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Danish, Estonian and Finnish NZEB requirements comparison with European Commission recommendations for office buildings in Nordic and Oceanic climates

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Abstract. Direct comparison of building energy performance levels between countries is usually not possible due to differences in climatic conditions, calculation methods, primary energy (PE) factors and input data. The aim of this paper is to analyse the differences in nearly zero energy office buildings requirements and energy calculation methodology in Denmark, Finland, and Estonia. The study is based on a newly built Estonian office building, designed to meet national NZEB requirements. To account for the climatic differences between the countries a heating-degree-days-based correction factor was applied for building envelope thermal transmittance. NZEB requirements for each country are compared with European Commission (EC) recommended values (EU 2016/1318) using normalization and benchmarking through detailed computer simulations. National NZEB primary energy threshold was needed to be reduced by 7% in Denmark and by 23% in Estonia to meet EC recommendations. At the same time, the flagship reference building, that was better than Estonian NZEB, met both Nordic and Oceanic EC recommendations. Finnish NZEB requirement was not exceeded with any building configuration applied in this study, indicating that Finnish NZEB is considerably less strict compared to Danish and Estonian ones.

1 Introduction

The EC recommendations on building energy performance levels, 2016/1318 [1] have been the basis for national NZEB requirements in EU Member State (MS) countries. Each MS has the freedom to implement its own methodology on estimating the energy consumption of building design as well as to set maximum limits for primary energy consumption. The country-specific differences in energy performance calculation procedures include a variety of standardized parameters and variables, specifics in energy consumption calculation methods [2] and differences in primary energy factors which heavily dictate the preferred technical solutions and define the calculated performance outcomes [3]. Due to the differences in the energy performance calculation methods, there is no direct method to compare the required level of energy efficiency of buildings between the MS countries.

This paper aims to compare and to give an overview of the "strictness" of requirements and the NZEB performance levels between Nordic and Oceanic countries.

2 Research methods

We used the following steps to analyse the energy performance requirements and compare the methodological differences between Nordic (Estonia, Finland), Oceanic (Denmark) countries, and EC recommendations on office buildings energy efficiency:

- Selecting a reference NZEB office building and creating a simulation model based on the building design documentation.
- Calculating and applying correction factors for envelope elements U-values for each country to account for climatic differences based on Test Reference Year (TRY) climate data.
- Conducting energy performance calculations by following country-specific methods and requirements [4-8] using IDA ICE software [9].
- Conducting energy performance calculations using national TRY weather and input data for standard use from EN 16798-1:2019 [10] to fulfil the EC PE recommendation for NZEB [1].
- Comparing and analysing the results to quantify the impact of climatic conditions, methodological differences, and strictness of the NZEB requirements.

The required NZEB performance level is achieved by accounting renewable energy production with on-site photovoltaic (PV) system. Weather data, occupancy and usage rates, internal heat gains, electricity consumption by lighting, appliances and distribution losses of the HVAC systems were changed accordingly to the values specified in the regional calculation methods.

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2.1 Energy calculations and requirements

Energy performance calculation methods between countries vary in terms of usage profiles, energy systems and include different aspects of building energy use. Table 1 presents PE factors for energy carriers used in EC recommendations and national energy performance calculations in Estonia, Denmark, and Finland. Overview of the energy flows included in the national calculations, accounted renewable energy sources (RES) and the allowed maximum PE values to comply with NZEB requirements are given in Table 2.

Table 1. Primary energy factors used in European Commission recommendations (EC), Estonia (EE) [4], Denmark (DK) [8] and Finland (FI) [11].

Energy carrier	Primary energy factors, -			
	EC	DK	EE	FI
Electricity	2.3	1.9	2.0	1.2
District heating	1.3	0.85	0.65	0.5
Natural gas	1.1	1.0	1.0	1.0

Table 2. National and EC NZEB PE requirements for office buildings and energy flows included in the PE calculations.

Region	Accounted energy	PE limit, kWh/(m^2·y)
EC, recommendation [1,10]	HVAC, DHW, aux	Oceanic: 40-55 (incl. 45 RES) Nordic: 55-70 (incl. 30 RES)
EE, requirement [4]	HVAC, DHW, aux, lighting, and appliances	100 (130^(*))
DK, requirement [8]	HVAC, DHW, lighting	41 + 1000 / A_{gross} (incl. max 25 RES)
FI, requirement [11]	HVAC, DHW, aux, lighting, and appliances	100

(*) Additional PE requirement without accounting RES

2.2 Climate corrected U-values

To account for the differences in climatic conditions, we used correction factors to calculate climate-corrected thermal transmittances (U-values) for the building envelope elements - windows, external walls, roof, and floor on ground. To calculate the specific correction factors, building use specific degree days are calculated using dry bulb outdoor temperatures from country-specific TRYs. The building specific degree days account for building use and internal heat gains and are calculated by summing up hourly temperature differences between indoor temperature and outdoor temperature. The correction method is based on the equation (1) developed by Kaiser et al [12]:

$$U_{opt}^{ref} = U_{opt}^{j}\sqrt{\frac{H_{DD^j}}{H_{DD^{ref}}}} \qquad (1)$$

where U_{opt}^{ref} is the optimal thermal transmittance of the respective building element for a reference climate (W/(m^2K), U_{opt}^{j} is the optimal thermal transmittance of the building element for a respective climate (W/(m^2K), H_{DD^j} is the number of heating degree days of the building for a respective climate (°Cd) and $H_{DD^{ref}}$ is the number of heating degree days of the building for a reference climate (°Cd).

2.3 Analysed building

The analysed building is designed and constructed to meet Estonian NZEB energy performance level requirement, i.e., the building envelope elements as well as technical and automation systems are designed as best practice cost optimal solutions to meet the NZEB energy efficiency requirements. Heated area of the analysed office section of the building is 4776 m^2. Energy efficient demand-controlled ventilation systems, low temperature radiator heating and high temperature cooling using active chilled beams ensures low energy consumption for space conditioning. Lighting system is equipped with occupancy sensors and dimming based on available daylight. Envelope air permeability rate q_{E50} is 1.0 m^3/(h m^2).

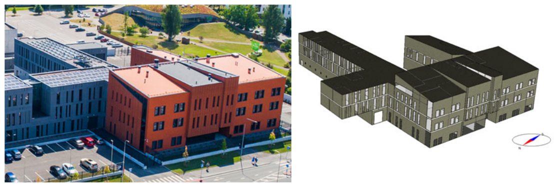

Fig. 1. Photo and energy model of the analysed NZEB office building.

3 Results and discussion

3.1 Effect of climate-corrected U-values

The TRY-based heating degree days with constant and dynamic internal base temperature, in which the changing internal heat gains in the building are accounted for, are shown in Fig. 2. As ambient temperature differences during heating period between Estonian and Finnish TRY-s are small, the summed degree days give also similar values. The relative differences increase marginally if dynamic base temperature is used instead of constant one. The correction factors and climate corrected thermal transmittances for envelope elements are shown in Table 3.The initial Estonian building values are used as a reference for transitioning from Estonian climate to Finnish and Danish climate.

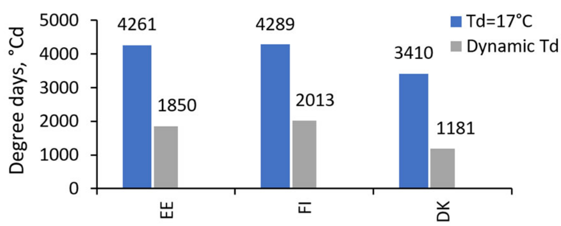

Fig. 2. Degree days calculated from country specific TRYs: calculated with typical constant 17°C and dynamic base temperatures.

Table 3. Climate corrected U-values.

Envelope element	Correction factor, -			U-value, W/(m^2 K)		
	EE	FI	DK	EE	FI	DK
Roof	1.000	1.017	0.914	0.10	0.098	0.109
Ext. walls				0.15	0.147	0.164
Floor				0.15	0.147	0.164
Windows				1.00	0.983	1.094

As the climate is slightly colder in Finland the correction factor is higher and thus U-values lower than the reference Estonian U-values. On the contrary, transitioning to Danish climate, the U-values increase. The differences in annual heating and cooling need when accounting for climate, energy calculation methodology and envelope U-values corrections based on specific climate is shown in Fig. 3.

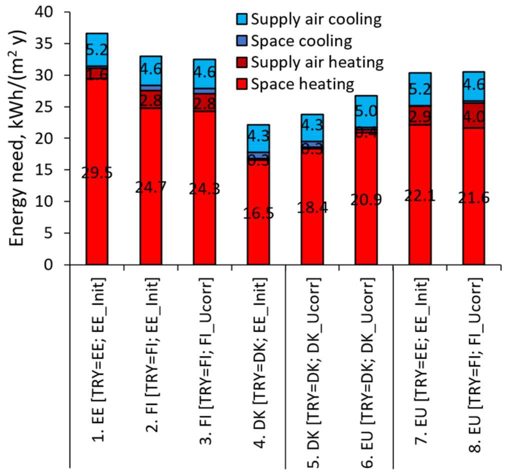

Fig. 3. Comparison of annual energy need (net energy) for heating and cooling using country specific climate data, methodologies, and climate corrected U-values. Calculated according to Estonian (*EE*), Finnish, (*FI*) and *EU* standardized (*EU*) methodology and input data.

Although Finnish TRY ambient temperatures are slightly lower compared to Estonian TRY data, calculations following the Estonian methodology result in higher heating energy need (Fig. 3 cases 1 and 2). Changes to U-values in Finnish case are marginal and don't affect energy need substantially (cases 2 and 3). There is some effect on Danish cases due to bigger differences in climatic data as well as in input data and calculation methodology (cases 4 - 8). Due to relatively small fraction of glazed area on the building façade and low g-value of the glazing, the cooling energy need between cases remains roughly the same with Estonian cases having 3% lower cooling need compared to Finnish cases and 7% lower cooling compared to Danish cases.

3.2 Energy performance

The reference case with initial "as-built" values and without accounting PV-production calculated with Estonian methodology and using Estonian TRY results in only 1.4 kWh/(m^2 y) over the national NZEB PE limit value (Fig. 4, case 1).With the maximum PV installation of 284m^2, 52kW in total, the building meets easily the NZEB requirement (case 2). When considering a building-as-usual case with reduced envelope insulation and typical windows with higher U-values compared to the initial case, it would require 42kW of PV-panels to meet the NZEB PE requirement (case 3). For exact requirement level for the initial case, only 4kW of PV-panels is needed (case 4). This however is not sufficient to reach the EC recommended minimum level performance when calculating with EU standardised input. Additional 39kW of PV-panels is required to achieve the recommended performance level. The latter analysis indicates that it is difficult to reach the recommended performance levels with typical Estonian office buildings designed to meet national NZEB requirements

The initial reference building without climate corrections to the U-values and without accounting local energy production, calculated according to Danish building regulations results in 5.8 kWh/(m2 y) of PE over the Danish NZEB requirement of 41.2 kWh/(m2 y) (Fig. 5, case 1). To achieve the required level, 14kW of PV is needed. Changing the U-values to minimally allowed, also considering the requirement for minimum allowed heat loss (case 2), the primary energy consumption rises 26% and 16.6 kWh/(m2 y) above the requirement. To achieve the limit value, 49kW of PV-panels are needed (case 3). Applying climate corrections to the initial building's envelope elements U-values (case 4) raises the heating energy need and thus also the PE consumption to 53.0 kWh/(m2 y) and by applying 34kW of PV (case 5), the national limit is achieved. This building configuration however does not meet the EC recommended minimum level (case 6) and additional 9kW of PV is required to reduce the PE consumption to reach the limit of 55 kWh/(m2 y) (case 7). The initial building, even with the corrections in U-values, outperforms a building designed to meet the Danish minimum NZEB PE requirement, indicating that the EC recommended level is stricter than the Danish NZEB requirement, as was also the case with Estonian requirement.

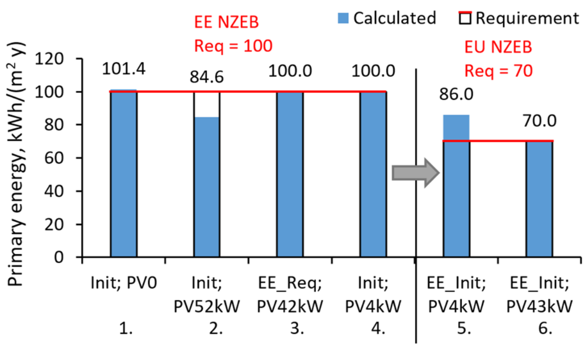

Fig. 4. Annual PE consumption of the reference office building. Estonian cases calculated according to Estonian methodology (cases 1-4) and EU standardized methodology (cases 5-6), all cases with Estonian TRY. [Code: *Init* – Initial building parameters; *EE_Req* – reduced requirements for U-values; *PV_42* – accounting for 42 kW of PV-panels].

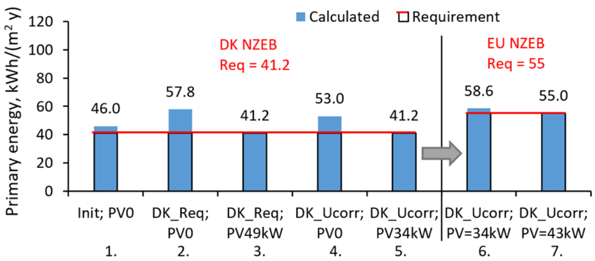

Fig. 5. Annual PE consumption of the reference office building. Danish cases calculated according to Danish methodology (cases 1-5) and EU standardized methodology (cases 6-7), all cases with Danish TRY. [Code: *Init* – Initial building parameters; *DK_Ucorr* – Danish climate-corrected U-values; *DK_Req* – Danish minimum requirements for U-values; *PV_49* – accounting for 49 kW of PV-panels].

The initial building (Fig. 6, case 1) as well as cases with maximum allowed U-values (case 2) and with climate corrected U-values (case 3) calculated according to the Finnish national methodology meet easily the national NZEB requirements without local energy production. The EC recommended level requires roughly the same amount of PV as was the case with Estonia and Denmark.

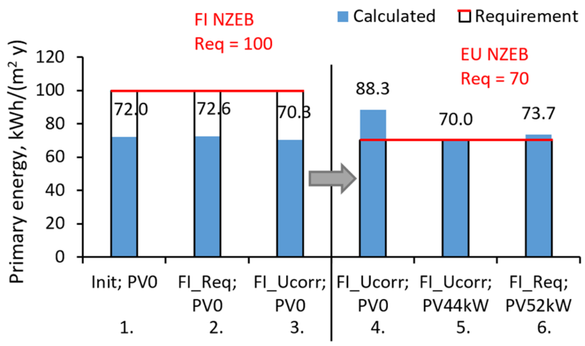

Fig. 6. Annual PE consumption of the reference office building. Finnish cases calculated according to Finnish methodology (cases 1-3) and EU standardized methodology (cases 4-6), all cases with Finnish TRY. [Code: *Init* – Initial building parameters; *FI_Ucorr* – Finnish climate-corrected U-values; *FI_Req* – Finnish minimum requirements for U-values; *PV_44* – accounting for 44 kW of PV-panels].

Analysis shows that the EU Commission recommended primary energy consumption values cannot be achieved without local energy production. Basically, in all the cases near maximum number of PV-panels are required to meet the target value.

4 Conclusions

The study illustrates the strictness of EC NZEB recommendations in Oceanic and Nordic regions. Similar conclusions were drawn by Simson et al. [13] in a previous study based on residential buildings. The study shows that it is difficult to achieve the target PE values in both climate zones. Buildings designed to meet national NZEB requirements did not meet EC recommended values in all three countries studied. National NZEB primary energy threshold was needed to be reduced by 7% in Denmark and by 23% in Estonia to meet EC recommendations. At the same time, the flagship reference building, that was better than Estonian NZEB, met both Nordic and Oceanic (with climate corrected U-values) EC recommendations. Finnish NZEB requirement was not exceeded with any building configuration applied in this study, indicating that Finnish NZEB is considerably less strict compared to Danish and Estonian ones.

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