

EPBD_wise

BRINGING EUROPEAN BUILDING POLICY TO LIFE

Guidelines for the development of a ZEB definition

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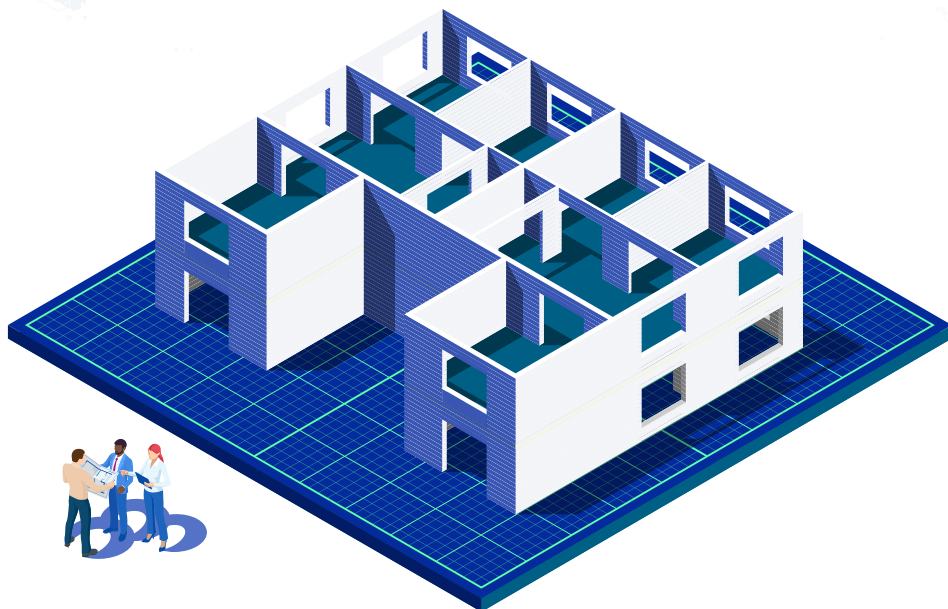
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CONTENTS

	About EPBD.wise.....	5
	Executive summary	6
	List of abbreviations.....	9
	List of Figures	9
	List of Tables	10
1	Introduction	11
	1.1 Scope and objectives of the deliverable	11
	1.2 Structure of the deliverable	12
	1.3 Description of the ZEB framework under the EPBD (2024/1275)	12
2	Suggestions for the development of a ZEB definition	13
	2.1 Sources of energy.....	13
	2.1.1 Energy from renewable sources, generated on-site or nearby	14



2.1.2	Energy from renewable sources provided by a renewable energy community	15
2.1.3	Energy from an efficient district heating and cooling system.....	16
2.1.4	Energy from carbon-free sources.....	16
2.2	Main indicators and maximum thresholds for ZEBs.....	17
2.2.1	Total annual primary energy	17
2.2.2	Operational CO ₂ emissions	18
2.2.3	Life-cycle global warming potential.....	19
2.3	Calculation framework for ZEBs.....	20
2.3.1	Primary energy calculation and assessment of renewable energy sources in the energy balance.....	21
2.3.2	Operational CO ₂ calculation.....	24
2.3.3	Life-cycle GWP calculation (for new buildings).....	25
2.4	Difference between new and existing buildings.....	27
2.5	Building energy flexibility	29

3 Interactions and inferences of the ZEB concept with other policy instruments 32

3.1	NBRP: Strategic roadmaps toward decarbonisation	33
3.2	MEPS and national trajectories: The regulatory delivery ladder.....	34
3.3	Renovation passports: The building-level planning tool....	35
3.4	EPCs: The monitoring/signalling instrument	36
3.5	Integrated interpretation	37

4 Conclusions, key considerations and recommendations .. 39

4.1	Legislative and regulatory framework	39
4.2	Institutional and governance considerations.....	40
4.3	Technical and implementation aspects.....	40

5 References..... 42

6 Annex A Current status of nZEBs in the priority countries.. 45

A1	Current status of nZEBs in Bulgaria	45
A2	Current Status of nZEBs in Hungary.....	46
A3	Current status of nZEBs in Ukraine.....	47
A3.1	Standards that can be adopted/developed.....	51



About EPBD.wise

EPBD.wise aims to kickstart action to bring Europe's buildings directive to life and make our climate goals a reality. Over the course of three years, project partners are working with public authorities (such as municipalities, energy agencies, etc.) in six European countries (Bulgaria, Greece, Hungary, Poland, Romania and Ukraine) for the design, implementation and evaluation of key provisions to ensure our buildings are in line with our climate goals. Starting with the six focus countries, EPBD.wise builds a replicable model to support the widespread implementation of these measures across Europe.



EXECUTIVE SUMMARY

This document provides guidance and suggestions for the development of the zero-emission building (ZEB) definition. Based on the ZEB framework defined by the Energy Performance of Buildings Directive (EPBD) (2024/1275), this document also takes into consideration priorities identified for the priority countries: Bulgaria, Hungary and Ukraine.

The main part of the document, where suggestions and guidance for the implementation of a ZEB definition are presented, deals with: ① sources of energy to cover a ZEB's total primary energy use; ② the concept of the building's boundary to define on-site and nearby energy production; ③ the main indicators and their maximum thresholds; ④ the calculation framework for ZEBs, integrating detailed energy demand estimation, renewable energy supply assessment, and compliance with maximum thresholds in terms of energy demand and operational carbon emissions; ⑤ the differences between new and existing buildings and the distinct challenges in achieving ZEB status; ⑥ energy flexibility in buildings and their capacity to react to external signals and adapt their energy use, generation and storage.

The last part of the document focuses on the interactions and inferences between the ZEB definition and other policy instruments: national building renovation plans (NBRPs), minimum energy performance standards (MEPS) and national trajectories, renovation passports, energy performance certificates (EPCs). These are summarised in the table below.



Policy instrument	Functional level	Primary function	Interaction with ZEB	Policy effect
NBRP	National strategy	Strategic planning, financing and monitoring	Defines national trajectories using ZEB thresholds	Aligns long-term planning and resources with the ZEB target
MEPS and national trajectories	Regulatory enforcement	Progressive mandatory standards	Use ZEB as an endpoint for performance thresholds	Create binding milestones toward ZEB compliance
Renovation passport	Building-level execution	Owner-based renovation plans	Designs stepwise paths to reach ZEB	Converts strategy into actionable renovations
EPC	Monitoring and communication	Data reporting, labelling, verification, first renovation recommendations	Class A = ZEB, includes ZEB indicators	Tracks, signals and validates progress, identifies first renovation actions

Key considerations and recommendations are:

- The main indicators to be adopted are the total annual primary energy indicator [kWh/(m².y)], the operational CO₂ emission indicator [kgCO₂eq/(m².y)], and the life-cycle global warming potential.
- Both total annual primary energy and operational CO₂ emissions maximum thresholds strictly depend on the cost-optimal calculations at the national level.
- Regarding the energy performance, a ZEB is an extension of the nearly zero-energy building (nZEB) standard, defined at the national level, which needs to be improved by at least 10%.
- When generated on-site, the energy required by the building must have no on-site carbon emissions from fossil fuels.
- Definitions of boundaries for the energy balance of a building, on-site perimeter, nearby and distant energy production are crucial. There are two potential approaches: building assessment boundary (EN ISO 52000-1:2017), and building site boundary, considering only the energy delivered at the site.
- Achieving zero-emission buildings requires a seamless integration of renewable energy sources, advanced storage technologies and efficient energy management systems.
- The achievement of zero-emission “status” for a building, given Article 11⁷ of the EPBD, may not only depend on the building itself, but also on the characteristics of the energy networks to which it is connected: whether the district heating and cooling system to which it is connected is efficient according to Directive (EU) 2023/1791, or whether the electricity in the network is generated from carbon-free sources.
- A comprehensive ZEB framework must acknowledge and recognise the distinct challenges and requirements associated with both new and existing buildings.
- For new buildings, the priority is achieving zero emissions through advanced design and construction techniques, ensuring energy needs are met entirely by on-site or nearby renewable sources.



- Existing buildings require a flexible approach that accounts for varying energy efficiency baselines, different building typologies, and specific technical and financial constraints.
- The capacity of a ZEB to react to external signals and adapt its energy use, generation and storage can be enhanced through building energy flexibility. It can be achieved on both the supply side and the demand side. On the supply side, on-site energy generation (e.g., PV, wind turbines, solar thermal) is deployed to decrease the building's net load imported from the utility grid (along with integrating building energy systems and energy storage systems – both electrical and thermal). On the demand side, various demand management measures can reduce or moderate some building loads, such as heating, ventilation and air conditioning (HVAC), electric appliances and electric vehicles.



LIST OF ABBREVIATIONS

DHC	District heating and cooling
DHW	Domestic hot water
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
EPC	Energy performance certificate
GHG	Greenhouse gas emissions
GWP	Global warming potential
HVAC	Heating, ventilation, and air conditioning
nZEB	Nearly zero-energy building
PEF	Primary energy factor
PV	Solar Photovoltaic
RED	Renewable Energy Directive
TBS	Technical building system
ZEB	Zero-emission building

LIST OF FIGURES

Figure 2.1:	EN ISO 52000:2017 defines the energy balance of a building (a), on-site perimeter (b), nearby (c), and distant energy production (d).....	15
Figure 2.2:	Diagram of building site boundary that complements building assessment boundary. Source:[8].....	22
Figure 3.1:	Summary diagram of inferences and relationships between ZEB and other policy instruments.....	38



LIST OF TABLES

Table 1.1:	Identified priorities for priority countries.....	11
Table 2.1:	Contributions of different energy sources to the rise of the total annual primary indicator.....	24
Table 2.2:	Key points and differences between new and existing buildings for achieving ZEB.....	28
Table 2.3:	Characteristics of different flexible loads in residential buildings. Source: [12]	30
Table 3.1:	Summary of the interactions and inferences between ZEB and the other policy instruments	37
Table A.1:	Maximum values for EP for class A for types of building categories in Bulgaria. Source: [16].....	46
Table A.2:	Maximum specific heat loss values for nZEB buildings in Hungary. Source: [17]	46
Table A.3:	Building energy efficiency class in Ukraine. Source: [18]	48
Table A.4:	Primary energy consumption limits from non-renewable energy sources for new constructions in Ukraine. Source: [21]	48
Table A.5:	Primary energy consumption limits from non-renewable energy sources for reconstructions in Ukraine. Source: [21].	49
Table A.6:	Minimum area values of devices that produce electrical and/or thermal energy from solar radiation. Source: [23]	50
Table A.7:	Set of EPB standards	52



INTRODUCTION

1.1 Scope and objectives of the deliverable

This document provides guidance and suggestions for the development of a zero-emission building (ZEB) definition, based on the ZEB framework defined by the Energy Performance of Buildings Directive (EPBD) (2024/1275) [1] (see §1.3). Although this document does not target a specific focus country, its development took into consideration priorities identified for the priority countries summarised in Table 1.1.

Table 1.1: Identified priorities for priority countries

Country	Priorities			
Bulgaria	Technical and economic feasibility	Indicators and metrics	Boundaries (site boundary, boundaries for renewables)	
Hungary	Energy efficiency first principle	Life-cycle global warming potential	Boundaries (site boundary, boundaries for renewables)	Calculation framework
Ukraine	Energy efficiency	Indicators and metrics	Calculation framework	

The ZEB standard is connected to other policy elements specified in the EPBD. The interaction and inferences will be analysed and summarised in Chapter 3.



1.2 Structure of the deliverable

This document aims to provide guidance and suggestions for the development of a ZEB definition in accordance with the EPBD (2024/1275) [1]. Chapter 2 is the main section of the document, presenting recommendations and guidance, considering the following aspects: sources of energy, metrics, main indicators and their thresholds, calculation framework, difference between new and existing buildings, and building energy flexibility. Chapter 3 outlines the interactions and inferences between the ZEB concept and the policy instruments covered in EPBD, wise, e.g., NBRPs, MEPS and national trajectories, renovation passports and EPCs. The final chapter, comprising conclusions and recommendations, summarises the findings and identifies the next steps. Annex A provides information on the current status of the definition and implementation of nZEBs in Bulgaria, Hungary and Ukraine, with a focus on the set of standards on energy efficiency and energy management adopted by Ukraine and a suggestion of standards to be possibly adopted/developed.

1.3 Description of the ZEB framework under the EPBD (2024/1275)

Zero-emission buildings are introduced within the EPBD [1] in Article 2 and Article 11. According to Article 2, a zero-emission building is a building with a very high energy performance, requiring zero or a very low amount of energy, producing zero on-site carbon emissions from fossil fuels, and producing zero or a very low amount of operational greenhouse gas emissions.

According to Article 11, a zero-emission building requires:

- No on-site carbon emissions from fossil fuels
- The capacity to react to external signals and adapt its energy use, generation or storage (where economically and technically feasible)
- Energy demand complying with a maximum threshold established at Member State level
- Operational greenhouse gas emissions complying with a maximum threshold established at Member State level
- Total annual primary energy use covered by:
 - energy from renewable sources generated on-site or nearby
 - energy from renewable sources provided from a renewable energy community
 - energy from an efficient district heating and cooling system
 - energy from carbon-free sources
 - where it is not technically or economically feasible to fulfil the energy covering with the above-mentioned energy sources, the total annual primary energy use may also be covered by other energy from the grid complying with criteria established at the national level.

In terms of implementation timeline, according to Article 7, from 2028 new buildings owned by public bodies and from 2030 all new buildings should be ZEBs. The same Article states that, from 2028 for new buildings with a useful floor area larger than 1,000 m² and from 2030 for all new buildings, the life-cycle global warming potential (GWP) is calculated and disclosed in the EPC of the building.



SUGGESTIONS FOR THE DEVELOPMENT OF A ZEB DEFINITION

This chapter presents suggestions and guidance for the development of the ZEB definition within the framework defined by the EPBD [1]. It tackles several aspects to consider: energy sources, metrics, calculation framework, differences between new and existing buildings, and building energy flexibility.

2.1 Sources of energy

Zero-emission buildings play a critical role in decarbonising the construction sector, which is responsible for around 34% of global CO₂ emissions, including both operational emissions and those embedded in construction materials. Buildings also account for approximately 32% of global energy consumption, offering significant potential for reducing primary energy use. By integrating renewable energy, we can substantially decrease traditional energy consumption and lower greenhouse gas emissions [2].

EPBD Article 11^o states that the total annual primary energy use of a new or renovated zero-emission building must be covered by:

- a) **energy from renewable sources generated on-site or nearby**, fulfilling the criteria laid down in Article 7 of **Directive (EU) 2018/2001** (Renewable Energy Directive II [3]);
- b) **energy from renewable sources provided from a renewable energy community** within the meaning of Article 22 of **Directive (EU) 2018/2001**;



- c) **energy from an efficient district heating and cooling system** in accordance with Article 26[ⓐ] of Directive (EU) 2023/1791 [4]; or
- d) **energy from carbon-free sources.**

2.1.1 Energy from renewable sources, generated on-site or nearby

Energy generated from renewable sources **on-site or nearby** refers to renewable energy that is **generated on-site or in close proximity** to where it is consumed, in accordance with **Article 7 of Directive (EU) 2018/2001**.

Recital 22 of the EPBD outlines **on-site renewable energy sources** like solar, geothermal and biomass. It clarifies that energy from the combustion of renewable fuels is considered on-site energy if the combustion occurs within the building. However, bioenergy produced outside the building's boundary will be treated as distant energy in the energy performance calculation of a ZEB, in line with Annex I of the Directive and the EN ISO 52000-1 standard.

Article 2(55) of the EPBD defines energy from renewable sources produced nearby as energy produced within a local or district-level perimeter around a building, subject to these conditions:

1. It can only be distributed and used within that perimeter through a dedicated distribution network.
2. It allows for the calculation of a specific primary energy factor for the energy produced within that perimeter.
3. It can be used on-site via a dedicated connection to the energy production source, with specific equipment for safe supply and metering for self-use in the building.

Additionally, the EN ISO 52000-1:2017 [5] standard defines "nearby" as energy at the local or district level and requires specific infrastructure, such as district heating or cooling, to connect buildings to the energy source.

A key point to consider is that energy allocation to buildings is determined by physical connection, whether through cables or pipework, rather than contractual or ownership arrangements. While there is mention of using different primary energy factors compared to distant energy production, further details on this are not specified.

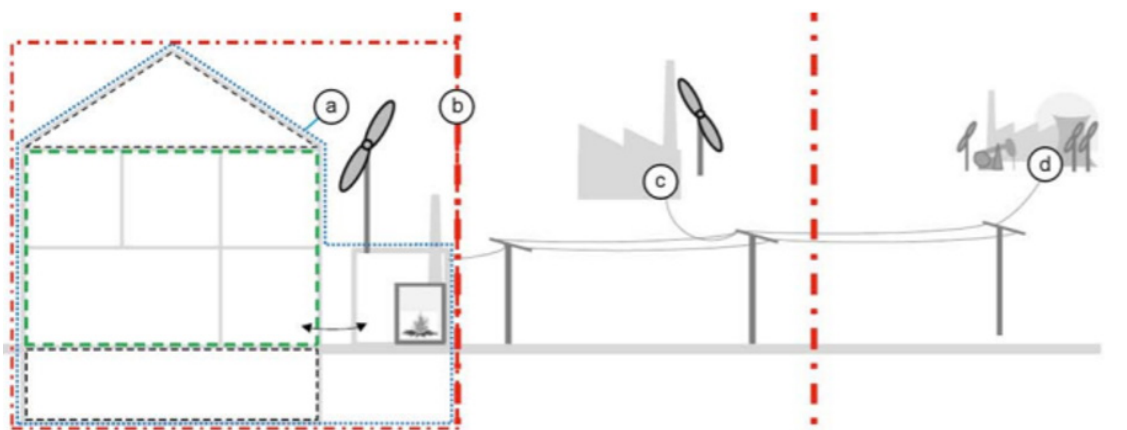


Figure 2.1: EN ISO 52000:2017 defines the energy balance of a building (a) on-site perimeter (b), nearby (c) and distant energy production (d).

Currently, the most widely used renewable energy sources for building applications include **solar, ambient, wind, geothermal and biomass**.

Key considerations

Each renewable energy source for buildings offers unique advantages and challenges, and only through the **integration of multiple energy systems** can we achieve net-zero energy targets. At present, the most commonly implemented systems in buildings are those based on heat pumps and PV panels.

However, these renewable sources have inherent limitations related to fluctuations and reliability, so it is crucial to integrate **energy storage solutions**. The combination of **thermal energy storage** (such as hot water storage tanks or phase change materials) and **electrical energy storage** (such as batteries) allows excess energy to be stored during periods of high production and used when demand exceeds generation. By incorporating both forms of storage, buildings can optimise the performance of their renewable energy systems, making them more efficient and adaptable to changing conditions.

2.1.2 Energy from renewable sources provided by a renewable energy community

This refers to energy that is generated from renewable sources (such as solar, wind, hydro or biomass) by a **renewable energy community** as defined in **Article 22 of Directive (EU) 2018/2001 [3]**.



Key aspects of a renewable energy community under Article 22 are:

- **Ownership and control:** A renewable energy community is an entity controlled by local shareholders or members, such as individuals, small businesses or local authorities.
- **Primary purpose:** Unlike traditional energy companies, renewable energy communities prioritise environmental, social and community benefits over financial profits.
- **Activities:** Renewable energy communities can generate, consume, store and sell renewable energy, as well as provide energy-sharing services.
- **Geographical proximity:** Members of the community typically operate within close proximity to the energy generation facilities.

2.1.3 Energy from an efficient district heating and cooling system

Article 26^① of Directive (EU) 2023/1791 focuses on the promotion of centralised systems using renewable sources like biomass, geothermal or solar thermal for efficient heating or cooling distributed to nearby buildings.

According to the directive, energy from an **efficient district heating and cooling system** refers to thermal energy supplied through a network that meets specific efficiency and sustainability criteria:

- Using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of these sources. These percentages will be valid until 31 December 2027, and the shares of renewable energy, waste heat or a combination of both will increase over time until they reach 100% by 1 January 2050.
- Ensuring the system significantly reduces primary energy consumption and greenhouse gas emissions compared to conventional heating and cooling solutions.

2.1.4 Energy from carbon-free sources

Energy from carbon-free sources refers to energy that is generated without emitting carbon dioxide (CO₂) or other greenhouse gases into the atmosphere. In addition to the renewable energy sources mentioned before, this kind of energy typically includes **nuclear energy, carbon-free hydrogen and waste heat from industrial processes** (if captured and used without additional fossil fuel combustion).

Key considerations

Achieving ZEBs requires a seamless integration of renewable energy sources, advanced storage technologies and efficient energy management systems. Innovations in battery storage, hydrogen technologies, and other emerging solutions will be essential in addressing the current limitations of renewable energy, making these systems more reliable, cost-effective and scalable for widespread adoption in the built environment.



To achieve the decarbonisation of the building sector, it is crucial to expand the options for meeting the renewable (and, generally, carbon-free) energy needs of zero-emission buildings. This includes utilising all renewable energy sources, such as those supplied through grids from off-site production facilities or seasonal storage systems.

The achievement of zero-emission “status” for a building, given Article 11⁷ of the EPBD, may not only depend on the building itself. For example, in highly urbanised settings, there may be neither the technical possibility of generating sufficient energy from on-site or nearby renewable sources, nor the possibility of forming renewable energy communities. A building may obtain its ZEB status from the characteristics of the energy networks to which it is connected: whether the district heating and cooling system to which it is connected is efficient according to Directive (EU) 2023/1791, or whether the electricity in the network is generated from carbon-free sources.

The definition of a ZEB must fully recognise the critical role of renewable energy in decarbonising buildings, regardless of whether it is generated on-site or nearby, stored on-site, or supplied through the grid. All renewable energy sources should be considered equally, with the most suitable option depending on national, regional, local and individual circumstances. This approach aligns with Article 15a of the revised Renewable Energy Directive, which allows national renewable energy targets for buildings to be met through on-site, nearby or grid-supplied renewable energy. Ensuring consistency within the Fit for 55 package is essential, along with providing Member States with the flexibility to achieve their targets and establish their own decarbonisation strategies.

2.2 Main indicators and maximum thresholds for ZEBs

The EPBD identifies two main indicators for zero-emission buildings with specific thresholds:

- **Total annual primary energy indicator** [kWh/(m².y)]
- **Operational CO₂ emission indicator** [kgCO₂eq/(m².y)].

They concur with the ZEB standard definition and require a detailed calculation framework for Member States. In the following, they are described in detail, along with the maximum thresholds stipulated in the Directive for ZEBs.

In addition to these two main indicators, Article 7 of the EPBD mandates that **life-cycle global warming potential** (life-cycle GWP) must be calculated for new buildings.

2.2.1 Total annual primary energy

To meet the ZEB standard, the building’s total annual primary energy consumption must be fully covered by specific energy sources, including on-site or nearby renewable energy, energy supplied by a renewable energy community, energy from efficient district heating and cooling systems or carbon-free energy sources, as described in section 2.1.



The **maximum threshold** for the energy demand of a ZEB must be at least **10% lower** than the threshold for total primary energy use in **nearly zero-energy buildings** (nZEBs) (EPBD Article 11③). This threshold will depend on national requirements for nZEBs, including renewable and non-renewable primary energy use. It is also linked to building types, climatic conditions and local context. The maximum thresholds must be aligned with **cost-optimal levels** established by Member States (EPBD Article 11③). They will be reviewed depending on the revision of the cost-optimality methodology at defined time intervals not longer than five years.

If achieving these conditions is technically or economically unfeasible, alternative energy sources from the grid may be used, provided they comply with national criteria (EPBD Article 11③). Each Member State must define clearly the conditions of technical and economic unfeasibility and should, in any case, promote high energy efficiency and a minimum percentage of renewable energy coverage. This approach reinforces the EPBD's commitment to reducing primary energy consumption and operational CO₂ emissions, contributing to the EU's broader decarbonisation goals.

ZEBs must achieve at least class A or A0 (EPBD Article 19②) in their energy performance certificates (EPCs), where the principal metric for assessing building energy performance is annual primary energy use (renewable and/or non-renewable) by floor area, in kWh/m².y (EPBD Annex I).

2.2.2 Operational CO₂ emissions

Annex I ② of the EPBD [1] states that Member States should define an additional indicator of operational greenhouse gas (GHG) emissions expressed in kgCO₂eq/m².y. This introduces a complementary metric to be used alongside the primary energy indicator for assessing zero-emission buildings.

Operational GHG emissions refer to the CO₂ equivalent emissions produced during the use phase of a building's life cycle due to energy consumption for heating, cooling, lighting and other functions. They include both direct emissions generated on-site and indirect emissions linked to the electricity and heat consumed by the building but produced off-site. As outlined in EPBD Article 11③, direct emissions from fossil fuels are not produced in a ZEB on an annual basis. The focus must therefore be on indirect operational emissions linked to energy-efficient district heating and cooling systems, electricity supplied by the grid, and other energy sources with carbon content (not compensated annually by the energy produced by renewable energy sources).

As stated in Article 11③ of the EPBD, Member States are required to implement measures ensuring that the operational (direct and indirect) greenhouse gas emissions of ZEBs remain within a **maximum limit**, set at the national level as part of their building renovation plans for new and existing buildings. This threshold is strictly linked to the results of the cost-optimal calculation at the national level.

To achieve the ZEB standard, a building must minimise operational emissions by relying on on-site or nearby renewable energy sources, energy from renewable energy communities, or carbon-free energy systems. The Directive specifies that total annual primary energy



demand should be covered by these clean energy sources, aiming at phasing out fossil fuels and directly lowering operational carbon emissions.

To reduce operational carbon emissions, it is necessary to enhance energy efficiency with better insulation, high-performance HVAC systems and LED lighting; to maximise renewable energy integration, such as solar panels; and to use energy storage solutions to balance demand and supply.

2.2.3 Life-cycle global warming potential

Article 2 of the EPBD introduces life-cycle GWP to measure the building's potential contribution to global warming throughout its entire life cycle. This metric accounts for both the embedded emissions from construction materials and the direct and indirect emissions generated during the building's operational phase. GWP refers to the total CO₂ equivalent emissions of a building over its entire life cycle. It includes:

1. Embodied carbon: emissions from materials, construction, maintenance and demolition.
2. Operational carbon: emissions from building operations (energy for heating, cooling, lighting, hot water, etc.).
3. Benefits and impacts beyond the life cycle: material recovery and emission offsetting.

Embodied carbon represents a significant portion of a building's total emissions, particularly for highly efficient buildings with low or no operational emissions, as in the case of ZEBs. It covers the emissions released throughout the entire life cycle of a building, excluding operational emissions, and is expressed in kgCO₂eq/m². This includes all emissions generated by the production and construction processes of a building, from material extraction to demolition. Embodied carbon can be divided into different phases according to the EN15978:2011 standard (currently being updated) [7]: production and construction, use and maintenance, end of life, benefits and impacts beyond the life cycle. To reduce embodied carbon emissions, it is necessary to opt for low-carbon materials (e.g., recycled steel, low-carbon concrete), use bio-based materials where feasible, use modular design, and prioritise reuse and recycling.

EPBD Article 7 introduces the **calculation of GWP as a mandatory requirement for new buildings**, representing an important step toward a more comprehensive evaluation of building performance and the circular economy.

The EPC must disclose the GWP by 2028 for all new buildings with a useful floor area greater than 1,000 m², and by 2030 for all new buildings (Article 7@ [1]). By 2027, Member States must set GWP thresholds for new buildings, ensuring a progressive reduction aligned with climate zones and building types (Article 7@ [1]).

For existing buildings classified A+, GWP must be calculated and disclosed in their EPC. According to Article 19@ [1], a class A+ can be defined for buildings with energy demand at least 20% lower than the ZEB maximum threshold. These buildings produce more on-site renewable energy than their primary energy demand, calculated on an annual basis. The



maximum threshold may vary depending on differences in climatic conditions, zones and building typologies.

2.3 Calculation framework for ZEBs

The energy performance of ZEBs needs to be assessed, addressing specific items:

- **Net zero energy balance:** achieved when annual renewable energy production equals or exceeds annual energy consumption.
- **Primary energy use:** evaluating energy efficiency based on the total annual primary energy use according to Article 11[Ⓞ] of the EPBD. Primary energy use must be covered by energy from on-site and nearby renewables, renewable energy communities, efficient district heating and cooling, and carbon-free sources.
- **Carbon neutrality:** attained when operational GHG emissions are zero or very low, and on-site carbon emissions from fossil fuels are zero.

The calculation framework in zero-emission buildings integrates detailed energy demand estimation, renewable energy supply assessment, and compliance with maximum thresholds in terms of energy demand and operational carbon emissions. This systematic approach ensures the design and operation of buildings align with sustainable energy and climate goals. It is necessary to consider both energy performance and carbon emission calculation, paying attention to the specific characteristics of a zero-emission building.

2.3.1 Primary energy calculation and assessment of renewable energy sources in the energy balance

The EPBD aims at lowering energy consumption and promoting the use of renewable energy resources, notably through solar power systems and heat pumps [8].

A ZEB must ensure that its total primary energy consumption over the course of a year is fully covered by the renewable or carbon-free energy sources outlined in Article 11[Ⓞ] (see Section 2.1). While Article 11[Ⓞ] prohibits on-site carbon emissions from fossil fuel use, ZEBs do not always need to rely exclusively on these approved energy sources. Instead, temporary use of other energy sources with a carbon footprint is allowed if it is compensated within the same year by an equivalent surplus of renewable energy, ensuring the building maintains a net-zero emissions balance annually.

Renewable energy sources play a pivotal role in the calculation of energy performance for zero-emission buildings by directly offsetting the energy demand with clean energy production. These sources enable buildings to achieve net-zero energy status by replacing non-renewable energy consumption with sustainable alternatives like solar, wind and geothermal energy. The integration of renewables is critical for meeting energy balance targets and complying with carbon neutrality goals. Renewable energy systems, combined with storage solutions, also enhance energy resilience by minimising reliance on fossil fuels.



In the calculation of the energy performance, a thorough evaluation is necessary to determine the total annual primary energy use and the contribution of renewable energy generated on-site and exported to the grid (for instance, if on-site solar PV generation should be treated as supplied energy, and whether ambient energy should be factored into or excluded from the annual primary energy indicator [8]).

The annual energy balance of the building must be calculated according to the methodology outlined in Annex I of the Directive, using estimates and projections of the building's energy demand and primary energy supply.

The calculation of a building's energy demand and consumption for heating, cooling, domestic hot water, ventilation, lighting and other technical systems must be carried out at monthly, hourly or sub-hourly intervals. This approach ensures that fluctuating conditions affecting energy consumption, generation and efficiency over time are accurately accounted for.

According to Annex I © of the EPBD, the primary energy calculation can be based on regularly updated and forward-looking **primary energy factors** (PEFs), distinguishing between non-renewable, renewable and total primary energy.

These factors, or alternative weighting factors per energy carrier, must be recognised by national authorities and consider the projected energy mix outlined in each country's national energy and climate plan. PEFs or weighting factors may be determined at national, regional or local levels and set on annual, seasonal, monthly, daily or even hourly scales, depending on available data and specific district energy systems.

Hourly calculations of both energy consumption and generation are necessary to accurately determine building self-consumption, the use of renewable energy for other on-site applications, and the quantity of electricity exported.

It is essential to consider both self-consumed and exported renewable electricity (e.g., PV) when calculating total or non-renewable primary energy. The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) document [8] deals with this issue, summarised below.

Primary energy is calculated starting from delivered energy, defined as the energy supplied to the building through the boundary used for the energy balance (i.e., energy imported from sources outside the boundary). According to [8, 9], two alternative approaches can be adopted, depending on the definition of the boundary. The boundary is the field where delivered and exported energy is measured and calculated, and it can be considered as:

- Building assessment boundary (EN ISO 52000-1:2017 [5])
- Building site boundary, considering only the delivered energy at the site.

For a better understanding, see Figure 2.2.

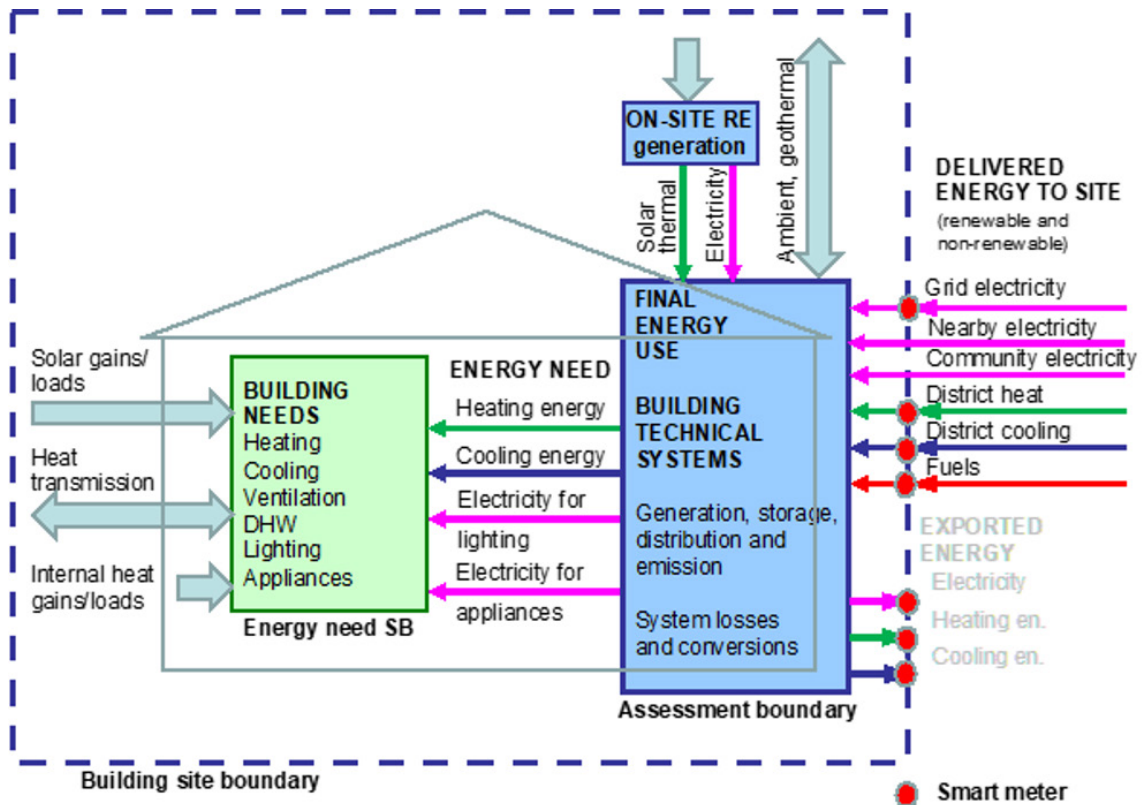


Figure 2.2: Diagram of building site boundary that complements building assessment boundary. Source:[8].

Defining the boundary is crucial because it determines **which energy sources are included in primary energy calculations.**

In the first option, a defined building **assessment boundary** separates energy demand (the consumption side) from energy supply. It accounts for energy used inside the building, which comprises on-site energy production and energy carriers delivered from both local and remote sources, and exported energy. The self-consumption of on-site renewable electricity partially satisfies energy demand, diminishing the reliance on grid-supplied electricity. Renewable electricity sourced from nearby or community-scale installations depends on specific technical and contractual arrangements; however, for energy calculation purposes, it may be treated as supplied energy and differentiated through distinct PEFs. Diverse fuels are treated as energy supplied with their corresponding PEFs [8], as well as other energy sources, such as biomass not generated within the building premises. By contrast, only on-site renewable energy produced and self-consumed – either directly or after storage within the building site – such as solar thermal, PV energy, ambient heat, geothermal energy used by heat pumps may be considered as supplied energy with no contribution to the total energy primary balance, in accordance with Commission Delegated Regulation (EU) 2025/2273 [10] on the cost-optimality methodology framework.



The total **primary energy indicator (EP_{tot})** is calculated using the formula [8]:

$$EP_{tot} = [\sum(E_{del,i} \cdot f_{del,tot,i}) - \sum(E_{exp,i} \cdot f_{exp,tot,i})] / A_{net} \quad [\text{kWh/m}^2 \text{ y}]$$

Where:

- $E_{del,i}$ = delivered energy for energy carrier i [kWh/y].
- $f_{del,tot,i}$ = primary energy factor for delivered energy carrier i.
- $E_{exp,i}$ = exported energy for exported energy carrier j [kWh/y].
- $f_{exp,tot,i}$ = primary energy factor for exported energy carrier j.
- A_{net} = net floor area [m²].

The exported energy may be considered with an appropriately adjusted PEF (less than 1 if it accounts for possible losses when the energy is used off-site) to reflect the benefits of surplus renewable energy production.

In the second option (**building site boundary**), the building's physical site boundary serves to differentiate between energy flows entering (supplied) and leaving (exported) the site. Energy consumption is determined using the assessment boundary specified in EN ISO 52000-1:2017 [5], but for the calculation of primary energy indicators, the building site boundary is employed [8].

Within this defined boundary, on-site renewable energy generation and self-consumption (solar thermal and PV, ambient heat and geothermal for heat pumps) are not included in the primary energy indicator calculation [8]. Assuming a building site boundary (considering only delivered energy at the site) ensures that only purchased or externally supplied energy is considered. In energy calculations, renewable electricity sourced from nearby or community-scale installations, district heating and cooling system, is treated as supplied energy but distinguished from grid electricity through differing PEFs to account for the benefits of such supply (EPBD Annex I³).

The advantage of using the building site boundary is that it aligns with energy metering practices and avoids complications arising from on-site renewable production.

Table 2.1 summarises the contribution of different energy sources to an increase in the total annual primary energy indicator.



Table 2.1: Contributions of different energy sources to a rise in the total annual primary energy indicator.

Energy source	Contribution to rise in the total annual primary energy
Grid electricity	✔ Yes
Nearby/community electricity	✔ Yes
Fossil fuels (gas, oil)	✔ Yes
District heating/cooling	✔ Yes
Solar PV (self-used)	✘ No
Solar PV (exported)	✘ No (contribution to decrease)
Ambient energy (heat pumps)	✘ No
Geothermal energy for heat pumps	✘ No

The implications of applying these approaches to the energy performance indicators are:

- Ambient energy (e.g., heat pumps) and on-site renewable energy like solar power are excluded from total primary energy calculations or counted with a PEF equal to zero. This is to avoid penalising renewable energy technologies by artificially inflating primary energy use.
- The calculation method should ensure that only delivered energy is counted in the primary energy calculation, while on-site renewable energy is encouraged without penalising the energy performance indicator.

2.3.2 Operational CO₂ calculation

For the purposes of calculating the related indicator, **operational CO₂ emissions** are derived from delivered energy, as in the primary energy calculation. The sole differentiating factor is the specific primary energy factors and CO₂ emission coefficients used [8].

To calculate operational carbon emissions, it is necessary to consider:

1. Energy modelling:
 - Estimate energy consumption for heating, cooling, lighting, appliances and ventilation.
 - Account for seasonal variations and occupancy patterns.
2. Emission factors:
 - Calculate emissions using local grid emission factors for electricity and direct fuel use.
 - Include both site energy use and source energy factors for a comprehensive assessment.



3. Monitoring (desirable):

- Incorporate smart meters to track real-time energy consumption.

A CO₂ coefficient is applied to each energy source to calculate emissions [8]:

$$EPCO_2 = [\sum(E_{del,i} \cdot K_{del,i}) - \sum(E_{exp,i} \cdot K_{exp,tot,i})] / A_{net}$$

Where:

- $E_{del,i}$ = delivered energy for energy carrier i [kWh/y].
- $K_{del,i}$ = CO₂ emission coefficient per the delivered energy source i [gCO₂/kWh].
- $E_{exp,i}$ = exported energy for exported energy carrier j [kWh/y].
- $K_{exp,j}$ = CO₂ emission coefficient per the exported energy source j [gCO₂/kWh].
- A_{net} = net floor area [m²].

This ensures a comparison between different energy sources, considering both energy efficiency and emissions.

The key points to consider for operational CO₂ emissions are:

1. Using the total primary energy indicator based on delivered energy only, excluding on-site renewable energy from primary energy calculations or considering PEF equal to zero when counting it in the calculation.
2. Using operational CO₂ indicators alongside primary energy to better reflect environmental impact.
3. Using the compensation mechanism to reduce GHG emissions when the renewable energy generated on-site exceeds the energy with carbon content consumed. This surplus contribution is then deducted as exported energy.

2.3.3 Life-cycle GWP calculation (for new buildings)

For new buildings, Article 7^o of the EPBD requires Member States to calculate the life-cycle GWP and to disclose it in EPCs from the following dates:

- From 1 January 2028 for all new buildings with a usable floor area greater than 1,000 m²
- From 1 January 2030 for all new buildings.

This requirement is not directly linked to the definition of ZEBs, but rather to the disclosure of GWP in EPCs. Nevertheless, it follows that all newly constructed ZEBs will also be subject to this disclosure. Moreover, Article 7^o of the Directive requires Member States to draw up national roadmaps by 1 January 2027 for the introduction of limit values on the life-cycle GWP of all new buildings, including newly constructed ZEBs.

According to Annex III of the EPBD, to determine the life-cycle GWP of new buildings, the total GWP is reported as a numerical value for each stage of the building's life cycle. This value is expressed in kgCO₂ equivalent per square metre of useful floor area and is calculated over a reference period of 50 years.

The selection of data, definition of scenarios and calculation process must follow the methodology outlined in EN 15978:2011 [7] and any future updates to relevant sustainability standards.



If a national calculation tool or method is available – or mandated for regulatory disclosures or building permits – it may be used for compliance. Alternative calculation tools can also be employed, provided they meet the methodological minimum requirements set by the Level(s) framework.¹ Additionally, whenever possible, data on specific construction products should be sourced from assessments carried out under Regulation (EU) No. 2024/3110 [11]. Such assessments are typically documented through environmental product declarations (EPDs), which provide standardised, third-party verified life-cycle environmental information on construction products and are the primary means of implementing the Construction Products Regulation requirements for environmental performance.

A possible comprehensive methodology to quantify both embodied and operational carbon over the entire lifespan of a building is the life-cycle assessment. Whole-life carbon represents a carbon balance that takes into account both emissions linked to operational carbon, determined by energy requirements for heating, cooling, lighting and domestic hot water, and embodied carbon emissions, calculated by considering all stages of the building's life cycle [12].

Life-cycle assessment includes:

- Material production and construction: assessing emissions from raw material extraction, processing and on-site construction activities.
- Operational phase: estimating emissions from heating, cooling, lighting and other energy demands, factoring in renewable energy contributions.
- End-of-life stage: considering emissions from demolition, waste processing and recycling.

To calculate the embodied carbon emissions specifically, it is necessary to consider [12]:

1. Material inventory:

- Create a detailed inventory of all construction materials, including concrete, steel, insulation and finishes.
- Use EPDs to obtain emission factors for each material. Emission factors can be taken either from default data (e.g., generic material databases included in life-cycle assessment software) or from specific data provided by EPDs for the actual products used in the building.

2. Life-cycle stages:

- Include emissions from raw material extraction, manufacturing, transportation, construction, maintenance and end-of-life processes.

By integrating life-cycle assessment into the design process, stakeholders (for example, but not limited to, associations of construction companies and professionals) can identify carbon-intensive materials and prioritise low-carbon alternatives, such as recycled steel, low-carbon concrete or bio-based materials. Additionally, strategies like modular construction and design for disassembly can further reduce embodied carbon.

¹ Level(s). European framework for sustainable buildings.
https://environment.ec.europa.eu/topics/circular-economy/levels_en



2.4 Difference between new and existing buildings

To achieve ZEBs, the EPBD establishes specific targets with distinct requirements for new and existing buildings, also depending on different building types and categories (single-family houses, apartment blocks, offices, educational buildings, hospitals, and so on).

All **new buildings** must be zero-emission by 2030, with public buildings required to comply by 2028. This entails that new constructions must have very low energy consumption, which should be fully covered by energy from renewable sources generated on-site or nearby.

They must meet high energy efficiency standards, incorporating renewable energy sources (such as solar panels, heat pumps, etc.) alongside smart energy management systems to eliminate on-site carbon emissions from fossil fuels. Strategies like high-performance insulation, airtight construction and passive design strategies further contribute to minimising energy demand.

The **existing building stock** must reach zero emissions by 2050 and presents several challenges. Intermediate targets include a 16% reduction in primary energy use in residential buildings by 2030 and up to 22% by 2035, compared to 2020 levels. Non-residential buildings must also improve energy performance, with the worst-performing 16% being renovated by 2030 and 26% by 2033.

Transitioning existing buildings to zero emissions is complex, requiring large-scale renovation efforts with significant financial and logistical challenges. One of the primary difficulties is the high cost and complexity of deep renovations. Improving older buildings' energy performance often requires extensive renovation, including improved insulation, replacement of outdated heating and cooling systems, installation of renewable energy sources and enhanced ventilation strategies.

Many existing buildings, particularly older ones, have structural limitations that make such renovations difficult or even technically unfeasible without major reconstruction. According to Article 17(11) [1], if the transformation into a ZEB is not technically or economically feasible, a minimum 60% reduction in primary energy use is required. Member States must also promote large-scale renovation programmes, targeting the worst-performing buildings, to achieve a 30% overall reduction in primary energy use.

Historical and protected buildings face specific regulatory and architectural constraints that may limit the extent of permitted modifications. They can be exempted from the energy requirements (Article 6 and Article 9 of the EPBD).

Also, in urban areas, the integration of renewable energy sources can be restricted by space limitations, shading or grid constraints. Natural obstructions in rural areas, as well as unfavourable climatic conditions, can further impact the efficiency of renewable energy systems.



Financing remains a major barrier, as high upfront costs and long payback periods deter property owners, particularly in the residential sector, despite available subsidies and incentives. Additionally, shortages of skilled labour and energy-efficient materials present further challenges as demand increases.

Behavioural and awareness factors also play a role, as many building owners lack awareness of deep renovation benefits or are discouraged by perceived inconvenience. Additionally, the complexity of regulatory frameworks across different EU Member States can create uncertainty, slowing down the adoption of renovation measures.

Table 2.2 below highlights the distinct challenges for new and existing buildings in achieving zero-emission status, underlining the need for tailored policies, financial mechanisms and technological solutions to meet the EPBD goals.

Table 2.2: Key points and differences between new and existing buildings for achieving ZEBs

Key aspect	New buildings	Existing buildings
Compliance deadline	2030 (2028 for public buildings)	2050 (intermediate targets: 2030, 2035)
Energy performance	Extremely low energy consumption	Energy use reduction targets (16% by 2030, 22% by 2035)
Renewable energy	Fully powered by on-site or nearby renewable sources	Gradual integration of renewable sources
Global warming potential	Calculated and disclosed in the EPC for all new buildings	For all existing buildings that achieve class A+
Technical challenges	Design optimisation, material selection, integration of new technologies	Structural limitations, retrofit feasibility, compatibility with existing conditions, historical constraints
Financial challenges	Higher initial investment but lower operational costs	High renovation costs, long payback periods, financial barriers
Regulatory barriers	Stricter building codes and standards	Variability in regulations, protected building restrictions
Key strategies	High-performance insulation, airtight construction, highly efficient plant systems, integration with renewable energy production systems, smart energy systems	Deep renovation, financial incentives, workforce training, innovative solutions

Overcoming these challenges to reach the EPBD targets requires stronger policy enforcement, financial support such as grants or low-interest loans, workforce training and innovative retrofit solutions (e.g., smart energy systems, district-based renewable energy strategies).



A comprehensive ZEB framework must recognise the distinct challenges and requirements associated with both new and existing buildings. For new buildings, the priority is achieving zero emissions through advanced design and construction techniques, ensuring energy needs are met entirely by on-site or nearby renewable sources. Existing buildings, however, require a flexible approach that accounts for varying energy efficiency baselines, different building typologies, and specific technical and financial constraints.

Achieving these targets requires adaptable and tailored strategies that account for different building types – residential, commercial, industrial and public – each with unique energy usage patterns and occupancy behaviours. The ZEB standard must incorporate these variables, setting clear and adaptable energy performance metrics to ensure all building types contribute effectively to the EU's climate neutrality goals. Coordinated efforts are essential to enhance energy efficiency, expand renewable integration and implement sustainable building practices.

2.5 Building energy flexibility

The EPBD, in Article 7 and Recital 23, requires a ZEB to offer the capacity to react to external signals and adapt its energy use, generation and storage, where economically and technically feasible. The Directive provides that buildings can contribute to demand-side flexibility, for instance, through demand management, electrical storage, thermal storage and distributed renewable generation to support a more reliable, sustainable and efficient energy system.

These requirements are directly related to the concept of energy flexibility of buildings, that is, the ability to manage buildings' energy demand and generation according to local climate conditions, user needs and grid requirements. This allows for demand-side management/ load control and demand response based on the requirements of the surrounding grids [13]. Building energy flexibility includes all flexible resources in a building, including building energy systems and the building itself (e.g., building envelope, HVAC systems, appliances, electric vehicles) [14]. It can be achieved both on the supply side and the demand side.

On the **supply side**, on-site energy generation (e.g., PV, wind turbines and solar thermal) is deployed to decrease the building's net load imported from the utility grid. The flexibility of the building energy system operation of a ZEB can be enhanced by integrating different technologies. For instance, integrating building energy systems and energy storage systems – both electrical (e.g., batteries) and thermal (e.g., thermal energy storage, building thermal mass, and phase change wallboards/walls) – can improve operational flexibility via optimised charging and discharging. A ZEB should be able to store excess energy produced on-site, or to store energy from the grid when cheaper energy is available, when energy with a higher carbon-free share is available or when the grid requires energy to be stored. It should also be able to dynamically adjust the exported quota of the renewable energy generated on-site to support the electricity grid to cope with demand. Supply-side flexibility can also be enhanced by employing technologies such as power-to-hydrogen in building energy systems.



A ZEB should have technical building systems with the capacity to communicate with the grid and to modify its grid-related energy demand accordingly. On the **demand side**, this can be enhanced by using various demand-management measures to shift, reduce or moderate some building loads, such as HVAC, electric appliances and electric vehicles. The technical building systems should have system-integrated control and management tools, such as building automation and control systems as required by Article 13 of the EPBD, energy management systems, sub-meters and dedicated measurement devices.

Among flexible loads, and particularly suitable for residential buildings, HVAC systems can provide demand flexibility for utility grids by resetting temperature set-points, reducing electric peak load; by pre-cooling/pre-heating, shifting electric peak load.

In general, flexible loads have different flexibility capabilities, as summarised in Table 2.3. Thermostatically controlled loads (HVAC systems and refrigerators) can be shed, shifted and modulated. Lighting loads can be shed and modulated, while wet appliances (dishwashers, washing machines and clothes dryers) can only be shifted.

Table 2.3: Characteristics of different flexible loads in residential buildings. Source: [14]

Category	Category	Category	Operation characteristics			Energy consumption changes	Time property	Weather property
			Running mode	Usage frequency	Seasonal features			
Compliance deadline	HVAC	shift, and modulate	Intermittently	Almost every day in winter and summer	Various operation modes in winter and summer	Increasing, decreasing, or remaining constant	Dependent	Dependent
	Electric water heaters	shift, and modulate	Intermittently	Running all day	Various temperature settings and standby heat losses	Increasing, decreasing, or remaining constant	Dependent	Dependent
	Refrigerators	shift, and modulate	Intermittently	Running all day	No obvious seasonal differences	Increasing, decreasing, or remaining constant	Dependent	Dependent



Shifting loads	Dishwashers	Shift	Finite cycle with sequential processing		No obvious seasonal differences	Remaining constant	Dependent	Independent
	Washing machines	Shift	Finite cycle with sequential processing	Depending on occupants; different on weekdays, weekends, and in different seasons	Various usage frequencies in different seasons	Remaining constant	Dependent	Independent
	Clothes dryers	Shift	Finite cycle with sequential processing	Depending on occupants; different on weekdays, weekends, and in different seasons	Various usage frequencies in different seasons	Remaining constant	Dependent	Independent
Shedding loads	Lighting	Shed and modulate	Continuously	Used every day	No obvious seasonal differences	Decreasing	Dependent	Independent

Electric vehicles can support building energy flexibility on both supply and demand sides. On the supply-side, through a bi-directional electric charger, they can act as batteries, storing energy produced on-site, storing energy from the grid or exporting electricity to the grid to temporarily support it. On the demand side, loads can be shifted, for example by charging when there is excess renewable energy available or avoiding peak times.

The capacity of a ZEB to react to grid signals can be assessed through a smart readiness indicator or by adopting a KPI such as the Building Energy Flexibility Index (BEFI) [15], defined as:

$$BEFI(t,\Delta t) = \frac{\int_{t_{start}}^{t_{start} + \Delta t} P_{pref}(t) dt - \int_{t_{start}}^{t_{start} + \Delta t} P_{flex}(t) dt}{\Delta t}$$

Where: $P_{pref}(t)$ is the power demand at time t of the baseline scenario; $P_{flex}(t)$ is the power demand at time t of the flexible building; t_{start} is the start timestamp of the peak period; Δt is the peak period duration.



INTERACTIONS AND INFERENCES OF THE ZEB CONCEPT WITH OTHER POLICY INSTRUMENTS

The EPBD introduces ZEBs as the central reference for the decarbonisation of the European building stock. The ZEB concept is more than a technical definition – it is a strategic benchmark and policy anchor for the entire EPBD framework. It connects long-term climate neutrality targets with national policy mechanisms and building-level instruments. ZEB becomes the reference target for new buildings (public by 2028; all new buildings by 2030) and for the 2050 building stock ambition. This transformation demands systemic alignment between the ZEB definition and four key policy tools:

- National building renovation plans (NBRPs) – the national-level strategic roadmaps.
- Minimum energy performance standards (MEPS) and national trajectories – the regulatory enforcement instruments.
- Renovation passports – the operational, building-level planning tools.
- EPCs – the performance monitoring and communication mechanism.

Together, these instruments form a multi-layered architecture:

ZEBs provide the target → NBRPs chart the path → MEPS and national trajectories enforce progress → renovation passports guide individual actions → EPCs track and communicate results.



This chapter analyses the interactions and inferences between ZEBs and each of these instruments, showing how a coherent, data-driven system can ensure successful EPBD implementation and the achievement of a fully decarbonised building stock by 2050.

3.1 NBRP: Strategic roadmaps toward decarbonisation

Policy role and framework

Under **Article 3** and **Annex II** of the EPBD, each Member State must prepare a national building renovation plan. These plans replace and strengthen the previous long-term renovation strategies, creating a unified framework for national renovation pathways consistent with ZEB objectives. Each NBRP must:

- Establish **quantitative national targets** for reducing operational GHG emissions and primary energy use.
- Include **ZEB-related thresholds** as defined in Article 11.
- Outline **measures to phase out fossil fuels** in heating and cooling.
- Define **financial and technical mechanisms** to support ZEB-compliant renovations.
- Include **monitoring and reporting cycles** every five years, assessing progress toward ZEB alignment.

Interaction with the ZEB concept

ZEBs constitute both the **reference and the objective** of NBRPs. The ZEB definition provides the **technical anchor** (GHG and primary energy thresholds), while NBRPs translate these standards into **national trajectories**. The interaction is twofold:

1. **Top-down:** The ZEB benchmark informs the design of national targets and thresholds.
2. **Bottom-up:** National progress reports feed into the EU's evaluation of progress toward a zero-emission building stock.

The NBRP translates the EU-level ZEB target into national implementation plans, ensuring that every measure – financial, regulatory and educational – contributes coherently to achieving a zero-emission building stock by 2050.

Inferences and systemic implications

- **Strategic coherence:** Aligning NBRPs with the ZEB framework ensures that planning, investment and skills policies are all directed toward a single decarbonisation target.
- **Data feedback:** NBRPs serve as national-level monitoring mechanisms for achieving ZEBs, integrating data from EPC registries and MEPS compliance reporting.
- **Governance continuity:** The five-year update cycle facilitates iterative learning, allowing adjustments in response to technological, economic or societal changes.
- **Cross-instrument synergy:** By embedding ZEB definitions, NBRPs set the parameters for MEPS thresholds, guide the development of building renovation passports and define benchmarks for EPC class equivalence.

Inference: NBRPs are the strategic roadmaps that operationalise ZEB objectives at the national level, making the long-term target measurable and accountable.



3.2 MEPS and national trajectories: The regulatory delivery ladder

Policy role and framework

Article 9 introduces the regulatory instruments designed to ensure that existing buildings, both non-residential and residential, are progressively upgraded to meet ZEB levels. **Minimum energy performance standards and national trajectories translate long-term goals into mandatory compliance obligations.** Member States must:

- **For non-residential buildings:** define energy performance thresholds to identify the worst-performing 16% and 26% of non-residential buildings, establish minimum energy performance standards ensuring that all non-residential buildings fall below the 16% threshold from 2030 and below the 26% threshold from 2033.
- **For residential buildings:** establish by 2026 a renovation trajectory for residential buildings to cut average primary energy use by 16% by 2030 and 20–22% by 2035, and continue reducing it through to 2050.

Interaction with the ZEB concept

MEPS and national trajectories are designed to gradually transform the building stock into ZEBs by 2050. Key functions include:

- Prioritising upgrades for the worst-performing buildings, driving significant reductions in energy use and emissions.
- Defining renovation trajectories that ensure continuous progress, with energy reductions measured every five years.
- Providing clear thresholds that guide gradual compliance, enabling a smooth transition toward zero-emission standards without disruptive changes.

Compliance mechanisms (e.g., energy performance certificates) allow monitoring of progress, ensuring that renovations and improvements contribute to measurable reductions in energy use and emissions.

ZEBs define the **endpoint** and **performance ceiling** for MEPS and trajectories. According to the Directive:

- The total primary energy use for ZEBs must be **at least 10% below** the previous nZEB limits (as of 28 May 2024).
- Operational GHG emissions must not exceed **NBRP-defined limits**, ensuring national consistency.

MEPS and national trajectories must ensure **convergence with ZEBs** over time. Each MEPS and trajectory milestone represents a regulatory “step” toward the ZEB target, giving the transition a clear, quantitative endpoint and preventing fragmented or short-term approaches.



Inferences and systemic implications

- **Regulatory integration:** MEPS and trajectories rely on NBRP data (stock characterisation, benchmarks) and feed compliance results back into EPC registries.
- **Market transformation:** By enforcing staged upgrades, MEPS and national trajectories drive demand for ZEB-ready technologies, skills and materials.
- **Socioeconomic synergy:** MEPS and trajectories support the “Renovation Wave” by providing a predictable regulatory framework for investment and financing.
- **Equity and just transition:** The integration of MEPS and trajectories with NBRP policies allows Member States to design support mechanisms for vulnerable households affected by mandatory renovation obligations.

Inference: MEPS and trajectories operationalise the ZEB vision through binding, stepwise requirements – the regulatory ladder of the zero-emission transition.

3.3 Renovation passports: The building-level planning tool

Policy role and framework

Renovation passports, set out in **Article 12** and **Annex VIII**, are **individualised** instruments designed to guide property owners through the renovation process. Each passport provides:

- A **building-specific renovation roadmap**.
- **Phased actions** leading progressively toward ZEB-level performance.
- Estimates of **energy savings, GHG reductions** and costs for each stage.

They are developed based on **building data, EPC assessments** and **national methodologies** aligned with NBRP strategies.

Interaction with the ZEB concept

The ZEB definition functions as the end-state benchmark within the passport. Each step in the renovation passport roadmap is designed to ensure that, upon completion, the building reaches or closely approaches ZEB status. Passports directly link individual building actions to national and EU targets, translating abstract policy goals into tangible, actionable renovation pathways. They also support MEPS compliance, enabling owners to anticipate future obligations and plan investments accordingly.

Inferences and systemic implications

- **Operational linkage:** Renovation passports are the micro-level instruments translating NBRP, MEPS and national trajectory requirements into individual action.
- **Data synergy:** Information collected through renovation passports enriches EPC registries and feeds back into NBRP monitoring systems.



- **Behavioural and financial alignment:** Renovation passports empower building owners to make informed, stepwise investments consistent with the trajectory toward ZEBs, increasing the feasibility of deep renovations.
- **Long-term continuity:** By linking each building's evolution to the ZEB endpoint, renovation passports ensure that short-term interventions do not lock in suboptimal performance.

Inference: Renovation passports convert the ZEB target into owner-level, time-sequenced action plans, closing the loop between policy planning and practical renovation.

3.4 EPCs: The monitoring/signalling instrument

Policy role and framework

Under **Article 19**, EPCs remain the principal **information, labelling and compliance verification** tools in the EPBD. They provide standardised indicators of building performance, forming the **data backbone** for national and EU monitoring frameworks. Key innovations in the recast directive include:

- Reclassification of energy performance scales so that **Class A = ZEB**.
- Optional introduction of **Class A+** for buildings performing **≥20% better than ZEB** thresholds and producing **net-positive on-site renewable energy**.
- Mandatory inclusion of **ZEB-relevant indicators**: primary and final energy use, on-site renewable contribution, operational GHGs, and, for newly constructed or renovated to A+ class ZEBs, life-cycle GWP.

Interaction with the ZEB concept

- The ZEB standard redefines the **top of the EPC scale**, turning the certificate from a static label into a **dynamic policy instrument**.
- ZEB indicators define **measurement and reporting metrics** within EPCs.
- EPC data validates **MEPS and national trajectory compliance** and tracks **progress toward NBRP targets**.
- Through digital EPC registries, Member States can monitor building stock evolution and identify gaps relative to ZEB pathways.

Inferences and Systemic implications

- **Transparency and accountability:** EPCs make ZEB alignment visible and comparable, supporting market valuation and consumer awareness.
- **Monitoring integration:** EPC registries aggregate data from MEPS and national trajectory enforcement and renovation passport implementation, creating an interoperable system for national reporting under the NBRP.
- **Policy feedback:** Aggregated EPC data informs the revision of national ZEB definitions and thresholds, ensuring adaptive governance.
- **Market signalling:** EPCs with ZEB equivalence (Class A) create a positive market incentive, reinforcing the link between regulatory compliance and property value.



Inference: EPCs are the communication and verification interface of the ZEB ecosystem, transforming technical performance into measurable, reportable policy evidence.

3.5 Integrated interpretation

Across all instruments, the ZEB concept functions as the strategic integrator of the EPBD's regulatory architecture, as represented in Table 3.1 and Figure 3.1.

Table 3.1: Summary of the interactions and inferences between ZEBs and the other policy instruments

Policy instrument	Functional level	Primary function	Interaction with ZEB	Policy inference
NBRP	National strategy	Strategic planning, financing and monitoring	Defines national trajectories using ZEB thresholds	Aligns long-term planning and resources with the ZEB target
MEPS and national trajectories	Regulatory enforcement	Progressive mandatory standards	Use ZEB as an endpoint for performance thresholds	Create binding milestones toward ZEB compliance
Renovation passport	Building-level execution	Owner-based renovation plans	Designs stepwise paths to reach ZEB	Converts strategy into actionable renovations
EPC	Monitoring and communication	Data reporting, labelling, verification, first renovation recommendations	Class A = ZEB, includes ZEB indicators	Tracks, signals and validates progress, identifies first renovation actions

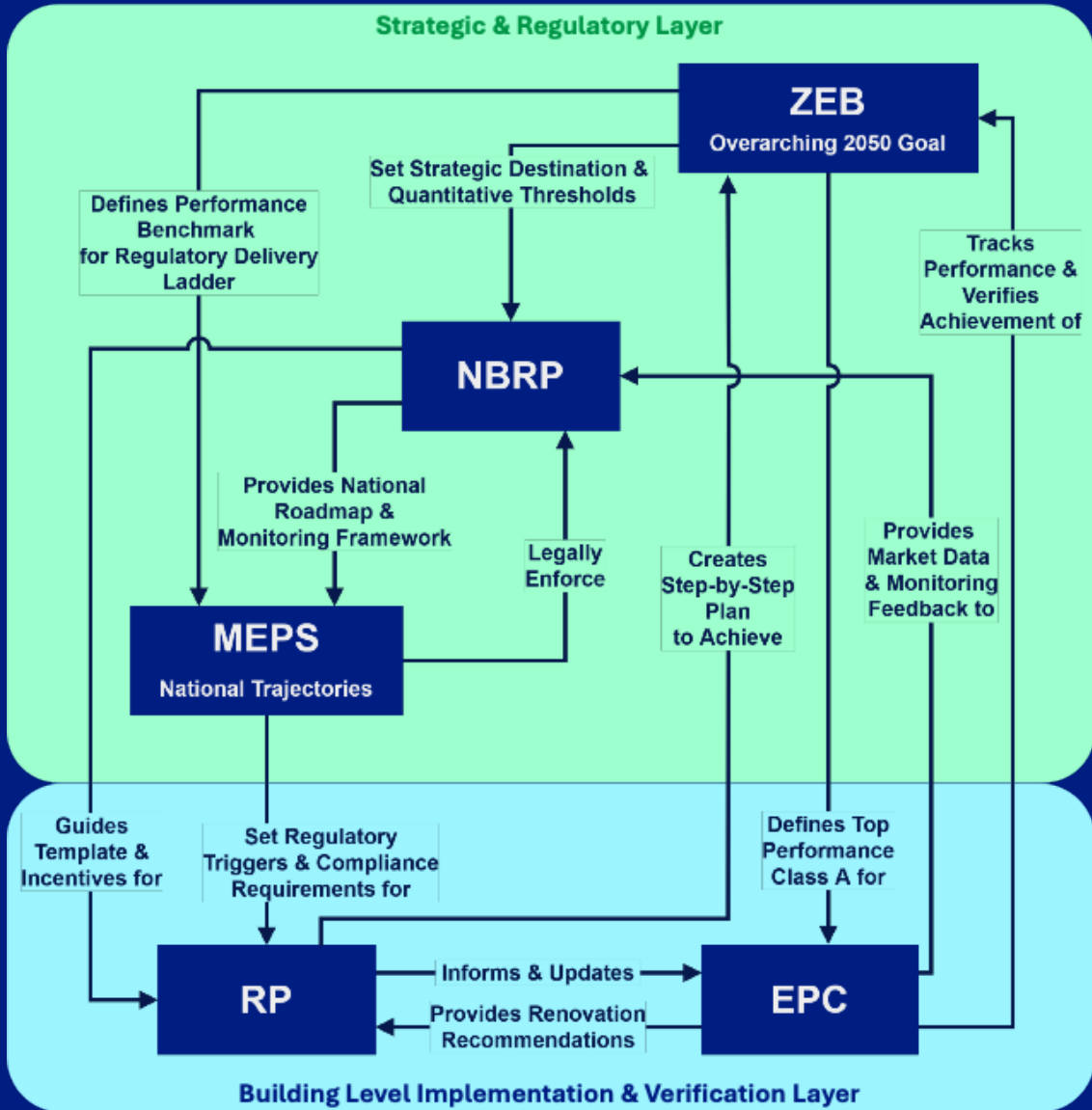


Figure 3.1: Summary diagram of inferences and relationships between ZEB and other policy instruments.



CONCLUSIONS, KEY CONSIDERATIONS AND RECOMMENDATIONS

The introduction of the ZEB concept in the EPBD establishes a new paradigm for the decarbonisation of the European building stock. By defining a harmonised endpoint for energy and emission performance, the ZEB framework connects technical, regulatory and financial instruments into a single integrated trajectory. This report provides guidance and suggestions for the development of the ZEB definition and focuses on the interplay between the ZEB concept and complementary policy tools – namely, the NBRPs, MEPS, national trajectories, renovation passports and EPCs.

The following conclusions and recommendations summarise the main findings and identify the next steps for implementation at legislative, institutional and technical levels.

4.1 Legislative and regulatory framework

- The ZEB definition (Articles 2 and 11 of the EPBD) introduces measurable indicators – total annual primary energy, operational CO₂ emissions and life-cycle GWP – that must be integrated into national calculation and certification frameworks.
- The transition from nZEB to ZEB requires revising national reference buildings, cost-optimal levels and primary energy factors.
- The ZEB status may depend not only on the building's intrinsic efficiency but also on the carbon intensity of supplied energy (Article 11②) – particularly electricity and district heating/cooling systems.
- Regulatory frameworks should explicitly address the interdependence between building-level compliance and energy network decarbonisation, ensuring that grids can deliver carbon-free energy consistent with ZEB requirements.



- Coordination with building codes and urban planning laws should guarantee that new developments are designed within ZEB-compatible infrastructure ecosystems (e.g., renewable districts, energy communities).
- National transposition must remain consistent with related EU legislation: the Energy Efficiency Directive (2023/1791) and the Renewable Energy Directive (2018/2001, as amended).
- National frameworks can remain flexible enough to differentiate between new and existing buildings, ensuring feasibility and cost-effectiveness.
- Member States must update national standards to include both operational CO₂ and life-cycle GWP indicators.
- Member States must define clear boundaries for “on-site”, “nearby” and “off-site” renewable energy contributions.

4.2 Institutional and governance considerations

- Administrative fragmentation needs to be overcome through exchange networks and the development of administrative skills.
- Data governance and monitoring are critical: EPC registries, building energy performance databases, renovation passports and financial databases need interoperability.
- Member States should develop digital, interoperable platforms linking EPCs, renovation passports and incentive schemes for transparent monitoring.

4.3 Technical and implementation aspects

- In energy performance, a ZEB builds on the nZEB standard, defined at the national level, which needs to be improved by at least 10%.
- The effective implementation of the ZEB concept depends on the integration of renewable energy sources, efficient technologies and energy flexibility systems within the building and its connected energy networks.
- The boundaries for assessing on-site, nearby and off-site renewable energy must be harmonised to ensure consistency in national calculations.
- Flexibility indicators (e.g., smart readiness indicator, Building Energy Flexibility Index) should be included in ZEB assessment frameworks to capture the dynamic interaction between buildings and energy systems.
- The transition from nZEB to ZEB requires the evolution of calculation methodologies, including possibly life-cycle carbon assessment and data exchange through digital building logbooks.
- Member States should promote the integration of flexibility metrics within building energy performance assessments and EPCs to incentivise demand-side response and smart operation.
- The ZEB framework may distinguish between new and existing buildings, with tailored implementation pathways.



- For new buildings, focus on advanced design and full integration of on-site or nearby renewables.
- For existing buildings, adopt phased renovation strategies through renovation passports, enabling deep renovation toward ZEB standards by 2050 while preventing lock-in effects and recognising technical and financial constraints.

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ANNEX A

CURRENT STATUS

OF NZEBs IN

THE PRIORITY

COUNTRIES

This annex outlines the implementation of nearly zero-energy buildings (nZEBs) in the priority countries (Bulgaria, Hungary and Ukraine). The nZEB regulations in Bulgaria, Hungary and Ukraine are all based on the Energy Performance of Buildings Directive, but each country has developed specific requirements based on its own national regulations and local characteristics.

A1 Current status of nZEBs in Bulgaria

In Bulgaria, in accordance with EU Directive 2010/31/EU [16], the requirements for nZEBs are defined by Order No RD-02-20-3 of November 9, 2022 [17] and its revisions (SG No. 3 of January 10, 2023, and SG No. 18 of March 1, 2024). These requirements apply to all new buildings. To be classified as an nZEB, a building must simultaneously meet the following:

1. **The primary energy consumption (EP)** of the building must correspond to Class A on the building energy performance certification scale. Table A.1 presents the maximum values for EP (EP_{max}) for Class A buildings; EP accounts for the energy performance parameters of the building's structural elements, such as walls, roofs and windows, as well as the efficiency of its technical systems (heating, ventilation, cooling and other technical building systems).
2. **At least 55% of the energy consumed** (supplied) for heating, cooling, ventilation, domestic hot water and lighting must come from renewable sources located on-site or nearby the building. However, if the building is connected to efficient district heating systems, this requirement is reduced to 15%.



Table A.1: Maximum values for EP for class A for types of building categories in Bulgaria. Source: [17]

Building categories	EP MAX kWh/m2*
Residential buildings: multi-family single-family	<90 <83
Public service buildings – Administrative buildings (offices)	<134
Public service buildings – Buildings for education and science: • schools • universities • kindergartens and nurseries	<35 <85 <60
Public service buildings – Buildings in the field of health care: hospitals, medical facilities for outpatient care, medical centres	<135
Public service buildings – Buildings in the field of hospitality, catering and public catering	<165
Public service buildings – Commercial buildings (buildings for wholesale and retail trade service)	<275
Public service buildings – Sports buildings	<175
Public service buildings – Buildings in the field of culture and arts	<110

A2 Current Status of nZEBs in Hungary

In Hungary, specific requirements for nearly zero-energy buildings are outlined in Annex 2 of Decree 9/2023 (V.25) [18]. The main prescriptions for nZEB buildings regard:

1. Maximum specific heat loss coefficient values

The maximum specific heat loss coefficient values for nZEBs are based on the building's surface-to-volume ratio (A/V) and are shown in Table A.2. The formula ensures heat loss is minimised:

Table A.2 Maximum specific heat loss values for nZEBs in Hungary. Source: [18]

A	B
$A/V \leq 0.3$:	Maximum specific heat loss $0.14 \text{ W/m}^2\text{K}$
$0.3 < A/V \leq 1.3$	Maximum specific heat loss $0.071 + 0.23(A/V) \text{ W/m}^2\text{K}$
$A/V > 1.3$	Maximum specific heat loss $0.37 \text{ W/m}^2\text{K}$

The formula incorporates the A/V ratio, which is the ratio between the conditioned surface (A) and the conditioned volume (V) of the building. This ratio helps determine how much surface area is available for heat loss or gain compared to the volume of air that needs to be heated or cooled within the building.



2. Specific energy performance requirements

For residential and hospitality buildings, the annual primary energy use (energy from renewable and non-renewable sources) must not exceed 76 kWh/m² per year (excluding lighting demand). An exception applies when dynamic simulation is used, in which case the requirement is determined as for the other building types.

For buildings with functions other than residential and hospitality, the energy performance requirement is based on the reference building and its specified technology system. The requirement is 80% of the primary energy consumption from non-renewable sources for the reference building, which represents the average energy performance for similar buildings. nZEBs must use 20% less energy than the reference.

3. Specific carbon dioxide emission requirements

For residential and hospitality buildings, the specific carbon dioxide emission requirement (excluding lighting demand) is 20 kg/m² per year. If dynamic simulation is used, the requirement is determined as for the other building types.

For buildings with functions other than residential and accommodation, the requirement is 80% of the specific carbon dioxide emissions for the reference building.

A3 Current status of nZEBs in Ukraine

In Ukraine, Order No. 169 of July 11, 2018 [19] approved the methodology for determining building energy efficiency. It was registered on 16 July 2018, and updated by Orders No. 261 (October 27, 2020) [20] and No. 486 (June 11, 2023) [21]. For nZEBs, it is mandatory to comply with all of the following requirements, in accordance with Order No. 168 dated February 6, 2025 [22]:

- Energy efficiency class
- Indicator of primary energy consumption from non-renewable energy sources
- Shares of energy produced from renewable energy sources
- Thermal characteristics of the building envelope
- Air permeability of building
- Technical building engineering systems.

Energy efficiency class requirements

New nZEB buildings must meet energy efficiency class “A”. For reconstruction, nZEBs must meet energy efficiency class “B”. The energy efficiency class is determined through certification and using the indicator ΔEP (%), as shown in Table A.3. This represents the percentage difference between the total specific energy consumption for heating and cooling of the building and the limit value of specific energy consumption for heating and cooling. It is calculated using the formula:

$$\Delta EP = [(EP_{use} - EP_p) / EP_p] \times 100$$



Table A.3: Building energy efficiency class in Ukraine. Source: [19]

Building energy efficiency class	Δ_{EP} (%)
A	$\Delta_{EP} < -50$
B	$-50 \leq \Delta_{EP} < -20$

Requirements for the indicator of primary energy consumption from non-renewable energy sources

This parameter is the primary energy consumption for heating and cooling from non-renewable energy sources. It differs for new constructions and for reconstructions. The upper limits for nZEB buildings are shown in Table A.4 and Table A.5.

Table A.4: Primary energy consumption limits from non-renewable energy sources for new constructions in Ukraine. Source: [22]

Primary energy consumption limits for nZEBs (new constructions) [kWh/m ² or kWh/m ³]		
Type of building	Climate zone I	Climate zone II
Residential buildings		
from 1 to 3 floors	70	60
from 4 to 9 floors	50	41
from 10 to 16 floors	45	38
17 floors and more	40	35
Public buildings		
from 1 to 3 floors	$22 \wedge b_{ci} + 9$	$18 \wedge b_{ci} + 7$
from 4 to 9 floors	17	13
10 floors or more	15	12
Other types of public buildings		
Hotel buildings	$33 \wedge b_{ci} + 30$	$26 \wedge b_{ci} + 30$
Buildings for educational institutions	$34 \wedge b_{ci} + 12$	$29 \wedge b_{ci} + 12$
Buildings for preschool educational institutions	19	15
Buildings for healthcare institutions	17	13
Commercial buildings	$19 \wedge b_{ci} + 9$	$13 \wedge b_{ci} + 8$

Where $\wedge_{b_{ci}}$ is the coefficient of compactness of the building [m⁻¹]



Table A.5: Primary energy consumption limits from non-renewable energy sources for reconstructions in Ukraine. Source: [22].

Primary energy consumption limits for nZEBs (reconstructions) [kWh/m ² or kWh/m ³]		
Type of building	Climate zone I	Climate zone II
Residential buildings		
from 1 to 3 floors	117	99
from 4 to 9 floors	83	67
from 10 to 16 floors	73	63
17 floors or more	69	59
Public buildings		
from 1 to 3 floors	37 \wedge bci +15	31 \wedge bci +12
from 4 to 9 floors	29	22
10 floors or more	25	17
Other types of public buildings		
Hotel buildings	55 \wedge bci + 50	45 \wedge bci + 50
Buildings for educational institutions	55 \wedge bci +21	48 \wedge bci +21
Buildings for preschool educational institutions	31	26
Buildings for healthcare institutions	29	24
Commercial buildings	32 \wedge bci + 16	24 \wedge bci + 14

Where \wedge_{bci} is the coefficient of compactness of the building [m⁻¹]

Requirements for the shares of energy produced from renewable energy sources

The share of energy for heating and cooling from renewable sources must be at least 53% in climate zone I and 57% in climate zone II.

Requirements for thermal characteristics of the building envelope

The building envelope must have heat-insulating materials with thicknesses ranging from 100 mm to 400 mm, depending on the type of surface, with the thickest insulation for coatings bordering the outside air. However, these requirements do not apply to areas where heat-insulating materials with a thermal conductivity coefficient lower than 0.009 W/mK are used.

Requirements for the airtightness of the building envelope

The air permeability of enclosing structures should not exceed:

- 1.0 m³/m²·h for new construction
- 2.0 m³/m²·h for reconstruction



These limits ensure optimal energy efficiency in nearly zero-energy buildings. Air permeability has to be tested according to DSTU EN ISO 9972:2022 [22].

Requirements for technical building engineering systems

Class of technical equipment, automation, monitoring and management for nZEB buildings must meet the following requirements, according to DSTU EN 15232-1:2017 [25]:

- Class 'A'''

nZEB buildings must be equipped with devices that produce electrical and/or thermal energy from solar radiation, the area of which must be at least the minimum value specified in Table A.6.

Table A.6: Minimum area values of devices that produce electrical and/or thermal energy from solar radiation. Source: [24]

N s/p	Type of building	Minimum area value of devices that produce electrical and/or thermal energy
1	Residential buildings (number of storeys):	
	1 to 3	2
	4 to 9	$A_f \times 0.035$
	from 10 to 16	$A_f \times 0.022$
	17 and more	$A_f \times 0.4/N$
2	Public buildings (number of storeys):	
	1 to 3	4
	4 to 9	$A_f \times 0.04$
	10 or more	$A_f \times 0.45/N$
3	Separate types of public buildings:	
3.1	Hotel buildings	$A_f \times 0.3/N$
3.2	Buildings of educational institutions	$A_f \times 0.3/N$
3.3	Buildings of preschool education institutions	$A_f \times 0.1$
3.4	Buildings of health care institutions	$A_f \times 0.2/N$
3.5	Commercial buildings	$A_f \times 0.2/N$

Where A_f is the heated area of the building (m²) and N is the number of floors of the building.



nZEB buildings must be equipped with external sun protection devices, designed in accordance with the relevant provisions of DBN V.2.5–28:2018 “Natural and Artificial Lighting” [26], ensuring appropriate daylighting and solar control. Air exchange within the premises of nZEB is to be provided by mechanical supply and exhaust ventilation systems equipped with Class H1 exhaust air heat recovery units, in accordance with DBN B.2.6–67:2013 “Heating, Ventilation and Air Conditioning” [27], to remove excess heat, moisture, harmful substances, and to maintain suitable indoor microclimate conditions.

For ventilation systems with an external air volumetric flow rate below 1.39 m³/h and an annual operating time less than 2,000 hours, an operation duration of 2,000 hours per year shall be assumed for the purpose of determining the class of the heat recovery unit.

During design and for the calculation of energy consumption and efficiency indicators, the seasonal energy efficiency ratio (SEER) and seasonal coefficient of performance (SCOP) of heat pumps shall be used as specified in the manufacturer’s technical documentation. These requirements do not apply to ventilation and local exhaust systems serving sanitary, hygienic or hazardous areas where harmful or toxic substances may be present.

A3.1 Standards that can be adopted/developed

Ukraine adopted a set of standards on energy efficiency and energy management, harmonised with international regulations, specifically ISO 50001:2018, ISO 50002:2018, ISO 50003:2014, ISO 50004:2014, ISO 50006:2014, ISO 50015:2014 [28]. The basis of the standard framework is DBN V.2.6–31:2021 [29], which defines technical parameters for achieving energy efficiency of buildings, establishing requirements for energy efficiency indicators, and energy performance of building envelopes and technical building systems. DBN V.1.2–11 [30] provides the requirements for regulatory documents in the field of energy savings in the building sector. DSTU B V.2.2–21:2008 [31] is more focused on building energy audits. DSTU B V.2.6–35:2008 [32] allows the calculation of the energy efficiency of transparent or translucent structures [28].

A key standard for assessing the energy performance of buildings is EN ISO 52000–1:2017 [5], which was adopted in Ukraine by DSTU EN ISO 52000–1:2023 [33]. ISO 52000–1 establishes a systematic, comprehensive and modular framework for assessing the energy performance of new and existing buildings in a holistic manner. It applies to the assessment of a building’s overall energy consumption, by measurement or calculation, and to the calculation of energy performance in terms of primary energy or other energy-related metrics. It considers the specific possibilities and limitations for different applications, such as building design, new buildings “as built,” and existing buildings in the use and renovation phase.

ISO 52000–1 introduces a modular structure of standards for the energy performance of buildings (set of EPB standards) and provides a list of reference standards related to different aspects: overarching, building-related, and related to the technical building systems (TBS). The set of EPB standards can be used by regulators in the context of national or regional legal requirements: in this case, mandatory choices may be given at the national or regional level for specific applications. The set of EPB standards that can be adopted at the national level, following the already adopted ISO 52000–1, is shown in Table A.7.



Table A.7 – Set of EPB standards

Aspect – Description	Standard
Overarching – General; common terms; applications; building categories and building boundaries; aggregation of energy and energy carriers; building zoning; calculated energy performance; measured energy performance.	ISO 52000-1
Overarching – Ways to express energy performance	ISO 52003-1
Overarching – Building occupancy and operating conditions; inspections	ISO 17772-1
Overarching – External environment conditions	ISO 52010-1
Overarching – Economic calculations	EN 15459-1
Building – Building energy needs	ISO 52016-1
Building – Indoor conditions without systems	ISO 52017-1
Building – Ways to express energy performance	ISO 52018-1
Building – Heat transfer by transmission; internal heat gains	ISO 13789, ISO 13370, ISO 6946 ISO 10211, ISO 14683, ISO 10077-1, ISO 10077-2, ISO 12631
Building – Building dynamics (thermal mass)	ISO 13786
Building – Solar heat gains	ISO 52022-3 ISO 52022-1
TBS Heating, DHW – General; ways to express energy performance	EN 15316-1
TBS Heating – Maximum load and power	EN 12831-1
TBS Heating, Cooling – Emission and control	EN 15316-2
TBS Heating, Cooling, DHW – Distribution and control	EN 15316-3
TBS Heating, DHW – Storage and control	EN 15316-5
TBS Heating, DHW – Generation and control	EN 15316-4-1, EN 15316-4-2, EN 15316-4-3, EN 15316-4-4, EN 15316-4-5, EN 15316-4-8
TBS Heating, DHW – Measured energy performance	EN 15378-3
TBS Heating, DHW – Inspection	EN 15378-1
TBS Cooling – General; ways to express energy performance	EN 16798-9
TBS Cooling – Maximum load and power	ISO 52016-1
TBS Cooling – Storage and control	EN 16798-15
TBS Cooling – Generation and control	EN 16798-13, EN 15316-4-5
TBS Cooling, Ventilation, Humidification, Dehumidification – Inspection	EN 16798-17
TBS Ventilation, Humidification, Dehumidification – General; ways to express energy performance	EN 16798-3
TBS Ventilation – Emission and control	EN 16798-7
TBS Humidification, Dehumidification – Distribution and control, generation and control	EN 16798-5-1, EN 16798-5-2



TBS Humidification, Dehumidification – Emission and control, generation and control	EN 16798-5-1, EN 16798-5-2
TBS DHW – Needs, maximum load, and power	EN 12831-3
TBS Lighting – General, needs, ways to express energy performance, measured energy performance, inspection	EN 15193-1
TBS Building automation and control – General, emission and control, distribution and control, storage and control, generation and control	EN 15232-1
TBS Building automation and control – Inspection	EN 16946-1
TBS Building automation and control – BMS	EN 16947-1
TBS PV, wind... – Generation and control	EN 15316-4-3, EN 15316-4-4, EN 15316-4-5, EN 15316-4-10

EPBDwise

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