How to calculate cost optimal nZEB energy performance?

EPBD requires evaluation of the cost optimality of current minimum requirements due June 30th 2012. A seven step procedure is discussed to conduct these calculations smoothly for residential buildings.

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EPBD recast [1] requires Member States (MS) to ensure that minimum energy performance requirements of buildings are set with a view to achieving cost optimal levels using a comparative methodology framework established by the Commission. Cost optimal performance level means the energy performance in terms of primary energy leading to minimum life cycle cost. MS have to provide cost optimal calculations to evaluate the cost optimality of current minimum requirements due June 30th 2012 (Articles 4&5).

The draft methodology called "delegated Regulation supplementing Directive 2010/31/EU" is now published and can be downloaded from [2]. In addition to cost optimal policy, EPBD recast established the political target of nearly zero energy buildings (nZEB) for all new buildings by 1 Jan 2021 according to Article 9. Because of current understanding about nZEB as not cost efficient yet, these both requirements will have to be reconciled so that a smooth transaction from cost optimal requirements to nearly zero energy buildings could be guaranteed, as communicated by the Commission [3]. Therefore, the meaning of nZEB is not fully explicit before that reconcilement. That is clear, both cost optimal and nZEB performance level calculations are to be shortly conducted in each MS to be able to adopt EPBD recast. Cost optimal levels by 2013 can be seen as a first step towards the nZEB target laid down in EPBD recast.

To be able to perform such calculations one needs relevant system boundary definition and calculation methodology. The guidance by the EPBD recast is on general level. In the directive 'nearly zero-energy building' means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. So: **nZEB = very high energy performance + on-site renewables**. Definition of "a very high energy performance" and "significant extent of renewables" is left for MS.

In the following, systematic and robust procedure to determine cost optimal energy performance levels is discussed. Model calculations and detailed description are reported in [4]. To perform cost optimal and nZEB calculations, REHVA nZEB technical definition, including system boundary and energy calculation methodology [5] is used. The procedure is based on careful definition of construction concepts leading to very limited amount of energy calculations, which combined with systems and economic calculations result in cost optimal primary energy use.

General methodology

This systematic and robust scientific procedure includes seven steps in order to determine cost optimal energy performance levels:

1. selection of the reference building/buildings
2. definition of construction concepts based on building envelope optimization for fixed specific heat loss levels (from business as usual construction to highly insulated building envelope in four steps)
3. specification of building technical systems
4. energy calculations for specified construction concepts
5. post processing of energy results to calculate delivered, exported and primary energy
6. economic calculations for construction cost and net present value of operating cost
7. sensitivity analyses (discount rate, escalation of energy prices and other parameters)

All this steps are independent and they do not lead to iterative approach or optimization algorithm for residential buildings. Cost optimal calculation to obtain the minimum net present value (NPV) can just done by straightforward calculation of steps 2 to 6 for all specified cases (according to steps 2 and 3). If specified cases will not show the minimum of the NPV, additional cases are to be specified to obtain the minimum.

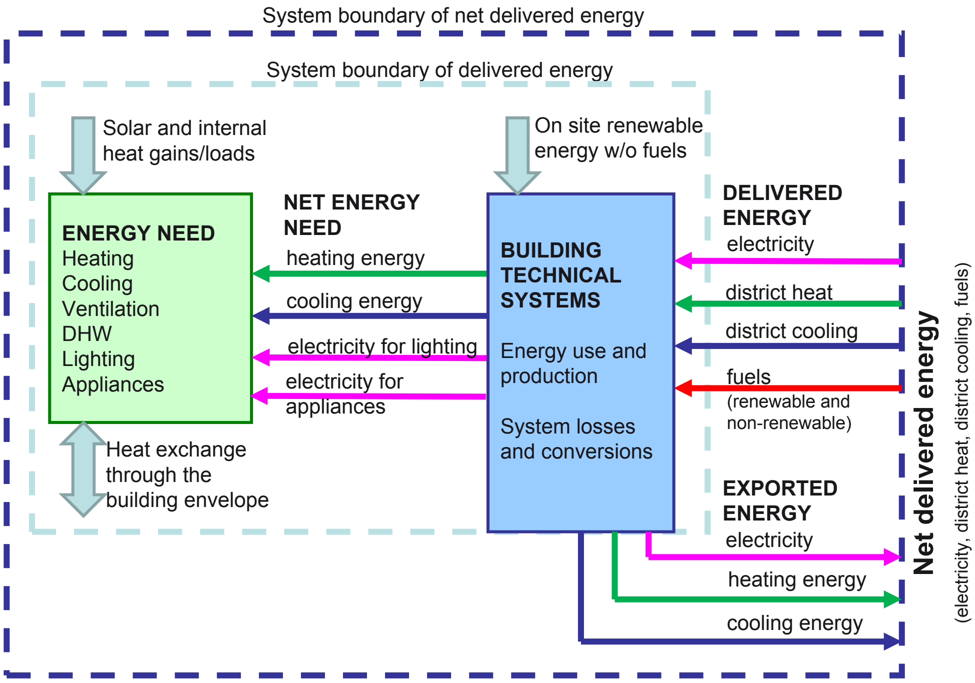

Figure 1. Energy boundary of net delivered energy and schematic representation, energy use of technical building systems, on-site renewable energy production, delivered energy and exported energy. The box of "Energy need" refers to rooms in a building and both system boundary lines may be interpreted as the building site boundary. (Adopted from REHVA Task Force "Nearly Zero Energy Buildings" [5])

Cost optimal primary energy use is determined by the solutions leading to minimum NPV of 30 years period for residential buildings and 20 years period for non-residential buildings according to the draft regulation [2]. Reference buildings are needed for calculations. For new buildings, one representative reference building is enough [2], however it may provide valuable information if in the sensitivity analyses another reference building will be used. Construction concepts to be studied have to represent building envelopes from business as usual construction to highly insulated building envelope. With building envelope optimization only four construction concepts are enough to change insulation thickness mainly with 5 cm step and with 10 cm step for thicker insulations. Heat recovery efficiency is the feature belonging to the construction concept, because of the gain utilization in energy calculations. To keep calculations simple, fixed heat recovery efficiency is to be used for each construction concept. All relevant heating (and cooling) systems can be calculated with reasonable effort, if the same distribution and emission systems will be used for all cases simplifying cost calculations and to ensuring equal comfort level.

General nZEB technical definition format by REHVA Task Force "Nearly Zero Energy Buildings" [5] can be used as a framework for cost optimal and nearly zero energy buildings' energy performance calculations. This framework uses the detailed system boundary modified from EN 15603:2008 [6] with the inclusion of on-site renewable energy production within the system boundary. This inclusion follows EPBD recast requiring that the positive influence of on-site renewable energy production is taken into account, **Figure 1**.

Input data selection principles

Step 1. The reference building

It can be recommended that architects will select the reference building as a typical representative building of new construction. Single family building, multi family building and office building (one for new built and two for existing) are required by [2]. An example is calculated with Estonian detached reference house with heated net floor area of 171 m², **Figure 2**.

Step 2. Definition of construction concepts

Proper definition of the construction concepts (=building envelope + heat recovery) is the cornerstone of the method. Careful selection of construction works allows reducing calculation effort drastically. In the example, four construction concepts (**Table 1**) were specified based on the specific heat loss coefficient.

DH 0.42 construction concept represents the best practice technology of highly insulated building envelope which may be associated with nearly zero energy buildings. DH 0.96 represents business as usual (BAU) construction. Building envelope has to be optimized for each specific heat loss value, so that the most cost effec-

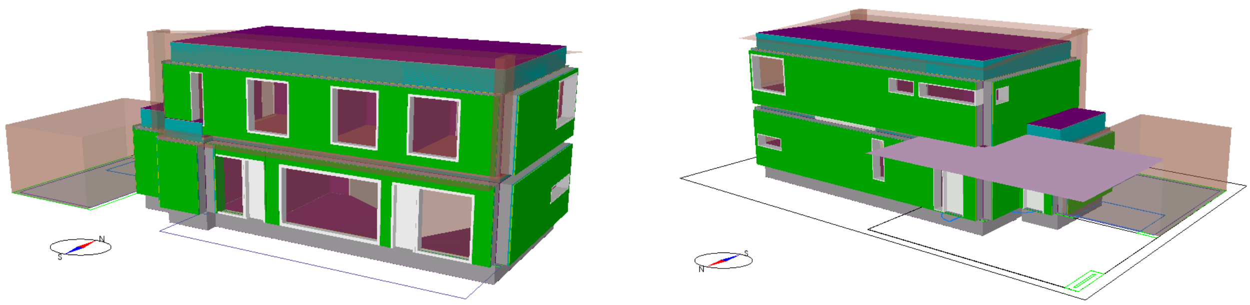

Figure 2. Energy simulation model of the reference detached house, perspective view from south-east in the left and from north-west in the right.

tive combination of insulation levels for windows, external walls, slab on ground and roof will used to achieve the given specific heat loss value. This means that one has to select a proper window and external wall insulation combination, to achieve the given specific heat loss value at the lowest possible construction cost. This is a basic construction cost calculation exercise, the professionals are doing daily. If this is followed, one will need to calculate net energy needs only once (four simulations in this case).

Step 3. Specification of building technical systems

All cases were equipped with effective heat recovery (as in a cold climate) and were calculated with almost all possible heating systems. For each construction concept, the following heating systems were considered with appropriate sizing:

- ground source heat pump
- air to water heat pump
- district heating
- direct resistance electrical heating
- condensing gas boiler
- condensing oil boiler
- pellet boiler

Sizing data of the systems is shown in Table 1 and performance data in **Table 2**. Because of the cold climate and dominating heating need, only one basic compressor cooling solution was used for all cases. Highly insulated DH 0.42 and DH 0.58 cases were calculated both with and without solar collectors of 6 m², providing an half of domestic hot water net energy need. Other cases were calculated without solar collectors. For nZEB, 5 kW solar PV installation was additionally used.

In principle, the number of technical systems to be studied can be high, because of the fast post processing of energy calculation results. All relevant technical

Table 2.
System efficiencies for delivered energy calculation.

Heat source (under floor heating)	Generation and distribution combined efficiency, -	
	Space heating/ cooling	Domestic hot water
Gas/oil condensing boiler	0.86	0.83
Pellet boiler	0.77	0.77
Air to water heat pump (elec)	1.98	1.62
Electrical heating	0.90	0.90
Ground source heat pump (elec)	3.15	2.43
District heating	0.90	0.90
Cooling (electricity)	3.0	

systems could be relatively easily calculated (resulting mainly as the effort for cost calculations) to be sure that the combination leading to minimum net present value will not missed due to limited systems specification.

Step 4. Energy simulations for specified construction concepts

All relevant energy calculation tools can be used, however the validated dynamic tools can be recommended. Such tools are contrasted in [8]. For the example, energy simulations were conducted with dynamic simulation tool IDA-ICE [9] for specified four construction concepts. Simulated net energy needs are shown in Table 1.

Step 5. Post processing of the simulation results to calculate delivered, exported and primary energy

Delivered energy can be easily calculated with post processing from simulated net energy needs. Net energy needs are to be divided with relevant system efficiencies. System efficiency values used in the example (combined efficiency of the generation, distribution and emission) are shown in Table 2. To calculate the combined efficiency, under floor heating distribution was considered

Table 1. Construction concepts and simulated net energy needs of the reference detached house of 171 m².

	Construction concepts			
	DH 0.42 "Nearly zero"	DH 0.58	DH 0.76	DH 0.96 "BAU"
Specific heat loss coefficient H/A, W/(K m²)	0.42	0.58	0.76	0.96
External wall 170 m²	20cm LECA block, plaster + 35cm EPS-insulation U 0.1 W/m²K	20cm LECA block, plaster + 25cm EPS-insulation U 0.14 W/m²K	20cm LECA block, plaster + 20cm EPS-insulation U 0.17 W/m²K	20cm LECA block, plaster + 15cm EPS-insulation U 0.23 W/m²K
Roof 93 m²	Wooden beams, metal sheet, 80cm min. wool insulation, concrete slab U 0.06 W/m²K	Wooden beams, metal sheet, 50cm min. wool insulation, concrete slab U 0.09 W/m²K	Wooden beams, metal sheet, 32cm min. wool insulation, concrete slab U 0.14 W/m²K	Wooden beams, metal sheet, 25cm min. wool insulation, concrete slab U 0.18 W/m²K
Ground floor 93 m²	Concrete slab on ground, 70cm EPS insulation U 0.06 W/m²K	Concrete slab on ground, 45cm EPS insulation U 0.09 W/m²K	Concrete slab on ground, 25cm EPS insulation U 0.14 W/m²K	Concrete slab on ground, 18cm EPS insulation U 0.18 W/m²K
Leakage rate q50, m³/(h m²)	0.6	1.0	1.5	3.0
Windows 48 m² U-value glazing/frame/total	4mm-16mmAr-SN4mm-16mmAr-SN4mm Insulated frame 0.6/0.7 W/m²K 0.7 W/m²K	4mm-16mmAr-4mm-16mmAr-SN4mm Insulated frame 0.8/0.8 W/m²K 0.8 W/m²K	4mm-16mm-4mm-16mmAr-SN4mm 1.0/1.3 W/m²K 1.1 W/m²K	4mm-16mmAr-SN4mm Common frame 1,1/1,4 W/m²K 1,2 W/m²K
g-value	0.46	0.5	0.55	0.63
Ext. door, 6 m²	U 0.7 W/m²K	U 0.7 W/m²K	U 0.7 W/m²K	U 0.7 W/m²K
Ventilation rate l/s, specific fan power SFP, temperature efficiency AHU HR	80 l/s, SFP 1.5 kW/(m³/s), AHU HR 85%	80 l/s, SFP 1.7 kW/(m³/s), AHU HR 80%	80 l/s, SFP 2.0 kW/(m³/s), AHU HR 80%	80 l/s, SFP 2.0 kW/(m³/s), AHU HR 80%
Heating capacity, kW	5	6	8	9
Cooling capacity, kW	5	5	5	8
	Net energy need kWh/(m² a)			
Space heating	22.2	36.8	55.1	71.5
Supply air heating in AHU	4.1	5.7	5.7	5.7
Domestic hot water	29.3	29.3	29.3	29.3
Cooling	13.6	11.1	9.2	15.0
Fans and pumps	7.9	8.8	10.0	10.0
Lighting	7.3	7.3	7.3	7.3
Appliances	18.8	18.8	18.8	18.8
Total net energy need	**103.2**	**117.8**	**135.5**	**157.7**

with average distribution and emission efficiency of 0.9 according to Estonian regulation [7].

To calculate primary energy, exported energy has to be reduced from delivered energy. National primary energy factors are to be used, the example used Estonian ones:

- fossil fuels 1.0
- electricity 1.5
- district heating 0.9
- renewable fuels 0.75

Step 6. Economic calculations: construction cost and net present value calculations

Economic calculations include construction cost calculations and discounted energy cost calculation for 30 years. To save calculation effort, construction cost is accepted to calculate not as a total construction costs, but only construction works and components related to energy performance are to be included in the cost (energy performance related construction cost included in the calculations) [2]. Such construction works and components are:

- thermal insulation (with cost implications to other structures)
- windows
- air handling units
- heat supply solutions (boilers, heat pumps etc.)

In the example, in all calculated cases an under floor heating system was considered, that was not included in the energy performance related construction cost. The effect of maintenance, replacement and disposal costs is required to be taken into account [2]. However, in the example, sensitivity analyses showed only minor differences between calculated cases, and these costs were not taken into account to keep calculations as simple and transparent as possible. Labour costs, material costs, overheads, the share of project management and design costs, and VAT are essential to include in the energy performance related construction cost.

Global cost, the term of EN 15459 used in the regulation [2] (=life cycle cost), and net present value (NPV) calculation have follow EN 15459 [10]. Global energy performance related cost has to be calculated as a sum of the energy performance related construction cost and discounted energy costs for 30 years, including all electrical and heating energy use. Because the basic construction cost was not included, the absolute value of the global energy performance related cost will have a little meaning. Instead of that, the global incremental energy performance related cost was used. This can be calculated relative to the business as usual (BAU) construction:

$$C_g = \frac{C_I + \sum_{i=1}^{30}\left(C_{a,i} \cdot R_d(i)\right)}{A_{floor}} - \frac{C_g^{ref}}{A_{floor}}$$

where:

C_g global incremental energy performance related cost included in the calculations, NPV, €/m²
C_I energy performance related construction cost included in the calculations, €
$C_{a,i}$ annual energy cost during year i, €
$R_d(i)$ discount factor for year i
C_g^{ref} global energy performance related cost incl. in the calculations of BAU reference building, NPV, €
A_{floor} heated net floor area, m²

This global incremental cost calculation is illustrated in **Table 3** for one case. A global incremental cost is negative if BAU is not cost optimal, and positive if the case studied leads to higher global cost than BAU.

To calculate the global energy performance related costs, the real discount rate and escalation of energy price has to be selected on national bases. In the example, the real discount rate of 3% and escalation of energy prices of 2% are used as basic case. The draft regulation [2] pro-

Table 3. Global incremental cost calculation. Global energy performance related cost included in the calculations is divided by net heated floor area of 171 m² and the values of the reference building (DH 0.96) are subtracted in order to calculate the global incremental cost. The global cost data shown corresponds to the "Gas" case in **Figure 3**.

Global energy performance related cost included in the calculations, net present value, €	DH 0.42	DH 0.58	DH 0.76	**DH 0.96 (ref.)**
Building envelope (thermal insulation and windows, structures not incl.)	30602	26245	21167	17611
Ventilation units (ductwork not included)	5474	3445	3445	3445
Condensing gas boiler (distribution system not included)	6917	6917	6917	6917
Solar collectors 6m²	4479	4479	0	0
Connection price: Gas	2455	2455	2455	2455
Energy cost for natural gas, NPV	10100	14063	22208	26196
Energy cost for electricity, NPV	20081	20081	20407	21422
Global cost included in the calculations, NPV, €	**80108**	**77685**	**76599**	**78047**
Global incremental energy performance related cost included in the calculations, relative to the reference building, net present value, €/m²	DH 0.42	DH 0.58	DH 0.76	**DH 0.96 (ref.)**
Building envelope (thermal insulation and windows, structures not incl.)	75,9	50,5	20,8	0,0
Ventilation units (ductwork not included)	11,9	0,0	0,0	0,0
Condensing gas boiler (distribution system not included)	0,0	0,0	0,0	0,0
Solar collectors 6m²	26,2	26,2	0,0	0,0
Connection price: Gas	0,0	0,0	0,0	0,0
Energy cost for natural gas, NPV	-94,1	-70,9	-23,3	0,0
Energy cost for electricity, NPV	-7,8	-7,8	-5,9	0,0
Global incremental cost included in the calculations, NPV, €/m²	**12,0**	**-2,1**	**-8,5**	**0,0**

vides long term price development data for main fuels (oil, coal, gas) which can be utilized when estimating national energy price developments.

Step 7. Sensitivity analyses

It is required in [2] to test at least the sensitivity to the discounting interest rate and energy prices. This will mean the calculation with lower and higher values.

Example:
Estonian reference detached house

Global incremental energy performance related costs included in the calculations is shown in **Figure 3** for discounted interest rate of 1 % that corresponds to real discount rate of 3% and escalation of 2%. The global incremental cost is therefore presented as relative to the business as usual (BAU) construction concept DH 0.96 with gas boiler, that is very close to Estonian minimum requirement of 180 kWh/(m² a) primary energy.

The results show two cost optimal values, as the construction concept DH 0.76 with gas boiler or ground source heat pump achieved the lowest net present value (NPV) of the global incremental cost with marginal difference less than 2 €/m² NPV between these two heating systems. Negative NPV values compared to BAU show that the better construction standard can save some global cost. The lowest NPV defines the cost optimal performance level which is achieved for DH 0.76 construction concept with primary energy of about 165 kWh/(m²a) for gas boiler and about 110 kWh/(m²a) for ground source heat pump. As the global cost is less than 2 €/m² higher for ground source heat pump, the primary energy value of it would be relevant to select for the cost optimal energy performance level. This primary energy of 110 kWh/(m²a) is also achievable with reasonable global cost increase with air to water heat pump, gas boiler and district heating.

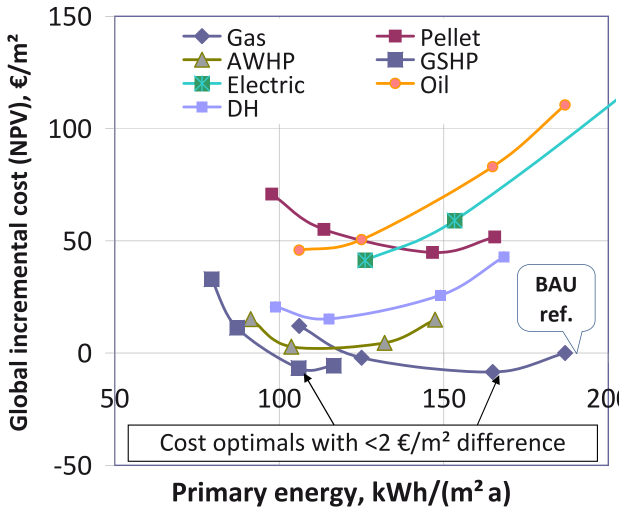

Figure 3. Global incremental energy performance related costs in the reference detached house calculated with the real discount rate of 3% and the escalation 2%, and 30 years time period. (AWHP – air to water heat pump, GSHP – ground source heat pump, DH – district heating.) For each heating system curve, the dots from left to right represent DH 0.42, 0.58, 0.76 and 0.96 construction concepts. The cost optimal values marked with arrows show that marginal, 2 €/m² change in the global cost led to highly significant change in the primary energy of about 55 units.

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