REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

Primary energy and operational CO_2 indicators calculation in revised EPBD

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Primary energy (PE) indicator is the main energy performance (EP) indicator in Energy Performance of Buildings Directive (EPBD). It is used for setting minimum requirements and in most Energy Performance Certificate (EPC) rating scale. The EPBD under revision has provided some important changes in the primary energy calculation having an impact both on indicators for Zero emission building/Nearly zero energy building (ZEB/NZEB) and EPC classes.

This document elucidates EPBD principles and provides examples of energy and operational CO_2 calculations for a NZEB reference building situated in three distinct European climates. While many articles on the EPBD employ vague terminology regarding 'primary energy,' the total primary energy is specified to denote the ZEB energy performance level, with primary energy factors (PEF) delineated for non-renewable, renewable, and total primary energy. This document clarifies the recommended methodology for calculating primary energy and operational CO_2 thresholds to facilitate national harmonised implementation.

Summary of key guidelines for primary energy calculation

The EPBD follows 'efficiency first' principle meaning that the total primary energy, including both renewable and non-renewable primary energy should be minimised. Transition to the total primary energy and operational greenhouse gas emissions are clearly expressed for ZEB while there is more freedom for EPC.

In buildings, calculating total primary energy can be challenging due to the utilization of freely available on-site ambient energy for technologies such as heat pumps, as well as the utilisation of on-site solar radiation for solar boilers or photovoltaic (PV) panels, which may not be fully accounted for. Applying the EPBD in accordance with the efficiency-first principle involves initially reducing energy consumption through efficiency measures and subsequently utilizing renewable energy sources to cover the remaining consumption. This document analyses how this fundamental principle can be applied in energy calculations and in establishing relevant primary energy indicators.

According to EPBD definitions, total primary energy should be calculated from delivered energy, which refers to the energy supplied through the assessment boundary. However, the EPBD does not explicitly define the assessment boundary, leading to various options and interpretations for primary energy calculation in national implementations.

In this document, it is proposed to calculate EP-values based on total primary energy and operational CO_2 from delivered energy to the building site. This approach ensures that on-site generated and self-used renewable electricity and ambient energy do not increase the EP-value, as they are not treated as delivered energy. Consequently, the calculation is based on the same energy flows for non-renewable, total primary energy, and operational CO_2, albeit with different factors. This principle aligns with the EPBD rationale of reducing energy consumption and increasing the use of energy from renewable sources, particularly through solar energy installations and heat pumps.

Two assessment boundary options are proposed, as illustrated in Figure 1 and 2, following the EN ISO 52000-1 building assessment boundary. These options are complemented either with an exclusion matrix or a building site boundary for primary energy calculation, both leading to the same result. Ambient energy and on-site generated renewable energy are not added to the total primary energy indicator, as the goal is to minimize total primary energy and operational CO_2 from the energy grids.

In addition to outlining the primary energy and operational CO_2 calculation procedure, this document discusses ZEB requirements, energy and operational CO_2 thresholds, and the coverage of total primary energy on an annual basis with renewable and carbon-free energy. Calculation examples for a NZEB reference building are provided for three European climates.

1 Table of Contents

1. Introduction

In principle, the EPBD follows the same energy definitions framework as utilized in directives like the Energy Efficiency Directive (EED) and Renewable Energy Directive (RED), with the shared objective of reducing total primary energy consumption and encouraging the use of renewable energy sources. However, applying the EPBD in the context of buildings presents challenges, particularly regarding the utilization of freely available on-site ambient energy for technologies such as heat pumps and solar panels. This raises the importance of adhering to the efficiency-first principle outlined in the EPBD, which prioritizes reducing energy consumption before utilizing renewable energy sources.

The application of this principle in energy calculations and the establishment of relevant primary energy indicators necessitates a thorough examination of the EPBD assessment boundary and key definitions, while also considering the principle's implications for accounting for the positive effects of renewable energy. For instance, determining whether on-site PV energy should be considered as delivered energy, and whether ambient energy should be included or excluded in the total primary energy indicator, requires careful analysis. Similarly, accounting for self-used and exported PV electricity when calculating total or non-renewable primary energy indicators is crucial.

Furthermore, while the EPBD introduces new requirements to cover ZEB total primary energy with renewable or carbon-free energy, as well as district heating/cooling, the calculation of these requirements warrants examination.

Additionally, while the primary energy indicator is supplemented with an operational CO_2 indicator, it is essential to note that the energy calculation remains fundamentally the same; only different factors are applied to calculate primary energy and operational CO_2 emissions from delivered energy values. The introduction of the operational CO_2 indicator serves as a new metric to be used alongside the total primary energy indicator for ZEBs, while other minimum requirements and the EPC rating scale will continue to be based on primary energy considerations.

2. EPBD ZEB requirements

Zero Emission Buildings are defined in EPBD Articles 2 (2), 7, and 11. ZEB requirements include as set in Article 11:

- ZEB cannot cause any on-site carbon emissions from fossil fuels (1).
- Maximum threshold for the energy demand of a ZEB shall be set with a view to achieving at least the cost-optimal levels (2). The maximum threshold for the energy demand of a ZEB shall be at least 10 % lower than the threshold for total primary energy use established for nearly zero-energy buildings (3).
- Maximum threshold for the operational greenhouse gas emissions of a ZEB shall be set (5).
- The total annual primary energy use of a new or renovated ZEB shall be covered, where technically and economically feasible, by (7):
    a) energy from renewable sources generated on-site or nearby, fulfilling the criteria laid down in Article 7 of Directive (EU) 2018/2001 (RED);
    b) energy from renewable sources provided from a renewable energy community within the meaning of Article 22 of Directive (EU) 2018/2001 (RED);
    c) energy from an efficient district heating and cooling system in accordance with Article 26(1) of Directive (EU) 2023/1791 (EED);
    d) energy from carbon free sources.
- ZEB shall offer the capacity to react to external signals and adapt its energy use, generation, or storage, where economically and technically feasible (1).

The EPBD does not explicitly define a threshold for energy demand, since the EPBD defines ‘energy needs’ and ‘energy use/energy consumption’, but not ‘energy demand’. Nevertheless, it stipulates that such a threshold should be at least 10% lower than the threshold for total primary energy for NZEBs. This requirement allows for the consideration of different energy indicators in addition to total primary energy when comparing to the total primary energy of NZEBs.

Furthermore, while the EPBD lacks clarity on the specification of energy demand thresholds, it clearly mandates the calculation of the total annual primary energy use for ZEBs. The subsequent analysis delves into how the calculation of total primary energy is specified within the EPBD.

3. Total primary energy calculation in revised EPBD

The EPBD includes main definitions and principles for setting an assessment boundary and calculating primary energy. The following definitions constitute the starting point for the primary energy indicator calculation in EPBD:

- Art 2 definition 53 '**assessment boundary**' means the boundary where the **delivered and exported energy are measured or calculated**;[1]
- Def 58 'energy use' means energy input to a technical building system providing an EPB-service intended to satisfy an energy need;
- Def 62 '**delivered energy**' means energy, expressed per energy carrier, **supplied** to the technical building systems **through the assessment boundary**, to satisfy the uses taken into account or to produce the exported energy;
- Def 63 '**exported energy**' means, expressed per energy carrier and per primary energy factor, the proportion of the renewable energy that is exported to the energy grid instead of being used on site for self-use or for other on-site uses;

Some more fundamental energy definitions are:

- Def 9 'primary energy' means energy from renewable and non-renewable sources which has not undergone any conversion or transformation process;
- Def 14 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic), and geothermal energy, osmotic energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas;[2]
- EED definition 4 'primary energy consumption' means gross available energy **excluding** international maritime bunkers, final non-energy consumption and **ambient energy**;
- RED definition 2 'ambient energy' means naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water;

In EPBD primary energy factor definitions (Art 2, 11-13) it is said that primary energy is calculated by multiplying the delivered energy and primary energy factor. Therefore, according to definition 62, the energy flows to be considered in PE indicator calculation are those supplied through the assessment boundary. If the assessment boundary is specified so that ambient energy and on-site photovoltaic are not supplied through the assessment boundary, they should not be considered in PE indicator calculation. However, a common building assessment boundary in EN ISO 52000-1 is specified so that both ambient energy, solar photovoltaic and solar thermal are supplied through the assessment boundary and should thus be added to primary energy which will increase the total primary energy indicator (EP-value). There are two options to avoid this situation where ambient and solar energy (promoted in EPBD) will increase the EP indicator value. Both options described in Sections 3.1 and 3.2 are in line with JRC (2023) ZEB zero balance proposal of the primary energy and the CO_2 emissions over a year, as well as with EED which excludes ambient energy in primary energy definition.

3.1 Building assessment boundary and specification of energy flows

An assessment boundary shown in Figure 1 separates the energy use (the demand side) from the energy supply consisting of on-site energy generation, delivered energy carriers from nearby and distant, and exported energy carriers. The self-use of on-site renewable electricity covers a part of energy use and thus reduces the amount of the delivered grid electricity. Nearby and community renewable electricity depend on technical and contractual arrangements, but in the energy

[1] Note that this may depend on national practices where energy meters are installed.
[2] The definition is identical to the definition from Directive (EU) 2023/2413 (amended RED)

calculation these can be treated as delivered energy carriers distinguished from grid electricity with different PEF. Fuels, both renewable and non-renewable, are treated as delivered energy with relevant PEF.

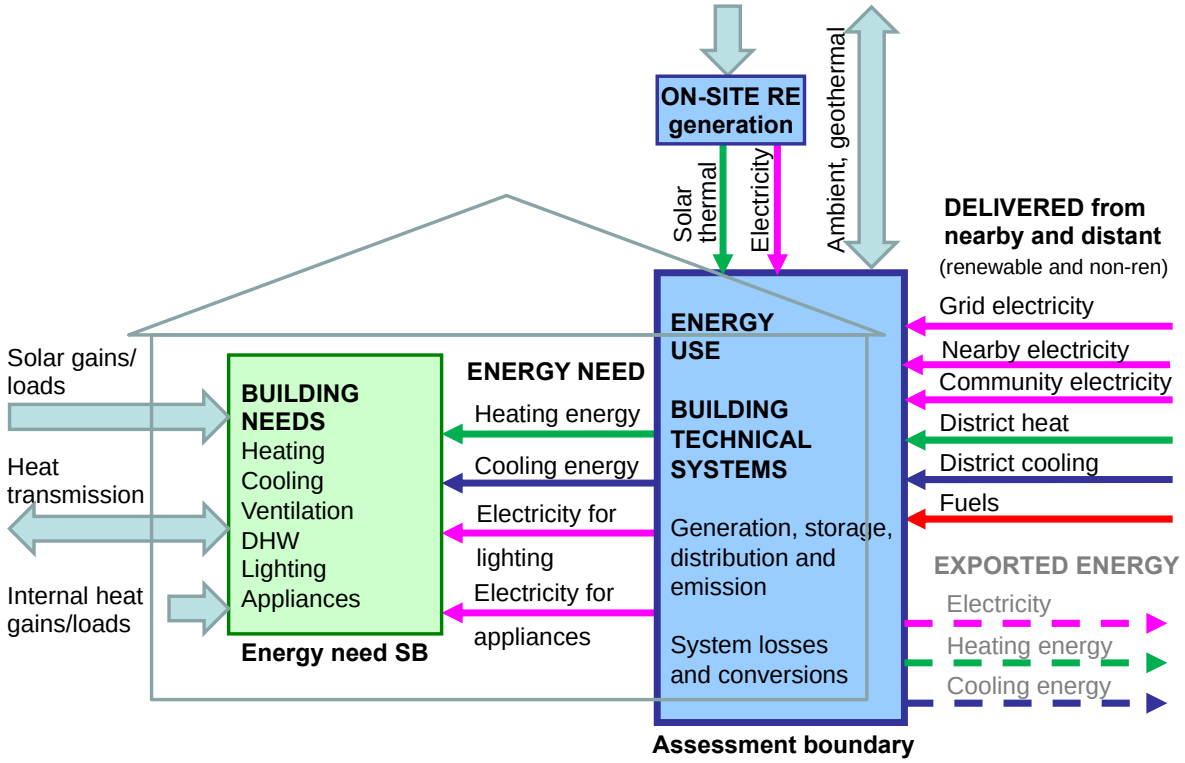


Figure 1. Assessment boundary definition (EN ISO 52000-1) that separates energy use from on-site generated, delivered, and exported energy. Exported energy is shown with dashed lines, indicating that exclusion or inclusion in EP calculation depends on k_{exp} factor 0 or 1.

The total primary energy, as defined in EN ISO 52000-1, is calculated as:

$$E_{P,tot} = \sum_i \left(E_{del,i} f_{del,tot,i}\right) - \sum_i \left(E_{exp,i} f_{exp,tot,i}\right) \quad (1)$$

In EN ISO 52000-1 k_{exp} factor 0 or 1 is defined to exclude or include exported energy. Often k_{exp}=0 is used to avoid overestimation of its impact, resulting in the total primary energy given by:

$$E_{P,tot} = \sum_i \left(E_{del,i} f_{del,tot,i}\right) \quad (2)$$

If exported energy is considered instead, a yearly calculation tends to overestimate the impact of on-site renewables because of surplus and low consumption situation in the summer period. To be correct, this calculation should be conducted on hourly basis with an hourly PEF instead of annual PEF. Total primary energy indicator is calculated by dividing total primary energy with useful floor area:

$$EP_{tot} = \frac{E_{P,tot}}{A_{net}} \quad (3)$$

where
EP_{tot} is the total primary energy indicator (kWh/(m^2 a));
$E_{P,tot}$ is the total primary energy (kWh/a);
$E_{del,i}$ is the delivered energy (kWh/a) for energy carrier *i*;
$E_{exp,i}$ is the exported energy (kWh/a) for energy carrier *i*;
$f_{del,tot,i}$ is the total primary energy factor (-) for the delivered energy carrier *i*;
$f_{exp,tot,i}$ is the total primary energy factor (-) of the delivered energy compensated by the exported energy for energy carrier *i*;

A_{net} is useful floor area (m^2).

In the operational greenhouse gas emissions calculation, in similar fashion, k_{exp} factor 0 or 1 is used to exclude or include exported energy. Operational greenhouse gas emissions are calculated from delivered and exported energy:

$$EP_{CO_2} = \frac{m_{CO_2}}{A_{net}} = \frac{\sum_i \left(E_{del,i} K_{del,i}\right) - \sum_i \left(E_{\exp,i} K_{\exp,i}\right)}{A_{net}} \quad (4)$$

where
EP_{CO2} is the operational greenhouse gas emissions indicator ($gCO_2/(m^2\ a)$);
m_{CO2} is the operational greenhouse gas emission (gCO_2/a);
$K_{del,i}$ is the CO_2 coefficient (gCO_2/kWh) for the delivered energy carrier *i*;
$K_{exp,i}$ is the CO_2 coefficient (gCO_2/kWh) for the exported energy carrier *i*.

For total primary energy indicator calculation, the assessment boundary in Figure 1 needs the specification of multiplier (1 or 0) to specify which energy flows through the assessment boundary are considered (1) and which ones will not (0), Table 1. An alternative method to specify the energy flows included, is to use the building site boundary instead of Table 1 as shown in Section 3.2.

Table 1. Specification of inclusion of energy flows through the assessment boundary.

Energy through the assessment boundary	Multiplier
Grid electricity	1
Nearby electricity	1
Community electricity	1
Fuels	1
District heat	1
District cooling	1
Solar thermal	0
Solar photovoltaic	0
Ambient energy	0
Geothermal	0

3.2 Building site boundary

The building site boundary, delineated by the borderline of the building plot as illustrated in Figure 2, serves as a means to differentiate between delivered and exported energy flows across the boundary. Energy use is calculated using the assessment boundary outlined in EN ISO 52000-1, but for primary energy indicator calculation, the building site boundary is utilized.

Within this boundary, on-site renewable energy, ambient energy, and geothermal energy are encompassed, and thus not supplied through the assessment boundary. Consequently, they are not accounted for in the primary energy indicator.

The positioning of the building site boundary in Figure 2 aligns with the typical location of main energy meters and connection points, ensuring full compliance with the EPBD assessment boundary definition 53. Notably, the figure does not indicate the location of energy meters for nearby or community renewable electricity due to varying technical and contractual arrangements, resulting in several possible options. In energy calculations, nearby or community renewable electricity is treated as delivered energy but is distinguished from grid electricity using different PEF.

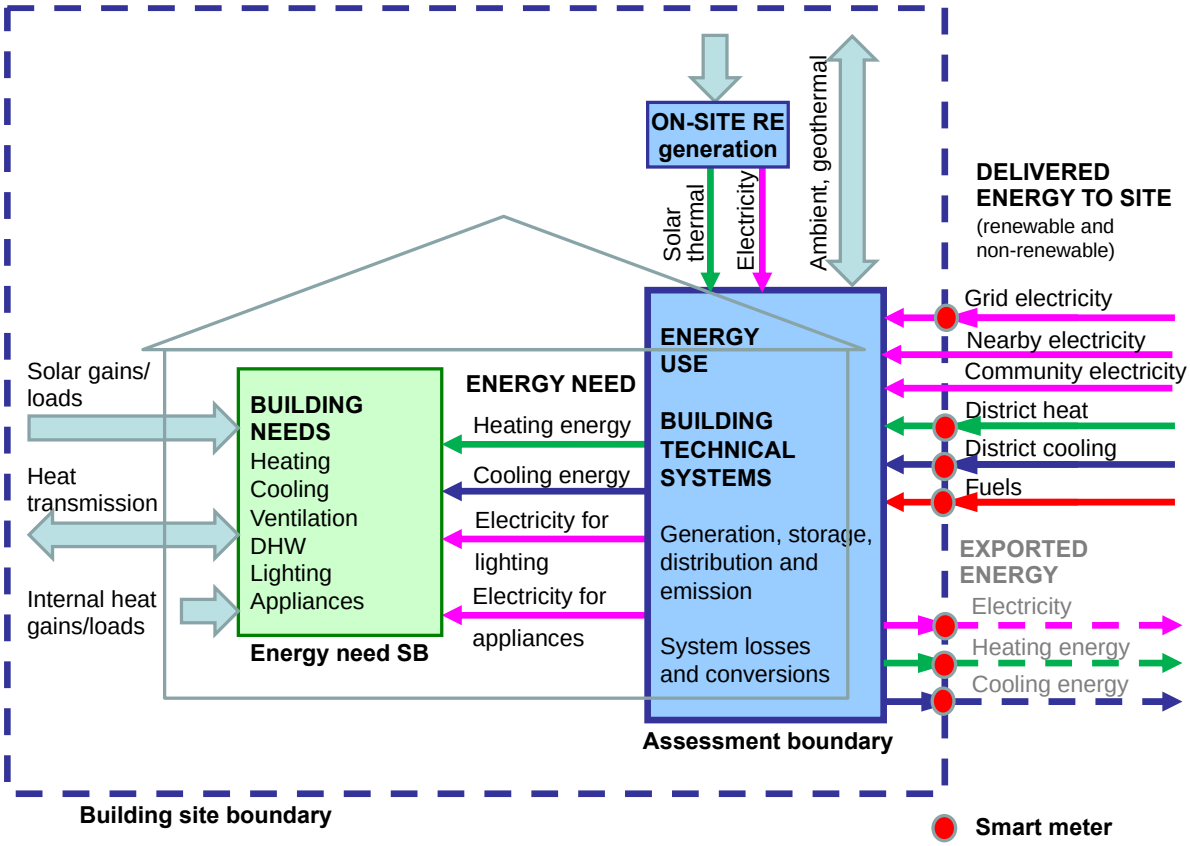
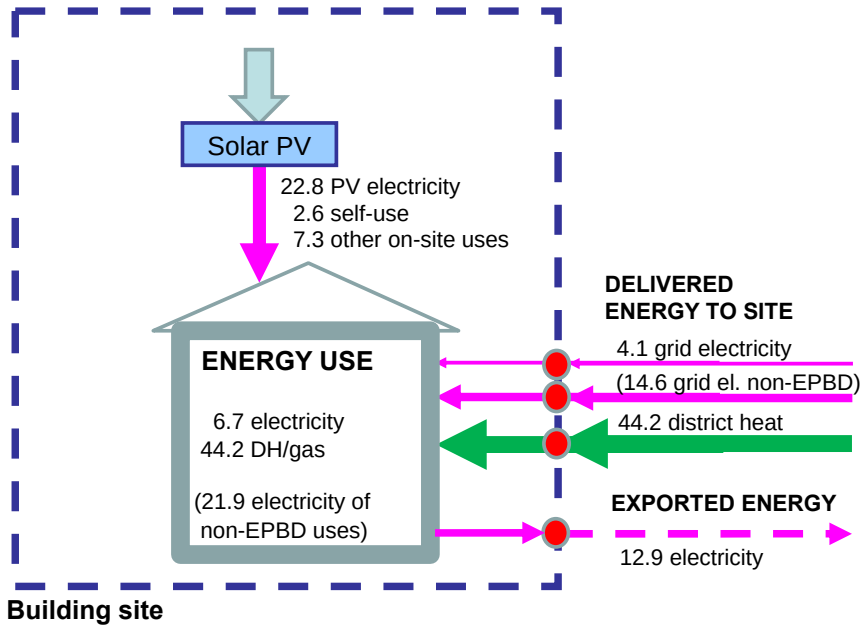


Figure 2. Building site boundary for primary energy calculation that complements building assessment boundary of EN ISO 52000-1.

With building site boundary on Figure 2, total primary energy indicator is calculated from delivered energy to building site, i.e. from delivered energy with nearby and distant origin. With data of model apartment building and PEF introduced in Section 5, total primary energy indicator calculation example is shown in Figure 3. Operational CO_2 calculation uses exactly the same delivered energy flows. Therefore, for the total primary energy indicator, non-renewable primary energy indicator (not shown in Figure 3) and operational CO_2 calculation, the only difference is in primary energy factors and CO_2 coefficients.

With regards energy calculation, hourly energy use and generation calculation is needed to know the self-use of PV, the use of PV in other on-site uses and exported electricity. Hourly energy calculation is mentioned in EPBD ANNEX I, but monthly calculation is also accepted. Similar calculation example than that in Figure 3 is provided in JRC ZEB report (2023) case studies. There is no exact definition for the assessment boundary in the JRC report, but the results of the case studies allow to see that the same assessment boundary has been used.

It should be noted that total PE is not able to distinguish the use of fossil fuels and energy from renewable sources including biofuels (all have total PEF of about 1.0). According to EPBD Article 11 ZEB '***energy demand***' requirement is '***maximum threshold established at the Member State level***'. Here each MS has a freedom to define ZEB by following cost optimality and EPBD ANNEX I principles (referred to in Article 2 ZEB definition). According to ANNEX I, '***a numeric indicator of primary energy use***' should be used and '***The calculation of primary energy shall be based on primary energy factors, (distinguishing non-renewable, renewable and total) or weighting factors***'. ANNEX I also requires recognising the **benefits of district heating and cooling**, and **positive influence of renewable energy** which is possible with non-renewable PE indicator but is neglected by total PE indicator. However, ZEB requirements (1) and (7) take care that these benefits are recognised.



EP_{tot} = 4.1 x 1.9 + 44.2 x 1.2 = 60.9 kWh/m² a

EP_{CO2} = 4.1 x 0.25 + 44.2 x 0.13 = 6.9 kgCO_2e/m² a

Figure 3. Recommended EP-value calculation for EPBD services from delivered energy to building site based on total PE and operational greenhouse gas emissions. Calculation methods introduced in sections 3.1 and 3.2 provide the same result.

4. Calculation of the ZEB requirement on the covering of total annual primary energy use

While the total primary energy indicator is calculated as reported in Sections 3.1 and 3.2, it is possible to check how it is covered according to ZEB requirement in Article 11 (7). According to this requirement, the total annual primary energy use must be covered by on-site, nearby, or renewable energy community generated renewable energy as defined in RED, energy from efficient district heating and cooling as defined in EED and energy from carbon free sources (nuclear and renewable grid electricity). This means that on annual basis the sum of on-site, nearby, and community renewable energy, efficient district heating and cooling and the carbon free fraction of grid electricity should be equal or higher than the total primary energy. Renewable energy as defined in RED includes the ambient energy (heat captured by heat pumps from the environment)[3], if seasonal performance factor of a heat pump is >2.4.

Example calculation is conducted in Table 2 for the model apartment building. As this requirement is set on annual basis, all PV generation is considered. It is well visible that the covering requirement is more challenging for Nordic climate, because in the case of smaller PV system it would not be fulfilled with district heating. However, in the case of decreasing primary energy factors in future this requirement is likely to be automatically satisfied if cost optimal thresholds are applied for the total primary energy indicator, therefore the covering requirement rather serves as a checklist showing which energy sources should be used in ZEB. With gas boiler that was included for illustrative purposes, the requirement is evidently not fulfilled.

[3] Note that for EPBD requirements in Article 11 (2,3) the ambient energy is not taken into account in the total primary energy indicator. But in the requirement of Article 11 (7) and RED definition for energy from renewable sources, ambient energy is included in the covering of the total annual primary energy use.

Table 2. Compliance with total primary energy covering requirement in the case of model apartment building. Input data for this calculation example is reported in Section 5.

	Nordic			Continental/Oceanic climate			Mediterranean		
PE covering requirement	AWHP	DH	Gas	AWHP	DH	Gas	AWHP	DH	Gas
Total primary energy	37.7	72.0	61.9	27.3	60.9	52.1	24.8	58.2	50.1
Covering by PV	-22.7	-22.7	-22.7	-22.8	-22.8	-22.8	-30.0	-30.1	-30.1
Covering by heat pump	-23.4			-21.6			-20.7		
Covering by efficient DH		-50.4			-44.2			-40.6	
Covering by ren. grid electr	-9.9	-3.0	-3.0	-7.2	-2.1	-2.1	-6.5	-2.5	-2.5
Total PE - covering	**-18.4**	**-4.2**	**36.2**	**-24.3**	**-8.2**	**27.2**	**-32.5**	**-15.0**	**17.5**
Requirement fulfilled	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No

Clause (22) in EPBD justification text (before articles) explains that: '*Different options are available to cover the energy needs of a zero-emissions building: energy generated on-site or nearby from renewable sources such as solar thermal, geothermal, solar photovoltaics, heat pumps, hydroelectric power and biomass, renewable energy provided by renewable energy communities, efficient district heating and cooling, and energy from other carbon-free sources. Energy derived from combustion of renewable fuels is considered to be energy from renewable sources generated on-site where the combustion of the renewable fuel takes place on-site.*' Therefore, combustion of biofuel is included in the covering of total annual primary energy. Note that in the total primary energy calculation for ZEB maximum threshold (3), as shown in Figure 1 and 2, renewable fuels are calculated with relevant primary energy factors.

5. Model building, primary energy factors and CO_2 coefficients to calculate EP indicators

A modern multifamily apartment building shown in Figure 4 and expected to correspond to present NZEB requirements has been used for calculation examples which are conducted for three European climates. The main data of the model building:

- 3-storey, 12 apartments, 1120 m^2 heated area
- Heat recovery ventilation
- 30 kW PV system
- Cooling system
- Air to water heat pump, effective district heating (50% renewables) or gas boiler for heating

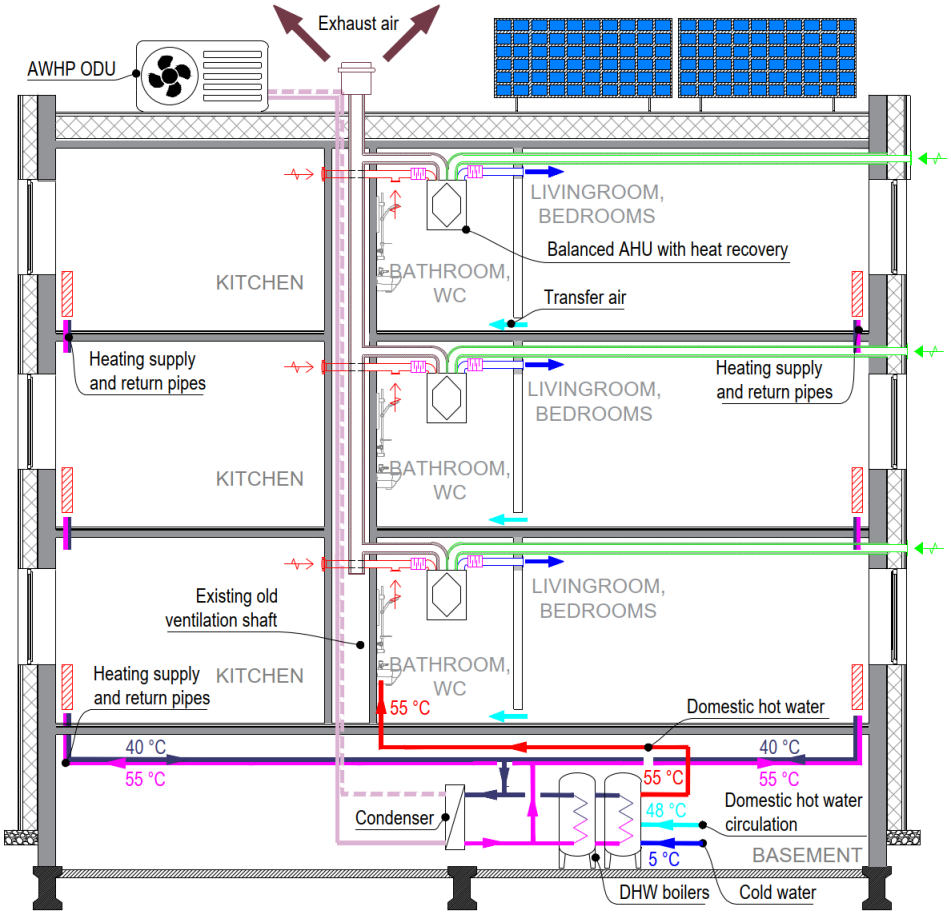


Figure 4. Schematic diagram of the model reference building with air to water heat pump. Cooling system with fan coils is not shown in the figure.
The model building is well insulated so that the U-values depend on the climatic zone as shown in Table 3. More detailed description of the building is reported in (Võsa et al. 2023).

Table 3. U-values of the model apartment building.

U-values W/(m^{2}K)	Nordic and Continental	Mediterranean
External walls	0.14	0.23
Cellar wall	0.15	0.23
Windows U_w	0.80	1.30
g-value	0.50	0.50
Roof (insulated)	0.11	0.20
Attic floor (insulated)	0.10	0.20
Ground floor to cellar	0.18	0.25
Floor on ground	0.49	0.49

Hourly simulated energy needs, energy use with studied heating sources and PV generation are shown in Table 4. Energy simulations were conducted with a commercial simulation tool enabling to include a heat pump, PV, and other technical systems in a multizone whole building simulation model (Võsa et al. 2023). For illustrative purposes the same boiler efficiency has been applied for the district heat and gas boiler, therefore, for these cases the energy use data is identical, and differences are solely caused by primary energy factors.

Table 4. Energy balance of the model building: hourly simulated energy needs and energy use. AWHP – air to water heat pump, DH – district heating.

Energy balance components	Nordic			Continental/Oceanic			Mediterranean		
	Energy need	Energy use & generation		Energy need	Energy use & generation		Energy need	Energy use & generation	
	kWh/m^2 a	AWHP	DH/Gas	kWh/m^2 a	AWHP	DH/Gas	kWh/m^2 a	AWHP	DH/Gas
Energy use									
Space heating	15.3	6.1	17.9	9.9	3.3	11.6	6.8	2.3	8.0
Domestic hot water	25.0	10.8	32.6	25.0	10.0	32.6	25.0	8.8	32.6
Supply air heating (electric)	2.7	2.7	2.7	0.5	0.5	0.5	0.1	0.1	0.1
Cooling	2.8	0.7	0.7	4.2	1.1	1.1	15.6	3.9	3.9
Fans, pumps, fixed lighting	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Lighting (non-EPBD)	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Appliances (non-EPBD)	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Energy generation									
PV self use		5.6	2.5		5.6	2.6		7.3	4.2
PV use in other on-site uses		6.0	6.7		6.6	7.3		7.5	8.1
PV exported to grid		11.1	13.5		10.6	12.9		15.3	17.8

Primary energy factors are selected to represent EU average primary energy factor for electricity in 2024 and to fulfil the minimum requirement of 50% of renewable energy sources in the efficient district heat production, Table 5. For electricity, total PEF = 1.9 is reported in (Trinomics, 2022). We assume 6% transmission losses, 50% renewable share in the generation and 38% average generation efficiency in other generation than renewables to estimate non-renewable PEF. These assumptions allow to calculate approximate PEF for electricity as follows:

- Total PEF = 0.5x1/0.94 + 0.5x1/0.94/0.38 = 1.9
- Non-renewable PEF = 0.5x1/0.94/0.38 = 1.4
- Renewable PEF 1.9–1.4 = 0.5

For efficient district heat we assume 50% share of renewables, 90% generation efficiency and 8% network losses:

- Total PEF = 1/0.92/0.9 = 1.2
- Non-renewable PEF (zero factor for renewable energy) 0.5x1/0.92/0.9 = 0.6
- Renewable PEF 1.2–0.6 = 0.6

For CO_2 coefficient of grid electricity, EU average value of 2022 is used (European Environment Agency 2023). CO_2 coefficient for efficient district heat is calculated from the value of natural gas with same assumptions as for PEF. It is assumed that renewable fuels have no operational CO_2 emissions.

Table 5. Primary energy factors (PEF) and CO_2 coefficients used in calculation examples.

Primary energy factors and CO_2 coefficients	nren PEF	ren PEF	tot PEF	CO_2 coefficient gCO_2e/kWh
Grid electricity	1.4	0.5	1.9	251
District heating	0.6	0.6	1.2	133
Natural gas	1	0	1	220

6. Comparison with present approaches in MS to calculate PE indicator

To illustrate the differences that the calculation approaches currently in use in MS may cause, primary energy indicators, non-renewable and total, are calculated for the model apartment building. Energy balance components reported in Table 4 and primary energy factors in Table 5 are used. Energy balance between the energy use and the delivered energy carriers for Continental/Oceanic climate zone is illustrated in Figure 5 which is used to explain step by step

primary energy indicators calculation with some of the used approaches. Because many MS include non-EPBD uses (lighting and appliances) in the primary energy indicator calculation, energy use and delivered grid electricity to these non-EPBD services is shown in parentheses in the energy balance Figure 5. This figure shows the summary of energy use (energy input to a technical building system), on-site electricity generation and delivered/exported energy without providing any assessment boundary definition. Therefore, any MS can apply national assessment boundary and calculation rules to this example and to calculate the primary energy indicator to compare with the results provided in the following.

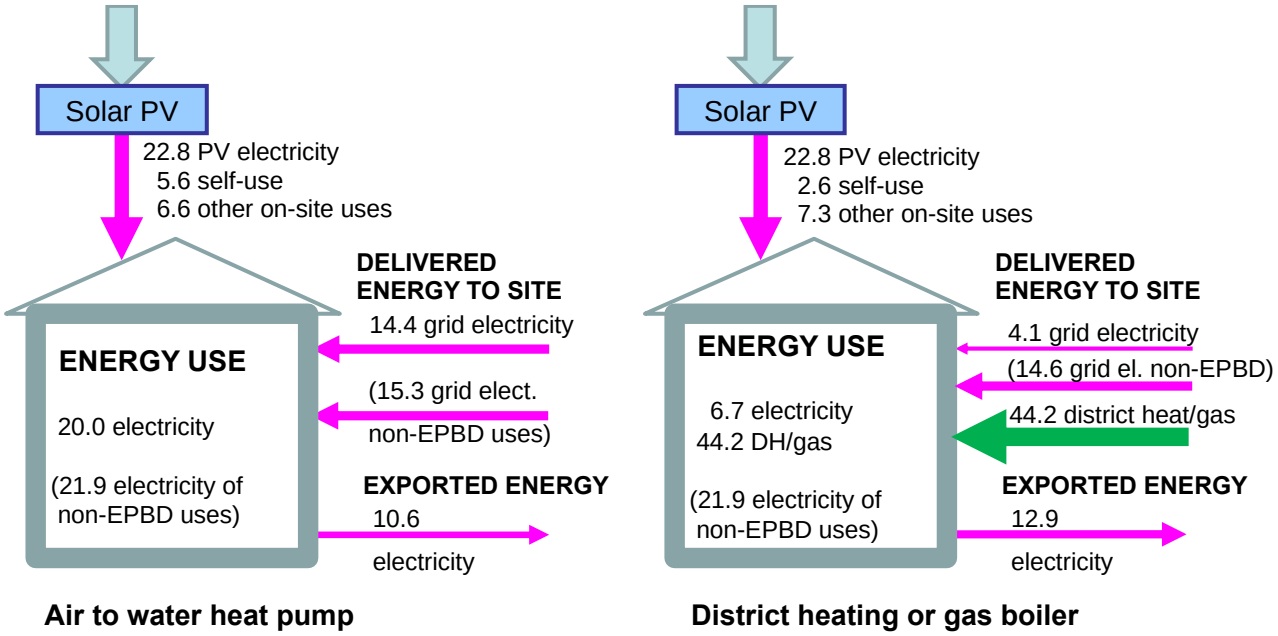


Figure 5. Energy balance of a model apartment building in Continental climate used for primary energy calculation.

There are 2-3 common approaches to calculate primary energy indicator (EP-value). Based on national regulations, it can be estimated that about 2/3 of MS consider only PV self-use and the use in other on-site uses. About 1/3 of MS account exported energy too, which may result in negative values of EP. In the first group (2/3) the majority of MS include both EPBD and non-EPBD services in the calculation. In the second group (1/3) only EPBD uses are typically included. Therefore, at least three usual approaches to calculate PE indicators can be identified. Some MS conduct this calculation with non-renewable and some MS with total PEF, but here we apply total PEF for electricity from Table 5. With air to water heat pump values shown in Figure 5, EP_{tot} indicators calculation result as follows:

1. PV self-use and used in other on-site uses, both EPBD and non-EPBD services included (used at least by 8 MS)
   EP_{tot} = (20 - 5.6)x1.9+(21.9 - 6.6)x1.9 = 56.2 kWh/m^2 a
2. PV self-use and EPBD services (used at least by 5 MS, corresponds to proposal in Ch 3)
   EP_{tot} = (20 - 5.6)x1.9 = 27.3 kWh/m^2 a
3. PV export (total generation) and EPBD services (used at least by 7 MS)
   EP_{tot} = (20 - 22.8)x1.9 = -5.4 kWh/m^2 a

In some MS there are limits for renewable energy maximum contribution to be accounted or another primary energy requirement to be fulfilled without considering on-site PV generation. In many cases such limits assuring energy efficiency do not exist and if exported electricity was accounted, negative EP values were achieved.

EP calculations with these three methods are summarised in Table 6 and 7, where also district heating and natural gas cases are included, and the calculation is conducted with both total and non-renewable PEF and with CO_2 coefficients. If non-renewable PEF are used, EP represents non-renewable primary energy indicator, and the calculation is in line with the methodology set in the

EPB overarching standard EN ISO 52000-1:2017. However, with total PEF, the calculation conducted does not represent total primary energy calculation in the sense of the overarching standard, because PV electricity and ambient heat of a heat pump are not included in EP-value. In this case the total primary energy calculation is finalised to the indicator calculation only from delivered energy to site, i.e, from imported/purchased energy, that is in line with EPBD definitions and principles as discussed in section 3. Operational greenhouse gas emissions are also calculated from the delivered energy to site – in this case PV and ambient heat are not an issue, because these do not cause operational CO_2.

Table 6. Primary energy and operational greenhouse gas emissions indicators calculation with three commonly used methods in Continental/Oceanic climate. Total primary energy, self-use EPBD option follows the calculation recommended in Section 3.

	Continental/Oceanic climate			
Energy balance components	Energy need	Energy use and generation, kWh/m^2 a		
(input data for PE calculation)	kWh/m^2 a	**AWHP**	**DH**	**Gas**
Space heating	9.9	3.3	11.6	11.6
Domestic hot water	25.0	10.0	32.6	32.6
Supply air heating (electric)	0.5	0.5	0.5	0.5
Cooling	4.2	1.1	1.1	1.1
Fans, pumps, fixed lighting	5.2	5.2	5.2	5.2
Lighting (non-EPBD)	6.8	6.8	6.8	6.8
Appliances (non-EPBD)	15.1	15.1	15.1	15.1
PV self use		-5.6	-2.6	-2.6
PV use in other on-site uses		-6.6	-7.3	-7.3
PV exported to grid		-10.6	-12.9	-12.9
Non-ren. primary energy				
self-use EPBD + non-EPBD		**41.4**	**52.6**	**70.3**
self-use EPBD		**20.1**	**32.3**	**50.0**
exported included EPBD		**-4.0**	**4.0**	**21.6**
Total primary energy				
self-use EPBD + non-EPBD		**56.2**	**88.5**	**79.7**
self-use EPBD		**27.3**	**60.9**	**52.1**
exported included EPBD		**-5.4**	**22.4**	**13.6**
Operational kgCO_2e/m^2 a				
self-use EPBD + non-EPBD		**7.4**	**10.6**	**14.4**
self-use EPBD		**3.6**	**6.9**	**10.8**
exported included EPBD		**-0.7**	**1.8**	**5.7**

Results in Tables 6 and 7 show that EP values strongly depend on the calculation approach. In Continental/Oceanic and Mediterranean climates EP indicators values may be negative if exported energy (total generation) is included in the calculation. Nordic climate shows the highest values, which all remain positive, but differ up to by factor 13. In the case of non-renewable PE and operational greenhouse gas emissions, air to water heat pump and district heating provide the lowest EP indicator values clearly followed by gas boiler. In the case of total PE, however, gas boiler provides better result than that of district heating, but it is automatically excluded by the ZEB requirement not to use fossil fuels on-site.

Table 7. Primary energy and operational greenhouse gas emissions indicators calculation with three commonly used methods in Nordic and Mediterranean climates. Total primary energy, self-use EPBD option follows the calculation recommended in Section 3.

Energy balance components	Nordic				Mediterranean			
	Energy need	Energy use and generation, kWh/m^2 a			Energy need	Energy use and generation, kWh/m^2 a		
	kWh/m^2 a	**AWHP**	**DH**	**Gas**	kWh/m^2 a	**AWHP**	**DH**	**Gas**
Space heating	15.3	6.1	17.9	17.9	6.8	2.3	8.0	8.0
Domestic hot water	25.0	10.8	32.6	32.6	25.0	8.8	32.6	32.6
Supply air heating (electric)	2.7	2.7	2.7	2.7	0.1	0.1	0.1	0.1
Cooling	2.8	0.7	0.7	0.7	15.6	3.9	3.9	3.9
Fans, pumps, fixed lighting	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Lighting (non-EPBD)	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Appliances (non-EPBD)	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
PV self use		-5.6	-2.5	-2.5		-7.3	-4.2	-4.2
PV use in other on-site uses		-6.0	-6.7	-6.7		-7.5	-8.1	-8.1
PV exported to grid		-11.1	-13.5	-13.5		-15.3	-17.8	-17.8
Non-ren. primary energy								
self-use EPBD + non-EPBD		**49.9**	**60.0**	**80.1**		**38.4**	**50.7**	**66.9**
self-use EPBD		**27.8**	**38.7**	**58.9**		**18.2**	**31.3**	**47.6**
exported included EPBD		**3.8**	**10.4**	**30.6**		**-13.7**	**-4.9**	**11.3**
Total primary energy								
self-use EPBD + non-EPBD		**67.8**	**100.8**	**90.7**		**52.1**	**84.4**	**76.3**
self-use EPBD		**37.7**	**72.0**	**61.9**		**24.8**	**58.2**	**50.1**
exported included EPBD		**5.1**	**33.6**	**23.5**		**-18.5**	**9.0**	**0.9**
Operational kgCO_2e/m^2 a								
self-use EPBD + non-EPBD		**9.0**	**12.0**	**16.4**		**6.9**	**10.1**	**13.6**
self-use EPBD		**5.0**	**8.2**	**12.6**		**3.3**	**6.7**	**10.2**
exported included EPBD		**0.7**	**3.2**	**7.5**		**-2.4**	**0.1**	**3.7**

7. Conclusions and recommendations

The EPBD follows 'efficiency first' principle meaning that the total primary energy, including both renewable and non-renewable primary energy should be minimised. However, in the context of energy use in buildings, it is important to distinguish ambient energy and on-site renewable energy generation, not causing operational CO_2 emissions, from delivered energy to the site consisting of purchased final energy products. If these energy products (grid electricity, fuels, district heating and district cooling) are partly based on non-renewable energy, they cause operational CO_2 emissions which needs to be minimised. As the use of on-site generated renewable energy reduces the amount of the delivered energy to the site, this on-site renewable energy should not be added to EP-value. Therefore, on-site generated renewable energy should not be considered as delivered energy carrier in the EP_{tot} indicator calculation.

Primary energy calculation is not explicitly defined in the EPBD, leaving many options and room for interpretation at national implementation. In this document it is proposed to calculate EP-value based on the total primary energy with one of two alternative options reported in Section 3 that will provide the same result. Either a building assessment boundary in Figure 1 with exclusion matrix (Table 1) of energy flows, or a complementary building site boundary in Figure 2 that accounts delivered and exported energy through the boundary, can be used. While Figure 1 and Table 1 follow the overarching EPB standard EN ISO 52000-1, for revised EPBD it would be more practical to use Figure 2 with straightforward energy calculation through the boundary. In both options on-site solar and ambient energy are not considered in the total primary energy indicator calculation, as the aim is, to calculate both total and non-renewable primary energy and operational CO_2 from delivered energy products to the site.

For the transition of national energy performance minimum requirements, i.e., to establish ZEB, NZEB, major/deep renovation and EPC rating scale based on the total primary energy the proposed

method in Section 3 can be implemented by three possible options:

1. **On-site renewable energy (both on-site generation and ambient energy) is not considered as delivered energy** – primary energy factors will only be applied for delivered and exported energy via energy carriers as shown in the proposed system boundary in Figure 2.
2. **Onsite renewable energy is considered as delivered energy, but with a zero primary energy non-renewable factor** when it comes to total primary energy requirements, as shown in Figure 1 and Table 1.
3. **Primary energy calculation is limited to imported/purchased final energy only.**

All these three options provide the same results and avoid that on-site produced and used renewable energy will be added to EP_{tot} value. This applies for:

- onsite produced PV or wind-electricity that is used onsite (at the same moment, or after onsite storage);
- ambient or geothermal energy that is used for an onsite heat pump;
- onsite solar thermal.

Otherwise, when calculating total primary energy, these technologies could be punished compared to alternative technologies, such as a conventional boiler, because total primary energy alone does not distinguish between non-renewable and renewable components. A threshold on total EP can be satisfied using smaller amount of non-renewable energy sources than renewable ones. Fortunately, the ZEB requirement not to use fossil fuels on-site avoids this problem. Regarding the building EPC market, today mostly being based on the non-renewable primary energy indicator, the proposed procedure slightly increases the EPC values for the same building, that is very small change comparing to the situation where on-site renewable energy will be added to EP_{tot} value.

Currently MS use either non-renewable or total PEF or weighting factors. In the transition to total primary energy, it should be noted that total PEF cannot recognise the benefits of district heating and cooling, and positive influence of renewable energy. A classic example of a heat pump in a building or in a district heating plant should lead to the same energy performance if the efficiency is the same and there are no network losses, but this is not the case if total primary energy factors, which cannot be by the definition smaller than one, are used. This problem illustrates the need for operational CO_2 indicator that is introduced by EPBD as one ZEB requirement.

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Colophon

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