Housing with Energy Self-sufficiency and Zero Co2 Emissions

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Abstract. One of the sectors with the greatest contribution to energy consumption and global CO2 emissions is construction. The typology of buildings and the technologies used to increase energy efficiency in use are becoming increasingly important. Global energy consumption is estimated to increase significantly. According the International Energy Agency (IEA) in 2018 the housing\residential consumption sector alone accounted 20% of global energy consumption in IEA Countries in 2018 [1].

In 2018, the Directorate-General for Energy and Geology (DGEG) reported that 27% of the need for primary energy consumption was met by Renewable Energy Sources. In 2020, the target set by a community directive is 31% for primary energy from Renewable Energy Sources [2]. It is therefore extremely important to create a strategy to boost construction with zero emissions, making an important contribution to the overall reduction of energy consumption and to the reduction of CO2 emissions. This work intends to identify the main concepts of construction with zero emission and present a case study of a multifamily housing following this concept. The case study presented demonstrated that the success of a zero-emission construction depends in large part on the elaboration of an energy budget based on consumption habits, on the energy production capacity of the house and on the energy performance that is intended to be achieved during use, as well as the effectiveness of how this budget is presented to the owners, demonstrating the cost vs benefit of the energy efficiency solutions presented. It is concluded that using the current technology combined with construction elements, it is possible to guarantee a Zero CO2 Emission in a self-sufficient housing in terms of energy. Given the current needs for energy savings and increased environmental sustainability, the future of civil engineering may be in zero-emission homes.

Keywords: House with self-sufficiency energy · Zero emission construction · ZEB · Sustainable construction

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1 Introduction

The construction sector is one of the sectors with the greatest contribution to energy consumption as well as to global CO2 emissions. Between 2010 and 2030 world marketed global energy consumption is estimated to increase by 33% [3, 4]. IAE published a report suggesting that the housing consumption sector represented 14% of global energy consumption in 2017 (see Fig. 1) [5].

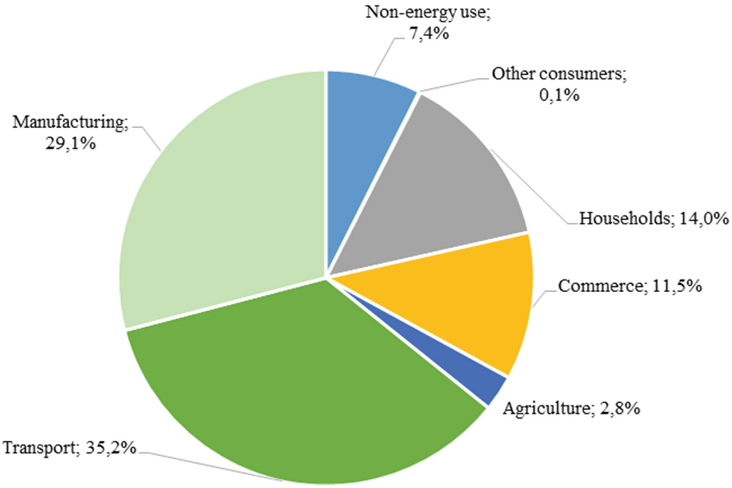

Fig. 1. Final consumption in Portugal for the year 2017

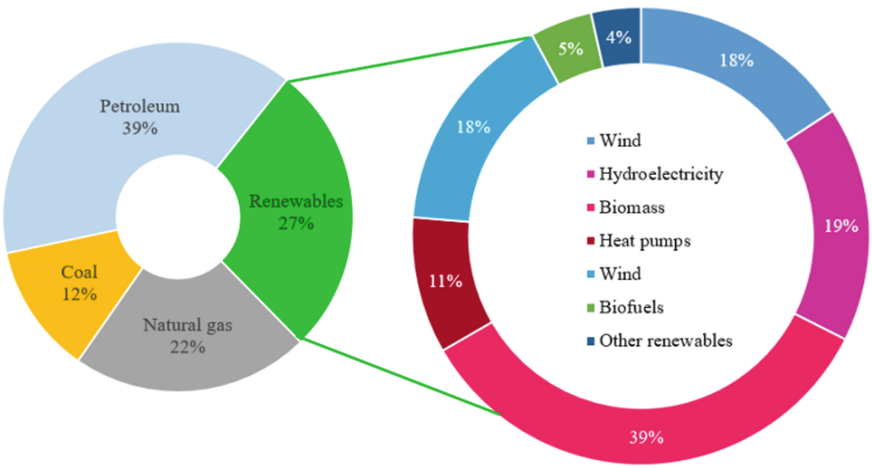

Fig. 2. The contribution of renewable energy to primary energy consumption 2018

The Directorate General of Energy and Geology (DGEG) states in the latest report issued that Renewable Energy Sources (RES) contributed 27% to primary energy consumption. Biomass represents a contribution of 43%, water 19%, wind 18%, heat pumps 11% and 5% biofuels (see Fig. 2) [6].

In relation to final energy consumption, RES accounted for 30% of the total need. Of these 41% it originates in biomass, 19% in hydroelectricity and 18% in wind power. At 13% and 5% respectively, heat pumps and biofuels are located [6] (see Fig. 3).

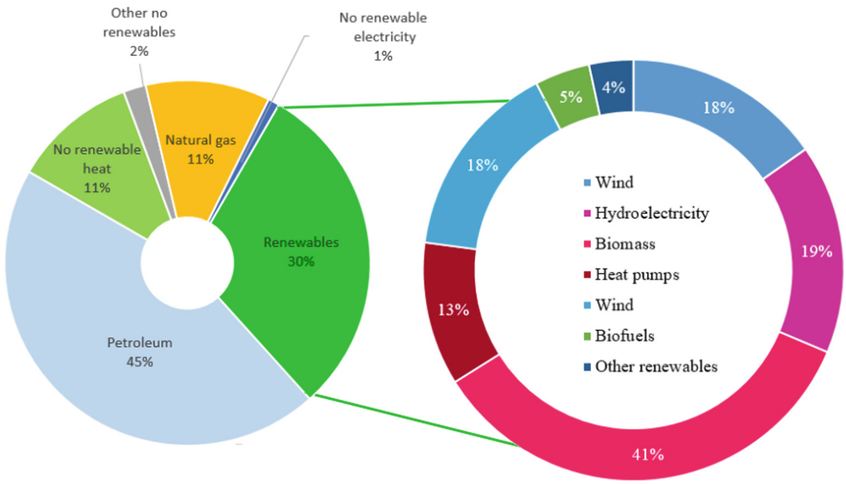

Fig. 3. The contribution of renewable energy to final energy consumption 2018

By 2020 the target of 31% of the contribution of RES to final energy consumption (Community Directive 2009/28/EC) should be reached [6] (see Fig. 4). In 2018, heat pumps used for heating were also considered AS FER.

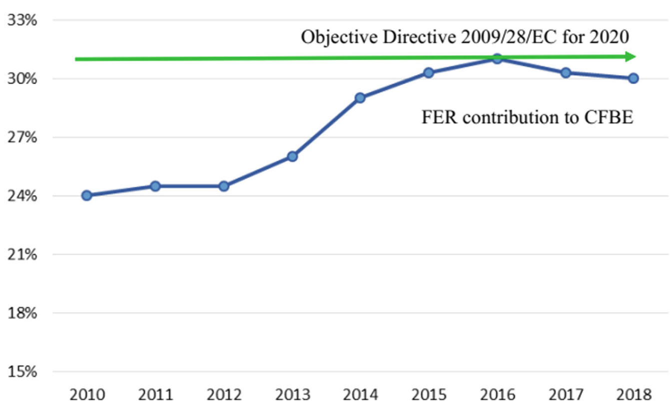

Fig. 4. Objective for the incorporation of RES in gross final energy consumption by 2020.

Zero emission building (ZEB) will be one of the most effective strategies for reducing global energy consumption and reducing CO2 emissions. However, it is often reported that the increased costs of a ZEB construction will be a significant barrier to the implementation of this strategy [7, 8]. Total construction costs include direct costs and indirect costs. Building materials, labor, construction equipment, energy, water will be the main direct costs. Indirect costs include costs related to the construction project, commissures, licensing fees, documentation, and other legal fees [9]. The normally higher construction cost of a ZEB construction will be something of a direct perception for the owner, on the other hand the gains of the ZEB construction are of low perception and are usually given only estimative to a certain number of years, and these estimates include the energy, water, and potential energy productivity gains. It is therefore very important to carry out an analysis and demonstrate the ecological advantages and cost-benefit ratio to convince the owners to proceed with a sustainable ZEB project [10].

The definition of the concept of "buildings with almost zero energy needs" (NZEB) deliberated in Article 16 of Decree-Law No. 118/2013 of 2013 of 20 August [11] and successive changes requires that new buildings be almost self-sufficient at the level of energy, and the need for energy is satisfied through renewable energy sources produced on site or nearby.

The case study presented aimed to develop the design, execution and occupation of a multifamily dwelling following the ZEB concept.

2 Objectives and Methodology

The present work aims to identify the main concepts of ZEB, demonstrate a case study of a Zeb multifamily dwelling, and answer the question, Is a habitation with energy self-sufficiency and zero CO2 emission possible with current technology?

The search for the literature review was done on the website of Elsevier publisher, ScienceDirect, Google Scholar and Google search engine. In the document search process, key words related to the theme of energy efficiency in construction were used, such as, "energy efficiency in construction"; " sustainable construction"; "energy efficiency"; "Zero Energy Building"; "low-energy buildings"; "Green buildings". The most relevant documents and most recent date between the periods 1950 and 2020 were considered in the selection.

3 Literature Review

Self-contained energy buildings (ZEBs) may be completely independent of an energetic external network. All the energy needed for own consumption originates from its own energy systems, usually solar energy systems and energy storage systems sized to ensure a continuous supply of energy [12]. The first attempts at zero energy constructions emerged in North America [13], reaching the concept in Europe in the late 1970s [14].

Energy Use Intensity (EUI) represents the energy use of a building depending on its size or number of users. The EUI is expressed as energy per square meter and per year (kWh/m^2 per year or kBTU/m^2 per year) or as per capita energy per year (see Fig. 5) [15].

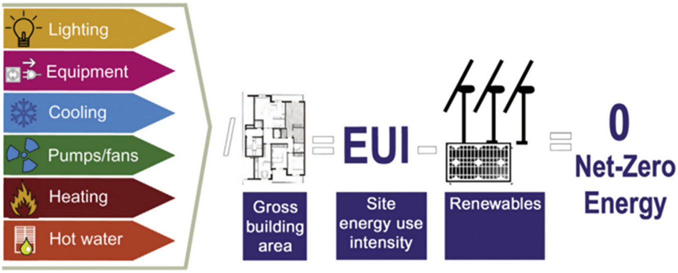

Fig. 5. Calculation of zero energy balance.

In the ZEB concept there are some fundamentals (see Fig. 6) and 4 basic principles to consider in the design phase.

Fig. 6. The fundamentals of the ZEB project.

Figure 7 shows a series of measures applicable to the 4 basic principles of this concept [15]. The project phase should include the four principles for identifying the most appropriate measures that respect these foundations or principles [15].

According to the information contained in the (DGEG) Member States have been encouraging the improvement of energy performance and comfort conditions of buildings through various initiatives in line with Directive 2002/91/EC of 16 December and its recast, Directive 2010/31/EU of 19 May, both European Parliament and of the Council, energy performance of buildings.

These Directives set out the general framework for a methodology for calculating the integrated energy performance of buildings, as well as the application of minimum requirements for the energy performance of new buildings and existing buildings that are undergoing renovation works.

Among all the legislation related to the energy efficiency of buildings available in DGEG, the most relevant for the theme of this work stands out.

Decrees-Law No 78/2006, 79/2006 and 80/2006, all of 4 April and successive amendments related to the Energy Certification of buildings, were revised considering an approach already oriented to the new European Energy Performance of Buildings Directive (EPBD). The Directive was published on 19 May 2010 by the Official Journal of the European Union as Directive 2010/31/EU and successive amendments by the European

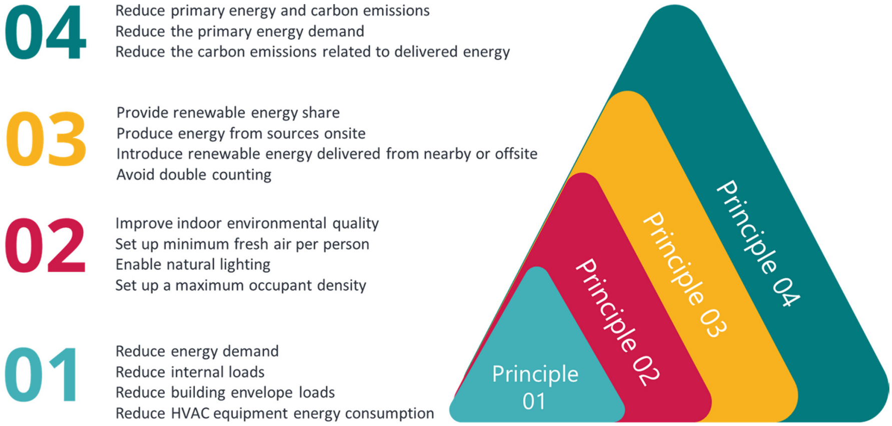

Fig. 7. The four principles of the ZEB project.

Parliament and the Council and reinforces minimum requirements for buildings in the context of energy efficiency. In Portugal, this new Directive presents aspects with great impact, such as the introduction of the concept of cost/benefit from an extended life-cycle cost perspective in buildings. The energy benefits will have to be thought of in the long run and not just considering the immediate cost of construction.

The concept of "buildings with near zero emission buildings" (NZEB) also emerges, requiring that, "by 31 December 2020 at the latest, all new buildings have very high energy performance", and that their energy needs should be covered by renewable energy sources.

Decree-Law No. 118/2013 of 20 August and successive amendments ensures the transposition into national law of Directive 2010/31/EU and successive amendments and the revision of the national legislation on the Energy Certification System (SCE) of Buildings, in force since 2006. For the citizen to be informed about the thermal quality of the buildings, when building, selling leases or leasing thereof, there is a legal obligation to implement an energy certification system.

In existing buildings with the aim of reducing energy expenditure and improving the energy efficiency of the property, the energy certificate demonstrates the possible measures to implement energy performance improvement and indoor air quality. In new buildings, energy certification proves the application of thermal regulation and indoor air quality, among other obligations, is the implementation of renewable energy systems.

The actual energy performance situation of a property is demonstrated through the SCE (EC) Certificate, which is a document issued by a qualified expert under the SCE. The property is classified according to its energy performance on a scale of 8 classes (from A+ to F), obtained by calculating the annual energy consumption scans and indoor air quality.

Directive 2010/31/EU and successive amendments by the European Parliament and the Council of 19 May 2010 relate to the energy performance of buildings. This Directive clarifies some of the principles of the text of the previous Directive 2002/91/EC of 16 December 2002 and successive amendments, introducing new guidelines strengthening measures to promote energy performance in buildings in accordance with the targets agreed by Member States for 2020.

Decree-Law No. 118/2013 of 20 August and successive amendments approves the Energy Certification System for Buildings, the Regulation on energy performance of residential buildings and the Energy Performance Regulation of Trade and Service Buildings, and transposes Directive 2010/31/EU and successive amendments, of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Among the various objectives of the Decree, it can be mentioned that it aims to ensure the regulatory application of energy efficiency conditions and the use of renewable energy systems, certify energy performance in buildings and identify corrective measures and/or improve energy performance.

The Regulation of Energy Performance of Housing Buildings (REH) promotes the improvement of thermal behavior, efficiency of technical systems and the minimization of the risk of occurrence of surface condensations in the elements of the surrounding.

The technical behavior and efficiency requirements of the technical systems of the buildings, as well as the methodology for determining the energy performance class of the pre-certificates and certificates of the SCE is defined by Ordinance No. 349-B/2013 of November 29 and successive amendments.

Ordinance No. 349-C/2013 of December 2 and successive amendments establishes the elements to be included in the licensing or prior reporting procedures of urban building operations and their authorization for use.

Order 15793-D/2013 of December 3 and successive amendments presents the conversion factors between useful energy and primary energy to be used in determining the annual nominal primary energy needs.

Order 15793-H/2013 of 3 December and successive amendments publish the rules for quantifying and accounting for the contribution of systems to the use of renewable energy sources. The calculation methodologies for determining the nominal needs of useful energy to produce sanitary hot water (AQS), the annual nominal requirements of useful energy for heating and cooling environment and the global nominal global primary energy needs are presented in Order 15793-I/2013 of 3 December and successive amendments.

Order 15793-J/2013 of 3 December and successive amendments publish the rules for determining the energy class.

Order 15793-K/2013 of December 3 and successive changes publish the thermal parameters for the calculation of the values of Global Heat Transfer Coefficient, Surface Thermal Transmission Coefficient, Solar Radiation Absorption Coefficient, Solar Factor of Glazed Spans, Air Renewal Rate, among others. Under the energy rationalization plan, in Order 15793-L/2013 of 3 December and successive amendments, the methodology for clearance the economic viability of the use or adoption of a certain energy efficiency measure was published.

Decree-Law No. 28/2016 of June 23 and successive amendments make the fourth amendment to Decree-Law No. 118/2013 of 20 August and successive amendments, which approved the Energy Certification System of Buildings, the Regulation of Energy

Performance of Housing Buildings and the Regulation of Energy Performance of Buildings of Commerce and Services, and transposed Directive 2010/31/EU of the European Parliament and the Council of 19 May 2010 on the energy performance of buildings.

The methodology for determining the energy performance class for the typology of pre-certificates and SCE certificates, as well as the requirements of thermal behavior and efficiency of technical systems of new buildings and subject to intervention was published in Ordinance No. 319/2016 of December 15 and successive amendments to the second amendment of Ordinance No. 349-B/2013, 29, amended by Ordinance No. 379-A/2015 of October 22.

4 Case Study

First self-contained multi-family building located in Switzerland (see Fig. 8).

Fig. 8. Self-contained multi-family construction project (ZEB) https://www.umweltarena.ch/

It was considered the first multifamily housing construction in the world 100% self-sufficient without the need for external supply of any type of energy. The Umwelt Arena Schweiz combined with its partners built the first housing with nine apartments fully supported in solar energy. This energy project was inaugurated on June 6, 2016, receiving its first residents, selected by casting process to identify the ideal profiles to test the project in real environment.

After the first winter the housing demonstrated a high energy efficiency without any electricity failure and guaranteed all the necessary thermal comfort. It was thus proved that the simulations in the development phase of the project carried out for the values of energy production and consumption corresponded to reality. Residents needed only half the energy (2,200 kWh) instead of 4,400 kWh per apartment/year, a figure considered normal for Switzerland. Only the fuel cell responsible for generating electricity and heat using hydrogen generated in the summer through solar energy was insufficient at the beginning of the cold season. However, this inefficiency can be easily addressed only with a review of the energy management system. At the end of the first winter the results showed a small difference of 10% of electricity below the estimated value, but that can be addressed by improving the efficiency of hydrogen production during the summer. Already in the summer of 2018 there was a surplus of energy produced. Hydrogen storage was at full capacity in August, the following year (2019) was even earlier, validating improvements to the energy management system.

In order not to waste the excess electricity produced and thus increase the efficiency of the system, the housing was connected to the electricity grid on 1 September 2019 thus becoming an energy producer.

In May 2016 the Dössegger family after being selected in the casting process went to live in the model dwelling. Benjamin Dössegger does not know exactly what were the characteristics that allowed the selection of his family, not least because he is not an environmental fanatic, however living in the unique model housing in the world has undoubtedly come to pay more attention to the use of energy efficiency equipment and energy consumption. Each apartment has a tablet installed on the wall (see Fig. 9), showing the percentage of compliance with the daily, and weekly and monthly energy consumption plan. At the time of the interview, energy consumption was 50 to 60% of what was planned.

Fig. 9. Tablet with control of energy consumption (https://www.umweltarena.ch/).

In housing (see Fig. 10) all equipment and systems are of high energy efficiency. One of the examples is the elevator, whenever you make a descent is creating electricity to power the system. As there is a great ease of access to energy consumption, being always available at all times and divisions of housing, residents start to pay special attention to their consumption, almost as if they were in a family game, where there is some competition to see who makes the least consumption.

As for performance, with 25 occupants the total consumption of housing is equal to 35 kWh/m^2 per year. Of this consumption, 14% goes to heating needs, 57% for varied equipment, 14% for mechanical ventilation and 15% for lighting.

Part of the energy efficiency concept includes thermal insulation of high-yield housing. Thermal insulation is responsible for reducing the energy requirement for thermal comfort by 50%. This thermal comfort was guaranteed through low temperature heating of the optimized distribution system by the housing, being this system powered by the energy generated by the Water Heat Pump with Geothermal probe. To reduce heat pump energy consumption, a exchanger system was also used to generate heat from the outside air and injecting it controlled into the ventilation circuit. There are two types of storage, the medium and short-term, 13 days of storage per battery, and the long-term one with 25 days of storage by gaseous medium in the form of hydrogen cells.

On the façade there are non-reflective photovoltaic energy modules, and these elements are integral in the aesthetics of the housing. The entire roof is covered with photovoltaic modules. Solar energy is converted into an electric current by solar cells and stored in batteries for short- or medium-term use. For long-term storage, up to 25 days, the electric current generated by solar modules undergoes a process of conversion into hydrogen thus leaving energy stored in the gaseous state. When necessary, usually in the winter months with less sun exposure, stored hydrogen is converted back into electrical and thermal energy. During hydrogen production there is a use of the heat generated by this process, which is used for heating domestic water.

Two water tanks with 250,000 L store hot water for use all year round. The management system adapts the storage temperature and the circulation flow through the housing according to the optimal conditions of thermal comfort.

The lighting of the housing is done exclusively through LED technology.

System management controls all smart devices with the possibility of connecting to PC, smartphone, or tablet. The lighting is turned on and off independently by the system, which also controls heating systems and blinds.

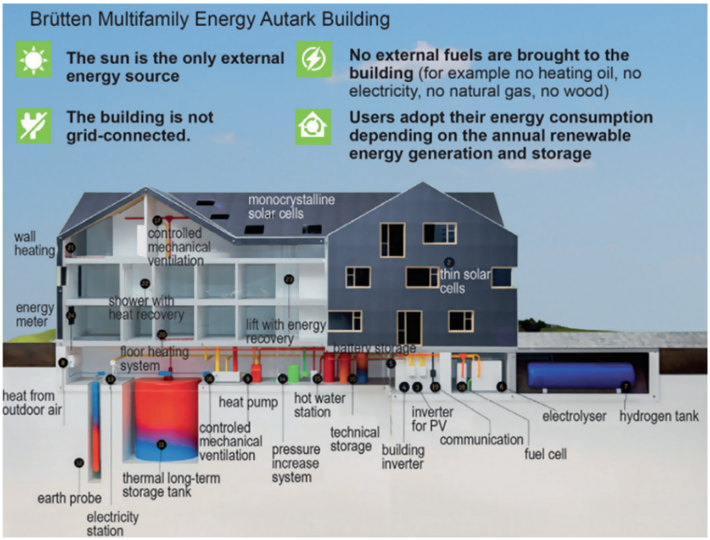

Fig. 10. Cross-section of self-contained multi-family construction project. (https://www.umweltarena.ch/)

5 Conclusions

The housing model design presented in the case study is considered a state-of-the-art ZEB construction. In this model project, it is possible to confirm the importance of permanent access of residents to information on system consumption, electricity, and water, to ensure their commitment to achieve or even exceed the objective of energy performance.

For the success of a ZEB construction, it is of great importance to draw up an energy budget based on consumption habits, the energy production capacity of the housing and the energy performance that is intended to be achieved. This budget will make residents rethink their style of energy consumption, thus ensuring a 100% clean power supply without interruptions or the need to obtain power by external supply network.

On the other hand, there was a greater concern of residents to acquire equipment of high energy efficiency, as well as all lighting by LED system. These residents became more aware of their environmental footprint and changed some attitudes towards developing a sustainable lifestyle for all.

To make ZEB construction sustainable and attractive to new owners, an assertive cost vs. benefit approach of this type of construction is needed, just in the initial phase of the construction project development process.

Today's architecture and technology make it possible to build ZEB by applying a variety of energy-efficient solutions, such as orientation of housing and openings for maximum use of sunlight and natural ventilation, thermal insulation of walls, automated blinds for the use of natural lighting and thermal optimization, generation of electricity by photovoltaic cells (solar energy) placed on facades and roofs, storage by hydrogen cells, etc.

A ZEB construction brings benefits such as reducing electricity consumption, possibility of selling surplus energy to the grid, contributing to the sustainability of the environment, housing with sustainable use, possibility of amortization of the initial extra cost in a few years.

With the model design shown in Sect. 4 of this work, it was possible to confirm that it is effectively possible to build a self-sufficient housing in energy terms, also ensuring zero CO2 emission only using current technology. Due to the characteristics of energy saving and sustainability, ZEB housing could be the future of civil engineering.

Using the ZEB concept of model housing presented in the case study of this work, new investigations may be considered using another type of buildings, other geographical areas with different environmental characteristics and other residents with different behaviors and concerns about the environment.

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