The energy renovation pathway to ZEB in Italy: analysis of typical buildings and methodological aspects

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Abstract. The evolution towards high-energy efficient buildings is one of the most important challenges today and is in line with the objectives set by the new European Directive on the Energy Performance of Buildings (EPBD) which provides for the decarbonization of entire building stock by 2050. The study starts from the analysis of the current regulatory framework in Europe and Italy, highlighting the lack of homogeneity in the methods of transposition of European directives by the Member States already at the "nearly zero energy buildings" level (nZEB). Starting from these considerations, the critical analysis of the European and Italian context highlights the need to overcome the standards currently in force and investigate new perspectives for the design of high-efficient buildings in the direction of "zero energy and zero emissions". For this reason, two residential and office buildings typologies are examined to confirm whether the net Zero Energy Building (ZEB) objective can be achieved through the legislation in force in Italy, starting from nZEB level. The study analyses the energy balance through dynamic simulations and evaluates energy needs of buildings and renewable energy production in order to verify the compliance to ZEB target, on yearly and monthly basis.

1 Introduction

According to the International Energy Agency [1], in 2022 the building sector was responsible for 30% of global final energy and for 27% of fossil CO2 emissions. Moreover, global buildings sector energy consumption increased from 2010 to 2022 by an average of 1.1% each year, totaling an estimated 133 EJ. In contrast, energy consumption decreased by 1.3% annually in the European Union (EU) due to the implementation of energy efficiency policies [1]. As stated in the last Directive of Energy Efficiency [2] the EU Member States should decrease their greenhouse gas (GHG) emissions by at least 55% compared to 1990 levels by 2030. The purpose is to achieve a climate-neutrality by 2050 and to become a world leader in the development and uptake of clean technologies in the global energy transition, including energy efficiency solutions. Indeed, despite the ongoing process of

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decarbonization, substantial efforts are still needed regarding the building stock. It represents 40% of final energy consumption in the EU and contributes to 36% of its energy-related GHG emissions, while 75% of buildings are still energy-inefficient. Space heating currently relies heavily on fossil fuels. Natural gas is the primary energy source for heating buildings, accounting for about 42% of the energy used for space heating in the residential sector, followed by oil and coal for 14% and 3%, respectively [3]. Nevertheless, there is a significant potential for electrification, particularly through the widespread adoption of efficient electric heat pumps. These heat pumps, used in both individual residences and district heating networks, can reduce energy consumption by three to five times compared to a typical gas boiler [1].

In the transposition of Energy Efficiency Directives [4,5], Italy has enacted Legislative Decrees 102/2014 [6] and 73/2020 [7], contributing to the achievement of the national energy savings goal by 2030 through the National Integrated Plan for Energy and Climate (PNIEC). Italy reduced total greenhouse gas (GHG) emissions by almost 30% between 2005 and 2019. Nevertheless, considerable additional efforts are required to achieve the more ambitious 2030 targets outlined in the EU Fit-for-55 (FF55) package (still in the process of definition) and in the REPowerEU plan. In 2021, natural gas constituted the primary fuel source in Italy's Total Energy Supply (TES), accounting for around 42%. Furthermore, natural gas held a dominant position in the electricity sector, representing 50% of electricity generation [8]. Expediting the implementation of renewable energy sources is crucial for Italy to realize the transition towards the achievement of carbon neutrality by the year 2050. PNIEC aims to achieve a target of 30% coverage of gross energy consumption with renewables by 2030, contrasting with the 19% recorded in 2021 [8].

Furthermore, previous EU Energy Performance of Building Directives (EPBD) [9,10] introduced energy performance requirements for building systems and the mandatory for all new buildings since 2021 to be nearly zero energy, defining nZEB “a building that has a very high energy performance, while 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 EPBD did not endorse a standardized method for deploying nearly Zero Energy Buildings (nZEBs) across Europe. Instead, it allows Member States to elaborate on their nZEB definitions, considering the different typology of building stock and climate zone of their territory. The result was a proliferation of different interpretations for nZEB due to the great variety of the calculation methods across Europe based on different indicators (primary energy, energy demand, CO₂ emissions, renewable energy generation), normalization factors (e.g., net floor area, gross area, conditioned area, gross volume), calculation methods and reference periods (monthly, annually), conversion factors for primary energy (PEF) [11]. In the transposition of the EPBD, Italy has implemented Legislative Decrees 192/2005 [12], which, in conjunction with the Interministerial Decree of June 26, 2015 [13], establishes the application of energy performance calculation methodologies and defines prescriptions and minimum requirements for buildings, including nZEBs.

Nonetheless, the recent proposal for the EPBD is geared towards attaining the emission reduction and climate neutrality objectives for 2030, along with establishing a zero-emission building stock by 2050. Many studies put in evidence the criticalities in buildings renovation in Italy, marked by an aging and inefficient building stock [14]. Galatioto et al. [15] argues that the same retrofitting actions varies results across all Italian climate zones. Moreover, the main issue is that the retrofit interventions on building envelope and technical systems and the installation of renewable energy sources are difficult, particularly in historical buildings like those found in Italy [15, 16]. In this context, the transition from nZEB to “Zero Emission Buildings” represents a challenging pathway, further complicated by the absence of a universally agreed-upon definition for the intended target [17]. In the more ambitious pursuit
of achieving a zero-energy, the goal is for the building to produce as much energy on-site as it consumes over the course of a year [18]. In other words, a ZEB is a building that is energy-neutral on an annual basis, exporting as much energy to the grid as it draws back [11, 19], and the imported and exported energy both contribute to a final energy balance that is equal to or less than zero. In addition, zero emission and zero carbon buildings definitions and related boundaries are discussed in several studies [20-23]. According to the current revision proposal of the new EPBD, a zero-emission building is defined as a building with a very high energy performance, where the very low amount of energy still required is fully covered by energy from renewable sources [24] and without on-site carbon emissions from fossil fuels. Consequently, the energy generated on-site by Renewable Energy Sources (RES), especially solar energy, plays a crucial role. However, the share of energy from renewable sources is frequently not tied to a specific minimum percentage but is instead based on qualitative considerations. In any case, to significantly meet the energy demand through renewable sources and decrease the primary energy requirement, it is essential to minimize the energy needs associated with heating and cooling.

This study deals with two residential and office high-efficient buildings, verifying whether the zero-energy goal (Net ZEB) is achievable under current regulation. Such buildings necessitate an integrated approach that combines energy-efficient technologies and renewable energy production. The simulations of both buildings have been carried out with a dynamic approach discussing the resulting energy balance on yearly and monthly basis.

The paper is organized as follows: Section 2 outlines the methodology, Section 3 gives a description of the cases study; Section 4 presents and discusses the results, and finally the conclusions are drawn.

2 Methodology

The aim of the study is to analyze two buildings with different use that comply with the existing nZEB regulatory requirements [13] and to verify whether they achieve the Net ZEB goal. This advanced objective aims to ensure that the energy produced in situ from renewable sources fully meets the annual energy demand. The building produces an amount of energy on-site that is equal to or greater than its energy consumption throughout the year. Furthermore, the analyses carried out intends to assess whether this goal is met also considering the monthly energy balance.

The initial step involved the modelling of two buildings, with residential and office use, defined by incorporating well-established technologies for both envelope components and system installations. The thermo-physical parameters and thermal transmittance of the building envelope components were set, respecting the minimum energy requirements defined by the Italian legislation in case of a new construction [13]. Schedules and profiles for occupancy, natural ventilation, utilization of HVAC systems for air conditioning and domestic hot water, and all aspects related to environmental control were specifically defined. RES and storage elements have been included in the buildings to ensure the maximization of the solar energy employ in the “all-electric” system (heating, cooling, DHW, CMV), to consider the zero-emission objective. The models of the two buildings have been simulated in representative locations of different Italian climate zones with a dynamic approach using EnergyPlus. It is widely utilized by academics and experienced designers and is gaining significance in the construction of low-energy buildings, due to its precision and adaptability [25]. The dynamic simulation analysis was assessed for both studied cases in climate zone B (Palermo), C (Naples), D (Rome), E (Milan) and F (Belluno). Specific weather files have been used to implement a climate-based calculation framework and improve the reliability of results. The simulations covered a one-year reference period, taking into account specific winter and summer periods for each climate zone. The energy balance on month and year
basis has been drawn and relevant considerations about zero energy and zero emission goals have been discussed.

3 Case studies

3.1 Residential building

As residential building case study (Figure 1), a linearly arranged five-story building was analyzed, featuring a total of 13 residential units distributed across floors, two or three units per floor, and with size ranging from 50 to 113 m² [26].

![Figure 1. Plan of the typical floor and related apartments layout of the residential building.](image)

The main façades of the building are exposed to South and North and incorporate loggias and balconies for shading. Additionally, there are adjustable louvres equipped with control systems for all openings in the South, East, and West facades. The building envelope meets the current minimum requirements with respect to the reference building given in Italian building code [13]. The chosen construction technology for walls and ceilings involves the use of brick and rock wool insulation. Its thickness is variable depending on the different climate zone. These constructive elements are one of the most common solutions in the field of constructions as it ensures high energy efficiency and cost-effectiveness. Openings are top-performing windows currently accessible in the market and adhere to the minimum standards. The thermophysical properties of the building envelope components and windows are outlined in Table 1.

Table 1. Characteristics of building envelope in the residential building.

<table>
<thead>
<tr>
<th>Building envelope</th>
<th>U-values per climate zone [W/m²K]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Wall</td>
<td></td>
</tr>
<tr>
<td>Porous bricks + rock wool</td>
<td>0.42</td>
</tr>
<tr>
<td>Ground Floor</td>
<td></td>
</tr>
<tr>
<td>Concrete + ventilated crawl space + EPS</td>
<td>0.23</td>
</tr>
<tr>
<td>Flat Roof</td>
<td></td>
</tr>
<tr>
<td>Concrete + rock wool</td>
<td>0.25</td>
</tr>
<tr>
<td>Double Glaze Windows</td>
<td>PVC – double glaze</td>
</tr>
</tbody>
</table>
Given that occupancy and usage significantly impact outcomes, the assumption was made for maximum occupancy and energy use during evening and night hours (from 18:00 p.m. to 8:00 p.m.), while a lower occupancy fraction of 0.2 was considered during the day (from 8:00 to 15:00), aligning with typical working or school hours. In the reference case study, the assumed average occupancy density was 0.044 people/m², with a metabolic factor of 0.90.

Regarding mechanical systems (Table 2), centralized systems were introduced for both air conditioning and domestic hot water (DHW).

Table 2. Main characteristics of heat pumps in the residential building.

<table>
<thead>
<tr>
<th>Energy services</th>
<th>Rated capacity [kW]</th>
<th>Electric Power [kW]</th>
<th>COP/EER [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>14.50</td>
<td>3.50</td>
<td>4.10</td>
</tr>
<tr>
<td>Cooling</td>
<td>16.00</td>
<td>4.20</td>
<td>3.81</td>
</tr>
<tr>
<td>DHW</td>
<td>90.00</td>
<td>24.30</td>
<td>3.70</td>
</tr>
</tbody>
</table>

Three air-to-water heat pumps were employed for both heating and cooling. The sizing of the heat pumps was determined by assessing the thermal requirements of the building. Autonomous and independent management systems are provided inside the accommodation through the installation of room chrono-thermostats. To generate DHW, a dedicated heat pump has been implemented, integrated with a storage tank. To concurrently ensure integrated production from renewable sources for DHW, the implementation of vacuum tube solar collectors was devised. These collectors boast an absorptive surface spanning approximately 36 m², with a total area reaching around 57 m² and a zero-loss efficiency of 76.7%, along with three storage tanks, each boasting a capacity of 1000 liters. Furthermore, monocrystalline photovoltaic panels, featuring a rated power of 370 W and an efficiency of 20.09%, have been strategically positioned on the roof, covering an overall area of approximately 94 m² and actively contributing to electricity generation. The building orientation aligns along the East-West axis, ensuring optimal exposure of the longest side to the South. This configuration with a tilt of 30° minimizes shading issues for the photovoltaic panels on the roof. The choice to utilize the maximum available space on the roof was made to guarantee comprehensive coverage for all energy consumption within the buildings, encompassing hypothetical electric equipment and lighting. It is worth noting that the latter is not considered in the current regulatory requirements for residential buildings [13].

3.2 Office building

The office building was selected in a prior study [27] to serve as a representative example of common features found in the Italian office building stock. The building consists of five levels, each featuring a net area of 481 m², with two staircases and two elevators. The ground floor presents a reception hall, a meeting room, offices, and open areas designed for collaboration, a layout consistent across all floors. The first floor (Figure 2) includes an extra meeting/conference room, later replaced by offices on higher floors.
The façades showcase a linear design with "ribbon" windows, and the building orientation emphasizes longer sides facing North and South, with shorter sides facing East and West. Even in this case, a reinforced concrete structure and brick masonry with rock wool external insulation was chosen for walls, the thickness of which varies depending on the climate zone. Moreover, the facades include double or triple glazing with argon in the cavity and an aluminum frame. Dynamic shading systems integrated into the windows adjust orientation based on solar radiation, optimizing solar gain in winter, and minimizing its impact in summer. The ground floor incorporates a crawl space and floating floor for housing potential plant systems. The thickness of the EPS insulation layer varies to meet minimum transmittance requirements in different climate zones. Intermediate floors feature traditional brick-cement ceilings with a thinner layer of thermal-acoustic insulation and a floating floor for accommodating and maintaining electrical and water systems. A false ceiling is installed to house components of the mechanical ventilation system. The roof consists of a flat brick-concrete floor with variable thickness EPS insulation based on climate zones. The thermophysical properties of the building envelope components and windows are detailed in Table 3, specified for each climate zone.

**Table 3.** Characteristics of building envelope in the office building.

<table>
<thead>
<tr>
<th>Building envelope</th>
<th>U-values per climate zone [W/m²K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Description</td>
</tr>
<tr>
<td>Wall</td>
<td>Porous bricks + rock wool</td>
</tr>
<tr>
<td>Ground Floor</td>
<td>Loose stone foundation + EPS</td>
</tr>
<tr>
<td>Flat Roof</td>
<td>Reinforced concrete + EPS</td>
</tr>
<tr>
<td>DG Windows</td>
<td>Aluminium - double glaze</td>
</tr>
</tbody>
</table>

About mechanical systems (Table 4), each floor is supported by an outdoor VRF unit, and an extra VRF unit is integrated into the air handling unit, equipped with a heat recovery exchanger. Each internal room is outfitted with a VRF indoor unit and an air distribution unit for both supplying fresh air and extracting used air. The six VRF systems have an identical rated power, determined by assessing both the heating/cooling demand and the efficiency decay linked to part-load operation. Finally, a specific heat pump meets the demand for DHW, that is moderate and confined to the operational hours in the office.
Table 4. Main characteristics of the HVAC components in the office building.

<table>
<thead>
<tr>
<th>Energy services</th>
<th>Rated capacity [kW]</th>
<th>Electric Power [kW]</th>
<th>COP/EER [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating - VRF</td>
<td>23.40</td>
<td>5.02</td>
<td>4.73</td>
</tr>
<tr>
<td>Cooling - VRF</td>
<td>21.10</td>
<td>4.37</td>
<td>4.83</td>
</tr>
<tr>
<td>DHW - Heat pump</td>
<td>1.90</td>
<td>0.56</td>
<td>3.40</td>
</tr>
</tbody>
</table>

Regarding the occupancy, two-employee offices, with a crowding index of 0.10 pers/m², are anticipated to be fully occupied from 8:00 to 17:00, accounting for a 3% probability of workday absence. A standard 8-hour workday plus a 1-hour lunch break is considered, with a 50% expected offices occupancy during this lunch hour. Reduced turnout (50%) is planned in August due to summer holidays, and zero occupancy is set for Italian public holidays. Open office spaces mirror the profile of individual offices, with a crowding index of 0.12 pers/m². Lunchrooms have varying maximum capacities with a crowding rate of 0.6 pers/m², reaching maximum occupancy fraction of 0.5 during the lunchtime. Meeting/conference rooms, are expected to be occupied for 25% of the workday at a 50% occupancy rate, corresponding to approximately two hours per day. The average metabolic rate was set at 1.2 met.

In the case of the office buildings, lighting and transport contributions were considered for the analysis of the electric energy consumptions, according to the current regulation [13,28]. Concerning artificial lighting, illuminance and power density values have been established for each room in accordance with standards UNI EN 12464 [29] and UNI CEN/TR15193-2 [30]. Finally, given the possibility to define a standard electrical equipment for the offices, that is more reliable to hypothesize in this case respect to the residential one, a thermal load reference value of 12 W/m² [31] was assumed for computers, printers, and other common office equipment. In this way it was possible to assess the total electric energy use of the buildings. Consequently, in order to supply all the electric uses with integrated renewable energy production systems, photovoltaic panels, with 415 W of rated power and 21.3% efficiency, were employed on an area ranging from about 270 to about 409 m² and a peak power from 57.3 to 86.9 kW, depending on the climate zone. Differently from the residential case study, the area allocated for the photovoltaic panels on the roof of the office building, as well as their peak power, were calculated and adjusted based on the climate zone. This was made feasible by the comprehensive assessment of all electrical uses within the building. Moreover, to harness any surplus electric energy from the photovoltaic system, an electrical storage unit with a round-trip efficiency of 96% was incorporated.

4 Results

4.1 Energy analysis – residential building

The electric energy balance and a focus on the thermal energy demand of DHW were obtained for all the climate zones and have been shown from Figure 3 to Figure 7, labelled as (a) and (b), respectively. All the energy charts are monthly based and have the same layout. The electric balance shows the energy demand made by HVAC (blue bar) and DHW (brown bar) for each month and the renewable generation driven by photovoltaic (solid black line). The thermal energy balance for the DHW need is composed of two stacked bars, a brown one standing for the energy supplied from the heat pump and a green one representing the thermal energy supplied from the solar collectors.
Considering the electric energy balance (a) for all the climate zone, it can be appreciated the trend of HVAC demand for both heating and cooling seasons: from the warmer (B) to the coldest (F) zone, the space heating load during the winter months increases while the space cooling load decreases. Moreover, the renewable electric energy produced has the expected trend, i.e. it grows from January to July when it is the highest and then decreases until December; this profile is favorable for four of the five climate zones, due to the greater HVAC energy demand in the summer season. However, the coldest zone (F) has summer temperatures significantly lower than other cases and consequently the energy demand for space cooling is moderate. From B to D zone, the energy produced is higher than the demand for each month, while for zone E and F, this condition is not verified in few winter months, when the space heating demand increases, and the solar radiation decreases at the same time. In January, November and December in zone E and F, the energy produced by PV covers only from 50% to 82% of the total demand, as Figure 6(a) and Figure 7(a) depict. It should be noted that the missing energy amount in these three months is such modest that the only surplus of May would be able to cover it. About the DHW demand, it is almost the same for all the studied cases since they share the same boundary condition in term of specific energy need. Nevertheless, charts (b) in Figure 3 - Figure 7 reveal that the part of thermal demand fulfilled by solar collectors is strictly related to the climate zone: the lowest coverage is related to December, and it ranges from 13% (zone E) to 27% (zone D), while the highest coverage is related to the month of July ranging from 75% (zone F) to 96% (zone D). On a yearly basis, the thermal energy produced by solar collector is able to cover up to 59% in B zone and 48% in F zone. Compared to the electric demand, the DHW need decreases during warmer months hence it does not take advantage of greater solar radiation.

![Figure 3](image3.png)

**Figure 3.** Energy balance for residential building in B zone.

![Figure 4](image4.png)

**Figure 4.** Energy balance for residential building in C zone.
Hence, the energy production from photovoltaic fields and solar collectors is not adequate to cover the overall energy demand for each climate zone on a monthly basis; this occurrence would suggest that the zero-energy goal cannot be ensured for the studied case. Switching to a yearly basis, the electric balance for the five residential studied cases has been depicted in Figure 8. For each climate zone, there are two bars; one shows the energy consumption made by HVAC (blue) and DHW (brown) and the other one shows the electric energy generated by the photovoltaic field located on the roof. It can be noted how the energy produced in situ is related to the climate zone, due to the different location of the representative cities: indeed, for a fixed PV panel layout and surface, the electric energy produced from photovoltaic field
in B zone is the highest and the energy produced in F zone is the lowest. Finally, in contrast with the monthly energy balances, all the five cases could be defined net ZEB and “positive house” on a yearly basis, because the electricity from PV is always greater than the total demand, i.e. the ratio between energy supplied and requested is 2.11, 1.81, 2.45, 2.46, 2.62 for zone F, E, D, C, B, respectively.

![Residential - Yearly electric energy balance](image)

**Figure 8.** Yearly electric energy balance for residential building.

### 4.2 Energy analysis – office building

The energy results for the office building in different climate zones are shown in Figure 9 (B-F). Each chart is monthly-based and is made by three stacked bars, that represent the energy demand for HVAC (blue), equipment (grey) and lighting (yellow), and a black solid line that reproduces the electric energy generated by the photovoltaic field.

The HVAC demand during the winter season grows from B to F zone, as expected, as well as the demand for space cooling increases from F to B zone. Moreover, the equipment load remains constant for each zone, while the lighting load experiences slight fluctuations, primarily due to differences in sunlight at each location. Concerning the renewable electricity generated by the photovoltaic field, it should be noted that the maximum production is related to F zone and the minimum production occurs in B zone: as stated in section 3.1, the PV field has different area for each zone, owing to the parametric study carried out to achieve the zero-energy target. The monthly energy balance has the same trend for all the climate zones, in which the production from photovoltaic is lower than the demand for January, February, March, November and December (30% to 80% of the total demand) and it is higher for the other months.

Figure 9(Y) summarizes the yearly energy balance of the office building in five climate zones: it shows two bars for each zone, one on the left representing the overall demand, i.e. HVAC (blue), equipment (gray) and lighting (yellow), and one on the right that depicts the electric energy produced by the PV field (green). The comparison of the two bars for each climate zone demonstrates the achievement of the desired goal, that is the coverage of the year energy demand by renewable sources. Similarly, to the residential building, the net zero energy goal is achieved by the office building only considering the yearly balance and not on monthly basis.
4.3 Discussion

As obtained by the results for the two studied cases, the production of energy from renewable sources is essential for the achievement of Zero Energy and Zero Emission objectives.

Thanks to the integration with RES, the residential multi-family building achieves the total coverage of electric energy needs for all months in the climate zones from B to D, producing a surplus especially in the summer months. However, in climate zones E and F, it still achieves satisfactory coverage annually but present critical issues monthly in January, November, and December. Moreover, the DHW need for dwellings is significant and the integration with solar collectors is mandatory to decrease the overall energy demand. On the other hand, the office building presents a different behavior; as in the residential, it achieves the total coverage of electric energy needs annually, even if in winter season in all the climate
zones the monthly balance is not satisfied and the buildings do not achieve the zero-energy goal. This can be attributed to several factors. Firstly, the total energy consumption in this case includes all the energy services, i.e. HVAC (as in residential buildings), lighting, transportation, and equipment too. In comparison to the residential building scenario, it is evident that certain services, such as the production of domestic hot water, have a lesser impact on the overall building energy demand. This allows for the possibility of opting not to install solar thermal panels and, instead, favoring the installation of PV panels to cover electrical loads. Furthermore, the predominantly daytime use of a typical building in the tertiary sector determines a reduction in the issue of photovoltaic production variability, which is more present in dwellings, as they are occupied more continuously and certainly at maximum occupancy in the afternoon and nighttime slot. However, the much larger consumption due to electrical devices used for work purposes has a significant impact on the electrical needs of tertiary buildings, while they are negligible in the residential ones. Thus, the sizing of PV power peak and dedicated area in the office achieves to guarantee the annual Zero energy balance but does not assure it monthly. Finally, the use of all-electric systems in the residential and office buildings with on-site renewable energy production ensure the achievement of phasing out fossil fuels and zero emission standard as the new EPBD recast requires.

5 Conclusions

This study focuses on evaluating the energy performance of representative residential and office buildings across different climate zones in Italy using dynamic simulations. The objective was to determine the feasibility of achieving the Zero Energy Building (ZEB) target in accordance with the current Italian building code. The key findings of this research are summarized as follows:

1. Residential and office buildings, equipped with established envelope components and plant systems available in the market, can attain a high level of energy efficiency without resorting to costly or cutting-edge technologies.

2. The Net ZEB target is achievable in current constructions, but a comprehensive and integrated approach is essential. This approach should encompass attention to the building envelope, passive strategies, plant systems, and the integration of renewable sources.

3. Implementing all-electric systems in both representative residential and non-residential buildings, coupled with on-site renewable energy production, ensures the phasing out of fossil fuels, and complies with the zero-emission standards proposed in the new Energy Performance of Buildings Directive (EPBD).

4. A detailed case-by-case study is necessary, employing advanced tools and dynamic calculation methodologies, to provide accurate results based on the selected time step of analysis. Choosing the appropriate reference period is crucial for controlling the building energy balance.

5. The Net Zero Energy Building objective can be achieved annually with appropriately sized photovoltaic fields. For all Italian climate zones, specific PV areas have been demonstrated to meet the energy demands of the studied buildings. On-site renewable energy production also ensures compliance with the Zero Emission Building outlined in the current European EPBD proposal.

6. Meeting the Net Zero Energy Building target is more challenging monthly, especially during the winter season. In residential buildings, the primary challenges are observed in climate zones E and F, while in office buildings, all climate zones face difficulties during the winter period due to increased energy consumption for various electric uses (HVAC, lighting, transportation, equipment).
It is important to note that the results obtained are strictly linked to the calculation approach used to carry out the energy balance of the building. Particularly, the use of dynamic calculation method, on hourly basis, and the availability of specific climate data was crucial to evaluate with more accuracy the efficiency of buildings, equipped with high performance HVAC systems integrated with renewable sources (i.e. Heat Pump or VRF, PV system, energy storage). Finally, assessing the contribution of renewable sources, on annual or monthly basis, is relevant to verify the compliance with Net ZEB or ZEB standards; these aspects will be essential to compare the results and technologies used to achieve the new energy efficiency targets set for building stock.

Symbology

- **CMV**: Controlled Mechanical Ventilation
- **DHW**: Domestic Hot Water
- **DG**: Double Glaze
- **EPBD**: European Directive on the Energy Performance of Buildings
- **EPS**: Expanded Polystyrene
- **EU**: European Union
- **GHG**: Greenhouse gas
- **HVAC**: Heating, Ventilation and Air Conditioning
- **nZEB**: nearly Zero Energy Building
- **PV**: Photovoltaic
- **PVC**: Polyvinyl Chloride
- **RES**: Renewable Energy Sources
- **TG**: Triple Glaze
- **VRF**: Variable Refrigerant Flow
- **U**: Thermal Transmittance, W/m²K
- **ZEB**: Zero Energy Building

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