nZEB energy performance comparison in different climates and countries

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In this article nZEB energy performance requirements of two Central European and two North European countries are compared. A reference office building with economic insulation thickness in all climates was used as a starting point of the comparison. Primary energy values were simulated with national input data and technical solutions were changed so that close enough compliance was achieved in every country. It is concluded that there is no direct way to compare the performance level of national nZEBs; instead a reference building simulation method has to be used. Generally, national input data caused much more difference than the climate did.

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Introduction

The European Energy Performance of Buildings Directive (EPBD) recast from 2010 set an ambitious energy performance target of nearly zero energy buildings (nZEB). According to the nZEB definition in the directive, these buildings shall have a very high energy performance. Definition of a very high energy performance is left to each Member State (MS) to decide based on local conditions and their own national methodology for energy calculations. This creates the need to be able to compare energy performance of buildings built according to the requirements of different MS.

The European Commission Joint Research Centre has recently evaluated all existing national nZEB definitions [1]. In 2016 the number of MS with an nZEB definition with a numerical target of primary energy use has increased, but still the definition was not approved in 9 countries, as shown in Figure 1, "NZEB Definition" column.

National nZEB requirements were found to be quite different in terms of numeric values, building categories for which they apply, energy flows included and renewable energy accounting, as well as national input data used for energy calculation. Most of the MS use primary energy requirements, i.e. delivered energy is multiplied with national primary energy factors and exported energy (multiplied with the same factors) is subtracted from the final requirement value. However, in some countries Class A or % of existing minimum level type of recommendations exist. A full set of national requirements can be found in the JRC report. In Table 1 these are shown for four countries, benchmarked in this article.

Table 1. The primary energy national requirements (PE indicator) for office buildings, energy flows included, and primary energy factors according to national regulations. For comparison, existing 2016 requirements are shown; nZEB is required for buildings completed in 2021.

	PE INDICATOR	ENERGY FLOWS	OFFICE BUILDINGS REQUIREMENT		PRIMARY ENERGY FACTORS	
			2016	nZEB	2016	nZEB
Finland	E [kWh/(m²·a)]	DHW, heating, ventilation, cooling, auxiliary, lighting appliances	170	100	Electricity 1.7 District heating 0.7 Natural gas 1.0	Electricity 1.2 District heating 0.5 Natural gas 1.0
Estonia	ETA [kWh/(m²·a)]	DHW, heating, ventilation, cooling, auxiliary, lighting, appliances	160	100	Electricity 2.0 District heating 0.9 Natural gas 1.0	Same as for 2016
France	C_{ep} [kWh/(m²·a)]	DHW, heating, ventilation, cooling, auxiliary, lighting	$C_{ep, max} = 50 \cdot M_{c, type} \cdot (M_{c, geo} + M_{c, alt} + M_{c, surf} + M_{c, ges})$ [1] 110 [3]		Electricity 2.58 District heating 1.0 Natural gas 1.0	Same as for 2016
Brussels Capital region	CEP [kWh/(m²·a)]	Heating, ventilation, cooling, auxiliary lighting	$45 + max(0; 30 - 7.5C) + 15 \cdot max(0; 192/V_{EPR} - 1)$ 88.2 [3]	$95 - (2.5C)$ **or** $95 - (2.5C) + 1.2(X - 15)$ [2] 88.2 [3]	Electricity 2.5 District heating 2.0 Natural gas 1.0	Same as for 2016

[1] Depending on building type, location, altitude and heating system
[2] If space heating $X<15.0$ kWh/m²·a then use this equation $95-(2.5C)$. Depending on net needed energy for heating
[3] for the reference building used in this study

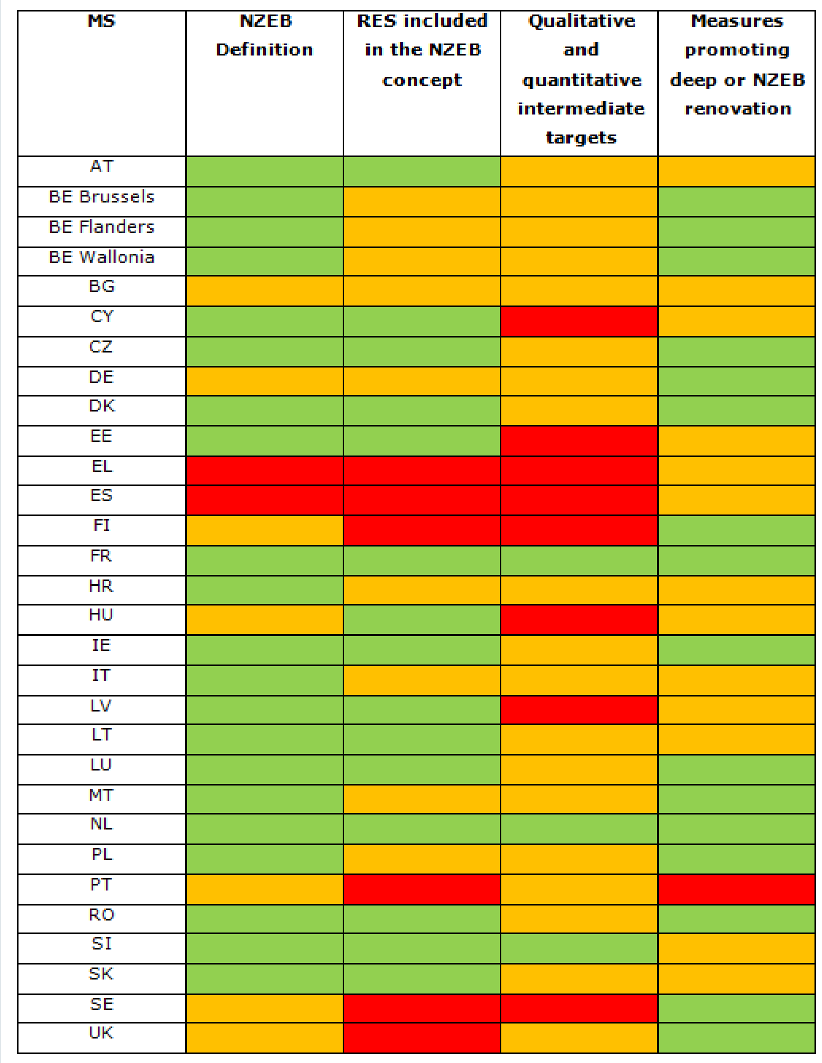

Figure 1. nZEB development evaluation in MS, available definitions, renewable energy included in definitions/system boundary, availability of intermediate targets and promotion measures [1]. Green: satisfactory development; orange: partial development; red: not defined/unclear.

According to national regulation, the Finnish and Estonian office buildings have to comply with fixed PE values (Table 1), which do not depend on geometry and location of offices. In contrast, the French regulation considers a coefficient that depends on the floor surface area ($M_{c,\ surf}$), which can influence the PE requirement. However, the coefficient is zero when it is considered as the average surface area of the building or part of the building. For the Brussels capital regulation, the net heated area, heat loss area and compactness (depends on region) determines the PE requirement.

Since comparison and assessment of national nZEBs is challenging, the European Commission has published official recommendations, EU 2016/1318 [2], in order to ensure that nZEB targets are possible to meet by 2020. The main recommendations reflect EC concerns about low ambition of national nZEB targets as well as the challenge with time schedule to deliver nZEB by the end of 2020.

Some highlights of the recommendations:

- Set national definitions of **nZEB at a high level of ambition** – not below the cost-optimal level of minimum requirements.
- Use **renewables in an integrated design concept** to cover the low energy requirements.
- Assure proper indoor environment to avoid deterioration of **IAQ, comfort and health**.

The recommendation of the nZEB ambition level states that the nZEB level for new buildings has to be determined **by the best technology that is available and well introduced on the market at that time, financial aspects, and legal and political considerations at national level**. In order to make proper ambitions transparent, EC has set **numeric benchmarks for nZEB** primary energy use in four climate zones, Table 2.

Table 2. Numeric benchmarks for nZEB primary energy use set by EC recommendations EU 2016/1318. Net primary energy means that primary energy from that on-site renewable energy is reduced. Default values of on-site renewables are also provided.

	MEDITERRANEAN	OCEANIC	CONTINENTAL	NORDIC
	Zone 1: Catania, Athens, Larnaca, Luga, Seville, Palermo	**Zone 4**: Paris, Amsterdam, Berlin, Brussels, Copenhagen, Dublin, London, Nancy, Prague, Warszawa	**Zone 3**: Budapest, Bratislava, Ljubljana, Milan, Vienna	**Zone 5**: Stockholm, Tallinn, Helsinki, Riga, Gdansk, Tovarene
Offices kWh/(m² · a)				
net primary energy	20-30	40-55	40-55	55-70
primary energy use	80-90	85-100	85-100	85-100
on-site RES sources	60	45	45	30
New single family house kWh/(m² · a)				
net primary energy	0-15	15-30	20-40	40-65
primary energy use	50-65	50-65	50-70	65-90
on-site RES sources	50	35	30	25

Compared to values in Table 1, EC values in Table 2 do not include appliances (small power loads) which are included in Finland and Estonia in Table 1, accounting for 27 and 38 kWh/(m^2 · a) respectively as regulated values. Therefore, Estonia complies well with the EC Nordic recommendation and Finland is very close, but France and Brussels are quite far from the Oceanic recommendations. However, such a direct comparison is very rough and can be biased by different EC vs. national input data and primary energy factors, which is demonstrated in the following analyses.

This article does not specifically focus on heat pumps. However, the subject is very relevant for the present and future legislative landscape that heat pumps are facing, thus motivating that it should be published in the HPT Magazine.

How compare energy performance requirements?

NZEB buildings represent the aspect of energy performance requirements comparison for high performance buildings. Similarly, energy performance comparison could be in the interest of investors or building owners for existing buildings with different locations. In the following, a new method enabling climate and national input data- and methodology-dependent comparisons is discussed.

In order to enable physically meaningful comparisons of energy performance, the method should be able to address three major issues:

1. To normalize heating, cooling and lighting needs in different climates;
2. To account for national methodology and input data differences;
3. To consider cost effectiveness constraints such as economic insulation thickness in different climates.

Because national energy performance values depend on energy calculation input data and calculation rules, it is important to know how much variation these can cause. If the difference is significant, as shown in this study, the comparison is more complicated. A building which exactly complies with requirements in one country can be simulated with input data and calculation methodology of another country in order to see how close the technical solutions of this building are to energy performance requirements of that other country.

In order to account for climate differences, an economic insulation thickness concept may be applied to ensure that buildings are optimally insulated in the climates under comparison. If an economic insulation thickness

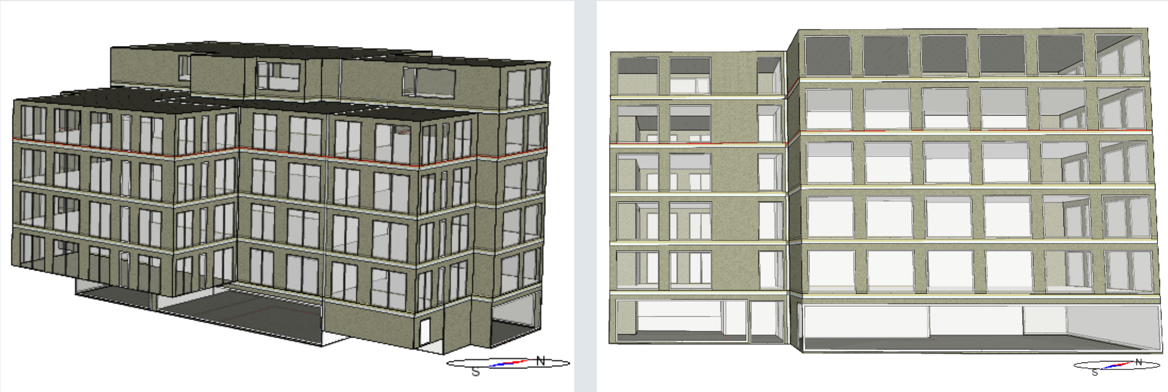

Figure 2. 3D model of simulated reference office building.

is known (or can be estimated) for one climate, it can be calculated for another climate as follows:

$$U_{opt}^{i} = U_{opt}^{ref}\sqrt{\frac{HDD_{ref}}{HDD_i}}$$

where
U^i_{opt} is the U-value in W/(m² · K) corresponding to an optimal insulation thickness in climate *i*;
U^{ref}_{opt} is the known reference U-value in W/(m² · K) corresponding to optimal insulation thickness in the reference climate;
HDD_i is heating degree days in K · d in climate *i*;
HDD_{ref} is heating degree days in K · d in the reference climate.

In the following, a reference office building complying with Estonian requirements is simulated with three other climates and input data in order to see how it complies with requirements of other countries. The building model is shown in Figure 2.

Four cases were simulated for the 2021 nZEB energy requirements as shown in Table 3. NOR (Normal) cases used the reference office building with the reference (Estonian) input data values for all countries, whereas NAT (National) cases used the national input data. NOR cases represent the situation where Estonian insulation thickness was applied to other countries, thus clearly over-insulating in France and Belgium. NOR*i* and NAT*i* cases applied economic insulation thickness to avoid this problem. As national input values deviate strongly, NAT and NAT*i* cases show the effect of this variation.

Reference (Estonian) and national input data as well as economic insulation thickness data are shown in Table 3. Energy need in the building was simulated according to the hourly weather data of respective countries. Building operation hours etc. data called 'Other parameters' in the Table 3 were set to NAT and NAT*i* cases according to the national regulation. It can be seen that economic insulation thickness and corresponding U-values change significantly according to the climate. On the other hand, national input data of occupancy, ventilation and temperature setpoints show quite a remarkable variation.

Table 3. Case description for simulation.

CASE CODE	CASE DESCRIPTION
Case 1: NOR	Reference office building with reference input data, but with national climate files
Case 2: NAT	Reference office building with national input data
Case 3: NAT*i*	Reference office building with economic insulation and national input data
Case 4: NOR*i*	Reference office building with economic insulation and reference input data

Table 4. Input data for NOR, NAT, NORi, NATi cases.

Building insulation thickness and U-values in NORi and NATi cases				
	FINLAND	ESTONIA[1]	FRANCE	BRUSSELS
External wall [m]	0.205	0.20	0.125	0.135
Roof [m]	0.308	0.30	0.188	0.20
External wall [W/(m² · K)]	0.168	0.17	0.268	0.25
Roof [W/(m² · K)]	0.111	0.11	0.175	0.166
Window glazing unit [W/(m² · K)]	0.607	0.62	1.007	0.935
Window 10% frame [W/(m² · K)]	0.646	0.66	1.006	0.942
Window 30% frame [W/(m² · K)]	0.725	0.74	1.005	0.955
Other parameters in NAT and NATi cases				
	FINLAND	ESTONIA[2]	FRANCE	BRUSSELS
Occupant [m²/person]	17	17	10	15
Appliances [W/m²]	12	12	1.6	3
Lighting [W/m²]	6	6	9.8	9.8
Appliances & lighting operation hour	7:00-18:00	7:00-18:00	8:00-18:00	8:00-18:00
Usage factor	0.65	0.55	0.6	0.6
Hot water consumption [l/m² · a]	100	100	35	0
Fan operation hour	6:00-19:00	6:00-19:00	6:00-19:00	6:00-19:00
Air flow rate [l/m² · s]	2.0	2.0	0.7	1.2
Heating set point [°C]	21	21	19	19
Cooling set point [°C]	25	25	26	23

1] Estonian input values of Building insulation thickness and U-values apply to NOR and NAT cases of other countries.
2] Estonian input values of Other parameters apply for NOR and NORi cases for all other countries.

With the input data of Table 4 energy simulations were run, Figure 3. For NOR cases, the variation of heating and cooling is caused by the difference in climate. In the Estonian case, there is no difference between NOR and NAT, because Estonian input data was used as a reference. In Finland only small changes can be seen, therefore the Finnish input data is similar to the Estonian one. In France and Belgium, the national input values have caused remarkable changes in delivered energy. This is because the lower ventilation rate, lower number of operation hours and different installed lighting and appliances power, which follow the French and Brussels capital regulation. Generally, it can be seen that national input data can cause more difference than the climate does.

In the NOR*i* cases, the heating need has significantly increased in France and Belgium, but is still smaller than in Estonia and Finland. In these cases the same cost-benefit-justified economic effort is done in

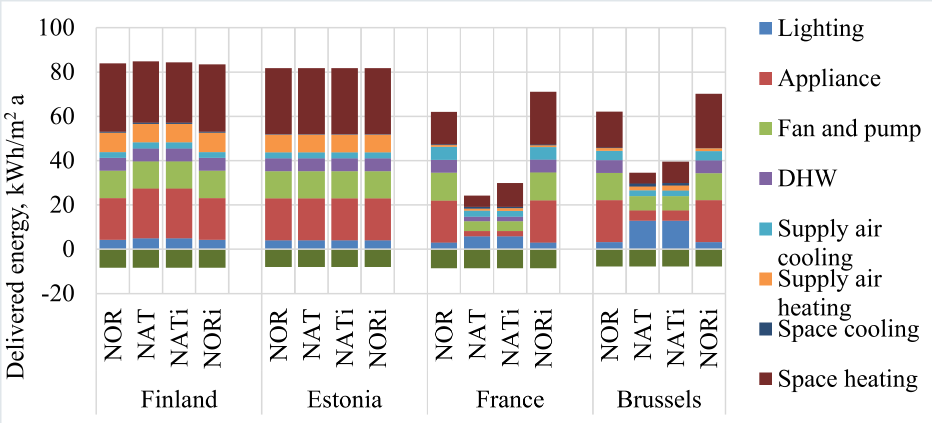

Figure 3. Comparison of delivered energy use in simulated cases with reference and national input values.

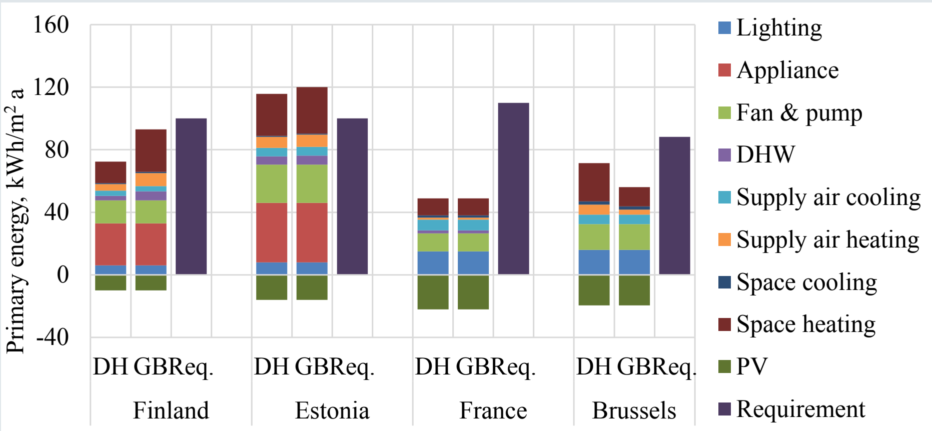

Figure 4. Primary energy in NATi cases office buildings compared with nZEB regulation. DH refers to district heating, GB to gas boiler and Req. to nZEB energy performance requirement. Negative values of PV have to be subtracted from positive values in order to obtain the primary energy value (which can be compared with the requirements).

insulation, which suggests that energy performance should be equal in all countries. However, in warmer climates the heating need naturally remains smaller.

Ambition of national nZEB requirements

The NAT*i* cases of all countries have economic insulation thickness as well as input values according to national regulation. The delivered energy reported in Figure 3 does not show the compliance with energy performance requirements, because the requirements are for primary energy and PE factors are to be applied. PE use in office buildings for NAT*i* cases are shown in Figure 4.

The Estonian nZEB requirement appears to be the strictest one of the building regulations. The Estonian building with DH system just fulfilled the nZEB requirements, whereas in the building with GB system it was necessary to increase the onsite electricity production (need to increase the PV panel area from 213 to 266 m²) to fulfill the nZEB requirements. For the other countries there was room to change some building and system parameters in order to be closer to nZEB requirement.

The following changes were made:

- In the Finnish, Belgium Brussels and French nZEB office building the PV system was removed,
- In Finland, the nZEB level was targeted with DH and in Brussels with GB, which are common heating solutions in these countries (due to lower primary energy factors these allow to use more delivered energy),
- In Finland and Brussels, 2016 building insulation, fan power, heat recovery efficiency, and glazing U value 1.4W/(m²·K) were applied,
- In France even less insulation was used, the U-value of external walls, roof and windows were changed to 0.6 W/(m²·K), 0.4 W/(m²·K) and 2.0 W/(m²·K), respectively. Specific fan power

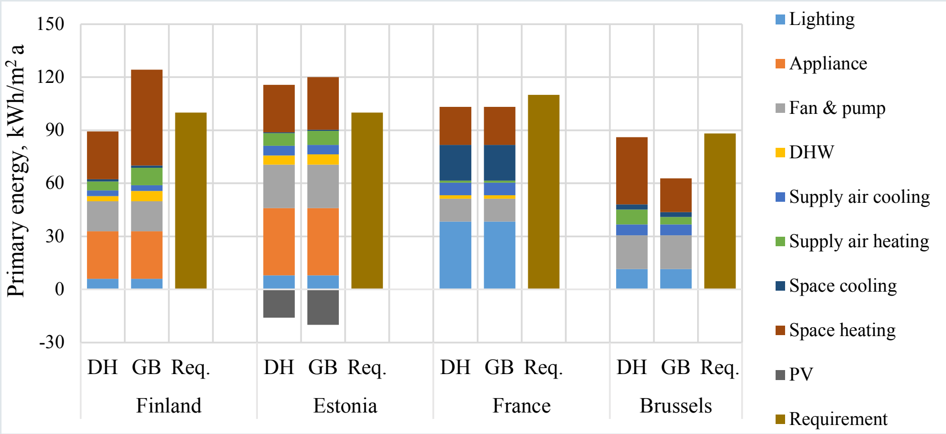

Figure 5. Primary energy in nZEB office buildings with changed parameters in order to target nZEB requirements.

(SFP) of ventilation system was increased to 1.82 kW/(m^3 · s) and daylight control of lighting was removed.

The results after these changes are shown in Figure 5.

It can be seen that the Finnish nZEB requirement can be considered the second strict after Estonia, because the result is closer to the requirement than that in Belgium Brussels. The French nZEB regulation appeared clearly the less strict, as it allowed to use highest U-values and SFP and no daylight control.

Conclusions

It may be concluded that there is no simple way to compare the performance level of national nZEB. In Central and North Europe comparisons, national input data caused much more difference than the climate. To make the comparison, a reference building with economic insulation thickness and otherwise with the same technical solution was simulated with national input data. The technical solutions were selected so that the building complied with requirements in one country. Primary energy values simulated with national input data were then compared with national requirements in other countries, and if a gap existed, the technical solutions were changed to minimize the gap. The requirement of the country needing the technical solutions with highest performance level corresponds to the strictest nZEB level. Results show that the strictest requirement did not necessarily have the lowest primary energy numeric value. The results are reported and discussed in more detail in the research article [3].

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