant floor and the production of DHW;

- the Controlled Mechanical Ventilation (CMV), which consists of an enthalpy exchanger operating 24 hours a day all year round and involves a flow of inlet air varying between 50 m^3/hour and 550 m^3/hour;
- a dehumidifier, necessary for radiant cooling in summer mode;
- a water storage tank, with a capacity of 500 litres, connected to the panels of the solar thermal system.

It is known that a NZEB, after carefully designing it, according to a synergic approach between the building envelope and the system, also requires a Building Control (BCS) and Management System (BMS), capable of maintaining the indoor comfort conditions required by users unchanged, and reducing the energy consumption. Therefore, a regulation system with climatic control unit has been provided, which acquires for each room temperature and humidity data from the climatic probe placed on the north side of the building.
In addition, one of the peculiarities of the building is the presence of a captive greenhouse facing south, as an extension of the living area on the ground floor. In the heating period only, it acts as a positive accumulation of heat, which can be exploited through a second intake-only system, which draws air from the greenhouse, by means of two 100 m³/h fans, when the greenhouse temperature exceeds 3°C the temperature of the internal environment, entering it in the living room. Another interesting applied technique is the free cooling, in order to reduce the temperature of the rooms up to 4°C in summer nights.
The 45% inclined coverage, with respect to the horizontal plane on the south side, houses both a photovoltaic system (about 79.5 m^2 and 10.33 kWp) that meets the electricity demand, and a solar thermal system (6.6 m^2), which assists the heat pump to produce Domestic Hot Water (DHW). This solution guarantees an almost total coverage of consumption from renewable sources (94%).

Finally, in addition to LED lighting both inside and outside, attention has also been paid to the recovery of rainwater, a need dictated by the not negligible amount of water (2800 m^3/year) for the garden.

5.2 Experimental monitoring results

The energy performance of the building was analysed by comparing the design and real energy performance, by means of the simulated results of a commercial software, taking into account reference monthly mean climatic data, and the experimental data by the monitoring carried out from the end of construction (data from May 2014 to January 2020).

In Figure 4 the comparison between calculated primary energy consumption (the same for each year, as the calculation doesn’t take into account real climatic conditions) and the measured one is shown, expressed in terms of electric energy, in kWh_e.

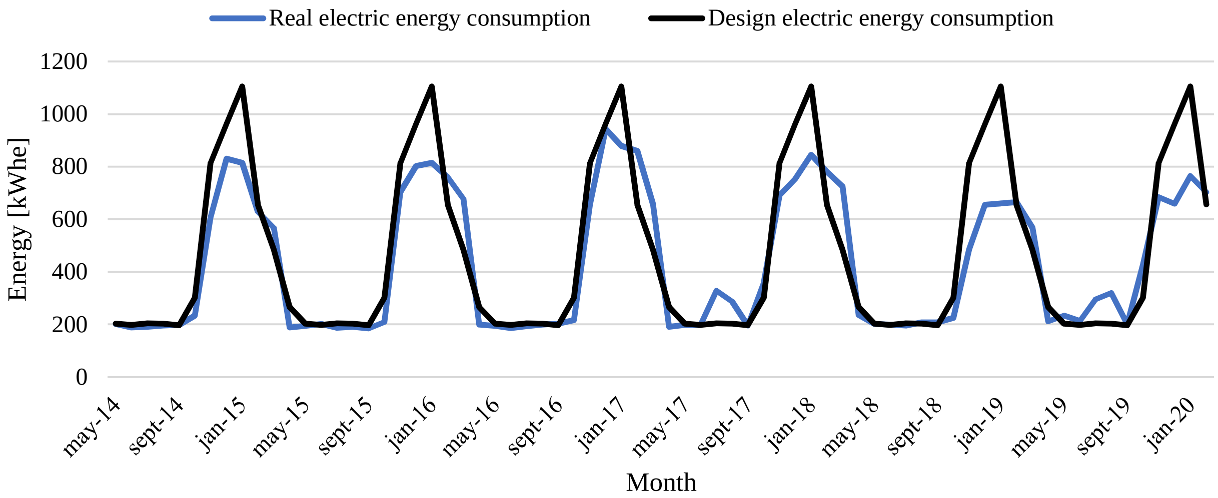

Figure 4 – Comparison between design electric energy consumption and real consumption.

It should be noted that in the summer period they can be superimposed, thus highlighting that the estimates made in the design phase reflect the actual energy behaviour of the building. Starting from year 2017, in summer, a peak is shown, due to the heat pump use for the dehumidification, depending on a different set-point adopted on cooling water. This effect is not visible in 2018 summer period because of a temporary failure. In winter the two trends show significant differences, with measured values lower than expected. This is probably due to the careful management of the systems: the adoption of a positive offset of 3°C of the internal temperature during the sunshine hours involves forcing the operation of the heat pump for air conditioning during photovoltaic self-production hours, in order to reduce the consumption of electricity from the network during the night.

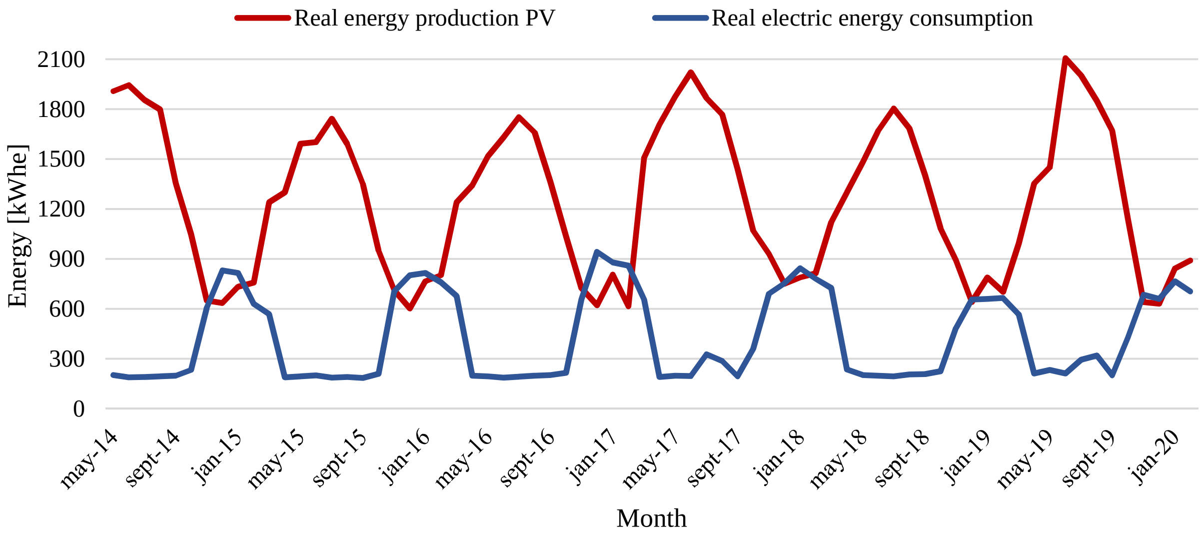

Figure 5 – Comparison between real electric energy consumption and real photovoltaic energy generation.

The comparison between the production of electric energy from the photovoltaic (PV) system and the consumption of total electricity taken from the network in the real case (Figure 5) shows that the electrical coverage from photovoltaics is guaranteed for almost the whole year, however in winter it is necessary to use electricity from the grid. All the not used energy, mostly from February to November, is transferred to the grid.

5.3 Discussion

The comparison between the overall share of electricity consumed and that produced by the photovoltaic system shows that the building uses only 34% of the energy available from photovoltaics to satisfy user’s needs. Therefore, the energy surplus is sold to the urban grid, with a consequent much higher economic return compared to the small expenses during the winter months, in which the solar radiation exploitation is not sufficient to cover energy consumption.

In particular, the last year of data collection of energy consumption and production (data from January 2019 to December 2019) has been analyzed. For this period, the maximum production of electricity by the photovoltaic system was recorded, equal to 2100 kWhe. In addition, for the winter months of January and February, consumption was lower than the energy generated by photovoltaics, while for the months of November and December, higher consumption was recorded, probably attributable to reduced solar radiation and a greater energy demand for indoor heating service.

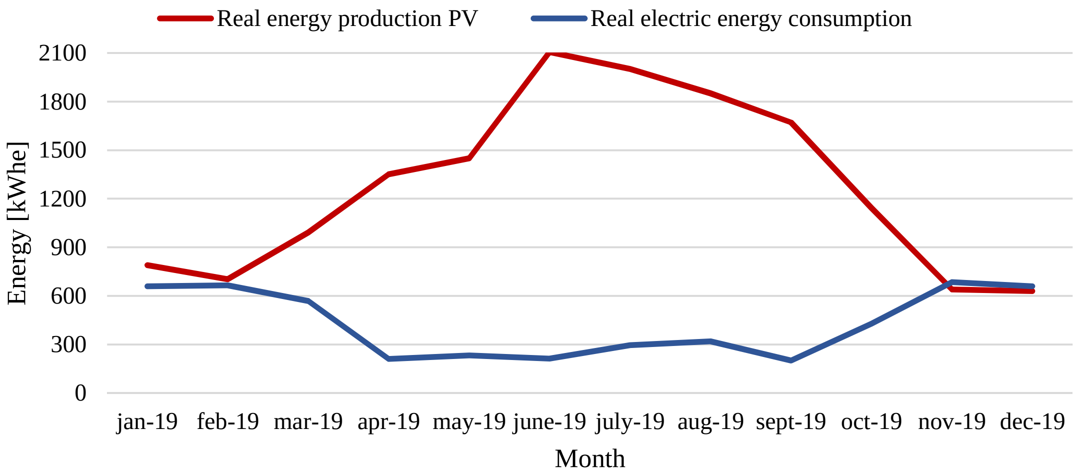

Figure 6 – Real electric energy consumption and real photovoltaic energy generation in the year 2019.

The most recent calculations have led to show that the building uses only 37% of the energy produced by the photovoltaic system for self-consumption. The remaining share of renewable energy is destined for sale in the urban network, with peaks of up to 1890 kWhe, recorded in the summer months.

By these results, it will be interesting to consider some improvements:

- the addition of a secondary generation system, such as a biomass boiler, which supports the heat pump in the winter months, while remaining a renewable energy source;
- to avoid the energy needs from the grid in the colder months, an energy storage system could use part of the considerable excess of energy produced by the photovoltaic system in the remaining months of the year;

Moreover, the building connection to smart grids would involve sharing about 1800 kWh of electric energy produced by the photovoltaic system in the summer months. This surplus could cover the energy needs of other buildings connected to the network, up to four times as much energy as necessary for heating and cooling this building.

The results of the analysis are also due to the importance of the provision of home automation management systems in the design phase which, has been properly used here, not only guarantee the expected performances but in some cases can even improve them, adapting the energy behaviour of an NZEB according to the specific user needs.

6. Challenges and future directions of the research

If the NZEB design model has now become part of the regulatory system of European countries, thanks to Directive 2010/31/EU, on the contrary the PEB model is not yet known uniformly at European level. Nevertheless, there are indications [69] that presume the introduction of guidelines and targets for the next drafting of the EPBD in 2026.

Some of the decisive reasons why the PEB model has not yet found wide and concrete application on the European territory are regulatory, economic, social and technological barriers [88], which make complex the diffusion of smart grids for energy sharing. Therefore, one of the future challenges will be to overcome the multiple obstacles met by member states, depending on territorial configuration and needs, in order to creating communities that work together to achieve energy autonomy.

A significant task is carried out by European observatories, who periodically monitor the conditions of the construction sector and of the buildings that make up the existing real estate assets. A further step for the future should consist in expanding these monitoring, down to national detail.

A deeper knowledge of exemplary buildings could help the diffusion of the PEB model: experimental data on energy consumption and production can help to analyse the best practices, also considering economic costs. Moreover, building performance dynamic simulation can help both to design accurately the building (envelope and systems) and to manage the energy use.

The location of the case study in an area not densely populated suggests the concrete possibility of creating energy-independent areas spread over the territory.

The study conducted so far is believed to represent a promising starting point for thinking about a new design approach, without a complete revolution of shape, materials or technologies: highly efficient individual buildings could connect to other buildings at the district level to contribute to the energy support of the community.

7. Conclusions

In the last decade, the European Union has been implementing energy efficiency policies that encourage the energy transition, abandoning fossil fuels in favour of renewable energy sources, which have less impact on the environment. Therefore, the construction sector must also necessarily align itself with the objectives set by the EU. This involves embracing an innovative design model for new buildings, but also for existing ones, which require interventions on the building envelope and on the energy supply systems.

The paper has presented some of the most recent developments of the EU dispositions related to high efficiency buildings, referred to NZEB, but also to PEB. These ones represent the enhancement of NZEB and consist of buildings interconnected with smart grids, capable of distributing the surplus of energy generated and not self-consumed by the building, to support other less performing buildings.

In summary, the following aspects have been analysed:

- European regulatory framework
- European energy policies
- Tools to improve the energy efficiency of the construction sector: observatories and action programmes
- Notes on promising technologies applied to the design of NZEB
- Theoretical bases and concrete promotional tools of the PEB model

Finally, to show the potential of the application of these design models, an exemplary building was described and its energy consumption were considered. Although this project was built before the NZEB concept was widespread, therefore largely in advance, respect the PEB target, it appears to comply with current European directives and national regulations, demonstrating an almost total coverage of energy consumption by RESs integrated into the building. In particular, thanks to the monitoring of the experimental data collected by the building accounting system, it was possible to conduct an extended monitoring from 2014 to 2020 and the comparison between the energy produced by the photovoltaic system and the electricity consumed by the building to satisfy user needs (heating, cooling, lighting and power supply of household appliances and equipment).

The study shows that, with a careful design and sizing of the building envelope and the plant system, it can be realised a production of electricity from renewable sources much higher than the energy that the building would need for self-consumption. This energy surplus demonstrates the PEB potential of the building. The results may allow to support the development of a roadmap for a greater diffusion of the PEB in the territory and to encourage the creation of energy independent districts.

The next step of the research will be represented by a more detailed analysis of the case study. In fact, through dynamic simulation, the emphasis will be placed on the energy needs of the building. Moreover, by means of the evaluation of some variants of design solutions, different plant management will be analysed, also in terms of costs, to give more detailed indications aimed at supporting the diffusion of the PEB model.

Conflict of interest

The authors declare no conflicts of interest

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] European Commission, European Construction Sector Observatory, Analytical Report on Improving Resource Efficiency, November 2018, [Online]. Available: https://ec.europa.eu/growth/sectors/construction/observatory_en

[2] A. Vilches, A. Garcia-Martinez, B. Sanchez-Montanes, Life cycle assessment (LCA) of building refurbishment: A literature review, Energy and Buildings 135 (2017) 286-301. DOI: 10.1016/j.jenbuild.2016.11.042

[3] European Parliament, Council of the European Union, Directive 2002/91/CE of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings (EPBD), 2002, Official Journal of the European Union, L 1, 04 January 2003

[4] Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation, C (2019) 3352, 16.5.2019, Official Journal of the European Union, L 127/34

[5] European Union, Directive 2010/31/EU of the European Parliament and of Council of 19 May 2010 on the energy performance of building (EPBD recast), Official Journal of the European Union, L 153, 18 June 2010

[6] Draft European Parliament legislative resolution on the proposal for a directive of the European Parliament and of the Council amending Directive 2010/31 / EU on the energy performance of buildings, 17 April 2018, COM (2016) 0765 - C8-0499 / 2016 - 2016 / 0381 (COD)

[7] European Union, Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, 19.6.2018, Official Journal of the European Union, L 156/75

[8] European Commission, Clean energy for all Europeans, July 2019. ISBN: 978-92-79-99843-0 DOI: 10.2833/21366

[9] European Commission, European Construction Sector Observatory, Analytical Report on Stimulating favourable investment conditions, November 2018, [Online]. Available: https://ec.europa.eu/growth/sectors/construction/observatory_en

[10] European Commission, European Construction Sector Observatory, Analytical Report on Improving the human capital basis, April 2017, [Online]. Available: https://ec.europa.eu/growth/sectors/construction/observatory_en

[11] European Commission, Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/31 / EU on the energy performance of buildings, Impact Assessment, Commission Staff Working Document, 2016, [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1490877353361&uri=CELEX:52016SC0414

[12] Commission Recommendation (EU) 2016/1318 of 29 July 2016 on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings, C/2016/4392, Official Journal of the European Union, 2.8.2016

[13] European Commission, Horizon 2020, [Online]. Available: https://ec.europa.eu/programmes/horizon2020/what-horizon-2020

[14] CoNZEBs – Solution sets for the Cost reduction of new Nearly Zero-Energy Buildings, [Online]. Available: https://www.conzebs.eu/

[15] CRAVEzero – Cost Reduction and market Acceleration for Viable nearly zero-Energy buildings, [Online]. Available: http://www.cravezero.eu/

[16] AZEB – Affordable Zero Energy Buildings, [Online]. Available: https://azeb.eu/

[17] ABRACADABRA – Assistant Buildings' addition to Retrofit, Adopt, Cure And Develop the Actual Buildings up to zeRo energy, Activating a market for deep renovation, [Online]. Available: http://www.abracadabra-project.eu/

[18] FIT-TO-NZEB – Innovative training schemes for retrofitting to nZEB levels, [Online]. Available: http://www.fit-to-nzeb.com/

[19] European Commission, Horizon Europe – the next research and innovation framework programme, [Online]. Available: https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en

[20] N. Pardo, K. Vatopoulos, A. Krook-Riekkola, J.A. Moya, A. Perez, Heat and cooling demand and market perspective. Joint Research Centre, European Commission, Publications Office of the European Union, 2012. ISBN 978-92-79-25311-9, DOI 10.2790/56592, [Online]. Available: http://publications.jrc.ec.europa.eu/repository/handle/JRC70962

[21] A. Kitous, J. Després, Assessment of the impact of climate change on residential energy demand for heating and cooling, Publications Office of the European Union, 2017. ISBN:978-92-79-77861-2, DOI 10.2760/96778

[22] H. Erhorn, H. Erhorn-Kluttig, New buildings & NZEBs. Concerted Action – Energy Performance of Building, (CT1), November 2016, [Online]. Available: https://www.epbd-ca.eu/ca-outcomes/outcomes-2015-2018/book-2018/ct/new-buildings-nzebs (accessed Aug.2019)

[23] L. Belussi et al., A review of performance of zero energy buildings and energy efficiency solutions, Journal of Building Engineering 25 (2019). DOI: 10.1016/j.jobe.2019.100772

[24] EeB PPP Project review – Energy Efficient Buildings, May 2019, [Online]. Available: http://heritage.ectp.org/fileadmin/user_upload/documents/E2B/0_EeB_PPP_Project-Reviews_Roadmaps/EeB_PPP_Project_Review_2019.pdf

[25] I. Moga, A. Bucur, Nano insulation materials for application in nZEB, Procedia Manufacturing 22 (2018) 309-316. DOI: 10.1016/j.promfg.2018.03.047

[26] P. K. S. Rathore, S. K. Shukla, Potential of macroencapsulated PCM for thermal energy storage in buildings: A comprehensive review, Construction and Building Materials 225 (2019) 723–744. DOI: 10.1016/j.conbbuildmat.2019.07.221

[27] B. Mu, M. Li, Synthesis of novel form-stable composite phase change materials with modified graphene aerogel for solar energy conversion and storage, Solar Energy Materials and Solar Cells 191 (2019) 466-475. DOI: 10.1016/j.solmat.2018.11.025

[28] M. Martin, A. Villalba, A.I. Fernandez, C. Barreneche, Development of new nano-enhanced phase change materials (NEPCM) to improve energy efficiency in buildings: Lab-scale characterization, Energy and Buildings 192 (2019) 75-83. DOI: 10.1016/j.enbuilding.2019.03.029

[29] C. Li, H. Yu, Novel hybrid microencapsulated phase change materials incorporated wallboard for year-long year energy storage in buildings, Energy Conversion and Management 183 (2019) 791-802. DOI: 10.1016/j.enconman.2019.01.036

[30] M. Gonçalves, N. Simões, C. Serra, I. Flores-Colen, A review of the challenges posed by the use of vacuum panels in external insulation finishing systems, Applied Energy 257 (2020). DOI: 10.1016/j.apenergy.2020.114028

[31] S. Fantucci, S. Garbaccio, A. Lorenzati, M. Perino, Thermo-economic analysis of building energy retrofits using VIP - Vacuum Insulation Panels, Energy & Buildings 196 (2019) 269–279. DOI: 10.1016/j.enbuild.2019.05.019

[32] Energy Efficient Buildings - EeB PPP Promising Technologies - Advanced material solutions, 2018. http://e2b.ectp.org/fileadmin/user_upload/documents/E2B/0_EeB_PPP_Promising_techno_brochures/EeB_PPP_Promising_techno_brochures_2018/Advanced_Materials_Solutions.pdf

[33] K. Zhong, S. Li, Y. Zhou, X. Zhang, Dynamic heat transfer characteristics of PCM-filled glass window and hollow glass window, CIESC Journal 65 (2014) 114–123.

[34] G. Murano, E. Primo, V. Corrado, The effect of glazing on nZEB performance, Energy Procedia 148 (2018) 320-327. DOI: 10.1016/j.egypro.2018.08.084

[35] I. Lahmar et al., Investigating the impact of electrochromic glazing on energy performance in hot arid climate using parametric design, IOP Conference Series: Materials Science and Engineering, 2019. 609 062027

[36] D. Li, Y. Wu, B. Wang, C. Liu, M. Arıcı, Optical and thermal performance of glazing units containing PCM in buildings: A review, Construction and Building Materials 233 (2020). DOI: 10.1016/j.conbbuildmat.2019.117327

[37] D. D'Agostino, A. Parker, A framework for the cost-optimal design of nearly zero energy buildings (NZEBs) in representative climates across Europe, Energy 149 (2018) 814-829. DOI: 10.1016/j.energy.2018.02.020

[38] A. Cannavale et al., Energy performance of building-integrated electrochromic and photovoltaic systems, IOP Conference Series: Materials Science and Engineering, 2019. 609 062004

[39] T. Ma, Z. Li, J. Zhao, Photovoltaic panel integrated with phase change materials (PV-PCM): technology overview and materials selection, Renewable and Sustainable Energy Reviews 116 (2019). DOI: 10.1016/j.rser.2019.109406

[40] R.J. Cole, L. Fedoruk, Shifting from net-zero to net-positive energy buildings, Building Research & Information (2015) 111-120. DOI: 10.1080/09613218.2014.950452

[41] K. Mahmud et al., An internet of energy framework with distributed energy resources, prosumers and small-scale virtual power plants: An overview, Renewable and Sustainable Energy Reviews 127 (2020). DOI: 10.1016/j.rser.2020.109840

[42] Y. Parag, B. K. Sovacool, Electricity market design for the prosumer era, Nature Energy 16032 (2016). DOI: 10.1038/nenergy.2016.32

[43] G. El Rahi et al., Managing Price Uncertainty in Prosumer-Centric Energy Trading: A Prospect-Theoretic Stackelberg Game Approach, IEEE Transactions on Smart Grid (2017).

[44] J. Rodriguez-Molina et al., Business Models in the Smart Grid: Challenges, Opportunities and Proposals for Prosumer Profitability, Energies 7 (2014) 6142-6171.

[45] A. C. Luna et al., Cooperative Energy Management for a Cluster of Households Prosumers, Consumer Electronics IEEE Transactions on 62 (2016) 235-242.

[46] D. Keiner et al., Cost optimal self-consumption of PV prosumers with stationary batteries, heat pumps, thermal energy storage and electric vehicles across the world up to 2050, Solar Energy 185 (2019) 406-423. DOI: 10.1016/j.solener.2019.04.081

[47] J. Green, P. Newman, Citizen utilities: The emerging power paradigm, Energy Policy 105 (2017) 283–293. DOI: 10.1016/j.enpol.2017.02.004

[48] I. Campos et al., Regulatory challenges and opportunities for collective renewable energy prosumers in the EU, Energy Policy 138 (2020). DOI: 10.1016/j.enpol.2019.111212

[49] K. Davis, Towards an ICT infrastructure for energy positive neighbourhoods. Report from ELSA thematic working group on ICT for energy efficiency, 2009, [Online]. Available: https://ec.europa.eu/information_society/activities/sustainable_growth/docs/elsa/elsa_1/ELSA-EnergyPositive-Report1.pdf (accessed August 2019)

[50] European Commission, COOPERATE Project, Control and Optimisation for Energy Positive Neighbourhoods https://cordis.europa.eu/project/rcn/105699/factsheet/en, ref. Pesch D, Ellis K, Kouramas K, Assef J. Deliverable D1.1 of the COOPERATE project: report on requirements and use cases specification (2013), [Online]. Available: http://www.ectp.org/fileadmin/user_upload/documents/E2B/COOPERaTE/COOPERATE_D11.pdf (accessed August 2019)

[51] M. Ala-Juusela, T. Crosbie e M. Hukkalainen, Defining and operationalising the concept of an energy positive neighbourhood, Energy Conversion and Management 125 (2016) 133-140. DOI: 10.1016/j.enconman.2016.05.052

[52] M. Bomberg, M. Furtak, D. Yarbrough, Buildings with environmental quality management: Part 1: Designing multifunctional construction materials, Building Physics 41 (2017) 193-208. DOI: 10.1177/1744259117711196

[53] G. Lydon, J. Hofer, B. Svetozarevic, Z. Nagy e A. Schlueter, Coupling energy systems with lightweight structures for a net plus energy building, Applied Energy 189 (2017) 310-326. DOI: 10.1016/j.apenergy.2016.11.110

[54] HiLo, Dübendorf (Switzerland), Empa, 2019, [Online]. Available: https://www.empa.ch/web/nest/hilo

[55] D. Kolokotsa, D. Rovas, E. Kosmatopoulos e K. Kalaitzakis, A roadmap towards intelligent net zero- and positive-energy buildings, Solar Energy 85 (2011) 3067-3084. DOI: 10.1016/j.solener.2010.09.001

[56] Positive Energy Buildings – wishful thinking or (built) reality, BPIE [Online]. Available: http://bpie.eu/event/positive-energy-buildings-wishful-thinking-or-built-reality/

[57] SET Plan Action 3.2 Implementation Plan, June 2018, [Online]. Available: https://setis.ec.europa.eu/system/files/setplan_smartcities_implementationplan.pdf

[58] JPI Urban Europe, Positive Energy Districts (PED) [Online]. Available: https://jpi-urbaneurope.eu/ped/

[59] EU Smart Cities Information System (SCIS) Workshops 2019 [Online]. Available: https://smartcities-infosystem.eu/newsroom/news/scis-workshops-eusew-2019

[60] Climathon, Citizens in Positive Energy Districts [Online]. Available: https://climathon.climate-kic.org/de/challenges/human-behaviour/citizens-in-positive-energy-districts

[61] ZERO-PLUS – Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology, [Online]. Available: http://zeroplus.org/index.php/

[62] RESPOND - Integrated demand REsponse Solution towards energy POsitive NeighbourhoodS [Online]. Available: http://project-respond.eu/

[63] ProGETonE - New solutions for more comfortable, efficient and seismic-safe homes [Online]. Available: https://www.progetone.eu/

[64] IRIS - Co-creating smart and sustainable cities [Online]. Available: https://irissmartcities.eu/

[65] Making City [Online]. Available: http://makingcity.eu/

[66] +CityxChange [Online]. Available: https://cityxchange.eu/

[67] EXCESS - FleXible user-CEntric Energy poSitive houseS -project investigates positive energy buildings in 4 climatic zones [Online]. Available: https://vito.be/en/news/excess-project-investigates-positive-energy-buildings-4-climatic-zones

[68] POCITYF - Leading the smart evolution of historical cities [Online]. Available: https://pocityf.eu/

[69] CULTURAL-E - Climate and cultural-based solutions for Plus Energy Buildings [Online]. Available: https://www.cultural-e.eu/

[70] ATELIER - AmsTErdam BiLbao cItizen drivEn smaRt cities [Online]. Available: https://smartcity-atelier.eu/

[71] Pécs, Reborn Home (2015) [Online]. Available: https://www.activehouse.info/cases/reborn-home/

[72] Lyon, HIKARI (2015) [Online]. Available: https://www.construction21.org/france/city/fr/hikari-premier-ilot-urbain-a-energie-positive.html

[73] Bergamo, Maison Verte, Atelier2 (2017) [Online]. Available: https://www.activehouse.info/cases/maison-verte-2/

[74] Solbjerg, Futura Home (2017) [Online]. Available: https://www.activehouse.info/cases/futura-home-2017/

[75] Trondheim, Powerhouse Brattørkaia, Snøhetta - The Demo: A society scale demo of an energy system running on renewables (2019) [Online]. Available : https://snohetta.com/projects/456-powerhouse-brattorkaia-the-worlds-northernmost-energy-positive-building

[76] Alcobendas, Detached House (2019) [Online]. Available: https://www.construction21.org/case-studies/es/detached-house-in-alcobendas.html

[77] Åland Island, Smart Energy Åland - The Demo: A society scale demo of an energy system running on renewables (2019-2021) [Online]. Available: https://flexens.com/the-demo/

[78] 2B House (2019-2021) [Online]. Available: https://www.activehouse.info/cases/2b-house/

[79] Limerick, +CityxChange (2018-2023) [Online]. Available: https://cityxchange.eu/our-cities/limerick/

[80] Võru, +CityxChange (2018-2023) [Online]. Available: https://cityxchange.eu/our-cities/voru/

[81] Groningen, Making City (2018-2023) [Online]. Available: http://makingcity.eu/groningen/

[82] Kadıköy, Istanbul, Making City (2019-2024) [Online]. Available: http://makingcity.eu/kadikoy/

[83] Vienna, Zukunftsquartier (2021-2024) [Online]. Available: http://www.urbaninnovation.at/de/Projects/Zukunftsquartier

[84] Neath, Active Homes (2018-) [Online]. Available: https://www.activebuildingcentre.com/project/active-homes-neath/

[85] Măgurele, Laser Valley - Land of Lights (2019-) [Online]. Available: http://landoflights.ro

[86] Eislingen, Bauen 4.0, Werkgemeinschaft Bohme Hilse (2020-) [Online]. Available: https://www.activehouse.info/cases/bauen-4-0-bad-kreuznach-the-interconnected-aktivplus-district/

[87] Italian Republic. (2015). Decree of the Ministry of Economic Development 26/06/2015 “Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici” (Application of the energy performance calculation methodologies, and definition of dispositions and minimum requirements for buildings). Official Journal of the Italian Republic; 15 July 2015 (in Italian).

[88] N. Good et al., Energy Positive Neighborhoods and Smart Energy Districts (2017) 251-274. DOI: 10.1016/B978-0-12-809951-3.00008-9

HIGHLIGHTS

Title

From Nearly Zero Energy Buildings (NZEB) to Positive Energy Buildings (PEB): the next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example

Highlights

Some of the most recent developments on the nearly zero energy buildings are resumed.

The European actions to promote, increase, and monitor NZEB diffusion, are indicated.

The next challenge, the Positive Energy Building and its diffusion is outlined.

The calculated and monitored energy consumption of a precursor NZEB are compared.

Title

From Nearly Zero Energy Buildings (NZEB) to Positive Energy Buildings (PEB): the next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example

Authors

Anna Magrini, Department of Civil Engineering and Architecture, University of Pavia, Pavia, Italy

Giorgia Lentini, Department of Civil Engineering and Architecture, University of Pavia, Pavia, Italy

Sara Cuman, Department of Civil Engineering and Architecture, University of Pavia, Pavia, Italy

Alberto Bodrato, Stecher Srl, Engineering Services, Ovada, Italy

Ludovica Marenco, IRE SpA (Regional Infrastructure for Energy Recovery), Genova, Italy

Corresponding Author

Anna Magrini, Department of Civil Engineering and Architecture, University of Pavia, via Ferrata 3, 27100 Pavia, Italy, magrini@unipv.it

Conflict of interest

The authors declare no conflicts of interest