How to set primary energy requirements so that poor building envelope cannot be compensated with extensive PV?

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Ongoing EPBD revision has brought up a question how the definition of zero-emission buildings (ZEB) should be established so that it will support the application of energy efficiency measures hand in hand with renewable energy measures and would avoid possible misuses based on compensation due to renewable energy production on-site when included in the annual balance calculation. More specifically the issue is related to on-site photovoltaic (PV) generation. In the winter there is no or very limited PV generation and buildings have to use grid electricity that will cause CO_2 emissions. These grid CO_2 emissions happen in the different time, the heating season, where sufficient PV generation is not available. Even in cases with very extensive PV installations and export in the summer buildings cannot benefit from this without seasonal electricity storage. On a shorter time scale, hourly variations during the day, similar effects occur.

Therefore, it is important to minimize the use of fossil energy at timesteps having a shortage of renewable energy, for which assessment an hourly energy use and generation calculation is needed. ZEB entirely or largely based on renewables, i.e. fossil energy use compensation by surplus of renewable energy in summer and during peak (sunny) hours will not be the case when hourly balances will be applied. When monthly or annual balances are applied (part of) the fossil energy use remains unknown: it is disguised by the averaging over a longer period; in other words, it is unintentionally and implicitly compensated.

In the following we look which energy performance indicator can avoid this compensation problem.

To illustrate the problem and to test relevant energy performance indicators a calculation example of a single-family house shown in **Figure 1** was prepared with two cases:

- Highly insulated building envelope and relatively small amount of PV
- Less insulated building envelope with an attempt to compensate with extensive PV

Figure 1. 176.5 m² single-family house used in energy calculations.

The highly insulated building had 5 kW PV system, U-values of external walls, roof, slab on the ground and windows were 0.13, 0.09, 0.1 and 0.82 W/m² K respectively, and a mechanical ventilation system with a heat recovery efficiency of 80%.

The less insulated building had corresponding U-values of 0.30, 0.22, 0.26 and 1.4, heat recovery efficiency of 60% and the PV system of 10.8 kW was selected so that with air to water heat pump the non-renewable primary energy with compensation for the surplus of electricity exported to the grid was the same as in the highly insulated case.

The values for the energy need and energy use were calculated on hourly basis following the assessment procedures in the set of EPB standards. Both cases were calculated with three energy sources:

- air to water heat pump (AWHP);
- gas boiler;
- district heating (DH).

The building was located in the Nordic climate zone and the highly insulated variant fulfilled present Estonian NZEB requirement with DH and AWHP, but not with gas boiler. Non-renewable (non-ren PE) and total primary energy (total PE) were calculated with PV electricity that is self-used and used in other on-site uses (lighting and appliances) and alternatively with export compensation to see which indicator would allow to set a threshold assuring efficiency and renewables go hand in hand and not allowing to compensate efficiency with extensive PV.

As EPBD recast proposal (dd 2021-12-13) defines ZEB as **a building with a very high energy performance, where the very low amount of energy still required is fully covered by energy from renewable sources**, the total amount of renewable energy (RE) including the export was also calculated. The primary energy factors (PEF) applied in the calculation are from informative Annex B of EN ISO 52000-1, with only exception for the efficient district heating which has a higher efficiency not defined in the standard and followed EED definition, see **Table 1**.

Table 2 reports energy calculation for the highly insulated building. It can be seen that non-ren PE shows the best result with efficient district heating (DH), followed by AWHP, while the gas boiler is clearly the worst one. Total PE provides a completely opposite result: efficient district heating is the worse one – so the gas would be better than district heating if the threshold of total PE would be used. This demonstrates that the **total PE is not a relevant indicator to assess energy performance of buildings**.

How the primary energy values are calculated can be seen from **Figure 2**, illustrating non-ren PE calculation for AWHP case. For DH and gas, the calculation is similar, but in addition to electricity use (blue values in **Table 2**) district heating/gas (yellow values in **Table 2**) are to be added with corresponding non-ren PEF values in **Table 1**. In the total PE calculation, total PEF values are used and RE (either the self-use, or the self-use and export) is also included because it has total PEF=1.0.

It should be noted that, to reduce the penalty for heat pumps, total PE was calculated without the ambient heat accounted as renewable energy, as would be required by EN ISO 52000-1. In principle, the heat extracted from outdoor air is RE, and therefore part of the total PE, with the amount of 33.4 kWh/m²·a. If it would be accounted, total PE value of AWHP would increase to 114.7 (81.3+33.4) kWh/m²·a. In the CO_2 emissions calculation, ambient heat has no meaning.

The ZEB requirement to fully cover with RE is fulfilled in case of DH, where **RE (68.1) fully covers non-ren PE (48.6).** In the case of AWHP a slightly larger PV system would be needed (62.4 > 62.2). In the case of gas boiler, this requirement is practically not achievable.

Similar energy balance calculation for less insulated building is shown in **Table 3**.

To illustrate the energy balance differences in **Tables 2 and 3**, energy flows for AWHP cases are shown in **Figure 2**. If non-ren PE is calculated with **PV export,**

Table 1. *Primary energy factors and CO_2 emission coefficients.*

	non-ren PEF	renewable PEF	total PEF	kgCO_2/kWh
Grid electricity & PV export	2.3	0.2	2.5	0.42
Natural gas	1.1	0	1.1	0.22
DH (district heat)	0.6	0.6	1.2	0.12
RE (solar, geo, ambient)	0	1	1	0

fossil energy use is compensated by surplus of renewable energy in summer –non-ren PE with export has exactly the same value for these cases. Therefore, to avoid this compensation, the export should not be accounted in the non-ren PE calculation. Non-ren PE value calculated with the self-use only is almost doubled in the case of less insulated building. Thus, **poor building envelope cannot be compensated with extensive PV if the non-ren PE is calculated with the PV self-use only**. In other words, this also means that ZEB energy performance can be controlled with this one indicator.

EPBD recast proposal (dd 2021-12-13) says that Member States shall take necessary measures to ensure that the energy use of a new or renovated ZEB complies with **a maximum threshold.** If we use data of highly insulated building in **Table 2**, it is possible to set the primary energy threshold that can be complied with AWHP and DH in between 40 and 120 kW/h·m², depending how the primary energy is calculated, see illustration in **Figure 3**. Here 40 kW/h·m² represents non-ren PV with self-use only and 120 kW/h·m² total primary energy where ambient heat is included. **Therefore, if EPBD will not specify that 'primary**

Table 2. *Energy calculation for highly insulated building with 5 kW PV.*

Energy balance	Energy need kWh/m²·a	Energy use kWh/m²·a DH	Gas	AWHP
Space heating	38.5	46.3	43.9	16.6
DHW	25.0	27.8	26.3	13.5
Supply air heating[1] (electric)	5.0	5.0	5.0	5.0
Fans and pumps[2]	5.5	7.5	7.5	5.5
PV self-use		10.7	10.7	13.4
PV export		12.6	12.6	9.9
Non-ren. primary energy, self-use only		48.6	81.3	62.4
Non-ren. primary energy, export included		19.6	52.4	39.7
Total primary energy, self-use only		104.1	92.4	81.3
Total primary energy, exported included		85.2	73.5	66.4
Renewable energy		68.1	23.7	62.2
CO_2 emissions, $kgCO_2/m^2 \cdot a$		4.4	10.9	7.2

[1] To ensure 18°C supply air temperature in cold winter and frost prevention conditions, ventilation unit is equipped with electric reheating coil after rotary heat recovery operating with frost prevention limit value for exhaust air temperature of 0°C.

[2] Fans and pumps include ventilation unit fan electricity (5.5) and electricity of circulation pumps (2.0). AWHP is calculated as a package where circulation pumps are included in space heating and DHW values.

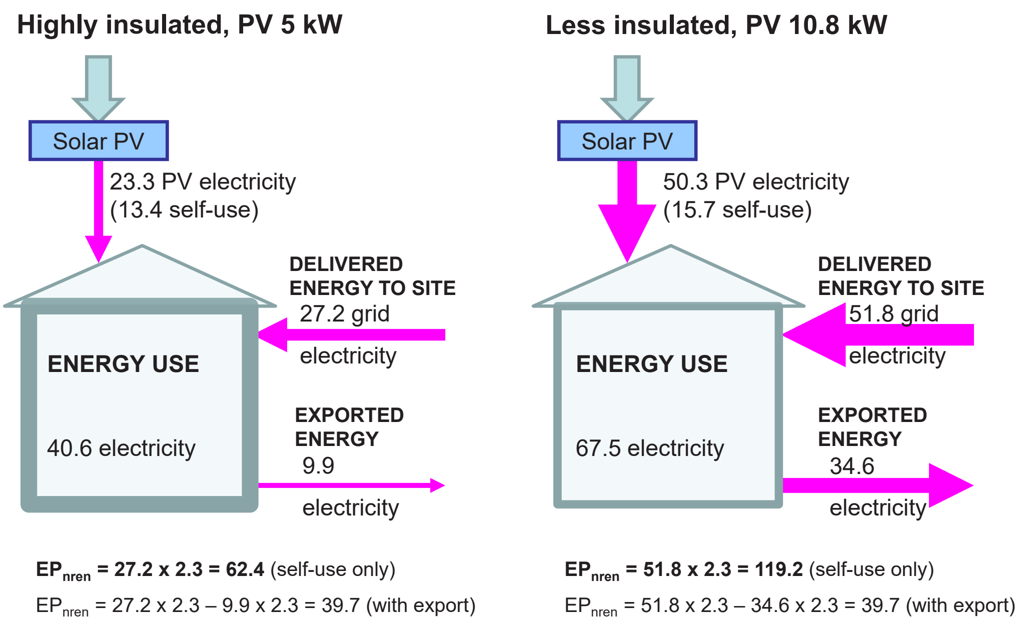

Figure 2. Illustration of energy flows and non-ren PE calculation in cases with AWHP.

energy' means non-renewable primary energy and its threshold needs to be calculated without compensation by PV export, it may lead to situation where ZEB requirements implemented in Member States may differ by factor 3 at the same performance level.

It is important to understand that the primary energy threshold (first EPBD requirement) should refer to the use of grid electricity (and district heating/cooling) that could not be avoided by efficiency measures and on-site/community renewable energy production because there is not enough solar PV generation available in the winter and a building without seasonal electricity storage must use the grid electricity. Therefore, in this threshold, all non-renewable primary energy delivered to the site should be accounted that means that only the 'self-used' and used in 'other on-site uses' PV electricity can be subtracted in the non-renewable primary energy calculation, and exported PV electricity compensation should not be calculated because this occurs mainly in the summer. At the same time, the second EPBD ZEB requirement, to fully cover with renewable energy, differently accounts for the full amount of renewable energy. This is an important detail that renewable energy is calculated differently in these two ZEB requirements according to policy choices used in the EPBD recast proposal.

Conclusions

Results show that current EPBD recast proposal (dd 2021-12-13) allows to specify the primary energy threshold (the first ZEB requirement) within extremely wide range – by factor 3 difference in the numeric value, depending on unspecified choices in the primary energy calculation. It was shown that this requirement will become meaningful and poor building envelope cannot be compensated with extensive PV, if primary energy is calculated as **non-renewable** primary energy with subtracting only the amount of PV that is **self-used and used in other on-site uses**. At the same time, the second ZEB requirement of fully covering with renewable energy should be calculated differently, as current EPBD recast proposal comprises that all renewable energy including also exported energy is accounted. **Therefore, for consistent and transparent ZEB definition according to current policy choices these two small technical details, marked with bold, have a great importance and should be addressed.**

Apart from this essential conclusion regarding non-renewable primary energy inclusion it is important to

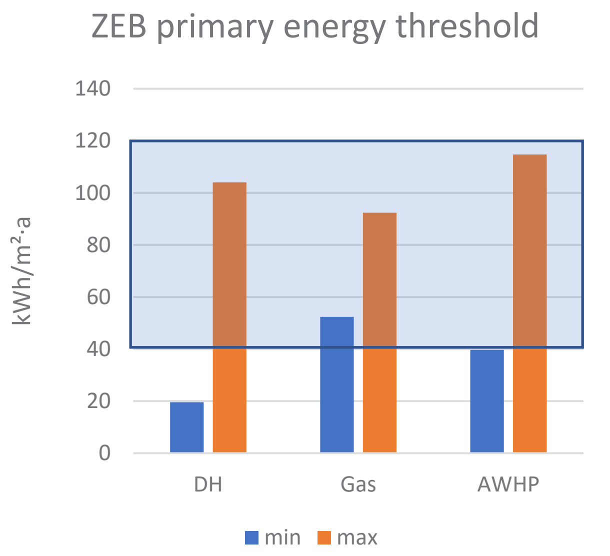

Figure 3. Possible range of the primary energy threshold of 40 – 120 kWh/(m²·a) following EPBD recast proposal 2021-12-13, based on the highly insulated building data in Table 2.

Table 3. *Energy calculation for less insulated building with 10.8 kW PV.*

Energy balance	Energy need kWh/m²·a	Energy use kWh/m²·a		
		DH	Gas	AWHP
Space heating	77.0	92.5	87.7	33.1
DHW	25.0	27.8	26.3	13.5
Supply air heating (electric)	15.4	15.4	15.4	15.4
Fans and pumps	5.5	7.5	7.5	5.5
PV self-use		12.3	12.3	15.7
PV export		38.0	38.0	34.6
Non-ren. primary energy, self-use only		96.5	149.8	119.2
Non-ren. primary energy, export included		9.3	62.5	39.7
Total primary energy, self-use only		183.1	164.2	145.2
Total primary energy, exported included		126.2	107.3	93.4
Renewable energy		124.5	52.4	116.0
CO_2 emissions, $kgCO_2/m^2 \cdot a$		2.9	13.6	7.2

realise the following: EPBD recast proposal defines in article 9 that during the coming years all new (from 2030 onwards) and existing building step by step should reach ZEB by 2050. The assessment of ZEB can only be done in a reliable fashion with hourly calculation to overcome the mismatch of energy use and availability of renewable energy. Therefore, in the longer run, hourly calculation methods should be required to be taken into use in all Member States. In this respect it is also important to note that with monthly or annual calculation energy balances, due to the averaging over longer periods, exported energy is disguised as self-use, which means: implicit, hidden compensation for exported energy. ■

Opinion on deep energy renovation by REHVA Member

Buildings in the European Union use around 40% of the final energy consumption for their operation, but it is clear that this refers to existing ones. Based on this and taking in to account that around 85–95% of the existing buildings will continue to be used in 2050, the decarbonization should tackle seriously this group of objects. But first step to carbon-neutral buildings is considerable increase of energy efficiency.

If the primary energy consumption in building is reduced by at least 60%, it may be called deep energy renovations. To reach such a goal, the activities should include not only ensuring the required thermal insulation of building envelope and air tightness, but also the high efficiency of HVAC in building. In specific cases, the additional layer of thermal insulation is even not considered, especially if the payback time of investment costs is not satisfactory for the investors or building managers. In this light the crucial role plays the HVAC systems, which deliver above mentioned amount of energy to specific rooms in existing buildings. So, it is necessary to first increase the energy efficiency of the existing building as much as possible that is technically and economically justified, considering besides the energy renovation of the building envelope, renovation/optimisation of all HVAC systems, and user education with the parallel improvement of IEQ and use of low embodied energy (carbon) materials. By this process the best available solutions should be used in order to be in line with preference of users and managers of existing buildings such as: easy implementation within the existing building and installed HVAC systems, minimal occupant disturbance during implementation, short implementation time in existing buildings, short payback time for investment costs and high potential for repeatability to other buildings.

Taking this in to account, it is important to address in this aspect all available HVAC systems and their components in specific buildings, particularly heating/cooling sources and main control systems, heating systems, domestic hot water systems, space cooling systems, ventilation systems and heat recovery.

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