Nordic-Baltic NZEBs

Exchange of experience

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1 PREFACE

In this report we investigate Nearly Zero Energy Buildings (NZEB) as they are defined in national legislation. We also compare the strictness of the requirements and compare with the recommendations for NZEB building by the European Commission as stated in Commission Recommendation (EU 2016/1318). Additionally, typical build examples in Denmark, Estonia, Finland, Latvia, and Lithuania of NZEB buildings have been identified as well as typical and future technical building installations used in NZEBs have been identified and described.

The project has been carried out as a collaboration between Aalborg University, Department of the Built Environment in Denmark and Tallinn University of Technology, School of Engineering in Estonia with contributions from Kaunas University of Technology, Lithuania and Riga Technical University, Latvia.

The work in this project has been supported by the Nordic Energy Research under the joint Baltic-Nordic Energy Research programme as “Knowledge sharing on NZEB buildings in the Nordic-Baltic region” (project, no. 96752).

SUMMARY

2 SUMMARY

Energy performance requirements in the Nordic and Baltic regions varies significantly. Differences in climate is naturally a significant factor, but the energy demands included in the requirements, calculation procedures, area metrics, and primary energy factors also deviates, so cross country comparisons are not straight forward. As an example, a 150 m² single-family house and a 3000 m² office building have the energy performance requirements shown in Table 1. One of the major reasons for the differences among the five countries is the inclusion of electricity for light and appliances or not.

Table 1 Maximum allowed primary energy demand for a 150 m² single-family house and a 3000 m² office building in the five countries.

	Single-family	Office building	
Denmark	36.7	41.3	kWh/m².yr
Estonia	120	100	kWh/m².yr
Finland	123.5	100	kWh/m².yr
Latvia	50	45	kWh/m².yr
Lithuania	200.4	143.7	kWh/m².yr

Additionally, some countries set requirements for minimum local production of renewable energy, while others define the phrase “a substantial contribution of renewable energy” as something that comes from the buildings’ connection to the utility grids.

One common feature for all NZEB buildings in the five countries is a highly insulated thermal envelope, typically with U-values for facades around 0.12 W/m²K and roofs/floors with typical U-values around 0.08 W/m²K. Windows are generally 2 or 3 pane low-energy glazing with an overall U-value below 0.9 W/m²K, and there is general focus on minimizing thermal bridges throughout the buildings.

District heating and heat-pumps are the most used installations for space heating. This is caused by the attractive primary energy factors for district heating and the high efficiency factors in modern heat-pumps, which more than equal out the high primary energy factors for electricity.

Installations for utilizing renewable energy sources are found in most NZEB buildings, and photo voltaic (PV) being the most used. This is either a result of a national requirement for a minimum amount of locally produced renewable energy on a building or a cost optimal way to meet the energy performance requirements.

Calculations of selected buildings’ energy performance in a uniform way in the project made it possible to compare the national requirements directly and compare with the recommendations for NZEB’s from the European Commission (EC). The study illustrates the strictness of EC NZEB recommendations in Oceanic and Nordic regions. The study shows that it is difficult to achieve the target for primary energy (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.

In case of the Oceanic zone, the EC recommendations for residential NZEB PE appear to require relatively higher energy performance compared to the Nordic zone recommendations. This is illustrated with the case of Denmark, located in colder part of the Oceanic zone. A highly insulated reference apartment building with district heating and PV fulfilling EC Nordic NZEB recommendation exceeded EC Oceanic NZEB recommendation. At the same time, a reference detached house with ground source heat pump and extensive PV installation was capable to meet EC Oceanic NZEB recommendation. However, this performance level clearly exceeded Danish NZEB and Low Energy.

In the Nordic climate zone, Estonian NZEB requirements complied very closely to EC Nordic NZEB recommendation. Finnish NZEB requirements were less strict and did not fulfil EC Nordic NZEB recommendation.

The study illustrates the need of having two sets of requirements: with and without renewable energy production, as is the case for Denmark and Estonia and for EC benchmarks. Denmark has solved the issue by setting the maximum amount of renewable energy allowed to account in the PE calculation, requiring the building to achieve a sufficient level of energy efficiency by means of thermal insulation and HVAC systems. In Estonia there are primary energy requirements for the building without accounting on-site renewable energy production as well as for the building including renewable energy sources. Finland with less strict requirements, however, has not followed the separation of requirements.

INTRODUCTION

3 INTRODUCTION

In this report we investigate the nearly zero energy buildings (NZEB) requirements as requested in the European Energy Performance of Buildings Directive (EPBD) (EU 2018/844) in the Nordic and Baltic region. NZEB level have been mandatory for new buildings since 1st January 2021. In Denmark however, it has been the minimum requirement since 2018, as the minimum requirements of that time was changed to be the NZEB level as the expected NZEB level (now a voluntary low-energy level) was not economic feasible. The national NZEB requirements are compared with the recommendations for NZEB buildings by the European Commission (EU 2016/1318) to investigate if the national requirements meet the recommendations and if the recommendations are sound for buildings located in the Nordic-Baltic region, but in different climate zones. This is especially valid for Copenhagen, located in the Oceanic climate zone, while Malmö (20 km East of Copenhagen) is in the Nordic climate zone (Hermelink et al., 2013). In this definition, the Oceanic climate zone (zone 4) covers cities like: Amsterdam, Berlin, Brussels, Copenhagen, Dublin, London, Macon, Nancy, Paris, Prague, and Warszawa, with very different heating degree days.

In addition, typical solutions for obtaining NZEB level in the different countries are investigated to identify differences and similarities to learn from each other and inspire across borders.

In the chapters with information on national requirements there are local reference lists, while a global reference list for the rest of the report is found in the References section at page 106.

3.1 National statistics on NZEBs

3.1.1 Denmark

In Denmark the NZEB requirement has been mandatory since 2015 (EPC label A2015) and in addition there was a voluntary low-energy class (EPC label A2020) which was expected to become the NZEB class by 1. January 2021. However, it was found evident, that the baseline of this would not be economical feasible and hence the A2015 class was named the official Danish NZEB class. Table 2 shows the number and heated gross floor area of NZEB (A2015) and low-energy buildings in Denmark by July 2020.

Table 2 Number and area of NZEB (A2015) and the voluntary low-energy class (A2020) in Denmark, July 2020.

	A2015		A2020	
	Buildings	Heated gross floor area	Buildings	Heated gross floor area
Single family houses	13 737	2 424 239	3 248	581 246
Blocks of flats	1 460	2 938 075	240	965 722
Office buildings	152	510.297	17	142 446

Due to the tight requirements in the NZEB classes and the primary energy factors, PV is often used to meet the requirements in a private economical feasible way. Figure 1 shows different combinations of heat supply and use of PV in buildings the comply with the minimum NZEB class (A2015) and the voluntary low-energy class (A2020). About 25 % of the A2015 single family houses use PV, while 68 % of the A2020 houses use PV. The same pattern is found for blocks of flats with 39 % and 71 % respectively and for office buildings with 50% and 94 % respectively. Especially for large buildings, PV is a cost-efficient way to meet the energy performance requirements of the NZEB class and better.

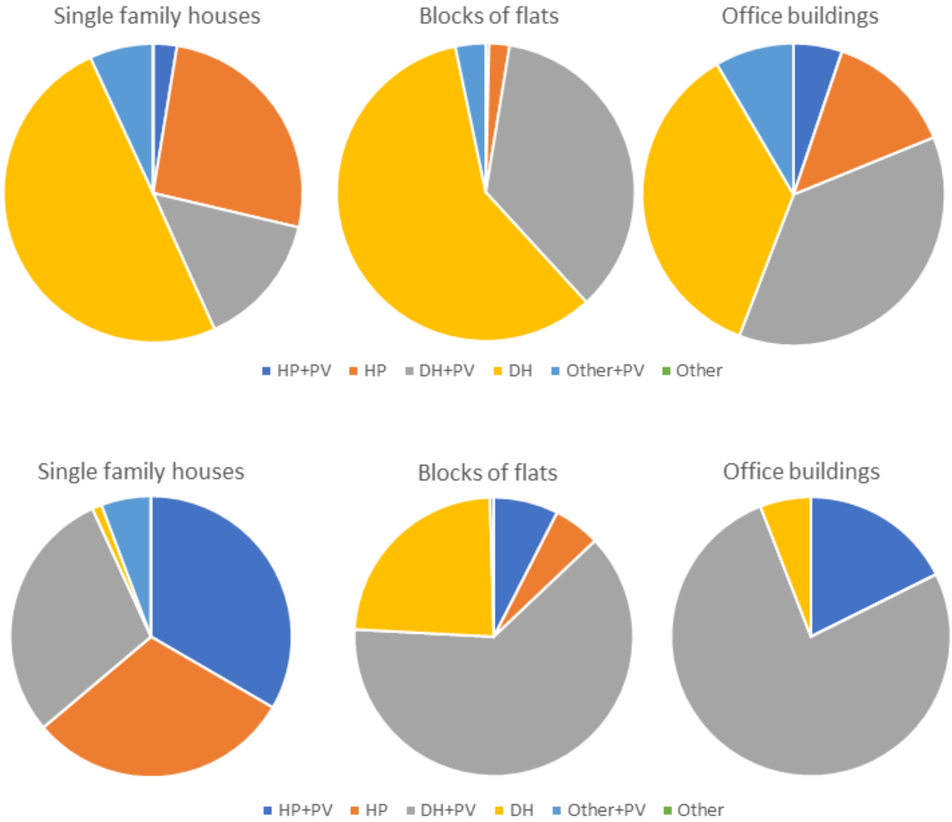

Figure 1 Distribution of combinations of heat supply and PV for Danish NZEB buildings (top) and the voluntary low-energy class (bottom). HP=heat pump; PV=photo voltaic; DH=district heating.

Many large blocks of flats and offices are located inside district heating areas, and this is naturally the dominating heat source, even though the primary energy factor is 0.85 in comparison with the factor 1.9 for electricity (heat pump). Even though, most of these buildings (73-94 %) are supplied with district heating. In single family houses it is different, many houses are outside district heating areas, but even those within the district heating areas often use a heat-pump as heat supply, and the share is increasing from 29 % in A2015 to 64 % in the A2020 class.

3.1.2 Estonia

An EPC certificate in Estonia is expressed in kWh/(m^{2}a), and is regarded as “KEK” if measured, or as “ETA” if calculated (usually with simulation software). As the national regulation does not distinguish between ETA (calculated) or KEK (measured), the names were eventually dropped and each ETA or KEK value was simply regarded as “EPC value” unless the distinction was essential for the analysis. As per European Union standard regulations, energy labels are rated from A (best) to H (worst), corresponding to energy consumption (=EPC value) bounds that are country-specific [1]. The Estonian EPC database consists of a total of 41 652 certificates that were issued between 2004 and 2022, however certificates issued before 2008 do not indicate energy performance levels and are thus regarded from the analysis (Figure 2). The database provides a thorough overview of the country’s building stock energetic history for nearly twenty years. The number of buildings, annual energy consumption and standard deviation of the building types is shown in Table 3 and illustrated in a boxplot in Figure 3 [1].

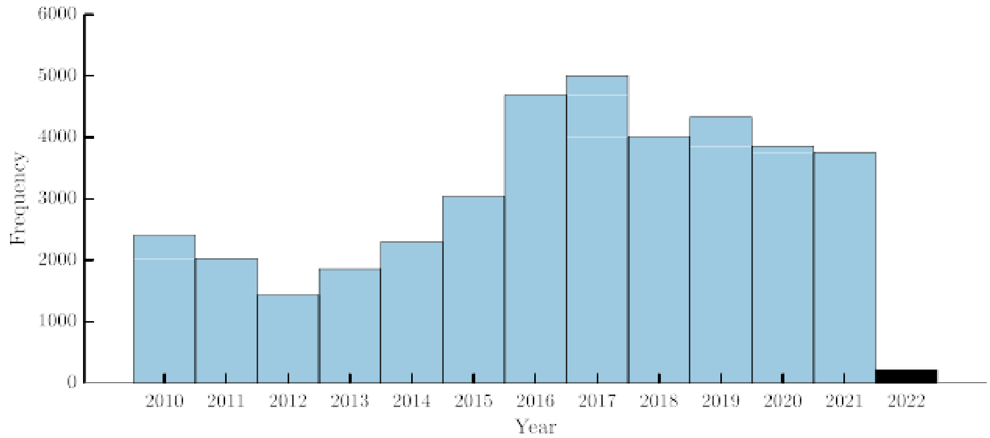

Figure 2. Total number of issued energy performance certificates per year for the Estonian building stock, full database including 41 652 entries [1].

Table 3. Estonian building clusters breakdown of 31 800 EPCs, including number N, mean annual energy consumption M and standard deviation SD (both in [kWh/(m^2 y)]) [1].

ID	Building type	N	M	SD
K1	Kindergartens	701	218.46	78.13
K2	Schools	88	185.9	66.76
K3	Educational (all)	1437	202.22	78.05
K4	Dwellings	21215	146.54	57.87
K5	Apartments	5302	173.8	63.69
K6	Office buildings	1081	197.97	113.83
K7	Commerce, services	731	223	141.38

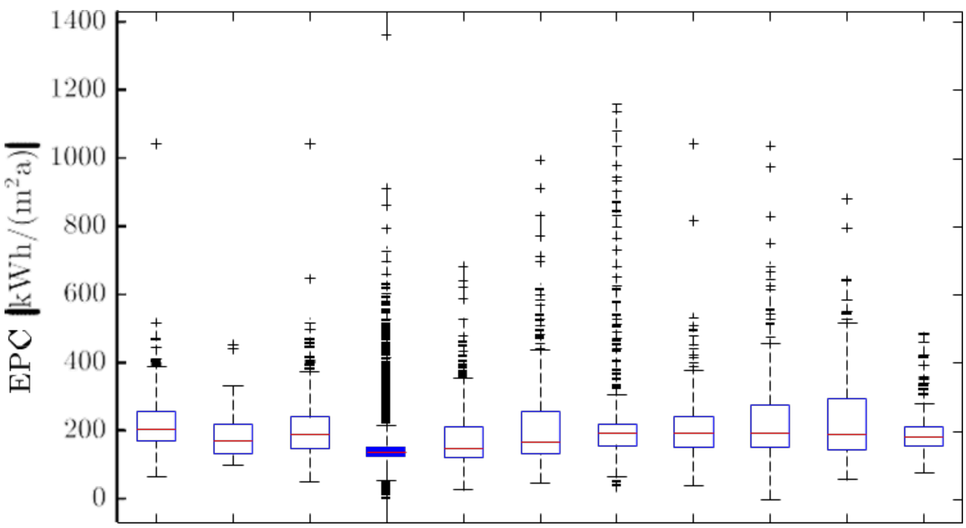

Figure 3. Box plot summarising the EPCs for all building categories [1].

The NZEB level in Estonia, i.e. the EPC value corresponding to class A, was first defined in 2013 and then revised in 2018. The reworked cost-optimality calculations and changes in non-renewable primary energy factors caused the revision of EPC values of class A. Typically, the changes did not exceed 5 kWh/(m2a) except for dwellings, which initially had an EPC value of 50 kWh/(m2a) regardless of the building heated floor area. During the revision, the corresponding values were increased significantly, and currently they depend also on the floor area. Additionally, the EPC certificate class A must be reached only by dwellings with heated floor area above 220 m^2, while other types of dwelling must meet class B requirements. The EPC certificate ETA values for Dwellings are presented in Figure 4, for Apartment buildings in Figure 5 and for Office buildings in Figure 6 [1].

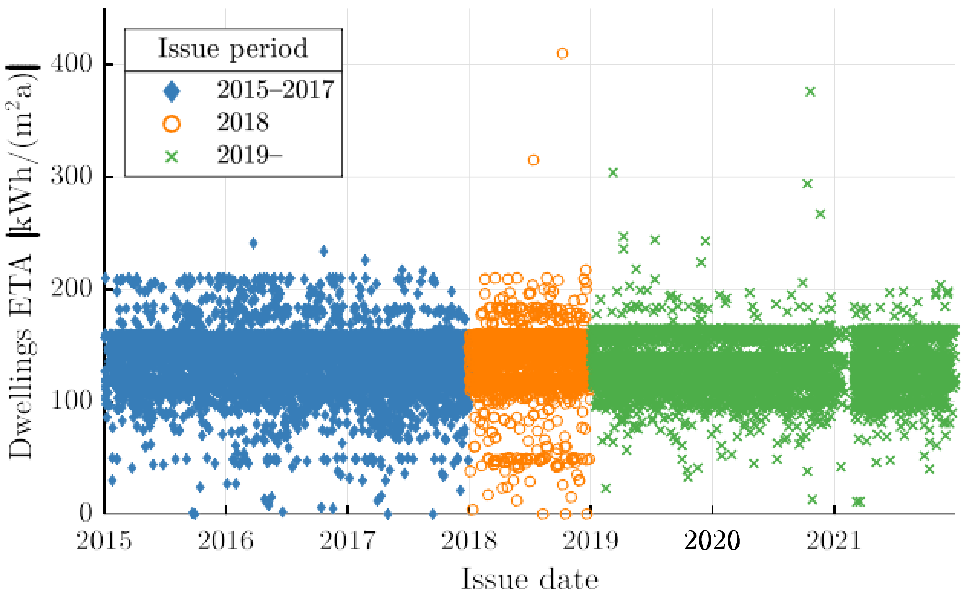

Figure 4. ETA certificates for Dwellings K4 versus date of issue: 2015–2017 (blue diamonds), 2018 (orange circles), 2019–2022 (green crosses) [1].

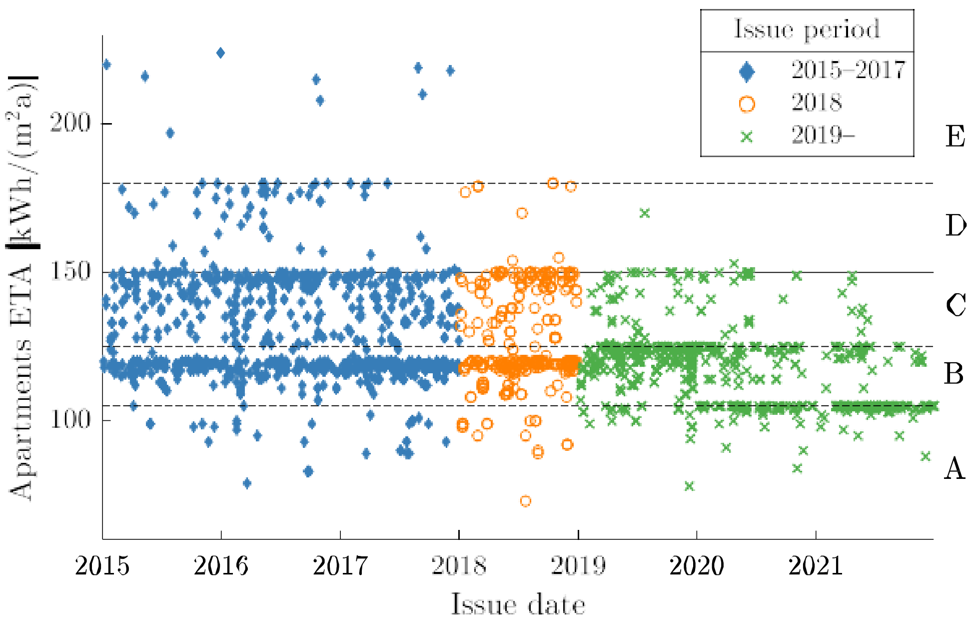

Figure 5. ETA certificates for Apartment buildings K5 versus date of issue: 2015–2017 (blue diamonds), 2018 (orange circles), 2019–2022 (green crosses). The dashed lines denote separation ranges with respect to the energy label [1].

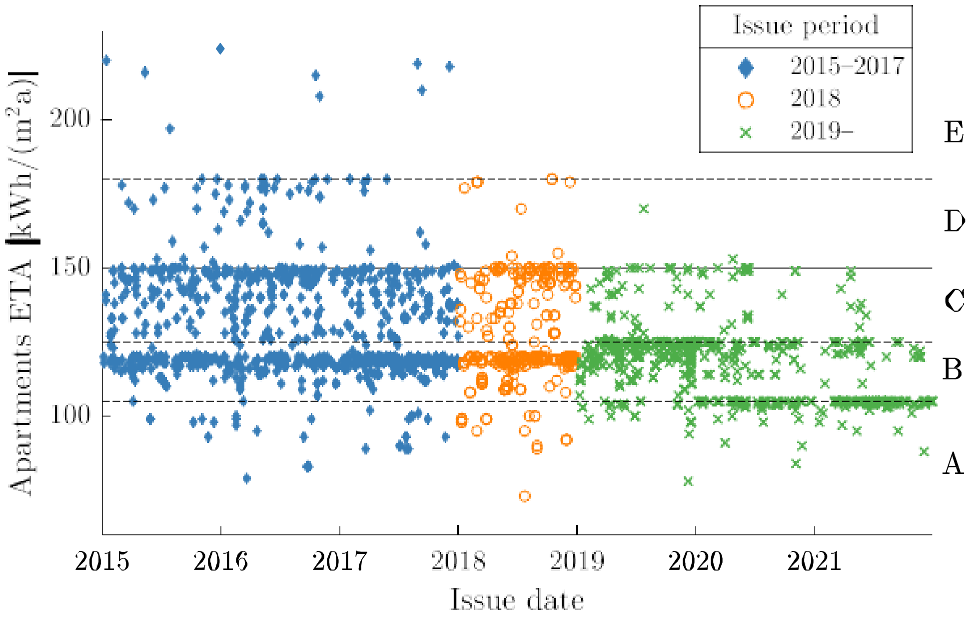

Figure 6. ETA certificates for Office buildings K6 versus date of issue: 2015–2017 (blue diamonds), 2018 (orange circles), 2019–2022 (green crosses). The dashed lines denote separation ranges with respect to the energy label [1].

References

[1] Ferrantelli, A., Belikov, J. Petlenkov, E., Thalfeldt, M., Kurnitski, J. Evaluating the energy readiness of national building stocks through benchmarking. IEEE Access, 2022 (submitted).

3.1.3 Finland

In Finland NZEB requirement corresponds to energy performance certificate class B. NZEB requirements came into force in 2018 when EPC scale and minimum energy performance requirements were updated. In total 46% of buildings for which EPC is issued under this regulation in force belong to NZEB (EPC class A and B), Figure 7. Because the change in 2018 energy performance requirements was done mainly by changing primary energy factors and in most of building categories the real improvement was less than 5%, older EPC-s also indicate the amount of EPC buildings. Figure 8 shows that 17% of buildings for which EPC was issued in between 2013 and 2017 may be considered as NZEB or close to NZEB. This estimate of 17% assumes that about 17% energy performance improvement in 2018 in office, commercial and educational buildings does not affect the classification.

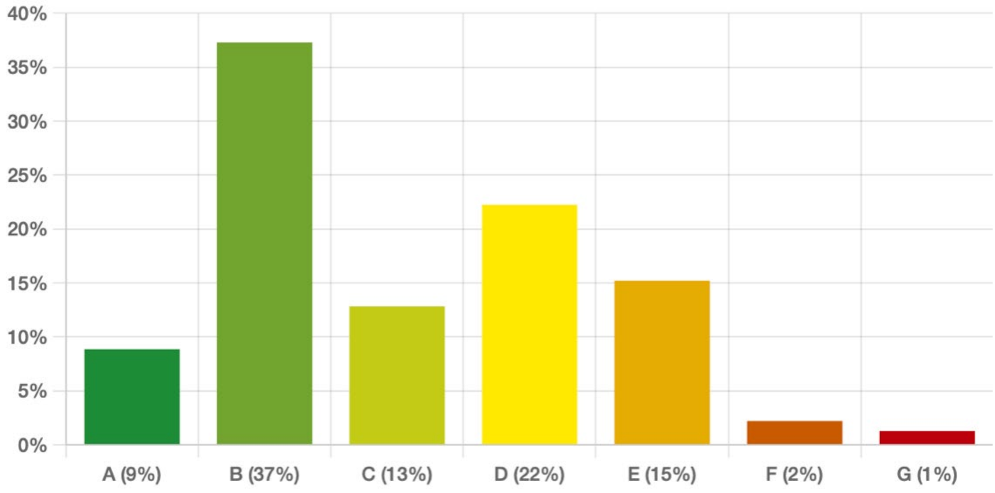

Figure 7 Distribution of EPC classes in buildings for which EPC is issued after launching NZEB requirements in 2018. Class A and B buildings fulfil NZEB requirements. Average: 165 kWh/m²year; Best 15%: 89 kWh/m²year; Worst 15%: 255 kWh/m²year.

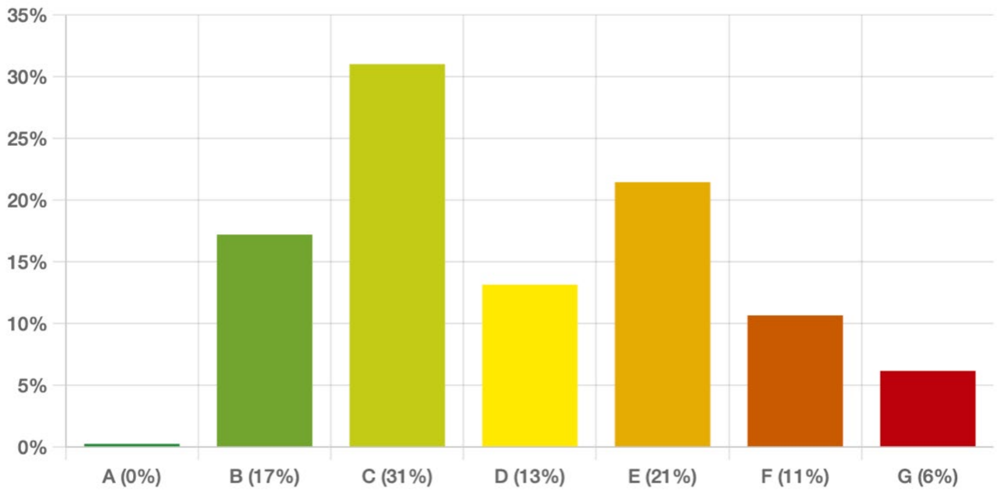

Figure 8 Distribution of EPC classes in buildings for which EPC is issued under the previous regulation of 2013-2017. Average: 217 kWh/m²year; Best 15%: 125 kWh/m²year; Worst 15%: 331 kWh/m²year.

3.1.4 Lithuania

Majority of buildings by heated area (75%) were built in Lithuania before 1993. 58% of the building stock (by area) consists of buildings constructed between 1961 and 1992. Most (83%) of buildings in the building stock do not have an EPC attribute in the national buildings database (Real Property Register) Table 4. Aggregated building stock data by EPC are presented in Figure 9 [1].

All new building since January 2021 are assumed to be constructed according to the Lithuanian NZEB requirements (see page 33). 2/3 (66%) of the building stock surface consists of buildings in energy performance class lower than C. Until 1 January 2021, there were 87 NZEB buildings in Lithuania (Figure 10).

Table 4. Building stock by energy performance class [1].

Group	Energy performance class						Total	Total (%)
	≤D	C	B	A	A+	A++		
1. Residential buildings	**342 160**	**176 116**	**43 305**	**8 077**	**837**	**19**	**570 513**	**86%**
1.1. Private houses	311 020	170 969	38 912	7 814	765	12	**529 492**	80%
1.2. Multi-apartment buildings	31 140	5 146	4 393	263	72	7	**41 021**	6%
2. Non-residential buildings	**78 175**	**6 059**	**5 689**	**713**	**125**	**9**	**90 770**	**14%**
2.1. Industrial buildings	44 552	2 091	1 920	178	29	5	**48 775**	7%
2.2. Administrative buildings	9 085	689	505	81	17	0	**10 377**	2%
2.3. Educational buildings	3 743	634	322	11	5	0	**4 715**	0.7%
2.4. Trading buildings	7 129	626	865	103	35	2	**8 760**	1.3%
2.5. Health care buildings	1 422	189	221	4	2	1	**1 839**	0.3%
2.6. Cultural facilities	4 474	1 066	1 095	246	18	1	**6 900**	1.0%
2.7. Accommodation buildings	2 029	155	147	7	3	0	**2 341**	0.4%
2.8. Service facilities	4 121	411	438	78	11	0	**5 059**	0.8%
2.9. Other buildings	1 620	198	176	5	5	0	**2 004**	0.3%
Total	**420 335**	**182 175**	**48 994**	**8 790**	**962**	**28**	**661 283**	100%
Total (%)	64%	28%	7%	1%	0%	0%	100%	

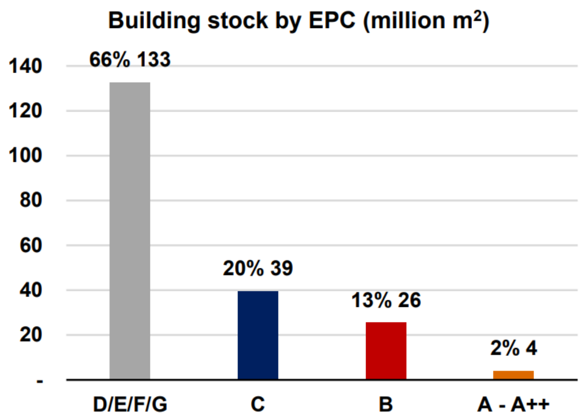

Figure 9 Lithuanian building stock by EPC (as of 31.12.2019) [1].

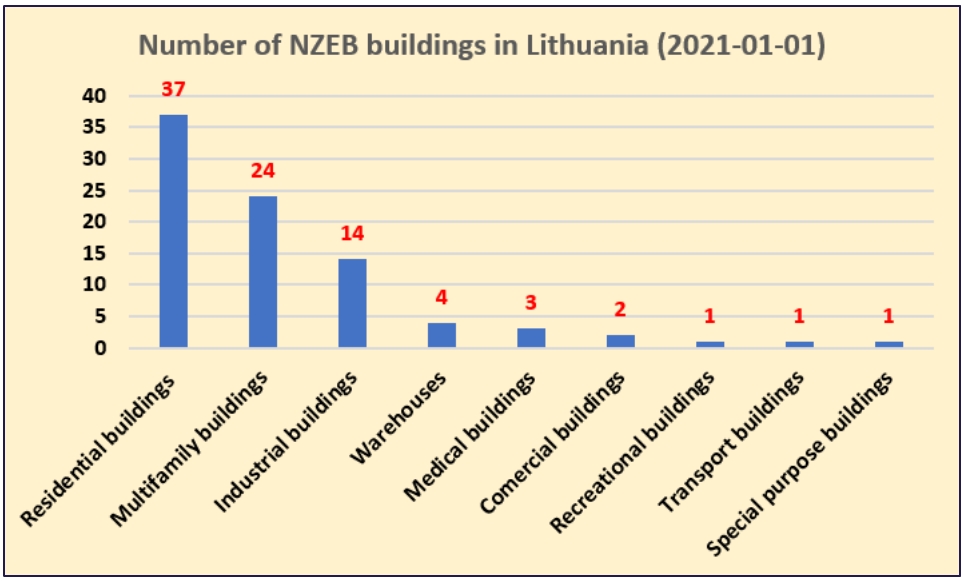

Figure 10 NZEB buildings in Lithuania by 1st January 2021.

References

[1] Long-term renovation strategy of Lithuania (2021). Available from: https://energy.ec.europa.eu/system/files/2021-08/lt_2020_ltrs_en_0.pdf

3.1.5 Latvia

Currently Latvia has little practical experience with nearly zero-energy buildings, mostly in the form of pilot projects, although more and more projects are approaching this level [1].

Near zero-energy buildings in Latvia are defined in Article 1(6) of the Law on the Energy Efficiency of Buildings: 6) a near zero-energy building – a high-efficiency class of building which uses high-efficiency energy supply systems [1].

A near zero-energy building may still be a class A building according to its energy efficiency class, even if a part of the energy consumed is not secured from renewable energy sources. With regard to near zero-energy buildings, Directive (EU) 2018/844 of the European parliament and of the Council on the energy performance of buildings and Directive 2012/27/EU on energy efficiency states that the energy required by near zero energy buildings should be sourced to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby [1].

The currently valid Cabinet Regulation No 383 of 9 July 2013 "Regulations on Energy Certification of Buildings" [2] stipulates that the use of renewable energy must be ensured at least partially in near-zero energy buildings, however, no more detailed requirements in respect of the share of renewable energy resources have been specified. In view of the above, with respect to zero-energy buildings, it is necessary to define the share of energy that is to be covered by renewable energy sources, at the same time keeping in mind the share of energy resources allocated to the centralised production of energy in Latvia. Active work is currently underway to define the necessary share of renewable energy so that a building qualifies as a near zero-energy building [1].

It should also be taken into account that the minimum permissible level of energy efficiency of buildings (by class) is not applicable to new buildings where the application of the relevant requirements would not be technically or functionally feasible or where a cost-benefit analysis across the lifetime of the building would indicate a loss.

Figure 11 shows the distribution of EPC classes in Latvia for the period between 2016 to 2020.

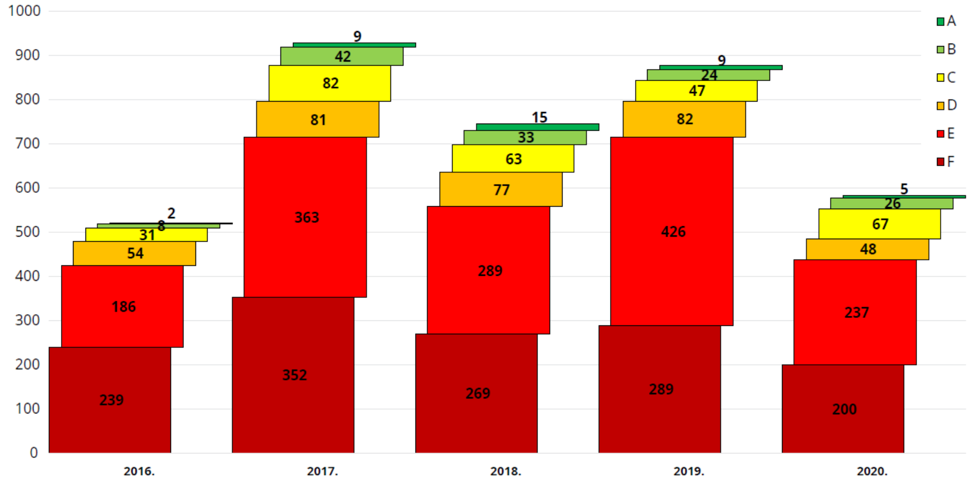

Figure 11. EPC distribution by buildings energy efficiency class by year from 2016 to 2020 [3].

References

[1] Long-term renovation strategy of Latvia (2021). Available from: https://energy.ec.europa.eu/system/files/2021-01/lv_2020_ltrs_official_translation_en_0.pdf

[2] Governmental Regulations No 383 „Regulations on Energy Certification of Buildings"

1

1 1 1 1 7 1 http://likumi.lv/doc.php?id=258322 (in Latvian).
[3] Gendel, S (2020). Building energy certificate statistics. *Civil Engineer*, vol 78, pp. 132-138 (in Latvian).

NATIONAL NZEB REQUIREMENTS

4 NATIONAL NZEB REQUIREMENTS

4.1 European recommendations on NZEBs in different climate zones

In the European Union (EU) the European Commission (EC) Directive on 16 December 2002 on the energy performance of buildings (EPBD) [1] was the first major legislative instrument promoting improvement on the energy performance of buildings on a ‘whole building’ approach. The EC recommendations on building energy performance levels, 2016/1318 [2] effective as of July 2016, have been the basis for national NZEB requirements in EU Member State (MS) countries. In the Commission Recommendation on guidelines for the promotion of nearly zero-energy [1] it is stated that there cannot be a single level of ambition for NZEB across the EU. Flexibility is needed to account for the impact of climatic conditions on heating and cooling needs and on the cost-effectiveness of packages of energy efficiency and renewable energy sources measures. It is emphasised that the NZEB level for new buildings cannot be below (less stringent) than the 2021 cost-optimal level that will be calculated in accordance with Article 5 of the Energy Performance of Buildings Directive (EPBD). The cost-optimal level should be the minimum level of ambition for NZEB performance.

The recommended benchmarks for energy performance of NZEB have been given for four EU climatic zones in the ranges shown in Table 5:

Table 5 EC recommendations for primary energy thresholds for new office buildings and single-family houses in different climate zones.

Mediterranean — Offices: 20-30 kWh/(m^2.y) of net primary energy with, typically, 80 — 90 kWh/(m^2.y) of primary energy use covered by 60 kWh/(m^2.y) of on-site renewable sources; — New single family house: 0-15 kWh/m^2.y) of net primary energy with, typically, 50-65 kWh/(m^2.y) of primary energy use covered by 50 kWh/(m^2.y) of on-site renewable sources;
Oceanic — Offices: 40-55 kWh/(m^2.y) of net primary energy with, typically, 85-100 kWh/(m^2.y) of primary energy use covered by 45 kWh/(m^2.y) of on-site renewable sources; — New single family house: 15-30 kWh/(m^2.y) of net primary energy with, typically, 50-65 kWh/(m^2.y) of primary energy use covered by 35 kWh/(m^2.y) of on-site renewable sources; and
Continental — Offices: 40-55 kWh/(m^2.y) of net primary energy with, typically, 85-100 kWh/(m^2.y) of primary energy use covered by 45 kWh/(m^2.y) of on-site renewable sources; — New single family house: 20-40 kWh/(m^2.y) of net primary energy with, typically, 50-70 kWh/(m^2.y) of primary energy use covered by 30 kWh/(m^2.y) of on-site renewable sources;
Nordic — Offices: 55-70 kWh/(m^2.y) of net primary energy with, typically, 85-100 kWh/(m^2.y) of primary energy use covered by 30 kWh/(m^2.y) of on-site renewable sources; — New single family house: 40-65 kWh/(m^2.y) of net primary energy with, typically, 65-90 kWh/(m^2.y) of primary energy use covered by 25 kWh/(m^2.y) of on-site renewable sources.

Member States are advised to use renewable energy sources in an integrated design concept to cover the low energy requirements of buildings.

4.1.1 References

[1] Directive 2002/91/EC of the European Parliament and of the council of 16 December 2002 on the energy performance of buildings (EPBD). Official Journal of the European Union; 2002.

[2] Commission Recommendation (EU) 2016/1318 of 29 July 2016 on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings (OJ L 208 02.08.2016, p. 46, CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016H1318)

4.2 Denmark

The responsible body for implementing the EPBD and thus NZEB definitions in Denmark is the Danish Energy Agency, under the Danish Ministry of Climate, Energy and Utilities.

The current energy performance requirement methodologies for new residential and non-residential buildings were implemented through the 2006 Danish Building Regulation as an implementation of Directive 2002/91/EC.

The Danish Building Regulations 2018 (BR18) [Danish Housing and Planning Authority, 2018] sets minimum energy performance requirements for all types of new buildings. In addition to the minimum requirements, the BR18 also sets requirements for a voluntary low-energy class.

The official NZEB definition is the minimum requirements for new buildings in the BR18.

Figure 12 Danish Building Regulations 2018 (left). The Danish Building Regulation (current and historic) can be found at http://bygningsreglementet.dk (right).

4.2.1 Energy frame

The minimum energy performance sets the limit in terms of maximum allowed primary energy demand for a building, including, e.g., thermal bridges, solar gains, shading, infiltration, ventilation, heat recovery, cooling, lighting (for non-residential buildings only), boiler and heat pump efficiency, electricity for operating the building as well as sanctions for overheating. The overheating penalty is calculated as a fictive energy demand, equal to the energy demanded (including primary energy factor of electricity) by an imaginary mechanical cooling system (COP = 3.0) to keep the indoor temperature at 26°C. This additional energy demand is included in the calculated overall energy demand of the building by the monthly-based compliance-checking tool, “Buildings’ energy demand - Be18” (www.sbi.dk/be18).

Renewable energy is included in the calculation. However, for all buildings, the maximum electricity production to be factored in from RES, e.g., solar cells and wind turbines corresponds to a reduction of the need for supplied energy of 25 kWh/m² per year in the energy performance framework (primary energy).

Buildings that comply with the BR18 and the voluntary low-energy class must prove that they have a good thermal indoor climate during hot periods. The indoor temperature in residential buildings must not exceed 27°C for more than 100 hours per year, and 28°C for more than 25 hours per year. This can be done either through "Be18" or via a dynamic simulation tool. In non-residential buildings, the building owner decides the temperature limits, and summer comfort must be proven using a dynamic simulation tool. The airtightness of BR18 buildings can be proven, through a pressurisation test, by meeting a maximum airflow rate of 1.0 l/s.m² (heated gross floor area) at a pressure difference of 50 Pa. If the airtightness is not proven by a test, then an airflow of 1.5 l/s.m² at a pressure difference of 50 Pa must be used in the calculation.

Additionally, the airtightness of the voluntary Low-energy class must be proven, through a pressurisation test, by meeting a maximum airflow rate of 0.7 l/s.m² at a pressure difference of 50 Pa.

The infiltration rate at normal pressure difference is calculated as:

$q = 0.04 + 0.06 \times q_{50}$ inside operational hours and,

$q = 0.06 \times q_{50}$ outside operational hours.

The minimum energy performance (energy frame) for the BR18 requirements (NZEB) is: 30 + 1,000 / A [kWh/m².year] for residential buildings, and 41 + 1,000 / A [kWh/m².year] for non-residential buildings. The minimum energy performance for the voluntary Low-energy class is: 27 [kWh/m².year] for residential buildings, and 33 [kWh/m².year] for non-residential buildings. Areas are defined as heated gross floor area for all requirements.

In buildings, when calculating the total supply of energy needed, the individual forms of supply must be weighed. The following factors are used:

– 1.9 for electricity.
– 0.85 for district heating.
– For other types of heat, a factor of 1.0 and the relevant utility are used.

Extension of the energy frame for non-residential buildings

Non-residential buildings can get an extension of the energy frame due to special use conditions in the building. The special conditions and standard values are listed below. The extension is calculated as a difference between a standard calculation and a calculation using actual values.

– Common lighting level above 300 lux
– Ventilation rate above 1.2 l/sec. per m² heated floor area in use hours during the heating season to meet the atmospheric indoor climate.
– Domestic hot water consumption above 100 l per m² heated gross floor area per year.
– Weekly usage hours above 45 hours per week.
– Average ceiling height above 4.0 m.

Default values for energy performance calculations

Table 6 Input parameters for compliance calculation.

	Residential (standard values)	Non-residential (normal values)
Indoor temperature	20 °C	20 °C
Ground temperature	10 °C	10 °C
Internal gains (loads) Persons Appliances *)	 1.5 W/m² (max 360 W/unit) 3.5 W/m² (min 210 W/unit; max 840 W/unit)	 4.0 W/m² 6.6 W/m²
Domestic hot water Usage temperature	 250 l/m²yr 55 °C	 100 l/m²yr 55 °C
Ventilation	0.30 l/m²s (occupied minimum) 0.15 l/m²s (unoccupied minimum)	

*) Residential buildings: incl. lighting; non-residential: excl. lighting. Energy demand is not included in the energy frame but contributes to heating of the building.

4.2.2 Summer comfort requirements

Methods for specification, verification and control of thermal indoor climate can be found in DS 474 Standard for specification of indoor thermal climate, i.e. thermal dynamic simulation.

For buildings other than dwellings, the client determines the maximum number of hours per. years of service life, where a room temperature (the operating temperature) of 26 °C and 27 °C respectively may be exceeded. For most types of buildings with a service life corresponding to office buildings, exceeding a maximum of 100 hours above 26 °C and 25 hours above 27 °C will normally comply with the provision.

For residential buildings where it is possible to open windows and create ventilation, the provision can usually be considered complied with when it can be demonstrated through a simple calculation that there is a maximum of 100 hours per. years of service life, where room temperature exceeds 27 °C and 25 hours per. years where the room temperature exceeds 28 °C. It is a prerequisite for the use of these temperature limits that it is possible to create ventilation, as ventilation makes it possible to accept higher temperatures. It is also recommended that the function of the rooms be considered when determining temperature levels. For example, rooms that will typically be used as bedrooms can be problematic if most overheating hours occur in the evening.

Documentation for the thermal indoor climate can be done on the basis of simulation of the conditions in the critical rooms on the basis of Design Reference Year, DRY 2013, for the calendar year 2010. For residential buildings, documentation can be done based on a simplified calculation, cf. SBi direction 213 Buildings' energy requirements [Aggerholm, 2006-2018].

4.2.3 Requirements for systems and building components

The Danish Building Regulations include requirements for a wide range of technical building systems.

There are specific energy-related requirements for boilers based on coal, biomass and similar fuels. Boilers operating on coal, biofuels and biomass should, as a minimum, meet the energy requirements of boiler class 5 in the standard EN 303-5. The Ecodesign Regulations include requirements for ventilation units, combined heat and power appliances, oil/gas boilers, heat pumps and circulation pumps for installations.

Opaque thermal envelope

Individual building envelope elements must be insulated to a level ensuring that the heat losses through them do not exceed the values included in the following table. Calculation of loss coefficients must be made in accordance with Danish Standard DS 418:2011 – Calculation of heat loss from buildings [Danish Standard DS418:2011].

Table 7. Maximum U-values and linear losses.

Building element	U-value [W/m²K]
External walls and basement walls in contact with the soil.	0.30
Suspended upper floors and partition walls adjoining rooms/spaces that are unheated or heated to a temperature which is 5°C or more below the temperature in the room concerned.	0.40
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space.	0.20
Suspended floors below floors with underfloor heating adjoining heated rooms/spaces.	0.50
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.20
External doors	1.00
External doors with functional requirements	1.40
Doors and hatches to the outside or to rooms/spaces that are unheated and these as well as glass walls and windows to rooms that are heated to a temperature which is 5°C or more below the temperature in the room concerned.	1.80
Skylight domes	1.40
Insulated sections in glazed external walls and windows.	0.60
Suspended upper floors and walls against freezer rooms.	0.15
Suspended upper floors and walls against cold stores.	0.25
Sliding and folding doors. Reference size is 2.50 m x 2.18 m in 2 and 3 lights respectively	1.5
Light tunnels or similar	2.0
Building element	Linear losses [W/mK]
Foundations around spaces that are heated to a minimum of 5°C.	0.40
Joint between external wall and windows or external doors and hatches.	0.06
Joint between roof structure and roof lights or skylight domes.	0.20

Windows and glazed outer walls

Additionally, the energy balance (E_{ref}) of windows and glazed outer walls must not be less than 0 kWh/m²/year (equal to a A-label window in the voluntary Danish window labelling scheme). The energy balance through roof lights and glazed roofs must not be less than 10.0 kWh/m² per year. The energy balance is calculated for a standard sized window with standardised outdoor conditions as:

Facade windows: $E_{ref} = I \times g_w - G \times U_w = 196.4 \times g_w - 90.36 \times U_w$

Roof windows: $E_{ref} = I \times g_w - G \text{ x } U_w = 345.0 \times g_w - 90.36 \times U_w$

Where I is the average solar irradiation on facades and roofs respectively; g_w is the g-value (solar transmittance) of the window element; G is the number of kilo-degree hours in the Danish climate reference year; and U_w is the overall U-value for the window element.

In the energy performance calculations, the actual windows and glazed outer walls are used in the calculations.

Overall thermal envelope insulation level

In addition to the energy frame, new buildings must be carried out so that the design transmission loss in W per m² floor area does not exceed 12.0 + 6.0/E + 300/A (voluntary low-energy class: 11.0 + 6-0/E + 300/A), where E is the number of floors and A is the heated floor area. Number of floors is a decimal number, which is calculated as heated floor area divided by built-up area (the building's vertical projection on the ground in case of split-levels). Buildings with an average room height above 4.0 meters receive a supplement of 1.0 W / m² per meter average room height above 4.0 meters. Heated basement, which is not part of the floor area, is included with 40% in number of floors and the heated floor area in the dimensioning transmission loss frame calculation.

4.2.4 References

1 Aggerholm S, 2006-2018. Buildings' Energy demand– Calculation guide (In Danish: Bygningers energibehov – Beregningsvejledning). SBi Direction 213. Danish Building Research Institute, Aalborg University, Copenhagen SV.

2 European Commission, 2017. REGULATION (EU) 2017/1369 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU.

3 Danish Housing and Planning Authority, 2018. Danish Building Regulations 2018. Available online in Danish at https://bygningsreglementet.dk/.

4 Danish Standard DS 418:2011 – Calculation of heat loss from buildings. Danish Standard, Copenhagen.

4.3 Estonia

4.3.1 Primary energy requirements

The energy efficiency requirements for buildings in Estonia are defined through the maximum allowed primary energy (PE) consumption and are set in the national regulation [1]. The building energy performance of presented as Energy Performance Indicator (EPI) value in kWh/(m2 a) and the allowed EPI value limit depends on the building type. The EPI value incorporates the energy use for space heating, space cooling, domestic hot water (DHW) production, lighting, appliances, and auxiliary devices, i.e. fans and pumps. The EPI value calculation follows the system boundaries of REHVA's definition [2], but only on-site produced and consumed by the building systems is taken into the account and is subtracted from the delivered energy [3]. Exported energy is not considered when calculating the EPI value. The system boundaries are shown in Figure 13.

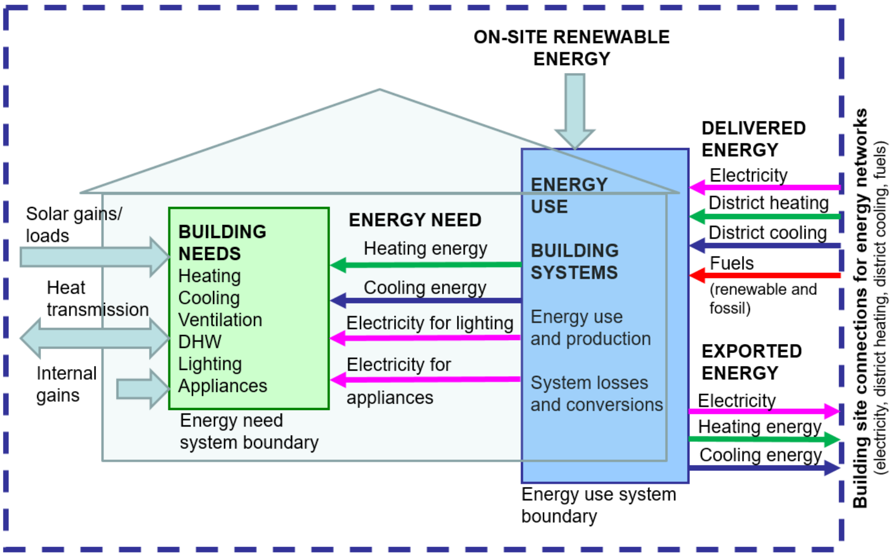

Figure 13. System boundaries for energy need, energy use, delivered energy, exported energy and on-site produced renewable energy [3].

The EPI value is resulted from the net purchased energy multiplied with the relevant primary energy factors (f). The calculation for delivered energy is based on hourly time step data (except for simplified calculations available for detached houses). The national requirements for NZEB building and primary energy factors are shown in Table 7 and Table 8.

Table 8. Maximal primary energy requirements for different building types, according to national regulations [1].

Building type	EPI value requirement, kWh/(m² a)		
	NZEB (class A)	Low energy building (class B)	Renovation of existing building (class C)
Small residential buildings (detached house, row house): a) net heated area <120 m² b) net heated area 120-220 m² and row house c) net heated area >220 m²	 145 120 100	 165 140 120	 185 160 140
Multi-apartment buildings	105	125	150
Military barracks	170	200	250
Office buildings, libraries and research buildings	100	130	160
Accommodation building, hotel	145	170	220
Commercial buildings	130	150	210
Public buildings	135	160	220
Commerce buildings and terminals	160	190	230
Educational buildings	100	120	160
Pre-school institutions for children	100	120	165
Healthcare buildings	100	130	170
Warehouse	65	80	100
Industrial building	110	140	170
Buildings with high energy consumption	820	850	950

Table 9. Primary energy factors (f) according to Estonian regulation [1].

Energy carrier	f
Electricity	2.0
District heating*	0.9
Efficient district heating	0.65
District cooling**	0.4
Efficient district cooling	0.2
Natural gas, oil, coal, peat, solid fossil fuel	1.0
Wood, bio-fuel	0.75

4.3.2 EPI value calculation

The calculation methodology includes the following factors [1]:

– Thermal transmittance of building envelope, linear and point thermal transmittance of thermal bridges, and air leakage
– Indoor air temperature
– DHW demand
– Ventilation
– Thermal loads from occupant, light, appliances, hot water, and solar heat
– Thermal and electrical energy use for spaces heating, ventilation heating, DHW system
– Electricity use for ventilation system (fan and pump), lighting, equipment
– On-site energy generation: with photovoltaic (PV) panels, solar thermal collectors, wind
– Heat recovery from wastewater and/or ventilation.

The EPI value is calculated according to the following equation [1]:

$$EPI = \frac{f_{DH.PF}\, Q_{DH} + \sum_i f_{F.PF}\, Q_F + f_{E.PF}\, Q_E}{A_{net}} \qquad (1)$$

where, $f_{DH.PF}$ is the primary energy factor for district heating, dimensionless; Q_{DH} is the annual district heating energy use, kWh/a; $f_{F.PF}$ is the primary energy factor for fuel, dimensionless; Q_F is the annual fuel use, kWh/a; $f_{E.PF}$ is the primary energy factor for electricity, dimensionless; Q_E is the annual electricity use, kWh/a; A_{net} is the net heated building area, m^2.

Heat losses from building envelope, thermal bridges, ventilation heat losses, system efficiency calculation method, and onsite electricity production are given in details at regulation [3].

4.3.3 Ventilation and temperature setpoints

The EPI value needs to be calculated using specific values for ventilation outdoor airflow rate as well as the room temperature heating and cooling limit temperature shown in Table 9.

Table 10. Ventilation outdoor airflow rates, heating, and cooling setpoints for different building types [1]

Building type	Outdoor air flow rate dm³/(s m²)	Heating set-point, °C	Cooling set-point, °C
Small residential buildings (detached houses) net heated area <120 m2	0.5	21	27
Small residential buildings (detached house, row house) 1	0.42	21	27
Multi-apartment buildings	0.5	21	27
Military barracks	0.5	21	27
Office buildings, service buildings, libraries and research buildings	2.0	21	25
Accommodation buildings, hotels	1.0	21	25
Commercial buildings	2.0	21	25
Public buildings	2.0	21	25
Sports facilities	2.0	18	25
Commerce buildings and terminals	2.0	18	25
Educational buildings	3.0	21	25
Day-care centres, pre-school institutions for children	2.0	21	25
Healthcare buildings	2.0	21	25
Industrial buildings	0.9	20	27
Warehouses	0.35	15	27

4.3.4 Building usage rates, internal heat gains, electricity and DHW use

Daily and weekly operational hours, usage rates for lighting, appliances and occupants need to be accounted to calculate the annual energy consumption of the building. The detailed information is given in Table 10.

Table 11. Building usages rates, internal thermal loads, and heat gains for different building types [3].

Building type	Operation Hours	h/day	Day/week	Usages rate	Lighting W/m²	Appliance W/m²	Occupant W/m²	DHW kWh/(m² a)
Small residential buildings (detached house) net heated area <120 m²	00:00-24:00	24	7	Lighting 0.1 Other 0.6	6	3	3	30
Small residential buildings (detached house, row house) net heated area 120-220 m²	00:00-24:00	24	7	Lighting 0.1 Other 0.6	6	2.4	2	25
Small residential buildings (detached house) net heated area >220 m²	00:00-24:00	24	7	Lighting 0.1 Other 0.6	6	2	1.4	20
Apartment building	00:00-24:00	24	7	Lighting 0.1 Other 0.6	8	3	3	30
Military barracks	00:00-24:00	24	7	0.4	10	2	10	35
Office building, library, and science building	07:00-18:00	11	5	0.55	10	12	5	6
Accommodation building, hotel	00:00–00:00	24	7	0.4	10	1	4	30
Commercial building	12:00–22:00	10	7	0.4	19	4	14	23
Public building	08:00–22:00	14	7	0.5	14	0	5	20
Commerce building and terminal	07:00–21:00	14	7	0.55	19	1	5	4
Educational buildings	08:00-16:00	8	5	0.5	12	8	14	10
Day-care centre, pre-school institution for children	07:00–19:00	12	5	0.4	12	4	8	15
Health care facility	07:00–20:00	13	5	0.6	10	4	8	12
Industrial building	07:00–19:00	12	5	0.55	12	12	4	0
Warehouse	00:00–00:00	24	7	0.2	10	0	0	6

Energy use for lighting and appliances is taken from the national regulation [3] and is to be multiplied with the national PE factor to obtain the PE use for lighting and appliances. The following equation is used to estimate the energy use for lighting and appliance.

$$Q = kP \frac{\tau_d}{24} \frac{\tau_w}{7} \frac{8760}{1000} \quad (2)$$

ing type, dimensionless; P is the thermal load

The net heating energy for domestic hot water is given as a default value depending on the building type.

4.3.5 Building air leakage

The leakage rate is calculated from the following equation:

$$q_{v,leakage} = \frac{q_{50}}{3600\,x} A_{env} \quad (3)$$

where, $q_{v,leakage}$ is leakage air flow rate, m³/s; q_{50} is building air permeability at 50 Pa of air pressure over the building envelope, m³/(h m²); A_{env} is the building envelope area, m²; x is a coefficient dependent of the building height: 35 for single story building, 24 for two story building, 20 for three and four storied buildings 20 and 15 for higher buildings (the coefficient accounts for 3 m for story height).

If the building air permeability is not to be measured or verified during or after the building process, then only base values can be used for the EPI calculation (Table 11). It is possible to use q_{50} value of 1.5 m³/(h m²) in the EPI calculations, however then the building leakage rate is mandatory to be measured (blower door test) or declared/verified via adequate methods.

Table 12. Base values for building envelope air permeability [3].

Building type	Air permeability rate q_{50}, m³/(h m²)	
	New building, substantial renovation	Renovation, existing building
Residential building	4.0	6.0
Non-residential building	2.5	4.0

4.3.6 Alternative simplified compliance assessment method

The simplified method can be used in case of small residential buildings for proving compliance with the limit value of EPI. The designed technical systems for the building must comply with the following requirements:

- The main heat source for space heating and DHW must be ground-source heat pump, air-to-water heat pump, wood-based boiler, district heating or gas-condensation boiler;
- The temperature efficiency of the ventilation system heat recovery must be at least 0.8;
- The ventilation system specific fan power (SFP) must be lower than 2.0 kW/(m^3 s).
- For the purposes of the simplified assessment, it is possible to use an MS excel based calculation tool.

4.3.7 Requirements for the building envelope

The building envelope must be sufficiently airtight and insulated. When determining the insulation suitable for the building, the factors to be taken into consideration are energy performance requirements, maintenance, thermal comfort and the avoidance of condensation and mould growth on thermal bridges, inner surfaces, and structural elements.

In order to maintain comfortable thermal environment in the building, the thermal transmittance of its envelope in general may not exceed 0.65 W/(m^{2}K). If the doors or windows have higher thermal transmittance value, thermal comfort must be ensured with a heating system solution.

The average leakage rate of the building envelope may not exceed the value used in the energy calculation performed to prove the building's compliance with the minimum requirements for energy performance.

4.3.8 Summertime overheating calculation procedure

If no cooling is installed, a dynamic temperature simulation for critical rooms is required to comply with summer temperature requirements. The requirement is regarded as complied with if during the period from 1 June to 31 August, the indoor temperature does not exceed the limit temperature (the cooling setting) by more than 150 degree-hours (°Ch) in residential buildings (base temperature 27 °C) and by more than 100 °Ch in non-residential buildings (base temperature 25 °C). In the case of educational and research buildings (except daycare facilities and pre-school institutions for children, educational and research buildings), the assessment period is set from 1 May to 15 June and from 15 August to 30 September. In this case the buildings are presumed to be closed from 15 June to 15 August. The cooling period may in some buildings be longer than the period referred to above, but this is not considered when assessing compliance with the temperature excess requirement. The energy need for cooling and the energy use of the cooling system are calculated in respect of the entire cooling period.

An exception for detached houses, there the compliance may be alternatively shown with tabulated values for solar shading, window sizes and window airing (4 key performance values).

4.3.9 References

[1] "REHVA NZEB
buildings. REHVA Journal, (03)," 2013.

[2] Estonian Government Ordinance No. 63: "Hoone energiatõhususe miinimumnõuded" [Minimum requirements for buildings energy performance] (in Estonain), RT I, 2018, redacted 25.08.2019.

[3] Estonian Government Ordinance No. 58: "Hoone energiatõhususe arvutamise metoodika" [Calculation methodology for building energy efficiency] (in Estonian), RT I, 2015, redacted 25.08.2019.

4.4 Finland

4.4.1 Primary energy requirements

The maximal primary energy (PE) requirement for Finnish buildings is set in the Finnish regulation [2]. The energy performance of a building is presented as E value (PE value), unit is kWh/(m² a), which is either a fixed value or depends on building type, function and geometry. The E number incorporates the energy use for space heating, space cooling, domestic hot water (DHW), lighting, appliances, and auxiliary devices, i.e., fan and pump. The E value follows the system boundaries of REHVA [1] definition, but only onsite renewable energy used in the building is taken into the account, reducing the delivered energy. Exported energy is not taken into account. The system boundaries are shown in Figure 14 [1].

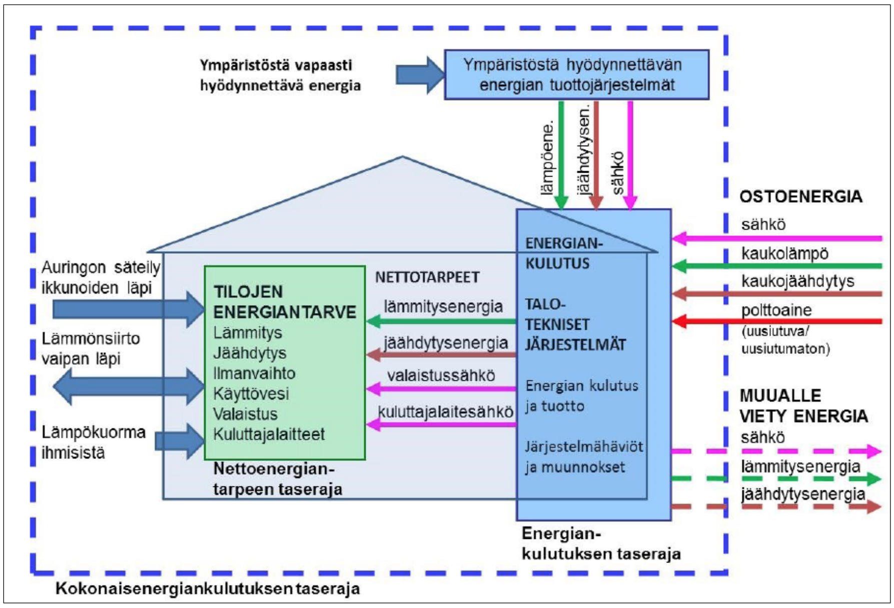

Figure 14. System boundary for energy need, energy use, delivered and exported energy on site.

The E value is resulted from the net purchased energy times the relevant primary energy factors and this calculation is based on hourly time step data. The national requirements for NZEB building and primary energy factors are shown in Table 12 and Table 13.

Table 13. National requirements for different Finnish building categories, according to national regulations [2].

Building type	PE requirements
Category 1. Small residential buildings: a) Separate detached house and a part of a building with net heated area of 50 to 150 m² (b) Separate detached house and a part of a building with net heated area of more than 150 m² but not exceeding 600 m² c) Separate small house and a part of a building with net heated area of more than 600 m² d) Row house and residential block with up to two floors	 200-0.6 A_{net} 116-0.04 A_{net} 92 105
Category 2. Residential block with at least three floors	90
Category 3. Office building	100
Category 4. Commercial building, department store, shopping centre, shop building except for grocery shops 2000 m² units, storage hall, theatre, opera, concert and congress hall, movie theatre, library, museum, art gallery, exhibition hall	135
Category 5. Accommodation building, hotel, dormitory, service house, home care centre, health care facility	160
Category 6. Education building and kindergarten	100
Category 7. Sports hall except for a swimming pool and the Ice Hall	100
Category 8. Hospital	320
Category 9. Other building, warehouse, traffic building, indoor swimming pool, ice rink, grocery store 2000 m^2 unit, transferable building	no limit value

* A_{net}, net floor area, unit of is kWh/(m² a).

Table 14. Primary energy factor [2].

Energy carrier	PEF
Electricity	1.2
District heating	0.5
District cooling	0.28
Natural gas	1.0

4.4.2 Calculation procedure

For small residential building and residential blocks, the calculated room temperature during summertime shall not exceed the cooling limit value of 27 °C and the cooling limit value of 25 °C in non-residential buildings for more than 150 °Ch (degree hours) between 1 June and 31 August using the design ventilation airflow rate. The compliance of summer room temperature must be demonstrated by calculating the temperature of the different room types [2].

4.4.3 Calculation of PE

The calculation method for PE needs to be consider the following factors [2]

– Thermal properties of building components, air leakage, airtightness,
– Indoor air temperature,
– DHW demand,
– Ventilation rate, draft, heat recovery of ventilation,
– Thermal loads from occupant, light, appliances, hot water, and solar heat,
– Thermal and electrical energy use for spaces heating, ventilation heating, DHW system,
– Electricity use for ventilation system (fan and pump), lighting, equipment,
– Onsite solar electricity, solar thermal production, heat recovery from wastewater.

The E number is calculated according to the following equation [2].

$$E = \frac{f_{DH.PF}\ Q_{DH} + f_{DC.PF}\ Q_{DC} + \sum_i f_{F.PF}\ Q_F + f_{E.PF}\ Q_E}{A_{net}} \tag{4}$$

where, $f_{DH.PF}$, district heating primary energy factor, dimensionless; Q_{DH}, district heating use annually, kWh/a; $f_{DC.PF}$, district cooling primary energy factor, dimensionless; Q_{CH}, district cooling use annually, kWh/a; $f_{F.PF}$, fuel primary energy factor, dimensionless; Q_F, fuel use annually, kWh/a; $f_{E.PF}$, electricity primary energy factor, dimensionless; Q_E, electricity use annually, kWh/a; A_{net}, net heated building area, m².

Heat losses from building facade, thermal bridges, ventilation heat losses, system efficiency calculation method, onsite electricity production are given in details at national building code of Finland, Part D5 [3].

4.4.4 Outdoor airflow and room temperature input data

The E number can be calculated using the following outdoor airflow rate and room temperature, accounting the heating and cooling limit.

Table 15. Outdoor airflow and room temperature input data for different building categories [2].

Building type*	Outdoor air flow dm²/(s m²)	Heating set point, °C	Cooling set point, °C
Small residential buildings	0.4	21	27
Apartment buildings (at least three storeys)	0.5**	21	27
Office buildings, healthcare centres	2.0	21	25
Commercial buildings	2.0	18	25
Hotels, nursing homes	2.0	21	25
Educational buildings/ kindergartens	3.0	21	25
Sport facilities	2.0	18	25
Hospitals	4.0	22	25

* Building categories are listed in Table 12.

**If ventilation can be controlled by occupant, 0.4 dm³/(s m²) is used

4.4.5 Electricity use for lighting, appliance, DHW input data

Daily operational hours, usages rate per week, utilization rate of lighting, appliances, occupant need to be considered to estimate the E number. The detailed information is shown in Table 15.

Table 16. Building usages rate, internal thermal load for different building categories [2].

Building type	Operation Hours	h/day	Day/ week	Usages rate	Lighting W/m²	Appliance W/m²	Occupant W/m²	DHW kWh/(m² a)
Small residential buildings	00:00-24:00	24	7	Light 0.1 Other 0.6	6	3	2	35
Apartment buildings (at least three storeys)	00:00-24:00	24	7	Light 0.1 Other 0.6	9	4	3	35
Office buildings, healthcare centers	07:00-18:00	11	5	0.65	10	12	5	6
Commercial buildings	08:00-21:00	13	6	1.0	19	1	2	4
Hotels, nursing homes	00:00-24:00	24	7	0.3	11	4	4	40
Educational buildings/ kindergartens	08:00-16:00	8	5	0.6	14	8	14	11
Sport facilities	08:00-22:00	14	7	0.5	10	0	5	20
Hospitals	00:00-24:00	24	7	0.6	7	9	8	30

Note. Building categories are well mentioned in Table 12.

Energy use for lighting and appliances is taken from Finnish national building regulations [2] and it will be multiplied with the national PE factor to obtain the PE use for lighting and appliance. The net heating energy for domestic hot water is given as a default value. The following equation is used to estimate the energy use for lighting and appliance [2].

$$Q_{Light+appl.} = kP \frac{\tau_d}{24} \frac{\tau_w}{7} \frac{8760}{1000} \tag{5}$$

ber of days usages per week of the building, days.

4.4.6 Leakage rate

The leakage rate is calculated from the following equation [2].

$$q_{v,leakage} = \frac{q_{50}}{3600\, x} A_{env} \tag{6}$$

where, $q_{v,leakage}$, leakage air flow rate, m3/s; q_{50}, building without leakage rate, m3/hm2; A_{env}, envelop area, m2; x, coefficient (for single story building of 35, two storied building of 24, three and four storied building of 20, other of 15), dimensionless.

4.4.7 Alternative simplified compliance assessment method

Heat transfer value for energy efficient building for small residential building and residential block with at least three floors as shown in Table 16.

Table 17. Minimum requirement of the simplified method [2].

Building type - Small residential buildings and residential block	U value	Unit
1. Thermal transmittance		
a) Exterior wall for Small residential buildings	0.12	W/(m² K)
b) Exterior wall for Residential block with at least three floors	0.14	W/(m² K)
c) Roof and base floor	0.07	W/(m² K)
d) Ventilated bottom and the ground adjacent to the crawl space	0.10	W/(m² K)
e) Window, sunroof, door, roof hatch, smoke exhaust and outlet	0.7	W/(m² K)
2. Air leakage, q50	0.60	m³/(h m²)
3. Energy efficiency of heat recovery	70	%
4. Mechanical ventilation with supply fan power not exceed 1.5 kW/(m³ s)		
5. The heating system of the building shall be district heating, geothermal heat pump or air-water heat pump.		

4.4.8 References

[1] "REHVA NZEB
buildings. REHVA Journal, (03)," 2013.

[2] Decree of the Ministry of the Environment on the energy efficiency of a new building (in Finnish) Ympäristöministeriön asetus uuden rakennuksen energiatehokkuudesta, 2017.

[3] "National Building Code of Finland, Part D5, Calculation of power and energy needs for heating of buildings, Ministry of the Environment, Department of the Built Environment," 2012.

4.5 Latvia

The Ministry of Economy is responsible for the implementation of the requirements of the EPBD directives for the energy performance of buildings in Latvia. These requirements were established as a subcontracting and involvement of national stakeholders on other ministries.

Latvia Minister Cabinet Regulations No. 280 “Regulations Regarding the Latvian Construction Standard LBN 002-19, Thermotechnics of Building Envelopes” and Regulations No. 222 “Methods for calculating the energy performance of buildings and energy certification rules for buildings” contradict with each other. Regulations No.222 are more detailed and unofficially are assumed to have a priority.

This is mainly because legislation on energy efficiency constantly updated. Regulations No. 280 limit maximum U-values and include outdated NZEB definition while Regulations No.222 provide more detailed data on NZEB requirements, including overheating.

4.5.1 Indicators determine the NZEB energy efficiency class

There are two energy efficiency classes: one is energy need for heating and second one total primary energy for all building systems. NZEB building should fulfil A-class both for heating energy and total primary energy.

The NZEB energy demand should be calculated considering the following boundary conditions:

– The indoor temperature conditions should be at least at the level of category II during the heating period and at least at the level of category III during the non-heating period (in accordance with the requirements of standard LVS EN 16798-1:2019 “Energy efficiency of buildings. Ventilation of buildings. Part 1. Climate input parameters for the design and assessment of the energy performance of buildings, considering the air quality, temperature regime, lighting, and acoustics of spaces. Module M1-6”, Annex B).

– The energy efficiency assessment must assume the air exchange conditions in rooms where people reside not less than the level of category III according to standard LVS EN 16798-1:2019.
– The building must have an assessed overheating risk indicator according to the standard LVS EN ISO 52016-1:2017. The assessment should be carried out for spaces in which people reside and which are oriented in the east-south-west direction and spaces with overhead solutions.
– For retrofitting, the requirements for premise overheating should be applied if the specific heating consumption of the building after the completion of renovation or reconstruction corresponds to at least energy efficiency class B.
– In energy balance the cooling system may be considered as “assumed value”: 30 kWh/m^2 per year for office buildings (the proportion of gazed surfaces exceeds 20% of the floor area) and 20 kWh/m^2 per year for other categories of buildings (if the proportion of glazed surfaces exceeds 15% of each floor). This “assumed value” could be neglected if, using the hourly calculation method, it is determined that the operating temperature of the premises above 27 ° C does not exceed 150 Kelvin hours (K h) during the period from 1 May to 30 September; in houses and hospitals the operational temperature of rooms above 25 °C does not exceed 100 Kelvin hours (K·h) during the period from 1 May to 30 September; in educational buildings the operating temperature of the premises above 25 °C does not exceed 150 Kelvin hours (K·h) during the periods from 1 May to 15 June and from 15 August to 30 September.

General guidance suggests energy calculation monthly method for residential (single and multiapartment) and dynamic for office buildings. Overheating should be calculated based on hourly method. Calculation of overheating is not necessary if the above energy consumption for cooling (calculated of “assumed values”) is used.

4.5.2 Requirements for the energy efficiency indicators

Minimum allowed reference levels of heating consumption (kWh / m^2) for newly designed and existing buildings are shown in Table 17 – Table 19. NZEB building should have at least A energy performance class.

Table 18. Minimum reference level of energy consumption for heating.

Energy performance class of buildings	Residential buildings and non-residential buildings		Residential buildings	Non-residential buildings	
	heated area, m²				
	from 50 to 120	from 120 to 250	> 250		
			Single-family houses, apartment buildings, cohabitation houses of different social groups, residential buildings for public use	Office buildings, educational buildings, hotels, restaurants, sports facilities, wholesale and retail buildings	Hospitals
A+ NZEB					
A NZEB	6				
B	7	6	6	6	7
C					1
D	150	1	1	11	1
E	1	1	1	1	16
F	> 180	> 150	> 125	> 150	> 160

Currently NZEB buildings definition considers also primary energy. The latest revision of Latvian legislation has replaced the total primary energy factor with non-renewable energy factor. Minimum allowed level of non-renewable primary energy consumption is shown in Table 18.

Table 19 Minimum level of non-renewable primary energy consumption for residential buildings.

Energy performance class of buildings	Residential buildings		Single-family houses, apartment buildings, co-habitation houses of different social groups, collaborative housing
	heated area, m²		
	from 50 to 120	from 120 to 250	> 250
A+ NZEB	6	6	6
A NZEB	11	1	
B	1	1	125
C	16	1	1
D		1	16
E		1	1
F	6	6	
G	> 260	> 260	> 220

Table 20 Minimum level of non-renewable primary energy consumption for non-residential buildings.

Energy performance class of buildings	Offices, educational institutions, sports facilities	Hospitals, hotels, restaurants	Wholesale and retail buildings
A+ NZEB	90	1	1
A NZEB	11	17	1
B	16		1
C	1		1
D			
E			
F			
G	virs 400	virs 450	virs 400

Primary energy and carbon dioxide weighting factor values are shown in Table 20.

Table 21 Primary energy and carbon dioxide (CO2) weighting factor values.

Nr.	Energy carrier		fPnren	fPren	fPtot	KCO2e (g/kWh)
Supply from outside						
1.	Fossil fuels	coal (anthracite)	1.1	0	1,1	354
2.		lignite (lignite)	1.1	0	1,1	364
3.		fuel oil	1.1	0	1,1	279
4.		natural gas	1.1	0	1,1	202
5.		liquefied petroleum gas	1.1	0	1,1	227
6.		other fossil fuels	1.1	0	1,1	[1]
7.	Biofuel	hard	0.2	1	1,2	40
8.		liquid	0.5	1	1,5	70
9.		gaseous	0.4	1	1,4	100
10.	Electricity from the grid		1,9	0.6	2.5	109

Nr.	Energy carrier		fPnren	fPren	fPtot	KCO2e (g/kWh)
Supply from nearby area						
11.	Thermal energy from district heating system, produced from fossil fuels without cogeneration		1.3	0	1.3	264
12.	Thermal energy from district heating system, produced from renewable fuels without cogeneration		0.2	1.1	1.3	50
13.	Thermal energy from district heating system, produced in cogeneration from fossil fuels		0.7	0	0.7	185
14.	Thermal energy from district heating system, produced in cogeneration from renewable fuels		0.1	0.6	0.7	25
15.	Thermal energy from a district heating system, from a particular supplier		Factors calculated for a particular thermal energy merchant or supplier of cooling energy based on the annual balance sheet of energy of that merchant or supplier.			
16.	Centralised cooling (cooling energy from the supplier of cooling energy)					
On-site production						
17.	Solar energy	PV electricity	0	1	1	0
18.		Thermal energy	0	1	1	0
19.	Wind energy		0	1	1	0
20.	Environmental energy	aerothermal, geothermal, hydrothermal and marine energy, hydropower	0	1	1	0
Exported						
21.	Electricity	to network	1.9	0.6	2.5	109
22.		for non-energy efficient use of buildings	1.9	0.6	2.5	109

4.5.3 Requirements for heat transfer coefficient of the building envelope

The heat transfer coefficient of the building envelope for NZEB buildings is not defined. NZEB relay on holistic design approach of all building's elements including HVAC, RES and building envelope. Only maximum heat transfer values are defined to avoid condensation on the indoor surface.

Table 22 Maximum values of heat transfer coefficient of external budling envelope, W/m^{2}K.

Construction	Residential buildings, nursing homes, hospitals, and kindergartens	Non - residential buildings	Industrial buildings
Floor on the ground	0,2	0,25	0,35
Suspended floor	0,3	0,35	0,40
External wall	0,23	0,25	0,30
Log buildings	0,65	0,65	0,65
Roof	0,20	0,23	0,25
Doors	1,80	2,00	2,20
Windows	1,10	1,10	1,30
Thermal bridges	0,20	0,20	0,35

4.5.4 Requirements for mechanical systems and equipment

There is no mandatory requirement to install the exhaust air heat recovery units in NZEB buildings. However, in practice it is not possible to reach as low energy consumption for space heating as A-class.

4.5.5 Air tightness requirements for NZEB buildings

The air permeability index q50 is initially indicated during design process. Real measurements of air tightness are voluntary. Air tightness measurements must be done in accordance with LVS EN ISO 9972: 2016 "Thermal efficiency of buildings. Determination of building air permeability: 2015) ".

No specific values for NZEB are defined. Depending on the method of ventilation of the relevant building, the following threshold values should be determined for residential houses, nursing homes, hospitals, kindergartens, and public buildings:

– for buildings with natural ventilation (airing) - $^3/(m^2 \cdot h)$,
– for buildings with mechanical ventilation system - $^3/(m^2 \cdot h)$,
– for buildings with mechanical ventilation system equipped with heat recovery devices - q50 1 $^3/(m^2 \cdot h)$,
– for production buildings - $^3/(m^2 \cdot h)$.

4.5.6 Requirements for the use of renewable energy

Latvian legislation does not require mandatory installation of on-site renewable energy production. This is indirectly regulated by amount of consumed non-renewable primary energy.

4.6 Lithuania

The Ministry of Environmental Protection is responsible for the implementation of the requirements of the EPBD directives for the energy performance of buildings in Lithuania. These requirements are enshrined in the Construction Law of the Republic of Lithuania and construction technical regulations.

In Lithuania, the requirements for the energy performance of buildings are set for newly constructed and modernized heated buildings for all purposes, except for buildings to which the requirements of the EPBD Directive for energy performance are exempted.

Requirements for almost non-energy consuming (NZEB, i.e. A ++ energy efficiency classes) buildings in Lithuania are set in the construction technical regulation STR 2.01.02: 2016 „Design and certification of energy efficiency of buildings”. The same regulation also contains requirements for buildings of other energy efficiency classes. The full text of the regulation in Lithuanian can be found here:
e-tar.lt/portal/lt/legalAct/2c182f10b6bf11e6aae49c0b9525cbbb/asr .

STR 2.01.02: 2016 is periodically updated and revised. The last update of the regulation was made in 2020, September 28 by the order of the Minister of Environment No. D1-576.

According to the existing requirements of Regulation STR 2.01.02: 2016, newly built state-owned buildings must comply with the NZEB energy efficiency class as of 1 January 2019. For all other newly constructed buildings, the requirement to comply with the NZEB energy performance class has been established since 1 January 2021.

4.6.1 Indicators are used to determine the NZEB energy efficiency class

The energy efficiency class of NZEB is determined according to the compliance of the following building indicators with the regulatory requirements:

1. the values of the energy efficiency indicators C1 (describing the energy efficiency of the building for heating, ventilation, cooling and indoor lighting) and C2 (describing the energy efficiency of the hot water system);
2. compliance of the heat transfer coefficient of the building envelope with the regulatory requirements;

3. compliance of the technical indicators of recuperators with the regulatory requirements;
4. compliance of structures separating parts of the building with autonomous heating systems to the standard level of insulation;
5. compliance of the tightness of the building with the regulatory requirements;
6. compliance of thermal energy consumption for heating the building with regulatory requirements;
7. compliance of the primary energy consumption of the building with the regulatory requirements;
8. compliance of the share of energy from renewable sources with regulatory requirements (this requirement only applies to NZEB buildings).

None of these requirements take precedence. The building of the relevant energy performance class must meet all the established requirements. If a building does not meet any of the regulatory requirements, it is assigned a lower energy performance class.

4.6.2 Requirements for the values of energy efficiency indicators C1 and C2

The values of non-renewable primary energy consumption of the building are used to calculate the values of the energy efficiency indicators C1 and C2 of the building.

The value of energy efficiency indicator C1 (describing the energy performance of a building for heating, ventilation, cooling and lighting) is calculated using the ratio of non-renewable primary energy consumption to the actual consumption of the building and the consumption that would result if the building met energy performance class C buildings. The value of energy efficiency indicator C2 (describing the energy efficiency of a hot water system) is calculated according to the same principle.

The results of the calculations of indicator C1 are greatly influenced by the normative reference point, which states that in Lithuanian climatic conditions, under typical conditions of building use, there must be no energy consumption for cooling buildings.

The values of energy efficiency indicators C1 and C2 for NZEB buildings shall meet the

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use 70% less non-renewable energy for heating, cooling and room lighting and 30% less non-renewable energy in the hot water system compared to a building built to energy efficiency class C.

For the calculation of non-renewable and renewable primary energy consumption in a building and CO_2 emissions of buildings in the environment in Lithuania, the values of primary energy factors and CO_2 emissions of energy sources listed below are used.

Table 23 Primary energy factors used in the calculation of buildings' energy performance.

No.	Energy sources	f_{PRn}	f_{PRr}	M_{CO2}, $kgCO_2/kWh$
1	Fuel oil	1.1	0	0.29
2	Orimulsion	1.1	0	0.29
3	Diesel, Furnace Liquid Fuel, Shale Oil	1.1	0	0.29
4	Liquid gas	1.1	0	0.22
5	Lubricants	1.1	0	0.36
6	Peat	1.1	0	0.37
7	Coal	1.2	0	0.36
8	Biofuels (wood, straw, biogas, bio-oil ...)	0.2	1	0.04
9	Natural gas	1.1	0	0.22
10	Electricity produced by hydropower plants	0.06	1	0.01
11	Average of the various ways of producing electricity	2.3	0.2	0.6
12	Photovoltaic Solar Collectors	0.01	1	0
13	Water Heated Solar Collectors	0	1	0
14	Wind farms	0.01	1	0
15	Heat from heat networks (Lithuanian average)	0.62	0.63	0.10

4.6.3 Requirements for the heat transfer coefficient of the building envelope

The heat transfer coefficient of the building envelope in NZEB buildings shall not exceed the normative heat transfer coefficient $H_{env.(A++)}$ (W / K), which is calculated as follows:

$$H_{env.(A++)} = K_{ds} \cdot [A_{w.sum} \cdot U_{(A++).w} + A_{r.sum} \cdot U_{(A++).r} + A_{ce.sum} \cdot U_{(A++).ce} +$$
$$+ A_{fg.sum} \cdot U_{(A++).fg} + A_{wd.sum} \cdot U_{(A++).wd} + A_{d.sum} \cdot U_{(A++).d} +$$
$$+ l_{\Psi.f-w.sum} \cdot \Psi_{(A++).f-w} + l_{\Psi.wdp.sum} \cdot \Psi_{(A++).wdp} + l_{\Psi.dp.sum} \cdot \Psi_{(A++).dp.} +$$
$$+ l_{\Psi.w-r.sum} \cdot \Psi_{(A++).w-r} + l_{\Psi.c.sum} \cdot \Psi_{(A++).c} + l_{\Psi.bc-w.sum} \cdot \Psi_{(A++).bc-w} +$$
$$+ l_{\Psi.c-w.sum} \cdot \Psi_{(A++).c-w} + l_{\Psi.s.sum} \cdot \Psi_{(A++).s}]$$

where: K_{ds} is the coefficient estimating the permissible errors of calculations of the U values of building envelope elements and possible small differences between the U values of this elements provided in the building design and actually installed in the building. K_{ds} = 1.05 should be taken;

$A_{w.sum}$, $A_{r.sum}$, $A_{ce.sum}$, $A_{fg.sum}$, $A_{wd.sum}$, $A_{d.sum}$ - total areas (m²) of walls, roofs, ceilings, floors, windows and doors (including gates);

$U_{(A++).w}$, $U_{(A++).r}$, $U_{(A++).ce}$, $U_{(A++).fg}$, $U_{(A++).wd}$, $U_{(A++).d}$ – U-values (W / (m²·K)) for walls, roofs, ceilings, floors on the ground, windows and doors (including gates) for the calculation of the normative heat transfer coefficient of building envelope in buildings of energy efficiency class A++. Taken from Table 23 below;

$_{(A++).f-w}$ $_{(A++).wdp}$ $_{(A++).dp}$ $_{(A++).w-r}$ $_{(A++).c}$ $_{(A++).bc-w}$ $_{(A++).c-w}$ $_{(A++).s}$ - is the thermal

values for calculating the normative heat transfer coefficient of the building envelope of Class A ++ (NZEB) buildings are given in Table 24;

$l_{-w.sum}$, l , l , $l_{-r.sum}$, l , $l_{-w.sum}$, $l_{-w.sum}$, l –total length of the respective type of longitudinal thermal bridge, m.

Table 24 U-value requirements for the thermal envelope.

No.	Description of building envelope element	Subscripts	Residential buildings	Non - residential buildings	
				Public buildings[1)]	Industrial buildings[2)]
			$U_{(A++)}$ (W/(m^2·K))		
1.	Roofs	*r*	0.1	0.11·κ_1[3)]	0.15·κ_1[3)]
	Ceilings (floors above passages)	*ce*			
2.	Floors of heated rooms adjacent to the ground	*fg*	0.12	0.14·κ_1[3)]	0.18·κ_1[3)]
	Floors above unheated basements and basements	*cc*			
3.	Walls	*w*	0.11	0.12·κ_1[3)]	0.17·κ_1[3)]
4.	Windows, skylights and other transparent building envelope element[4)]	*wda*	0.8	0.9·κ_1[3)]	1·κ_1[3)]
5.	Doors and gates	*d*	1.2	1.4·κ_1[3)]	1.7·κ_1[3)]
6.	Notes: [1)] public buildings include: administrative, commercial, service, catering, transport, cultural, scientific, medical, recreational, sports, hotel and special purpose buildings; [2)] industrial buildings include: storages, garages and industrial buildings; [3)] $\kappa_1 = 20/(\theta_{iH} – 0,6)$- temperature correction for building envelope elements of industrial, service, transport and special purpose buildings, θ_{iH} - internal temperature of industrial services, transport and special purpose buildings during the heating season (°C). Taken from the building design and, in the absence of data, taken from STR 2.01.02:2016, Annex 2, Table 2.4; [4)] windows elements also include glazed and non-glazed doors to glazed balconies, glazed galleries, and greenhouses.				

Table 25 Thermal bridge requirements.

No.	Description longitudinal thermal bridge	$\Psi_{(A++)}$ coefficient notation	$\Psi_{(A++)}$ value for longitudinal thermal bridge, W/(m·K)
1.	Between the foundations of the building and the external walls	$\Psi_{(A++).f-w}$	0.1
2.	Around the window openings in the walls	$\Psi_{(A++).wdp}$	0.05
3.	Around the exterior entrance door openings in the walls	$\Psi_{(A++).dp}$	0.05
4.	Between the walls of the building and the roof	$\Psi_{(A++).w-r}$	0
5.	In the outer and inner corners of facades	$\Psi_{(A++).c}$	0
6.	Balcony floors at intersections with external walls	$\Psi_{(A++).bc-w}$	0.01
7.	Between the ceilings bordering the outside and the walls	$\Psi_{(A++).c-w}$	0
8.	On the perimeter of openings in skylights and other transparent building envelope elements	$\Psi_{(A++).s}$	0.05

4.6.4 Requirements for technical indicators of recuperators

There is no mandatory requirement to install a recuperator in NZEB buildings. However, if the building is equipped with a mechanical ventilation system with recuperation, the efficiency of the recuperator must be at least 0.80 (if a building with special hygiene requirements for microclimate and air quality is allowed to install separate flow recuperators with an efficiency of at least 0.68), and the amount of electricity used by the recuperator fans must not exceed 0.45 Wh/m³. This requirement does not apply to storage, garages, and industrial buildings.

4.6.5 Requirements for the insulation level of structures separating parts of a building with autonomous heating systems

The average U2 value of new building partitions and internal ceilings separating heated buildings (parts thereof) with separate (autonomous) heating systems, or separate (autonomous) energy consumption heating of a building (part thereof) shall not exceed the normative value, specified in Table 25. The requirements in Table 25 do not apply if, in buildings (parts thereof) with separate heating systems or separate metering for heating the energy consumption of the building (part thereof), the heating system control devices do not reduce the room temperature by more than 4 °C during the heating season, which is specified in Table 2.4 of Annex 2 to STR 2.01.02: 2016.

Table 26 Requirements for internal constructions.

No.	Building elements	Residential buildings	Non - residential buildings	
			Public buildings[1)]	Industrial buildings[2)]
		U_2 (W/(m²×K))		
1.	Internal partitions	0.37	$0.4 \cdot k_1$[3)]	$0.57 \cdot k_1$[3)]
2.	Internal ceilings	0.33	$0.37 \cdot k_1$[3)]	$0.5 \cdot k_1$[3)]
[3)] - see Table 23, item 6				

4.6.6 Tightness requirements for NZEB buildings

Buildings of the A++ (NZEB) energy efficiency class in Lithuania must meet the normative tightness requirements. Measurements of the tightness of the building must be performed by laboratories accredited for testing in accordance with the requirements of LST EN ISO 9972: 2015. The tests shall be performed according to both the pressurized and reduced pressure test methods specified in the standard LST EN ISO 9972: 2015. The airtightness of a building with the requirements of energy efficiency class A++ (NZEB) can only be confirmed if the value of air circulation n50 determined by each of the high-pressure and reduced-pressure test methods specified in the test standard does not exceed the value of n50.N given in Table 26.

Table 27 Air-tightness requirements.

No.	Purpose of the building	$n_{50.N}$, (1/h)
1.	Residential, administrative, scientific, and medical	0.60
2.	Catering, trade, culture, hotels, services[1)], sports, transport[1)], special[1)] and leisure	1.00[2)]

Notes:

[1)] for heated spaces of services, transport and special purpose buildings, where a gate is installed between these heating spaces and external or any type of unheated spaces (greenhouse, glazed galleries, unheated building, unheated insulated premises), no sealing requirements shall be imposed.

[2)] in the case of service, transport and special purpose buildings, this requirement applies to that part of the building where there is no gate between the heated spaces and the outside or any type of unheated spaces (greenhouse, glazed galleries, unheated building, unheated insulated spaces).

The time interval between the date of measurement of the tightness specified in the building leak test report and the date of issue of the energy performance certificate of the building shall not exceed 1 year.

There are no tightness requirements for NZEB industrial buildings, but a tightness test is mandatory, and the results of this test are used in the calculations to determine the energy performance of the building.

4.6.7 Requirements for thermal energy consumption for heating the building and total primary energy consumption

The annual thermal energy consumption of A ++ (NZEB) buildings for the heating of the building and the annual primary energy consumption shall not exceed the standard values given in Table 27..

Table 28 Thermal and primary energy requirements for different building types.

No.	Purpose of the building	Thermal energy consumption for heating a building		Primary energy consumption of the building	
		Maximum allowable thermal energy consumption for heating the building, kWh/m² per year	Correction factor for heated spaces height k_h	Maximum allowable primary energy consumption, kWh/m² per year	Correction factor for heated spaces height k_h
1.	Single family buildings	$k_h \cdot 451 \cdot A_p^{-0,39}$	1	$k_h \cdot 546 \cdot A_p^{-0,2}$	1
2.	Multifamily buildings	$k_h \cdot 197 \cdot A_p^{-0,23}$	1	$k_h \cdot 307 \cdot A_p^{-0,07}$	1
3.	Office buildings	$k_h \cdot 221 \cdot A_p^{-0,28}$	1	$k_h \cdot 320 \cdot A_p^{-0,1}$	1
4.	Educational buildings	$k_h \cdot 707 \cdot A_p^{-0,41}$	1	$k_h \cdot 444 \cdot A_p^{-0,15}$	1
5.	Medical buildings	$k_h \cdot 941 \cdot A_p^{-0,44}$	1	$k_h \cdot 519 \cdot A_p^{-0,1}$	1
6.	Catering buildings (restaurants, cafes...)	$k_h \cdot 600 \cdot A_p^{-0,41}$	1	$k_h \cdot 621 \cdot A_p^{-0,1}$	1
7.	Commercial buildings (shops, supermarkets...)	$k_h \cdot 240 \cdot A_p^{-0,24}$	$0,14 \cdot h+0,47$	$k_h \cdot 409 \cdot A_p^{-0,1}$	$0,04 \cdot h+0,85$
8.	Sports buildings, except swimming pools	$k_h \cdot 647 \cdot A_p^{-0,39}$	$0,12 \cdot h+0,53$	$k_h \cdot 439 \cdot A_p^{-0,07}$	$0,03 \cdot h+0,89$
9.	Swimming pools	$k_h \cdot 1969 \cdot A_p^{-0,47}$	$0,13 \cdot h+0,51$	$k_h \cdot 626 \cdot A_p^{-0,05}$	$0,02 \cdot h+0,91$
10.	Cultural buildings	$k_h \cdot 685 \cdot A_p^{-0,4}$	$0,19 \cdot h+0,29$	$k_h \cdot 430 \cdot A_p^{-0,12}$	$0,04 \cdot h+0,85$
11.	Garages and industrial buildings	$k_h \cdot 251 \cdot A_p^{-0,19}$	$0,09 \cdot h+0,66$	$k_h \cdot 487 \cdot A_p^{-0,11}$	$0,04 \cdot h+0,84$
12.	Storage buildings (warehouses ...)	$k_h \cdot 225 \cdot A_p^{-0,17}$	$0,08 \cdot h+0,7$	$k_h \cdot 419 \cdot A_p^{-0,14}$	$0,07 \cdot h+0,75$
13.	Hotel buildings	$k_h \cdot 407 \cdot A_p^{-0,34}$	1	$k_h \cdot 375 \cdot A_p^{-0,08}$	1
14.	Service buildings	$k_h \cdot 448 \cdot A_p^{-0,3}$	$0,11 \cdot h+0,65$	$k_h \cdot 507 \cdot A_p^{-0,16}$	$0,06 \cdot h+0,81$
15.	Transport buildings	$k_h \cdot 563 \cdot A_p^{-0,38}$	$0,17 \cdot h+0,47$	$k_h \cdot 439 \cdot A_p^{-0,14}$	$0,06 \cdot h+0,83$
16.	Recreational buildings	$k_h \cdot 314 \cdot A_p^{-0,32}$	1	$k_h \cdot 578 \cdot A_p^{-0,09}$	1
17.	Special purpose buildings	$k_h \cdot 789 \cdot A_p^{-0,45}$	1	$k_h \cdot 530 \cdot A_p^{-0,11}$	1

In the table: Ap - total area of heated premises in the building, m²; h - average height of heated premises of the building, m.

4.6.8 Requirements for the use of renewable energy

NZEB buildings are required to account for more than half of the total primary energy consumed in the building, excluding renewable energy consumption for cooling the building, for heating the building + ventilation equipment + cooling the building. So far, it is not required to use more than half of the renewable energy in the building's hot water system, building electrical appliances and lighting.

In Lithuanian climatic conditions, buildings must be designed in such a way that they do not require energy to cool the buildings. For this reason, the standard energy consumption for cooling buildings has been adopted at 0 kWh/m² per year.

The energy consumption of cooling buildings for all energy efficiency classes of buildings is calculated regardless of whether the building has cooling equipment or not. If there is no cooling equipment, the cooling unit with EER = 2.8 is estimated in the calculations. If cooling equipment is available, the EER of this equipment shall be assessed. The energy consumption of cooling a building increases the consumption of non-renewable primary energy and total primary energy in the building and worsens the energy performance of the building. Meanwhile, the consumption of renewable primary energy by refrigeration equipment, which could improve the ratio between the consumption of renewable and non-renewable energy in the building, is not included in the calculation of this ratio. The resulting thermal energy demand for cooling buildings in NZEB buildings resulting from such an assessment of the primary energy consumption for cooling buildings hinders the implementation of the requirement to use more than half of the energy from renewable sources. However, this requirement can be met by increasing the share of renewable primary energy consumption in other building systems. The current standardization principle limits the energy consumption for cooling buildings.

EXAMPLE CASES

5 EXAMPLE CASES

In this section there are descriptions of typical buildings in each of the categories (generally single-family house, multi-family house and office building) from each of the countries in this investigation. The buildings are selected as typical examples of each building type and do thus represent the typical market solutions to meet the national NZEB requirements.

5.1 Denmark

5.1.1 Single-family house

Building type	Detached single-family house
Photo or illustration	
Construction year	2011
Location	Denmark, North of Zealand (cold/moderate climate)
Building description	Energy rating A2020. The house is a typical Danish detached single-family house with masonry outer walls and lightweight concrete inner walls. Heating and domestic hot water is provided from an efficient ground source heat pump and heated by a floor heating system. Additionally, the house is equipped with 24 m² east-facing PV panels.
Heated/conditioned area	165 m^2
Number of floors	One floor single-family house without basement.
Mean occupant density	1.5 W/m² corresponding 67 m²/person.
Occupied hours	8760 hrs/year
Building envelope	
Description	Roof construction towards unheated attic is isolated by 400 mm mineral wool with a total U-value equal to 0.09 W/m²K. External walls are constructed by a masonry external leaf and a lightweight concreate inner leaf. The total wall thickness is 36 cm, and the cavity is insulated with mineral wool with an average U-value of 0.29 W/m²K. This is a traditional external wall construction where masonry is the predominant building material for external walls. The slab on ground construction (with floor heating) is a concrete slab above 275 mm Super EPS styrol and a capillary breaking layer. The insulation level of the floor construction is 0.12 W/m²K. Joints between external walls and foundation are made of lightweight cinder blocks with centre insulation. Joints for windows and exterior doors are well insulated. The line-loss coefficients are 0.17 and 0.03 W/mK respectively.

	Windows are with 2-pane low-energy glazing with an overall U-value of 1.3-1.5 (small windows) W/m²K and a g-value for the glazing of 0.63.
Envelope air permeability, q_{50}	1.5 l/m² of heated floor area per sec at 50 Pa or approx. 0.13 l/m² per sec at normal pressure difference.
Windows U-value	1.3 (large windows) to 1.5 (small windows) W/m²K
Windows g-value	0.63
External walls U-value	0.29 W/(m² K)
Base floor U-value	0.12 W/(m²K)
Roof U-value	0.09 W/(m² K)
Building systems	
Description	The house is mechanically ventilated by a Nilan Comfort 300 balanced ventilation system with a heat recovery (88%) unit located at the attic. The ventilation rate is approx. 0.5 air changes per hour. The house is heated by floor heating from a ground source heat pump. Hot water is supplied by the same heat pump as the floor heating.
Heat sources	Ground source combined (heat and hot water) heat pump, Vølund Fighter 1245-6, with a COP 3.58 and a nominal put of 5.21 KW.
Heating systems	Low temperature underfloor heating (water temperatures 40/30 °C); Ventilation heating coils – water based (water temperatures 45/30°C)
Cooling sources	No cooling system.
Cooling systems	None
Design temperature for heating	20 °C
Design temperature for cooling	-
Cooling load (typical room)	-
Heating load (space heating and ventilation)	24.2 W/m² (dimensioning)
Ventilation system types	Mechanical balanced ventilation, heat recovery, CAV (1 unit)
Ventilation airflow rates /total air flow	Whole house 0.3 l/s per m² heated gross floor area; The total air flow rate of the house is +/-0.8 m³/s. Kitchen have a cooker hood with an air-flow of 370 m³/hour (operated in 5% of the time)
Ventilation systems specific fan power (SFP)	1000 J/m³ (average)
Ventilation heat recovery types	Cross plate exchanger
Ventilation heat recovery efficiency	Temperature efficiency (average): 88%
Domestic hot water production	A default (standard) consumption of domestic hot water is included in the calculation equal to 250 litres per m² heated gross floor area per. year. Water is stored in a Vølund-NIBE-1245 tank of 180 litres. Hot water is provided from the heat pump.
Lighting systems	None. National standard excludes lighting from the energy performance calculation in residential buildings. Heat load from lighting and appliances is included as 3.5 W/m² heated gross floor area, but not part of the calculated energy demand.
Renewable energy systems	
Photovoltaic panels (PV)	PV system consists of 14 panels, each 1.7m² = approx. 24 m². The panels are facing east with a tilt from horizontal of 25 °. In the calculated energy performance, a maximum of 25 kWh/(m²y) can be deducted from locally produced electricity (local PV, wind turbines and hydro power). Annual yield of the PV system is calculated to 2870 kWh or 17.4 kWh/(m²y).

		There is no difference between exported or locally used electricity.
Climatic conditions		
Location (country/city)		Denmark, Zealand (coastal European climate)
Design outdoor temperature for heating		-12 °C
Design outdoor temperature and RH for cooling		-
Average annual outdoor temperature		+8.1 °C (+4.7 °C for heating season)
Heating degree days		3410 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2017
Delivered energy use	Electricity	14.1 kWh/(m^{2}y) (fans and pumps)
	Electricity	43.8 kWh/(m^{2}y) (lighting and appliances) not part of the building's energy performance, but serves as internal load
	District heat	0 kWh/(m^{2}y)
	Other (specify)	
On-site generation, electricity (PV)		17.4 kWh/(m^{2}y)
Primary Energy Index		28.1 kWh/(m^{2}y) (excludes appliances in dwellings, PE factor 1.9 for electricity and 0.85 for district heat)

5.1.2 Multi-family house

Building type	Multi-family house
Photo or illustration	
Construction year	2016
Location	Øresund Strandpark Blok A, Lergravsvej 64-76, 2300 Copenhagen S, Denmark (moderate coastal European climate).
Building description	The building is constructed in a recent development Southeast of the Copenhagen city centre and is typical for new multi-family residential buildings in Denmark. The building has 4-7 floors and comply with the voluntary low-energy class requirements stated in the Danish 2010 Building Regulations. There is a central balanced mechanical ventilation system in the flats with heat recovery. A PV system with 134 m² collector area on the green flat roof helps to meet the target value for low-energy buildings.
Heated/conditioned area	8826 m² heated gross floor area
Number of floors	4-7
Mean occupant density	1.5 W/m² (national default) approx. 66 m2/person
Occupied hours	8760 hrs/year
Building envelope	
Description	The building façade is a sandwich construction with an inner leaf of concrete elements XX mm of insulation and an outer shell of brickwork. Insulation thickness varies for different parts of the façade, resulting in U-values varying between 0.16 and 0.2 W/(m²K). Windows are all three-layered glazing with an overall U-value of 0.83 W/(m²K) and a g-value of 0.53. A small part of the basement (142 m²) is heated while the rest (1461 m²) is unheated.

Envelope air permeability, q50	1.0 l/(m²s) of heated gross floor area at 50 Pa pressure difference (design value for low-energy buildings)
Windows U-value	0.83 W/(m² K)
Windows g-value	0.53
External walls U-value	Facades: 0.16-0.20 W/(m² K), basement walls: 0.12-0.14 W/(m² K)
Base floor U-value	0.13 W/(m² K) towards parking 0.20 W/(m² K) towards ground
Roof U-value	0.09 W/(m² K) (green roof)
Building systems	
Description	Heating is delivered from the district heating system of the area, based on waste incineration. The ventilation system is a traditional, central balanced ventilation system with inlet and exhaust ducts over the roof. Heating is delivered from radiators in all primary rooms and with hydronic floor heating in the bathrooms.
Heat sources	District heating based on waste incineration via RECI 195 kW heat exchanger,
Heating systems	Radiators in the primary rooms and hydronic floor heating in bathrooms. Balanced mechanical ventilation with preheating of the inlet air to avoid cold draught.
Cooling sources	Natural ventilation.
Cooling systems	None
Design temperature for heating	20 °C
Design temperature for cooling	No cooling in Danish residential buildings.
Cooling load (typical room)	N/A
Heating load (space heating and ventilation)	22 W/m2
Ventilation system types	Central mechanical ventilation with heat recovery.
Ventilation airflow rates /total air flow	Normal operation 0.3 l/(m²s) Accelerated operation 0.73 l/(m²s) in 2% of the time
Ventilation systems specific fan power (SFP)	1.26 kJ/(m³)
Ventilation heat recovery types	Counter-flow heat exchangers
Ventilation heat recovery efficiency	80% (normal flow) 70% (accelerated flow)
Domestic hot water production	250 l/(m²yr) (national default)
Lighting systems	
Renewable energy systems	
Photovoltaic panels (PV)	PV system with 134 m² collector area on the green flat roof. Estimated annual production is 21209 kWh.
Climatic conditions	
Location (country/city)	Copenhagen, Denmark – costal European climate. The Danish reference year is based on measurements during the period 2001-2010.
Design outdoor temperature for heating	-12 °C
Design outdoor temperature and RH for cooling	27 °C; 80% RH
Average annual outdoor temperature	+8.1 °C (4.7 °C during heating season)
Heating degree days	3410 (base 17°C)

Energy performance		
Energy Performance Certificate (EPC) acquisition year		2016 Calculations are performed using the Danish national energy compliance-checking tool, Be15.
Delivered energy use	Electricity	0.6 kWh/m2y (fans and pumps)
	Electricity	3.5 kWh/m2y (lighting and appliances – national standard)
	District heat	27.8 kWh/m2y (space heating: 7.5, DHW: 19.8, losses 0.5)
	Other (specify)	
On-site generation, electricity (PV)		2.44 kWh/m2y (per heated gross floor area) or 21209 kWh/yr. (installed power 24.3 kWp).
Primary Energy Index		27 kWh/m2y (PE factor 1.9 for electricity and 0.85 for district heat).

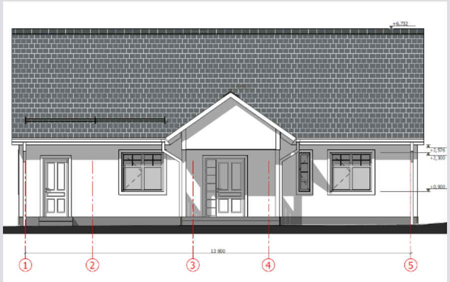
5.1.3 Office building

Building type	Office building
Photo or illustration	
Construction year	2014
Location	Denmark, Copenhagen (moderate climate)
Building description	The Plaza 1 building is U-shaped and located at the harbour front in a recently developed area of Copenhagen. The building is, as most buildings in Copenhagen, heated by district heating via radiators. The building is designed with focus on passive measures (high insulation levels and 3-layer windows) supplemented by PV-panels on the roof. A building management system (BSM) control and monitor the technical building systems in a state-of-the-art optimal way.
Heated/conditioned area	4975 m² gross floor area plus 1100 m² unheated basement.
Number of floors	5-6 on ground, 1 underground
Mean occupant density	25 m^2/person (default in EPC calculations)
Occupied hours	2300 hrs/year (45 hrs/week, used in EPC calculation)
Building envelope	
Description	Building envelope is constructed mostly from pre-cast concrete elements. External walls are insulated with 250 mm mineral wool (total thickness 510 mm), roof with 350 mm mineral wool and floors with 300 mm expanded polystyrene (EPS). Thermal bridges are at a reasonable level. The windows have 3-pane glazing with low-E coatings and Al-based frame with low thermal transmittance. Northeast and Northwest facing windows are equipped with movable solar shading.
Envelope air permeability, q_{50}	0.32 l/(s.m² heated gross floor area) at 50 Pa pressure difference (measured value)
Windows U-value	0.84 W/(m² K)
Windows g-value	0.46
External walls U-value	0.12 W/(m² K), 0.22 W/(m² K) for 79 m² light wall on 5th floor towards roof terrace.
Base floor U-value	0.10 W/(m² K)

Roof U-value		0.10 W/(m² K)
Building systems		
Description		Ventilation systems have heat recovery efficiency of 0.82 controlled individually depending on room type and use. The ventilation system have integrated mechanical cooling on 75% of the area. For the heating, district heating is used. Lighting (6-8 W/m²) are continuously controlled according to daylight level and motion (PIR) sensors.
Heat sources		District heating.
Heating systems		High temperature radiators (70/40°C)
Cooling sources		Electricity.
Cooling systems		Ventilation cooling coils
Design temperature for heating		20 °C
Design temperature for cooling		25 °C
Cooling load (typical room)		? W/m^2
Heating load (space heating and ventilation)		? W/m^2
Ventilation system types		Mechanical supply/exhaust ventilation, heat recovery 82% efficiency
Ventilation airflow rates /total air flow		Offices: 1.2 l/(s.m²) Meeting rooms 1.5 l/(s.m²) Canteen: . 1.1 l/(s.m²) The total air flow rate of the building is 3.8 m^3/s
Ventilation systems specific fan power (SFP)		1.34 kJ/m^3 (average)
Ventilation heat recovery types		Cross flow heat exchangers
Ventilation heat recovery efficiency		Temperature efficiency (average): 82 %
Domestic hot water production		District heating Hot water consumption 100 l/m² (calculation default)
Lighting systems		Occupancy and photocell controlled dimming LED; installed power 6-8 W/m^2 (200 lux)
Renewable energy systems		
Photovoltaic panels (PV)		The installed power of PV system is 49.1 kWp on 332 m² south facing PV panels with a 10° tilt on the roof. Annual yield of the PV system is 39.8 MWh.
Climatic conditions		
Location (country/city)		Denmark, Copenhagen (moderate climate)
Design outdoor temperature for heating		-12 °C
Design outdoor temperature and RH for cooling		27 °C; 50% RH
Average annual outdoor temperature		+8.1 °C (4.7 °C during heating season)
Heating degree days		3410 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2014
Delivered energy use	Electricity	5.20 $kWh/(m^2y)$ (fans and pumps)
	Electricity	6.49 $kWh/(m^2y)$ (lighting)
	Electricity	13.77 $kWh/(m^2y)$ (appliances) calculation default, not included in the EPC index
	District heat	17.3 $kWh/(m^2y)$
	Other	0.67 kWh/(m²y) (cooling)
On-site generation, electricity (PV)		7.8 $kWh/(m^2y)$
Primary Energy Index		23.3 $kWh/(m^2y)$ (excluding appliances, PE factor 1.9 for electricity and 0.85 for district heat)

5.2 Estonia

5.2.1 Single-family house

Building type	Single family house
	
Construction year	2017
Location	Estonia, Tallinn (cold climate)
Building description	The building is a single floor detached house. The architecture features a roof overhang, optimal window sizes with low-E and optimal solar factor glazing to maximize solar gains during wintertime and minimize the risk for summertime overheating. Heating energy is provided by ground source heat pump and rooms are heated with underfloor heating utilising low temperature supply water. The ventilation system consists of mechanical supply-exhaust unit with high heat recovery rate. To achieve NZEB energy efficiency level, one side of the roof is filled with PV-panels for local electricity production.
Heated/conditioned area	101 m^2
Number of floors	1
Mean occupant density	40 m^2/person
Occupied hours	8760 hrs/year
Building envelope	
Description	The building envelope is wood structured and insulated with mineral wool. Thermal bridges have been minimized with optimized joints between construction elements, windows and walls. The windows have 3-pane glazing with low-E coatings and PVC-based frame with low thermal transmittance. Roof overhangs and optimized window sizes are used to achieve solar gains in winter and to prevent summertime overheating.
Envelope air permeability, q_{50}	<1.5 m^3/h per m^2 of ext. walls at 50 Pa pressure difference (design value)
Windows U-value	<0.9 W/(m² K) [frame<1.0 W/(m² K); glazing<0.5 W/(m² K)]
Windows g-value	0.55
External walls U-value	0.12 W/(m² K), basement walls 0.17 W/(m² K)
Base floor U-value	0.12 W/(m² K)
Roof U-value	0.10 W/(m² K)
Building systems	
Description	The ventilation unit has a rotary heat exchanger with high heat recovery efficiency. The building is designed with low temperature heating system to ensure low energy consumption.
Heat sources	Air-to-water heat pump
Heating systems	Low temperature underfloor heating (2.9kW, water +32/29°C)
Cooling sources	No active cooling systems.

Cooling systems		No active cooling systems. Passive cooling solutions are achieved with architectural elements and optimized window glazing parameters
Design temperature for heating		21 °C
Design temperature for cooling		27 °C
Cooling load (typical room)		-
Heating load (space heating and ventilation)		28 W/m^2
Ventilation system types		Mechanical supply/exhaust ventilation, heat recovery (rotary heat exchanger)
Ventilation airflow rates /total air flow		Average 0.42 l/s per m^2 floor area; The total air flow rate of the building is +/-0.042 m^3/s
Ventilation systems specific fan power (SFP)		1.5 kW/(m^3/s) (average)
Ventilation heat recovery types		Rotary heat exchanger
Ventilation heat recovery efficiency		Temperature efficiency (average): 80%
Domestic hot water production		Heat-pump based
Lighting systems		LED lighting
Renewable energy systems		
Photovoltaic panels (PV)		The installed power of PV system is 4.0 kW, with 35° tilt angle. Annual yield of the PV system is 1 MWh_e of which 90% is consumed on-site and 10% is exported.
Climatic conditions		
Location (country/city)		Estonia, Tallinn (cold climate)
Design outdoor temperature for heating		-22 °C
Design outdoor temperature and RH for cooling		27 °C for overheating calculations
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		4518 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2017
Delivered energy use	Electricity	5.3 kWh/(m^2y) (fans and pumps)
	Electricity	29.1 kWh/(m^2y((lighting and appliances)
	District heat	38.1 kWh/(m^2y) (underfloor heating, ventilation air heating, domestic hot water)
	Other (specify)	
On-site generation, electricity (PV)		10.5 kWh/(m^2y)
Primary Energy Index		95 kWh/(m^2y) (includes appliances, PE factor 2.0 for electricity and 0.9 for district heat)

5.2.2 Multi-family house

Building type	Apartment building
Photo or illustration	
Construction year	2016
Location	Estonia, Tallinn (cold climate)

Building description	The apartment building has 4 residential floors, 1 commercial floor and an underground garage. The architectural design utilizes a combination of passive cooling measures such as massively structured envelope, optimal window sizes with low-E and optimal solar factor glazing together with shading balconies to minimize the risk for summertime overheating. Heating energy is provided by district heating network and rooms are heated mostly with underfloor heating utilising low temperature supply water. The ventilation system consists of apartment-based ventilation units with high heat recovery rate. To achieve NZEB energy efficiency level, the roof of the building is filled with PV-panels for local electricity production.
Heated/conditioned area	2170 m^2
Number of floors	5 on ground, 1 underground
Mean occupant density	60 m^2/person
Occupied hours	8760 hrs/year
Building envelope	
Description	Building envelope is constructed mostly from prefabricated concrete elements: with precast concrete sandwich panel external walls and hollow core concrete slabs. External walls are insulated with 200mm expanded polystyrene (EPS) and roof with 250mm polyisocyanurate (PIR) and 200mm EPS; floors with 200mm (EPS). Thermal bridges have been minimized with optimized joints between construction elements, windows and walls. The windows have 3-pane glazing with low-E coatings and PVC-based frame with low thermal transmittance. In east, south and west façades shading balconies and architectural elements are used to prevent summertime overheating.
Envelope air permeability, q_{50}	<1.5 m^3/h per m^2 of ext. walls at 50 Pa pressure difference (design value)
Windows U-value	<0.9 W/(m^2 K) [frame<1.0 W/(m^2 K); glazing<0.8 W/(m^2 K)]
Windows g-value	0.55
External walls U-value	0.12 W/(m^2 K), basement walls 0.17 W/(m^2 K)
Base floor U-value	0.12 W/(m^2 K)
Roof U-value	0.08 W/(m^2 K)
Building systems	
Description	The installed apartment-based ventilation units have rotary heat exchangers with high heat recovery efficiency. The building is designed with low temperature heating systems to ensure low energy consumption.
Heat sources	District heating based
Heating systems	Low temperature radiators in common spaces, e.g. hallways (13kW, water +55/40°C); Underfloor heating (90kW, water +37/32°C)
Cooling sources	No active cooling systems.
Cooling systems	No active cooling systems. Passive cooling solutions are achieved with massive structures, architectural elements and optimized window glazing parameters
Design temperature for heating	21 °C
Design temperature for cooling	27 °C
Cooling load (typical room)	-
Heating load (space heating and ventilation)	39 W/m^2
Ventilation system types	Mechanical supply/exhaust ventilation, heat recovery (rotary heat exchangers), apartment-based ventilation units (51 units)

Ventilation airflow rates /total air flow		Average 0.5 l/s per m^2 floor area; The total air flow rate of the building is +/-1.8 m^3/s
Ventilation systems specific fan power (SFP)		1.5 kW/(m^3/s) (average)
Ventilation heat recovery types		Rotary heat exchangers
Ventilation heat recovery efficiency		Temperature efficiency (average): 80%
Domestic hot water production		District heating based
Lighting systems		No specific data available for dwellings. LED lighting in common spaces.
Renewable energy systems		
Photovoltaic panels (PV)		The installed power of PV system is 65.4 kW. Annual yield of the PV system is 57 MWh$_e$ of which 90% is consumed on-site and 10% is exported.
Climatic conditions		
Location (country/city)		Estonia, Tallinn (cold climate)
Design outdoor temperature for heating		-22 °C
Design outdoor temperature and RH for cooling		27 °C for overheating calculations
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		4518 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2017
Delivered energy use	Electricity	5.8 kWh/(m^{2}y) (fans and pumps)
	Electricity	29.5 kWh/(m^{2}y((lighting and appliances)
	District heat	50.6 kWh/(m^{2}y) (underfloor heating, radiator heating, domestic hot water)
	Other (specify)	2.9 kWh/(m^{2}y) (ventilation air electric heating)
On-site generation, electricity (PV)		13.3 kWh/(m^{2}y)
Primary Energy Index		95 kWh/(m^{2}y) (includes appliances, PE factor 2.0 for electricity and 0.9 for district heat)

5.2.3 Office buildings

Building type	Office building #1
Photo or illustration	
Construction year	2015
Location	Estonia, Rakvere (cold climate)

Building description	'Rakvere Smart Building' is the first NZEB office demo building in Estonia that also demonstrates smart building automation systems. The building has 3 office floors, a heated atrium, an unheated atrium and a basement with a garage and technical rooms underground. The building is designed with a combination of passive measures such as compact massing, optimal window sizes and a smart façade with external shading, heat pump, district heating, free cooling, PV-panels and high-performance automation system.
Heated/conditioned area	2170 m^2
Number of floors	3 on ground, 1 underground
Mean occupant density	17 m^2/person
Occupied hours	2870 hrs/year
Building envelope	
Description	Building envelope is constructed mostly from monolithic concrete; external walls are insulated with 200mm polyurethane (PUR), roof with 400mm extruded polystyrene (XPS) and floors with 200mm expanded polystyrene (EPS). Thermal bridges have been minimized with optimized joints between construction elements, windows and walls. The windows have 3-pane glazing with low-E coatings and either wood-, PVC- or Al-based frame with low thermal transmittance. For west façade a double skin façade with automated solar blinds and in south façade fixed shades are used to reduce cooling need and prevent solar glare.
Envelope air permeability, q_{50}	3.0 m^3/h per m^2 of ext. walls at 50 Pa pressure difference (design value)
Windows U-value	<0.76 W/(m^2 K) [frame<0.8 W/(m^2 K); glazing<0.5 W/(m^2 K)]
Windows g-value	0.40
External walls U-value	0.10 W/(m^2 K), basement walls 0.17 W/(m^2 K)
Base floor U-value	0.15 W/(m^2 K)
Roof U-value	0.10 W/(m^2 K)
Building systems	
Description	Ventilation systems have high heat recovery efficiency and are DCV (demand controlled) or CAV depending on the room category. The building is designed with high temperature cooling and low temperature heating systems to ensure low energy consumption. Two energy wells (aquifer) are used as the main heat source of the water to water heat pump and for direct free cooling (there is no additional mechanical cooling). For the heating top-up, district heating is used.
Heat sources	Energy wells (2 pcs q=5.0 l/s, water 7…9°C) -based heat pump system, with district heating top-up
Heating systems	Low temperature radiators (32kW, water +55/40°C); Floor heating, basement and 1st floor (23kW, water +45/40°C) Ventilation heating coils (52kW, water +45/30°C)
Cooling sources	Direct free cooling via energy wells (2 pcs q=5.0 l/s, water 7…9°C)
Cooling systems	Passive chilled beams and fan-coils (68kW, water +16/18°C); COP = 17.5 (free-cooling) Ventilation cooling coils (8kW, water +9/13°C)
Design temperature for heating	21 °C
Design temperature for cooling	25 °C
Cooling load (typical room)	65 W/m^2
Heating load (space heating and ventilation)	42 W/m^2

Ventilation system types		Mechanical supply/exhaust ventilation, heat recovery, DCV (4 units) and CAV (2 units)
Ventilation airflow rates /total air flow		Offices: 1(min)…2(max) l/s per m^2 floor area; The total air flow rate of the building is +/-3.7 m^3/s
Ventilation systems specific fan power (SFP)		2.0 kW/(m^3/s) (average)
Ventilation heat recovery types		Hygroscopic rotary heat exchangers
Ventilation heat recovery efficiency		Temperature efficiency (average): 80%
Domestic hot water production		Heat pump and district heating based (top-up)
Lighting systems		Occupancy and photocell controlled dimming LED; installed power 4.8W/m^2
Renewable energy systems		
Photovoltaic panels (PV)		The installed power of PV system is 33.8 kW. Annual yield of the PV system is 28.8 MWh_e of which 85% is consumed on-site and 15% is exported.
Climatic conditions		
Location (country/city)		Estonia, Rakvere (cold climate)
Design outdoor temperature for heating		-24 °C
Design outdoor temperature and RH for cooling		27 °C; 50% RH
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		4518 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2014
Delivered energy use	Electricity	11 kWh/(m^2y) (fans and pumps)
	Electricity	31 kWh/(m^2y((lighting and appliances)
	District heat	46 kWh/(m^2y) (as the heat pump was installed later, EPC calculation is with district heating)
On-site generation, electricity (PV)		13 kWh/(m^2y)
Primary Energy Index		98 kWh/(m^2y) (includes appliances, PE factor 2.0 for electricity and 0.9 for district heat)

Building type	Office building #2
Photo or illustration	
Construction year	2021
Location	Estonia, Pärnu (cold climate)
Building description	This modern office building is designed and constructed according to Estonian NZEB requirements in force from 2019/2020. Building site and functions have led to low-rise architecture with not maximized compactness, but with careful façade design and application of passive and active measures. Highly insulated building envelope, effective HVAC, BACS, lighting, and renewable energy systems represent a state of the art of best available technologies, making this building an exemplary implementation of Estonian new NZEB requirements. At the same time there is no overinvestment and good indoor climate (Category I or II depending on the parameter) is achieved in cost effective manner.
Heated/conditioned area	12 789 m^2

Number of floors	3/4 on ground
Mean occupant density	17 m^2/person
Occupied hours	2870 hrs/year
Building envelope	
Description	Building envelope is constructed mostly from monolithic concrete; external walls are insulated with 200mm polyurethane (PUR), roof with 400mm extruded polystyrene (XPS) and floors with 200mm expanded polystyrene (EPS). Thermal bridges have been minimized with optimized joints between construction elements, windows, and walls. The windows have 3-pane glazing with low-E and low g coatings and either wood-, PVC- or Al-based frame with low thermal transmittance.
Envelope air permeability, q_{50}	1.0 m^3/h per m^2 of ext. walls at 50 Pa pressure difference
Windows U-value	0.68 W/(m^2 K)
Windows g-value	0.27
External walls U-value	0.15 W/(m^2 K)
Base floor U-value	0.15 W/(m^2 K)
Roof U-value	0.10 W/(m^2 K)
Building systems	
Description	The air conditioning system with active chilled beams and mechanical supply and exhaust ventilation with heat recovery. Larger rooms have demand-controlled ventilation (based on CO2 and temperature) and lighting control with occupancy sensors, photocell-controlled dimming, and time control. Cooling system includes free cooling up to +10 °C outdoor temperature. Heating system consist of effective district heating and water radiators with actuators controlled by room temperature sensors. Modern BACS system enables remote monitoring of energy, indoor climate, and technical systems performance. Energy meters are installed so that the breakdown of energy balance main components can be easily metered. This includes heat meters for space and ventilation heating, DHW and cooling. Electricity is metered for chillers, air handling units, circulation pumps, lighting and appliances (in Estonia included into EPBD assessment) with zoning for facility and tenants. Non-EPBD uses (hot kitchen, serves, etc.) are equipped with separated electricity meters. Indoor climate monitoring is possible via data from CO_2, temperature, and occupancy sensors available in most of zones. System performance can be monitored from rooms (controllers, actuators and dampers), from air handling units, ductwork, heating and cooling system plants, distribution systems and PV systems.
Heat sources	Efficient district heating
Heating systems	Low temperature radiators Ventilation heating coils
Cooling sources	Compressor-based (EER 4.5) / Free cooling
Cooling systems	Active chilled beams Ventilation cooling coils
Design temperature for heating	21 °C
Design temperature for cooling	25 °C
Cooling load (typical room)	50 W/m^2
Heating load (space heating and ventilation)	35 W/m^2
Ventilation system types	Mechanical supply/exhaust ventilation, heat recovery, VAV and CAV
Ventilation airflow rates /total air flow	Offices: 1(min)…2(max) l/s per m^2 floor area
Ventilation systems specific fan power (SFP)	1.7 kW/(m^3/s) (average)

Ventilation heat recovery types		Hygroscopic rotary heat exchangers
Ventilation heat recovery efficiency		Temperature efficiency (average): 80%
Domestic hot water production		District heating based
Lighting systems		Occupancy and photocell controlled dimming LED; installed power 8W/m^2
Renewable energy systems		
Photovoltaic panels (PV)		The installed power of PV system is 108 kW. Annual yield of the PV system is 119 MWh_e of which 90% is consumed on-site and 10% is exported.
Climatic conditions		
Location (country/city)		Estonia, Pärnu (cold climate)
Design outdoor temperature for heating		-24 °C
Design outdoor temperature and RH for cooling		27 °C; 50% RH
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		4518 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2020
Delivered energy use	Electricity	10.9 kWh/(m^2y) (fans and pumps)
	Electricity	31 kWh/(m^2y((lighting and appliances)
	District heat	32.7 kWh/(m^2y)
	Other (specify)	
On-site generation, electricity (PV)		9.3 kWh/(m^2y)
Primary Energy Index		86 kWh/(m^2y) (includes appliances, PE factor 2.0 for electricity and 0.65 for district heat)

5.3 Finland

5.3.1 Single family house

Building type	Single family house
Photo or illustration	
Construction year	2017
Location	Finland, Kuovola (cold climate)
Building description	The building is a typical two-storey single family detached house. Architectural elements, such as overhangs and balcony provide passive shading for overheating prevention. The building envelope is reasonably insulated and airtight. Technical systems are optimised for energy efficiency considering cold climate conditions.
Heated/conditioned area	177 m^2

Number of floors	1
Mean occupant density	40 m^2/person
Occupied hours	8760 hrs/year
Building envelope	
Description	External walls are wooden frame construction with 200+50 mm of mineral wool insulation which gives a U-value of =0.16 W/m2K. The roof is insulated with at least 500 mm of mineral wool insulation to reach the design U-value of 0.08 W/m²K. The roof construction consists of steel metal plate, wooden truss, joist, thermal insulation, vapour barriers and cladding. The designed insulation value of the ground floor is 0.14 W/m²K, which is achieved by using floor covering, concrete slab, insulation and gravel layer. The building has a pile foundation. U-value for windows and doors are 1.0 W/m²K. Windows G value is 0.64. It has triple-glazed windows with low-e coating. All structural elements of the building are made of a wooden frame. The building's structural and roof are made of a wooden frame and the floors are made of a concrete slab. The building has a pile foundation.
Envelope air permeability, q_{50}	2 m^3/h per m^2 of ext. walls at 50 Pa pressure difference (design value)
Windows U-value	<0.9 W/(m² K) [frame<1.0 W/(m² K); glazing<0.64 W/(m² K)]
Windows g-value	0.55
External walls U-value	0.16 W/(m² K), basement walls 0.17 W/(m² K)
Base floor U-value	0.14 W/(m² K)
Roof U-value	0.08 W/(m² K)
Building systems	
Description	The ventilation is supplied via a balanced mechanical ventilation system with a heat recovery of at least 79%. The fan power is 1.8 kW/m3s. The district heating system provides the floor and DHW heating. The efficiency of the heating system is 94%. Both supply and return air flow rate is 0.06 m3/s, and the electric heater heats supply air. The extract air tem-
Heat sources	Air-to-water heat pump
Heating systems	Low temperature underfloor heating (2.9kW, water +32/29°C)
Cooling sources	No active cooling systems.
Cooling systems	No active cooling systems. Passive cooling solutions are achieved with architectural elements and optimized window glazing parameters
Design temperature for heating	21 °C
Design temperature for cooling	27 °C
Cooling load (typical room)	-
Heating load (space heating and ventilation)	28 W/m^2
Ventilation system types	Mechanical supply/exhaust ventilation, heat recovery (rotary heat exchanger)
Ventilation airflow rates /total air flow	Average 0.4 l/s per m^2 floor area
Ventilation systems specific fan power (SFP)	1.8 kW/(m^3/s) (average)
Ventilation heat recovery types	Rotary heat exchanger
Ventilation heat recovery efficiency	Temperature efficiency: 79%
Domestic hot water production	Heat-pump based
Lighting systems	LED lighting
Renewable energy systems	

Photovoltaic panels (PV)		The installed power of PV system is 4.0 kW, with 35° tilt angle. Annual yield of the PV system is 1 MWh_e of which 90% is consumed on-site and 10% is exported.
Climatic conditions		
Location (country/city)		Finland, Kuovola (cold climate)
Design outdoor temperature for heating		-26 °C
Design outdoor temperature and RH for cooling		27 °C for overheating calculations
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		4392 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2017
Delivered energy use	Electricity	5.3 kWh/(m^2y) (fans and pumps)
	Electricity	29.1 kWh/(m^2y((lighting and appliances)
	District heat	38.1 kWh/(m^2y) (underfloor heating, ventilation air heating, domestic hot water)
	Other (specify)	
On-site generation, electricity (PV)		10.5 kWh/(m^2y)
Primary Energy Index		95 kWh/(m^2y) (includes appliances, PE factor 1.2 for electricity and 0.5 for district heat)

5.3.2 Day-care centre

Building type	Day-care building
Photo or illustration	
Construction year	2015
Location	Finland, Kuovola (cold climate)
Building description	The day-care centre is a single-storey wooden building that became operational in 2015. The building has 6 separate sections, home areas, of which one is so called third-shift home area. The building is designed for 120 children. The rooms facing the inner yard consist of entrance halls, bathrooms, and small office rooms.
Heated/conditioned area	1192 m^2
Number of floors	1
Mean occupant density	10 m^2/person
Occupied hours	3120 hrs/year
Building envelope	
Description	External wooden (48 x 198 c/c 600) framed walls have 200 0.031 W/mK) of 50 mm on the external side of the frame. The building has been founded on driven steel piles. Aerated base floor has a 800 mm crawlspace underneath. The floor girders are of wood 45x100 c/c 400 laminated veneer wood with 260 mm of mineral wool 7 -between. Under the floor girders there is separate wind barrier sheeting of 12 mm. Roofing has girder trusses and upper roof has the stiffer base mineral wool insu- 7 1 blown mineral woo 1

Envelope air permeability, q_{50}		1.3 m^3/h per m^2 of ext. walls at 50 Pa pressure difference (design value)
Windows U-value		0.84 W/(m² K)
Windows g-value		0.36
External walls U-value		0.15 W/(m² K)
Base floor U-value		0.16 W/(m² K)
Roof U-value		0.08 W/(m² K)
Building systems		
Description		Heating system utilizes geothermal heat for space and supply air heating. Heat is transferred to the rooms via floor heating, which covers the whole building. Room temperatures are automatically controlled by room-specific temperature sensors. The building is equipped with three air handling units. The building has no active cooling system. The air handling units are equipped with air filtering and heat recovery unit. AHU1 is used for play and office rooms and is demand-based, controlled by indoor air quality, temperature, and occupancy presence. While occupied, ventilation rates in play and office rates are 40% of the maximum. AHU2 ventilates the toilets and AHU3 is for the kitchen. The total maximum airflow rate 7 1
Heat sources		Ground source heat pump
Heating systems		Low temperature underfloor heating
Cooling sources		No active cooling systems
Cooling systems		No active cooling systems. Passive cooling solutions are achieved with architectural elements and optimized window glazing parameters
Design temperature for heating		21 °C
Design temperature for cooling		27 °C
Cooling load (typical room)		-
Heating load (space heating and ventilation)		28 W/m^2
Ventilation system types		Mechanical supply/exhaust ventilation, heat recovery, DCV
Ventilation airflow rates /total air flow		Average 3.1 l/s per m^2 floor area
Ventilation systems specific fan power (SFP)		1.9 kW/(m^3/s) (average)
Ventilation heat recovery types		Rotary heat exchanger
Ventilation heat recovery efficiency		Temperature efficiency: 76%
Domestic hot water production		Heat-pump based
Lighting systems		LED lighting
Renewable energy systems		
Photovoltaic panels (PV)		-
Climatic conditions		
Location (country/city)		Finland, Kuovola (cold climate)
Design outdoor temperature for heating		-26 °C
Design outdoor temperature and RH for cooling		27 °C for overheating calculations
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		4392 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2016 (measured)
Delivered energy use	Electricity	38.5 kWh/(m^2y) (fans and pumps)
	Electricity	32.5 kWh/(m^2y) (lighting and appliances)

	Heat pump	59.5 kWh/(m^2y) (heat)
	Other (specify)	
On-site generation, electricity (PV)		-
Primary Energy Index		121 kWh/(m^2y) (includes appliances, PE factor 1.2 for electricity and 0.5 for district heat)

5.3.3 School buildings

Building type	School building #1
Photo or illustration	
Construction year	2017
Location	Finland, Espoo (cold climate)
Building description	Karhusuo school is located in northern Espoo. The building was constructed from elements in 2017 by Parmaco. The building is a two-storied wooden building used by 246 primary school students, 16 full-time staff members and 4 part-time members. The gross area of the building is 3078 m2, heated net area 2830 m2 and volume 12423 m3. Energy Performance Certificate (EPC) class is B.
Heated/conditioned area	2830 m^2
Number of floors	2
Mean occupant density	7 m^2/person
Occupied hours	2080 hrs/year
Building envelope	
Description	The external walls have a 9 mm wind barrier, 250 mm of mineral wool with a vapor barrier and 13 mm gypsum board. The roof is made of bitumen with 420 mm blow wool, 15 mm fire gypsum board, and 100 mm mineral wool with vapor barrier. Base floor has 22 mm chipboard, vapor barrier and 270 mm mineral wool.
Envelope air permeability, q_{50}	1.3 m^3/h per m^2 of ext. walls at 50 Pa pressure difference (design value)
Windows U-value	0.84 W/(m^2 K)
Windows g-value	0.36
External walls U-value	0.15 W/(m^2 K)
Base floor U-value	0.16 W/(m^2 K)
Roof U-value	0.08 W/(m^2 K)
Building systems	
Description	Heating system utilizes geothermal heat for space and supply air heating. Three ground-source heat pumps are connected to a total of 15 heat wells. Back-up heating is done with a 105 kW electric boiler. Heat is transferred to the rooms via ceiling panels. Wet spaces are heated with floor heating. Ceiling panels and floor heating are both separate systems. During summer, the ceiling panel system can be used for cooling. The cooling system is also its separate system, and it uses the ground-source heat pumps as its source. The building is connected to the local (HSY) water and sewage system. Design indoor environment including room specific ventilation rates are followed according to class S2 (Finnish indoor

		environmental class). Air handling units are equipped with filtering, heat recovery and heating facilities. The building has a total of 9 air handling units. AHUs 1-4 serve the classrooms and dining hall on both floors of the building. Ventilation oper- 6 -17.00 and at 30% of design value during unoccupied hours. Night cooling is used if room temperature is 2°C over set point and outside air is 12-22 °C. AHU 5 ventilates the kitchen during 7.00-15.00, otherwise ventilation is completely turned off. AHUs 6-9 serve the bathrooms and lobby hall of both floors and are run constantly. The combined maximum supply air flow rates for the air handling units is 9.16 m³/s, which equals to an av- Classrooms have a total of four ceiling heating panels, which are controlled with a single controller. Target room temperatures for winter were 20-22 °C and summer 23-27 °C. All the classrooms can be separated into two different rooms with a movable partition wall, after which an additional controller should be added to the other room. Ventilation system is implemented so that both halves of the initial room will have sufficient ventilation.
Heat sources		Ground source heat pump, heat wells
Heating systems		Low temperature ceiling panels and underfloor heating
Cooling sources		Ground source heat pump, heat wells
Cooling systems		High temperature ceiling panels
Design temperature for heating		21 °C
Design temperature for cooling		25 °C
Cooling load (typical room)		-
Heating load (space heating and ventilation)		W/m^2
Ventilation system types		Mechanical supply/exhaust ventilation, heat recovery, DCV
Ventilation airflow rates /total air flow		Average 3.2 l/s per m^2 floor area
Ventilation systems specific fan power (SFP)		1.8 kW/(m^3/s) (average)
Ventilation heat recovery types		Rotary heat exchanger
Ventilation heat recovery efficiency		Temperature efficiency: 73%
Domestic hot water production		Heat-pump based
Lighting systems		LED lighting
Renewable energy systems		
Photovoltaic panels (PV)		-
Climatic conditions		
Location (country/city)		Finland, Espoo (cold climate)
Design outdoor temperature for heating		-26 °C
Design outdoor temperature and RH for cooling		25 °C
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		3878 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2017
Delivered energy use	Electricity	36 kWh/(m^{2}y) (fans and pumps)
	Electricity	25 kWh/(m^{2}y) (lighting and appliances)
	Heat pump	42 kWh/(m^{2}y) (heat)
	Other (specify)	-
On-site generation, electricity (PV)		-
Primary Energy Index		104 kWh/(m^{2}y) (includes appliances, PE factor 1.2 for electricity and 0.5 for district heat)

Building type	School building #2
Photo or illustration	
Construction year	2017
Location	Finland, Espoo (cold climate)
Building description	The Niipperi school is a two-storey wooden building with 3045 m2 of space designed for 320 students and 20 staff members. The building also has a kindergarten with 38 children and 4 staff members. There are a total of 19 classrooms, some of which can be divided into two rooms with a movable partition wall.
Heated/conditioned area	2912 m^2
Number of floors	2
Mean occupant density	7 m^2/person
Occupied hours	2080 hrs/year
Building envelope	
Description	Under the building facade, the external walls have an air gap 19+19 mm, wind barrier 9 mm, mineral wool 250 mm, vapor barrier and gypsum board 13 mm. The roof is made of bitumen, fire retardant mineral wool 100 mm, mineral wool 300 mm, vapor barrier and gypsum board 13 mm. Aerated base floor have a 800 mm crawlspace underneath. The base floor has a vapor barrier under the top level, with normal and fire-retardant mineral wool 300+100 mm. Outer level has a porous wind barrier 25 mm.
Envelope air permeability, q_{50}	1.3 m^3/h per m^2 of ext. walls at 50 Pa pressure difference (design value)
Windows U-value	1.0 W/(m² K)
Windows g-value	0.56
External walls U-value	0.16 W/(m² K)
Base floor U-value	0.16 W/(m² K)
Roof U-value	0.09 W/(m² K)
Building systems	
Description	Niipperi school is connected to the district heating network. Heat is provided to ventilation (197 kW), floor heating (94 kW) and DHW (200 kW), which all have their own network. The whole building area is covered with floor heating and also equipped with a total of five fan coil units. Floor heating is controlled according to outdoor temperature. The building has a mechanical supply and exhaust ventilation. The building has a total of 8 air handling units, with AHU 1-4 serving the classrooms, AHU 5 serving the dining hall, AHU 7 the kitchen and AHU 6 and 8 the bathrooms and social rooms. Ventilation rates are constant and run according to present schedules. Ventilation to classrooms is at 100% for 12 hours a day during occupied hours and at 50% for the other half of the day. Ventilation to dining hall is at 100% for 4 hours and 50% for 20 hours. Supply air in classrooms and dining hall is heated with water radiators and cooled down by fluid coolers located on the roof. Heat is recovered with thermal wheels. Ventilation in bathrooms and social rooms is

		constant. AHU 6 air is heated using water radiators and AHU 8 with electric heating coils. In both AHUs heat is recovered using plate heat exchangers. The combined maximum supply air flow of the air handling units is 10.45 m³/s which equals to 6
Heat sources		District heating
Heating systems		Radiator heating
Cooling sources		Chiller with dry-cooler
Cooling systems		Ventilation air cooling
Design temperature for heating		21 °C
Design temperature for cooling		25 °C
Cooling load (typical room)		-
Heating load (space heating and ventilation)		W/m^2
Ventilation system types		Mechanical supply/exhaust ventilation, heat recovery, DCV
Ventilation airflow rates /total air flow		Average 3.6 l/s per m^2 floor area
Ventilation systems specific fan power (SFP)		1.8 kW/(m^3/s) (average)
Ventilation heat recovery types		Rotary heat exchanger
Ventilation heat recovery efficiency		Temperature efficiency: 77%
Domestic hot water production		District heating based (200kW)
Lighting systems		LED lighting
Renewable energy systems		
Photovoltaic panels (PV)		6.5kW
Climatic conditions		
Location (country/city)		Finland, Espoo (cold climate)
Design outdoor temperature for heating		-26 °C
Design outdoor temperature and RH for cooling		25 °C
Average annual outdoor temperature		+4.2 °C (-1.5 °C for heating season)
Heating degree days		3878 (base 17°C)
Energy performance		
Energy Performance Certificate (EPC) acquisition year		2017
Delivered energy use	Electricity	13 kWh/(m^2y) (fans and pumps)
	Electricity	19.4 kWh/(m^2y) (lighting and appliances)
	Heat pump	42 kWh/(m^2y) (heat)
	Cooling	1.5 kWh/(m^2y)
On-site generation, electricity (PV)		2.2 kWh/(m^2y)
Primary Energy Index		95 kWh/(m^2y) (includes appliances, PE factor 1.2 for electricity and 0.5 for district heat)

5.4 Latvia

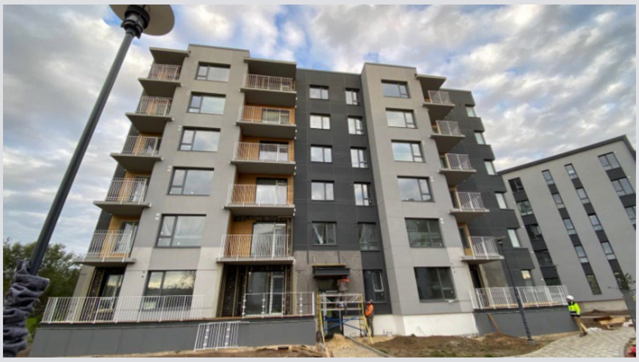
5.4.1 Single family house

Building type	Single family building
	
Construction year	2021
Location	City of Jelgava, Latvia
Building description	Building has a slab on the ground. Building has an efficient compactness ration. It doesn’t have special sun shadings (both internal and external). Floor slab made of prefabricated reinforced concrete panels. Partition walls are made of light-weight plasterboard structures. The roof has a ventilated airspace above thermal insulation, with steel coating.
Heated/conditioned area	167,1 m^2
Number of floors	1 on ground
Mean occupant density	40 m^2/person
Time of stay of people in the **building** per day (average per month)	12 hours per day
Typical building electricity consumption for indoor lighting, appliances inside and outside the building	7.30 kWh/m² per year
Design temperature for heating	21 °C
Design temperature for cooling	25 °C (for energy consumption calculations for building cooling/overheating)
The method of calculating the energy performance of a building	Monthly calculation method
Building envelope	
Description	Walls made out of clay concrete and extra thermal insulation. Window frame 6 7 -TERMO/GENEO
Building airtightness, n_{50}	n_{50} =0,6
Windows U-value (average)	0,75 W/(m² K) (average value) .
Windows g-value	0.49
External walls U-value	0.144 W/(m² K)
Slab on the ground U-value	0.15 W/(m² K)
U-value of the ceiling between the ventilated shelter and the premises	0.066 W/(m² K)
Building systems	
Description	A local pellet fireplace with boiler connection is used for space heating and hot water preparation. Floor heating on first floor and partly on the second floor. Hot tap water system with circulation.
Heating system	
Heat source	Inverter heat pump ground/water
Heat source efficiency	SPF=4.17
Heat source capacity	5.5 kW

	Energy source for heating	Grid electricity for pump operations. Pellets for thermal energy production
	Heating system control devices	Heating device thermostats and room temperature sensor
Ventilation system		PH certified Brink Flair ventilation unit with exhaust air heat exchanger
	Outdoor air volume for 1 m^2 building ventilation	1.8 m^3/m^2 per hour
	Ventilation system type	Mechanical balanced ventilation with exhaust heat recovery
	Ventilation heat recovery type	With cross-counterflow plate heat exchanger
	Temperature efficiency of the recuperator	0.91
	Ventilation systems specific power input (SPI)	0.21 Wh/m^3
	Energy source for heating the outside air supply	Pellet fireplace connected to accumulation tank 600l. Warm floor system on the first floor and partly on the second floor, hot water with circulation.
Domestic hot water system		Pellet fireplace connected to accumulation tank 600l. Warm floor system on the first floor and partly on the second floor, hot water with circulation.
	Annual thermal energy demand for hot water production per 1 m^2 of building	29.90 kWh/m^2 per year
	Heat source for hot water production	Pellet fireplace
	Heat source efficiency	-
	Energy source for hot water production	Pellet boiler and electricity
	Insulation of hot water pipes	No data available
Cooling system		No active cooling systems.
Lighting system		LED lighting
Renewable energy systems		
Photovoltaic panels (PV)		n/a
Compliance of the building with NZEB requirements		
The annual thermal energy consumption for heating < 50 kWh/m2		Actual value: 27.20 kWh/m^2
Air change rate 0.35 l/sm2 or ach 0.5		Actual value: ach 0.5
The efficiency of the recuperator		Actual value: 0,84.
The amount of electricity used by the recuperator fans - not specified		0.5 kWh/m^2 year
The insulation level of NZEB building structures separating parts of a building with autonomous heating systems		Requirements do not apply because there are no autonomous heating systems in individual parts of the building
Building airtightness defined as 1.5 m^3/m^2h		Actual values: tests were performed; n_{50} = 0,60, which approximately gives – q_{50} 0.9 m^3/m^2h.
The annual primary energy consumption 1 2		Actual value: 35.99 kWh/m^2 per year.
The use of renewable energy		Not relevant
Energy consumption of different building systems		
Heating system		
	Annual non-renewable primary energy consumption	5,44 kWh/m^2 per year
	Annual renewable primary energy consumption	27.20 kWh/m^2 per year
Domestic hot water system		
	Annual non-renewable primary energy consumption	26.31 kWh/m^2 per year

	Annual renewable primary energy consumption	25.12 kWh/m² per year
Cooling system		
	Annual non-renewable primary energy consumption	3.50 kWh/m² per year
	Annual renewable primary energy consumption	1.61 kWh/m² per year
Electricity consumption for lighting		7.30 kWh/m² per year (is not mandatory and not included in NZEB definition)
Annual CO_2 emissions of a building		3.46 $kgCO_2/m^2$ per year
Date of issue of the Energy Performance Certificate		2021-02-05

5.4.2 Multi-family house

Building type	Multifamily building
Photo or illustration	
Construction year	2020
Location	City of Riga, Latvia
Building description	Building 6 floor with basement. The building is made of factory reinforced concrete three-layer wall panels. The roof is horizontal. All facades of the building have windows. There are no other heat sources in the building.
Heated/conditioned area	2739.81 m^2
Number of floors	6 on ground 1 – underground for storage and technical rooms
Mean occupant density	30 m^2/person
Time of stay of people in the building per day (average per month)	16 hours per day
Typical building electricity consumption for indoor lighting, appliances inside and outside the building	5.97 kWh/m² per year
Design temperature for heating	20 °C
Design temperature for cooling	Not relevant. Used assumed values (wasn't included in initial energy performance)
The method of calculating the energy performance of a building	Monthly calculation method
Building envelope	
Description	Walls made of three-layer reinforced concrete panels. The roof is flat horizontal with thermal insulated.
Building airtightness, q_{50}	q_{50} =0,56 m^3/hm^2
Windows U-value (average)	1.001 W/(m²· K)
Windows g-value	Not defined
External walls U-value	0.17 W/(m²· K)
Base floor U-value	0.35 W/(m² ·K)
Roof U-value	0.13 W/(m²· K)
Building systems	

Description	Building is connected to district heating systems. No any RES are installed.
Heating system	Thermal energy for heating the building is supplied from district heating systems.
Heat source	Heating point of the building
Heating system efficiency	1
Heat source capacity	Over 100 kW
Energy source for heating	Heat from district heating networks
Heating system control devices	Heating device thermostats and outdoor temperature sensor
Ventilation system	Natural ventilation with local exhaust in kitchens, bathrooms and toilets
Outdoor air volume for 1 m² building ventilation	0.7 m³/m² per hour
Ventilation system type	Recuperative ventilation system without supply air heating
Ventilation heat recovery type	Wall-mounted mini recuperators with ceramic heat exchangers
Temperature efficiency of the recuperators (average)	Not relevant
Ventilation systems specific power input (SPI) (average)	0.25-0.35 Wh/m³
Energy source for heating the outside air supply	The supplied outside air is not heated.
Domestic hot water system	The building's hot water system is equipped with a circulating hot water circuit. Domestic hot water distribution pipelines are installed in ducts in the walls, insulated. Indoor distribution piping is also installed in ducts in the walls and insulated.
Annual thermal energy demand for hot water production per 1 m² of building	25 kWh/m² per year
Heat source for hot water production	Hot water heat exchanger at the heating point of the building
Heat source efficiency	1
Energy source for hot water production	Heat from district heating networks
U' value of the pipes up to the circulation circuit	No data is available
U' value of circulating circuit pipelines	No data is available
U' value of indoor distribution pipelines	No data is available
Cooling system	No active cooling systems.
Lighting system	No data is available
Renewable energy systems	There is none
Compliance of the building with NZEB requirements	
The annual thermal energy consumption for heating < 40 kWh/m2	Actual value: 39.51 kWh/m^2
Air change rate 0.35 l/sm2 or ach 0.5	Actual value: ach 0.3 (average weighted value)
The efficiency of the recuperator	Not relevant
The amount of electricity used by the recuperator fans - not specified	1.67 kWh/m^2 year
The insulation level of NZEB building structures separating parts of a building with autonomous heating systems	Requirements do not apply because there are no autonomous heating systems in individual parts of the building
Building airtightness defined as 1.5 m^3/ h m^2	Actual value: 0.56 kWh/m^2 1.5 m^3/ h m^2

The annual primary energy consumption [2]	Actual value: 75 kWh/m² per year.
The use of renewable energy	Not relevant
Energy consumption of different building systems	
Heating system	
Annual non-renewable primary energy consumption	22.7 kWh/m² per year
Annual renewable primary energy consumption	0 kWh/m² per year
Domestic hot water system	
Annual non-renewable primary energy consumption	18.06 kWh/m² per year
Annual renewable primary energy consumption	0 kWh/m² per year
Cooling system	Non defined in energy performace certificate. Adopted form new regulation for this study
Annual non-renewable primary energy consumption	10.6 kWh/m² per year
Annual renewable primary energy consumption	3.4 kWh/m² per year
Electricity consumption for lighting	5.67 kWh/m² per year
Annual CO_2 emissions of a building	13,75 $kgCO_2/m^2$ per year
Date of issue of the Energy Performance Certificate	2020-11-03

5.4.3 Office building

Building type	Office building
Photo or illustration	
Construction year	Building project. Construction is scheduled for 2022.
Location	City of Riga, Latvia
Building description	Building 2 floor without basement. Precast concrete structure with thermal insulation
Heated/conditioned area	1153,60 m^2
Number of floors	2 on ground
Mean occupant density	20 m^2/person
Time of stay of people in the buiding per day (average per month)	12 hours per day
Typical building electricity consumption for indoor lighting, appliances inside and outside the building	20 kWh/m² per year
Design temperature for heating	20 °C
Design temperature for cooling	24 °C (for energy consumption calculations for building cooling/overheating)
The method of calculating the energy performance of a building	Monthly calculation method
Building envelope	

Description		Wall 170mm thermal insulation
Building airtightness, q_{50}		q_{50} =1.5
Windows U-value (average)		1.1 W/(m²· K)
Windows g-value		0.6
External walls U-value		0.19 W/(m²· K)
Floor on the ground		0.16 W/(m² ·K)
Roof U-value		0.13 W/(m²· K)
Building systems		
Description		Natural gas boiler installed for heating and tap how water preparation
Heating system		Two pipe systems with radiators
	Heat source	Natural gas boiler
	Heating system efficiency	0,98
	Heat source capacity	Over 170 kW
	Energy source for heating	Natural gas
	Heating system control devices	Heating device thermostats and indoor temperature sensor
Ventilation system		
	Outdoor air volume for 1 m² building ventilation	0.7 m³/m² per hour
	Ventilation system type	Mechanical balanced ventilation with exhaust air heat recovery
	Ventilation heat recovery type	Rotary heat exchangers
	Temperature efficiency of the recu-perators (average)	No less 0.806
	Ventilation systems specific power input (SPI) (average)	0.88 Wh/m³
	Energy source for heating the out-side air supply	Electricity
Domestic hot water system		DHW with recirculation DHW temperature control is automatic, constantly maintaining the DHW temperature.
	Annual thermal energy demand for hot water production per 1 m² of building	8.03 kWh/m² per year
	Heat source for hot water production	Natural gas boiler
	Heat source efficiency	0.95
	Energy source for hot water produc-tion	Electricity
	U’ value of indoor distribution pipe-lines	U’= 0.20 W/(m·K)
Cooling system		Mechanical cooling systems.
Lighting system		LED lighting
Renewable energy systems		No data
Compliance of the building with NZEB requirements		
The annual thermal energy consumption for heating < 45 kWh/m2		Actual value: 44.31 kWh/m^2
Air change rate 3319.2 m^3/h		Actual value: ach 0.52 or 2280 m3/h (6700 m3/h during occupancy hours)
The efficiency of the recuperator		Actual value: 0,84.
The amount of electricity used by the re-cuperator fans - not specified		8.03 kWh/m^2 year
The insulation level of NZEB building structures separating parts of a building with autonomous heating systems		Requirements do not apply because there are no autonomous heating systems in individual parts of the building

Building airtightness defined as 1.5 m3/m2h	Default value 1.5 m3/m2h
The annual primary energy consumption 11 ^{2}	Actual value: 110 kWh/m² per year.
The use of renewable energy	No information available
Energy consumption of different building systems	
Heating system	
Annual non-renewable primary energy consumption	48.7 kWh/m² per year
Annual renewable primary energy consumption	0 kWh/m² per year
Domestic hot water system	
Annual non-renewable primary energy consumption	kWh/m² per year
Annual renewable primary energy consumption	0 kWh/m² per year
Cooling system	
Annual non-renewable primary energy consumption	4.9 kWh/m² per year
Annual renewable primary energy consumption	1.55 kWh/m² per year
Electricity consumption for lighting	14.36 kWh/m² per year
Annual CO_2 emissions of a building	13.6 $kgCO_2/m^2$ per year
Date of issue of the Energy Performance Certificate	2024.06.03

5.5 Lithuania

5.5.1 Single family house

Building type	Single family building
Photo or illustration	
Construction year	2020
Location	Lithuania, near the city of Kaunas
Building description	Building 1 floor without basement. The internal heat capacity of the building is 40640.6 kJ/K, i.e. the building is massive. Next to the residential building is a garage with a sloping roof. An 84 m² photovoltaic solar power plant (monocrystalline silicon PV panels) is installed on the slopes of this roof. The electricity generated by the PV power plant is used to cover all the electricity needs of the building. Excess electricity produced by the solar power plant is supplied to the electricity grid and "stored" there. The amount of electricity stored in the electricity networks in the building is used throughout the year.
Heated/conditioned area	156,31 m^2

Number of floors		1 on ground
Mean occupant density		60 m^2/person
Time of stay of people in the **building** per day (average per month)		12 hours per day
Typical building electricity consumption for indoor lighting, appliances inside and outside the building		20 kWh/m² per year
Design temperature for heating		20 °C
Design temperature for cooling		24 °C (for energy consumption calculations for building cooling/overheating)
The method of calculating the energy performance of a building		Monthly calculation method
Building envelope		
Description		Walls without external ventilated air gap, brick, with thermal insulation in the inner layer of the wall. A ventilated unheated shelter is installed under the sloping roof. The ceiling between this ventilated shelter and the premises is insulated. The floor is insulated over the entire floor area, the total thermal resistance of the floor is 6.17 m²·K/W and the foundation of the building is additionally insulated vertically 250 mm EPS 0.45 m from the ground. The windows of the building are plastic with double-glazed units with two selective glazing. The U-values of the windows range from 0.66 to 1.12 W/(m²·K), i.e. each size of window has the manufacturer's declarations of performance.
Building airtightness, n_{50}		n_{50} =0,20
Windows U-value (average)		0.74 W/(m² K)
Windows g-value		0.50
External walls U-value		0.114 W/(m² K)
Base floor U_{fg}-value		0.124 W/(m² K)
U-value of the ceiling between the ventilated shelter and the premises		0.136 W/(m² K)
Building systems		
Description		A heat pump is used to heat the building and prepare hot water. A recuperator is installed in the ventilation system of the building. There are no cooling facilities in the building.
Heating system		An inverter heat pump ground/water is used to heat the building. The heat pump uses electricity from PV collectors, and in the absence of a sufficient amount of electricity produced and stored from PV collectors in the electricity grids, the energy is used from the electricity grids. The building is equipped with heated floors, i.e. heating at low temperatures. The heating system includes heating devices and internal temperature control devices.
	Heat source	Inverter heat pump ground/water
	Heat source efficiency	SPF=4.17
	Heat source capacity	5.5 kW
	Energy source for heating	Electricity from PV collectors, and in the absence of a sufficient amount of electricity produced and stored from PV collectors in electricity networks, energy is used from electricity networks.
	Heating system control devices	Heating device thermostats and room temperature sensor
Ventilation system		Recuperator with cross-counterflow air heat exchangers. The recuperator is used for ventilation of 146.51 m² premises. The air supplied to the premises by the recuperator is heated by electricity. 9.8 m² indoor ventilation is natural.
	Outdoor air volume for 1 m² building ventilation	0.7 m³/m² per hour
	Ventilation system type	Recuperative ventilation system with supply air heating
	Ventilation heat recovery type	With cross-counterflow plate heat exchanger

Temperature efficiency of the recuperator	0.84
Ventilation systems specific power input (SPI)	0.29 Wh/m³
Energy source for heating the outside air supply	Electricity from PV collectors, and in the absence of a sufficient amount of electricity produced and stored from PV collectors in electricity networks, energy is used from electricity networks.
Domestic hot water system	Electricity from PV collectors, and in the absence of sufficient electricity produced and stored from PV collectors, electricity. The inverter heat pump is connected to the ground/water with a 0,18 m³ hot water preparation tank. The heat pump uses electricity from PV collectors, and in the absence of a sufficient amount of electricity produced and stored from PV collectors in the electricity grids, the energy is used from the electricity grids. Hot water pipes are installed in the walls under the plaster. The pipes are insulated.
Annual thermal energy demand for hot water production per 1 m² of building	10 kWh/m² per year
Heat source for hot water production	Inverter heat pump ground/water
Heat source efficiency	2.75
Energy source for hot water production	Electricity from PV collectors, and in the absence of a sufficient amount of electricity produced and stored from PV collectors in electricity networks, energy is used from electricity networks.
Insulation of hot water pipes	U'= 0.64 W/(m·K)
Cooling system	No active cooling systems.
Lighting system	LED lighting
Renewable energy systems	
Photovoltaic panels (PV)	Monocrystalline silicon PV collectors are attached to the sloping roof of the building (not ventilated). 50.4 m² PV collectors at an angle of 30° in the SE direction and 33.6 m² PV collectors at an angle of 20° in the NW direction.
Compliance of the building with NZEB requirements	
The energy efficiency indicators C1 and C2 of the building	1 7 C1=0.0006; C2=0.013.
Heat transfer coefficient of the building envelope	NZEB requirements: $H_{env.(A++)}$ $H_{env.}$= 97.78 W/K.
The efficiency of the recuperator	0.84.
The amount of electricity used by the recuperator fans	0.29 Wh/m³..
The insulation level of NZEB building structures separating parts of a building with autonomous heating systems	Requirements do not apply because there are no autonomous heating systems in individual parts of the building
Building airtightness	NZEB requirements: tests according to LST EN ISO 9972: 2015 and n_{50} 0.60. Actual values: tests were performed; n_{50} = 0.20.
The annual thermal energy consumption for heating	6 0 kWh/m² per year - all thermal energy for heating the building is generated using electricity from PV panels.
The annual primary energy consumption	1 8.79 kWh/m² per year. Actual value: 57.25 kWh/m² per year.
The use of renewable energy	NZEB requirements: the ratio between the consumption of renewable and non-renewable energy must be 1
Energy consumption of different building systems	
Heating system	
Annual non-renewable primary energy consumption	0.13 kWh/m² per year

Annual renewable primary energy consumption	13.07 kWh/m² per year
Domestic hot water system	
Annual non-renewable primary energy consumption	0.09 kWh/m² per year
Annual renewable primary energy consumption	8.96 kWh/m² per year
Cooling system	
Annual non-renewable primary energy consumption	0.15 kWh/m² per year
Annual renewable primary energy consumption	0.65 kWh/m² per year
Electricity consumption for lighting	0.90 kWh/m² per year
Annual CO_2 emissions of a building	6.12 $kgCO_2/m^2$ per year
Date of issue of the Energy Performance Certificate	2020-04-16

5.5.2 Multi-family house

Building type	Multifamily building
Photo or illustration	
Construction year	2019
Location	Lithuania, city Vilnius
Building description	Building 6 floor without basement. The internal heat capacity of the building is 709020 kJ/K, i.e. the building is massive. The building is made of factory reinforced concrete three-layer wall panels. There is no basement in the building. Ground floor on the ground. The roof is horizontal. All facades of the building have windows. Balconies are located on the east and west sides of the building. Thermal energy for the building is supplied from district heating networks. There are no other heat sources in the building.
Heated/conditioned area	2727 m^2
Number of floors	6 on ground
Mean occupant density	40 m^2/person
Time of stay of people in the building per day (average per month)	12 hours per day
Typical building electricity consumption for indoor lighting, appliances inside and outside the building	30 kWh/m² per year
Design temperature for heating	20 °C
Design temperature for cooling	24 °C (for energy consumption calculations for building cooling/overheating)
The method of calculating the energy performance of a building	Monthly calculation method
Building envelope	

Description		Walls made of three-layer reinforced concrete panels. Stainless steel reinforcement is used for the joints between the inner and outer reinforced concrete layers of the panels, therefore, due to the influence of these joints, the thermal properties of the thermal insulation layer of the panels deteriorate very little. Reinforced concrete slabs for the balcony floor are attached to the wall with stainless steel bars, and a thermal insulation layer is installed between the wall and the balcony floor slab. This fastening method minimizes heat loss through the longitudinal thermal bridge between the walls and the balcony floor panel. The roof is horizontal, insulated. The ground floor is insulated over the entire floor area, the total thermal resistance of the floor is 4.97 m²·K/W and the foundation of the building is additionally insulated vertically 370 mm EPS 0.5 m from the ground. The windows of the building are plastic with double-glazed units with two selective glazing. The U-values of the windows range from 0.74 to .0.83 W/(m²·K), i.e. each size of window has the manufacturer's declarations of performance.
Building airtightness, n_{50}		n_{50} =0.15
Windows U-value (average)		0.73 W/(m²· K)
Windows g-value		0.50
External walls U-value		0.13 W/(m²· K)
Base floor U_{fg}-value		0.12 W/(m² ·K)
Roof U-value		0.09 W/(m²· K)
Building systems		
Description		Heat from heating networks is used to heat the building and prepare hot water. The building is equipped with an automated heating point with an outdoor air temperature sensor. Room heating appliances with thermostatic valves. Recuperators are installed in each apartment for room ventilation. There are no cooling facilities in the building.
Heating system		Thermal energy for heating the building is supplied from the building's automated heating point. The heating system includes heating device thermostats and outdoor temperature sensor.
	Heat source	Heating point of the building
	Heating system efficiency	0.98
	Heat source capacity	Over 100 kW
	Energy source for heating	Heat from district heating networks
	Heating system control devices	Heating device thermostats and outdoor temperature sensor
Ventilation system		Recuperators with ceramic heat exchangers. The recuperators are used for ventilation of 2 376.44 m² premises. The air supplied to the premises by the recuperators is heated by electricity. 350.56 m² indoor ventilation is natural.
	Outdoor air volume for 1 m² building ventilation	0.7 m³/m² per hour
	Ventilation system type	Recuperative ventilation system without supply air heating
	Ventilation heat recovery type	Wall-mounted mini recuperators with ceramic heat exchangers
	Temperature efficiency of the recuperators (average)	0.84
	Ventilation systems specific power input (SPI) (average)	0.20 Wh/m³
	Energy source for heating the outside air supply	The supplied outside air is not heated.
Domestic hot water system		Hot water is prepared at an automated heating point in the building. The building's hot water system is equipped with a circulating hot water circuit. Domestic hot water distribution pipelines are installed in ducts in the walls, insulated. Indoor distribution piping is also installed in ducts in the walls and insulated. The total length of the hot water system pipelines is 680 m. Hot water temperature control is automatic, with constant hot water temperature maintenance.

Annual thermal energy demand for hot water production per 1 m² of building	20 kWh/m² per year
Heat source for hot water production	Hot water heat exchanger at the heating point of the building
Heat source efficiency	0.93
Energy source for hot water production	Heat from district heating networks
U’ value of the pipes up to the circulation circuit	U’= 0.34 W/(m·K)
U’ value of circulating circuit pipelines	U’= 0.29 W/(m·K)
U’ value of indoor distribution pipelines	U’= 0.21 W/(m·K)
Cooling system	No active cooling systems.
Lighting system	LED lighting
Renewable energy systems	There is no
Compliance of the building with NZEB requirements	
The energy efficiency indicators C1 and C2 of the building	1 7 C1=0.17; C2=0.44.
Heat transfer coefficient of the building envelope	NZEB requirements: $H_{env.(A++)}$ 7 6 $H_{env.}$= 715.10 W/K.
The efficiency of the recuperator	0.85.
The amount of electricity used by the recuperator fans	0.20 Wh/m³.
The insulation level of NZEB building structures separating parts of a building with autonomous heating systems	Requirements do not apply because there are no autonomous heating systems in individual parts of the building
Building airtightness	NZEB requirements: tests according to LST EN ISO 9972: 2015 and n_{50} 0.60. Actual values: tests were performed; n_{50} = 0.15.
The annual thermal energy consumption for heating	1 9.25 kWh/m² per year.
The annual primary energy consumption	176 6 1 6 kWh/m² per year.
The use of renewable energy	NZEB requirements: the ratio between the consumption of renewable and non-renewable energy must be 1 1 66
Energy consumption of different building systems	
Heating system	
Annual non-renewable primary energy consumption	7.11 kWh/m² per year
Annual renewable primary energy consumption	5.51 kWh/m² per year
Domestic hot water system	
Annual non-renewable primary energy consumption	22.48 kWh/m² per year
Annual renewable primary energy consumption	22.84 kWh/m² per year
Cooling system	
Annual non-renewable primary energy consumption	3.90 kWh/m² per year
Annual renewable primary energy consumption	0.34 kWh/m² per year
Electricity consumption for lighting	1.35 kWh/m² per year

Annual CO_2 emissions of a building	13.44 $kgCO_2/m^2$ per year
Date of issue of the Energy Performance Certificate	2019-12-20

5.5.3 Office building

Building description	
Building type	Office building
Photo or illustration	
Construction year	Building project. Construction is scheduled for 2021.
Location	Lithuania, city Kaunas
Building description	Building 2 floor without basement. The internal heat capacity of the building is 1320170 kJ/K, i.e. the building is massive. An underground car park is installed under the entire building. Roof covering is reinforced concrete, roof is horizontal, insulated. The building is planned to be equipped with a green roof. It is planned to use factory facade glass systems for all walls of the building. It is planned to use a ground-water heat pumps to heat the building, and electric volume heaters to prepare hot water. The building will be equipped with an 80 m^2 (about 12 kW) photovoltaic solar power plant.
Heated/conditioned area	5078 m^2
Number of floors	2 on ground
Mean occupant density	20 m^2/person
Time of stay of people in the buiding per day (average per month)	6 hours per day
Typical building electricity consumption for indoor lighting, appliances inside and outside the building	20 kWh/m^2 per year
Design temperature for heating	20 °C
Design temperature for cooling	24 °C (for energy consumption calculations for building cooling/overheating)
The method of calculating the energy performance of a building	Monthly calculation method
Building envelope	
Description	An underground car park is installed under the entire building. The roof above the underground car park is insulated with 200 mm thick EPS 150N panels. It is planned to use facade glass systems with a U value of 0.8 W / (m U · K) for glazed parts of walls. Facade glass systems with double-glazed units with two selective glazing. The roof is horizontal, insulated, planted.
Building airtightness, n_{50}	n_{50} =0,6
Windows U-value (average)	0.80 W/(m^2·K)
Windows g-value	0.50
External walls U-value	0.12 W/(m^2 K)
Floors above the underground car park U_{fg}-value	0.105 W/(m^2·K)
Roof U-value	0.091 W/(m^2 K)
Building systems	

Description	Ground-to-water heat pumps are used to heat the building. Hot water is prepared in electric volume heaters. Recuperators with supply air heating are used for ventilation of the whole building (electricity is used for air heating). There are no cooling facilities in the building. A photovoltaic solar power plant has been installed to partially cover the electricity needs of the building's engineering systems.
Heating system	Ground-to-water heat pumps are used to heat the building. The heating system includes heating device thermostats and indoor temperature sensor.
Heat source	Ground-to-water heat pumps
Heating system efficiency	0.98
Heat source capacity	Over 170 kW
Energy source for heating	Electricity
Heating system control devices	Heating device thermostats and indoor temperature sensor
Ventilation system	Recuperators with supply air heating are used for ventilation of the whole building (electricity is used for air heating).
Outdoor air volume for 1 m² building ventilation	0.7 m³/m² per hour
Ventilation system type	Recuperative ventilation system with supply air heating
Ventilation heat recovery type	Recuperators with crossflow heat exchangers
Temperature efficiency of the recuperators (average)	No less 0.80
Ventilation systems specific power input (SPI) (average)	Not more 0.30 Wh/m³
Energy source for heating the outside air supply	Electricity
Domestic hot water system	18 units of 10 litre and 2 units of 200 litre electric volume heaters are used for hot water preparation. Internal distribution pipes with thermal insulation (in ducts in the walls). DHW temperature control is automatic, constantly maintaining the DHW temperature.
Annual thermal energy demand for hot water production per 1 m² of building	10 kWh/m² per year
Heat source for hot water production	Electric water heaters
Heat source efficiency	0.95
Energy source for hot water production	Electricity
U' value of indoor distribution pipelines	U'= 0.64 W/(m·K)
Cooling system	No active cooling systems.
Lighting system	LED lighting
Renewable energy production systems	80 m² (about 12 kW) photovoltaic solar power plant
Compliance of the building with NZEB requirements	
The energy efficiency indicators C1 and C2 of the building	1 7 C1=0.12; C2=0.32.
Heat transfer coefficient of the building envelope	NZEB requirements: $H_{env.(A++)}$ $H_{env.}$= 2925 W/K.
The efficiency of the recuperator	0.80.
The amount of electricity used by the recuperator fans	0.30 Wh/m³.
The insulation level of NZEB building structures separating parts of a building with autonomous heating systems	Requirements do not apply because there are no autonomous heating systems in individual parts of the building
Building airtightness	NZEB requirements: tests according to LST EN ISO 9972: 2015 and n_{50} 0.60. Actual values: design value n_{50} = 0.6.

The annual thermal energy consumption for heating	7 6.04 kWh/m^2 per year.
The annual primary energy consumption	1 6 7 6 kWh/m^2 per year.
The use of renewable energy	NZEB requirements: the ratio between the consumption of renewable and non-renewable energy must be 1 1 1
Energy consumption of different building systems	
Heating system	
Annual non-renewable primary energy consumption	11.39 kWh/m^2 per year
Annual renewable primary energy consumption	15.56 kWh/m^2 per year
Domestic hot water system	
Annual non-renewable primary energy consumption	24.57 kWh/m^2 per year
Annual renewable primary energy consumption	2.57 kWh/m^2 per year
Cooling system	
Annual non-renewable primary energy consumption	22.28 kWh/m^2 per year
Annual renewable primary energy consumption	1.94 kWh/m^2 per year
Electricity consumption for lighting	0.9 kWh/m^2 per year
Annual CO_2 emissions of a building	12.21 kgCO_2/m^2 per year
Date of issue of the Energy Performance Certificate	-

GENERIC NZEB SOLUTIONS

6 GENERIC NZEB SOLUTIONS

One of the first and most defining steps to design a nearly zero energy building is optimizing the architectural elements of the building, with focus on facades and shading. With the combination of climate responsive design and passive techniques, the energy consumption of the building can be reduced considerably.

Architecture has a significant impact on the energy efficiency of the building. With the improved architectural design, the window area can be optimized taking into account the daylight to lower the energy need for the lighting. Lighting is a significant electricity consumer in buildings. In order to lower the energy use of the building it is essential to perform the illuminance calculations to use lighting with lower wattage in NZEB building. Windows have also an effect on the energy need during the heating period and cooling period. During the heating period windows allow to use solar energy to lower the heating need utilizing the possible free energy from the sun. On the other hand, the windows have an effect on the room temperature and possible overheating during the summer period and therefore influence the need of the cooling energy. Architects have the complicated task; in some cases the architectural design has to be replaced with the rational solutions in case of the NZEB buildings. An early-stage energy performance assessment could help to find the compromise between art and energy performance.

The thinking of designers, constructors and supervisors has to change because compared to traditional construction project, NZEB projects are more challenging because of the different aspects. To design NZEB building, it needs more analyses in the early stage. Even in regulation there are exception that allow adjustment if more detailed calculations are performed and presented with energy performance calculations. For example, to use lower wattage of the lighting the illuminance calculations must be presented. The HVAC systems can have effect on the energy use and architectural design. For example, to ensure the lower electricity use of the ventilation systems (lower SFP of the fans) in some case the space for the installation of the air handling units and ventilation air ducts need larger space compared to traditional HVAC systems. The problem can be the space needed for the installation of the HVAC systems. To use the VAV system the HVAC systems of the building and the everyday usage of the building should be more thought-out before the energy calculations.

In NZEB buildings the building envelope must be highly insulated and airtight, the building service systems have to be state of the art and renewable energy systems can be considered a standard feature. The know-how concerning the NZEB features among project managers and designers is one main concern.

A well-insulated, airtight and thermal bridge free building envelope is a key factor for nearly zero energy buildings. Minimising heat losses and combining a thermally optimised building envelope with the passive use of solar energy allows a significant reduction in the heat load and heating energy demand of the buildings. To achieve small heat loss, building envelope of NZEB in cold climate should be more insulated and airtight. Suggested thermal transmittance values of the external envelope of the buildings are as follows shown in the table below.

Table 29 Recommended thermal transmittance for envelope elements for different building types.

Building type	Building component	Value
Single family house	External wall	U 0,12 W/(m^2·K)
	Window	Uw 0,9 W/(m^2·K)
	Roof	
	Floor on ground	1
	Floor above ground	1
	Air leakage rate	q_{E50}
Apartment buildings	External wall	1
	Window	Uw
	Roof	1
	Floor on ground	1
	Floor above ground	1
	Air leakage rate	1
Office buildings	External wall	1
	Window	
	Roof	1
	Floor on ground	1 W/(m^2·K)
	Floor above ground	1
	Air leakage rate	1

Fulfilling the thermal transmittance requirements for external walls usually means the creation of an insulation layer that is 250-350 mm thick. Fulfilling the thermal transmittance requirements for the roof usually means 300-400 mm of insulation layer and for floors 200-300 mm of insulation layer.

The information about the building should be obtained from the building design documentation. The building design documentation consists of the architectural plans, the thermal transmittance of the building envelope, windows, and doors. In the calculation of the heat losses, the calculation should be done for every room. The heat loss through the building envelope is calculated based on the thermal transmittance and areas of the exterior walls, floors, roofs, windows, and doors. The area of the building envelope is calculated based on the internal dimensions of the building. The junctions between the different envelope parts are considered separately using the linear thermal transmittance values of the thermal bridges.

For buildings with better air tightness target including buildings with higher designed energy efficiency and quality management similar sealing measures are utilised including systematic use of specialised membranes and sealing tapes with a significant attention to connections between openings and external wall.

In NZEB buildings the building envelope must be highly insulated and airtight, the building service systems must be state of the art as well as the appliances and lighting. The ventilation system must be designed to ensure low SFP and the artificial lighting power must be optimized according to needed level of illuminance and availability of natural lighting to minimize electricity usage.

When building envelope is well insulated, service systems and energy source become more important factors achieving NZEB.

To design and to build a cost optimal NZEB building, it needs more analyses in the early stage. Successful execution of the project needs involving all the parties starting from the future building owner, architect, designers, and the contractor.

The final energy consumption of a building is also heavily influenced by its orientation. Sustainable low-energy building design requires sophisticated analysis and cooperation between every party included, starting from architects, energy efficiency specialists and HVAC engineers. While designing a nearly zero-energy building it is important to consider the geometry of the house. Designers should know that any irregular shapes in the house design could result in unwanted increases of energy demand. The more compact the building is, the less is the area of thermal envelope that causes transmission heat losses. The compactness ratio has a pronounced influence on the heating and cooling demand, independently of the thermal transmittance of the building envelope.

It is vital that optimizing building performance to ensure low energy consumption must not compromise good indoor climate. However, with the trends in architecture and envelope design, an increasing number of low-energy buildings are built with a tendency to overheat. Overheating has become a common problem also in temperate and cold climate countries. As the design implications mostly consider heating, such as the passive house standard, can cause unacceptably high indoor temperatures in warmer seasons. This is especially the case in new residential and school buildings with improved air tightness, higher levels of insulation, large glazing areas and lack of mechanical cooling. Achieving a balance between thermal and visual comfort is one of the key aspects especially in buildings without mechanical cooling, in terms of low heating energy need, low risk of overheating and sufficient direct sunlight and daylighting. In moderate and cold climate countries, maximizing the utilization of solar heat gains during the heating season can benefit substantially in lowering the heating need.

6.1 Thermal envelope

Typical construction of office and apartment buildings is a concrete bearing structure with stone and concrete walls. Typical external walls are precast concrete sandwich panels with 250-350 mm of thermal insulation, depending on thermal conductivity of thermal insulation material, which gives a U-value of 0.12 W/m²·K. The roof is typically prefabricated hollow-concrete slabs and thermal insulation. The roof is insulated with at least 300-400 mm of thermal insulation to reach the design U-value of 0.08 W/m²·K. General characteristics of windows in buildings are double and triple glazing windows with low emissivity coating and with gaps filled with argon or krypton between panes that have lower U-value.

6.1.1 Apartment building sections

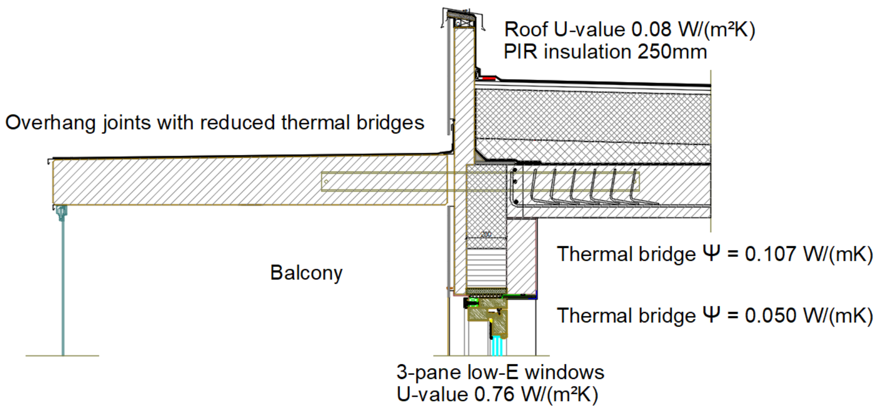


Figure 15. Roof and balcony section.

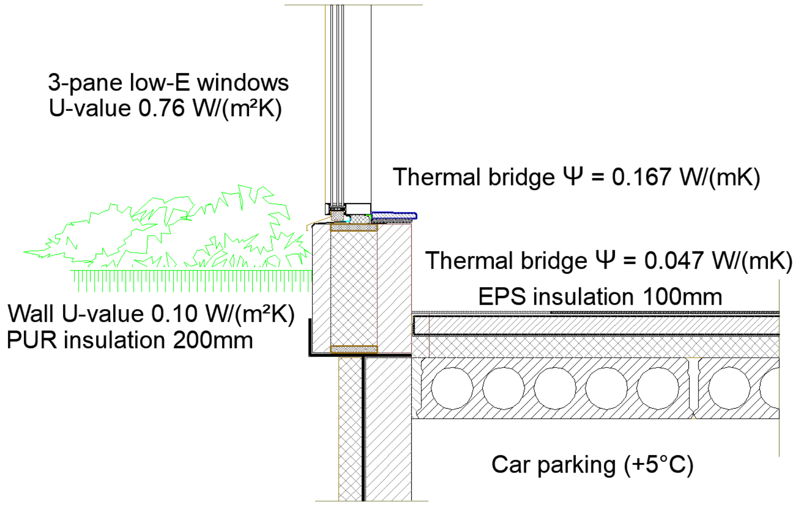


Figure 16. First floor and underground car parking section.

6.1.2 Single family building sections

External walls are wooden frame construction with 250+100 mm of mineral wool insulation which gives a U-value of =0.12 W/m²·K. The roof is insulated with at least 400 mm of mineral wool insulation to reach the design U-value of 0.10 W/m²·K. The roof construction consists of steel metal plate, wooden truss, joist, thermal insulation, vapour barriers and cladding.

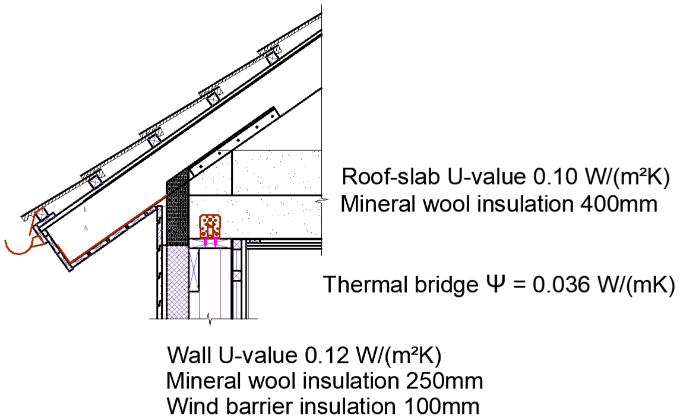


Figure 17. Roof-external wall section.

The designed insulation value of the ground floor is 0.12 W/m²K, which is achieved by using floor covering, concrete slab, insulation and gravel layer. U-value for windows and doors are 0.9 W/m²K. It has triple-glazed windows with low-e coating. All structural elements of the building are made of a wooden frame. The floors are made of concrete slabs.

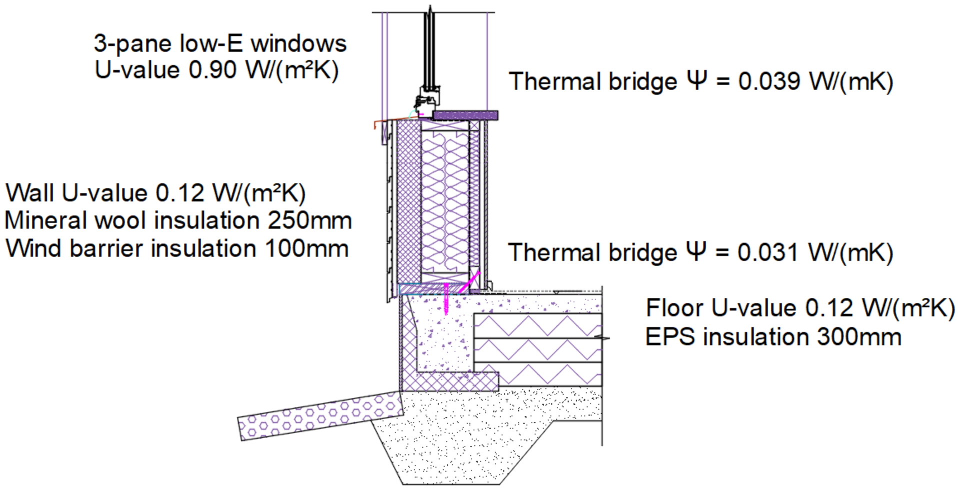


Figure 18. Floor-external wall section.

6.1.3 Office building sections

Office buildings are usually concrete frame buildings with energy efficient façade systems or prefabricated concrete buildings. In case of the concrete frame buildings when the structural frame of the building consists of the concrete columns, and beams, and floor slabs the energy efficiency depends mostly on the façade framing solution and glazing properties (number of the panes, filling of the panes, coating of the glazing). In case of the prefabricated concrete buildings the energy efficiency depends on the properties and thickness of insulation material. Office buildings with prefabricated elements are often seen with external walls of concrete elements with 250 mm of EPS insulation. Roof has 400-500 mm of thermal insulation. Ground floor is 200 mm concrete with 150-200 mm of thermal insulation. Windows are aluminium frame windows with triple glazing.

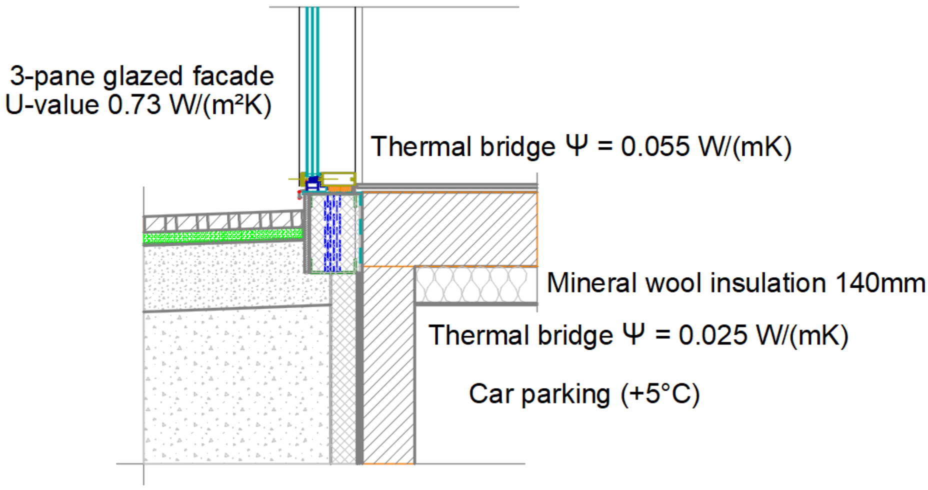


Figure 19. Floor-external wall section.

6.2 Technical building systems

6.2.1 Heating and ventilation systems in apartment buildings

The most common ventilation solution in Nordic and Oceanic nearly zero energy apartment buildings is decentralised ventilation system (Figure 20), in which case each apartment is equipped with its own air handling unit (AHU). Typically, AHUs with rotary (regenerative) heat exchangers (HEX) are used to enable high heat recovery efficiency and have lower sensitivity to HEX frosting. The cooker hood is connected to the AHU to allow balanced operation. For AHUs with rotary HEX, a by-pass connection is used, separate from general extract air.

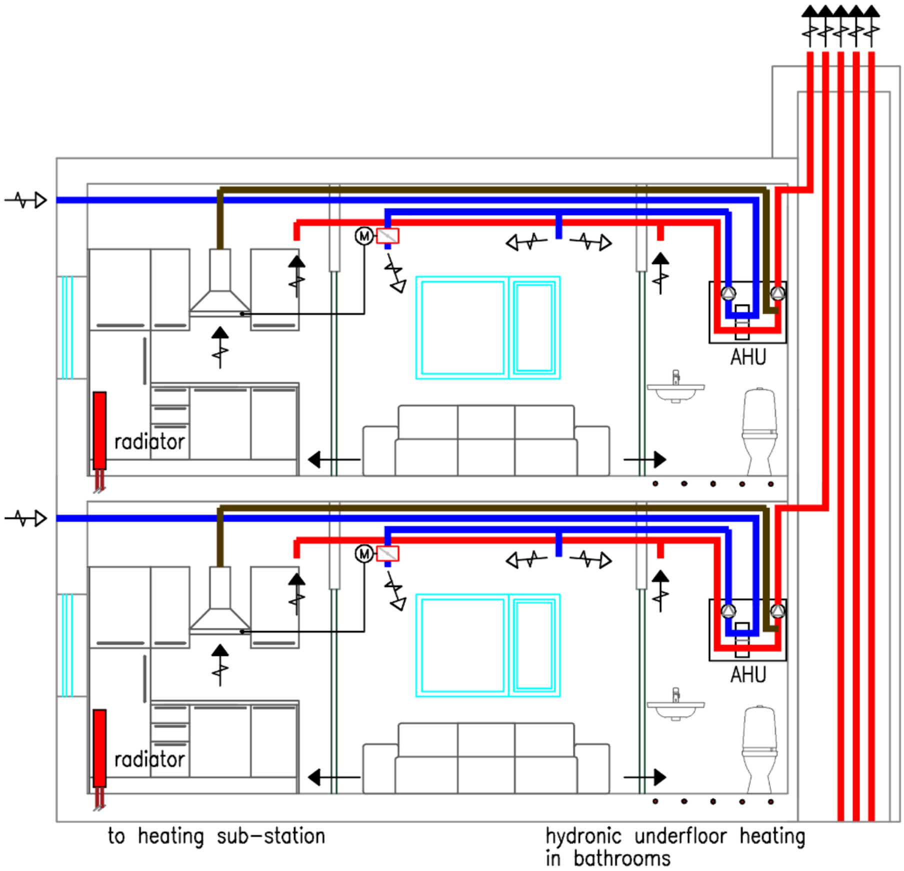


Figure 20. Apartment building mechanical supply-exhaust ventilation with apartment-based air handling units.

Another option, used mostly in renovated apartment buildings, is based on central AHUs. Usually for each staircase section there is one central system with its own AHU. Due to the risk of supply air contamination via extract air mixing, the AHU is equipped with recuperative plate heat exchanger, usually counter-flow plate. The kitchen hood extract air flow is controlled with pressure sensor on the main duct and the flow is compensated with on/off supply valve on the supply air duct system (Figure 21). With such systems, the main problem is frost emergence on the plate HEX, which requires more energy, compared to the rotary HEX, to avoid frost on or to defrost the HEX.

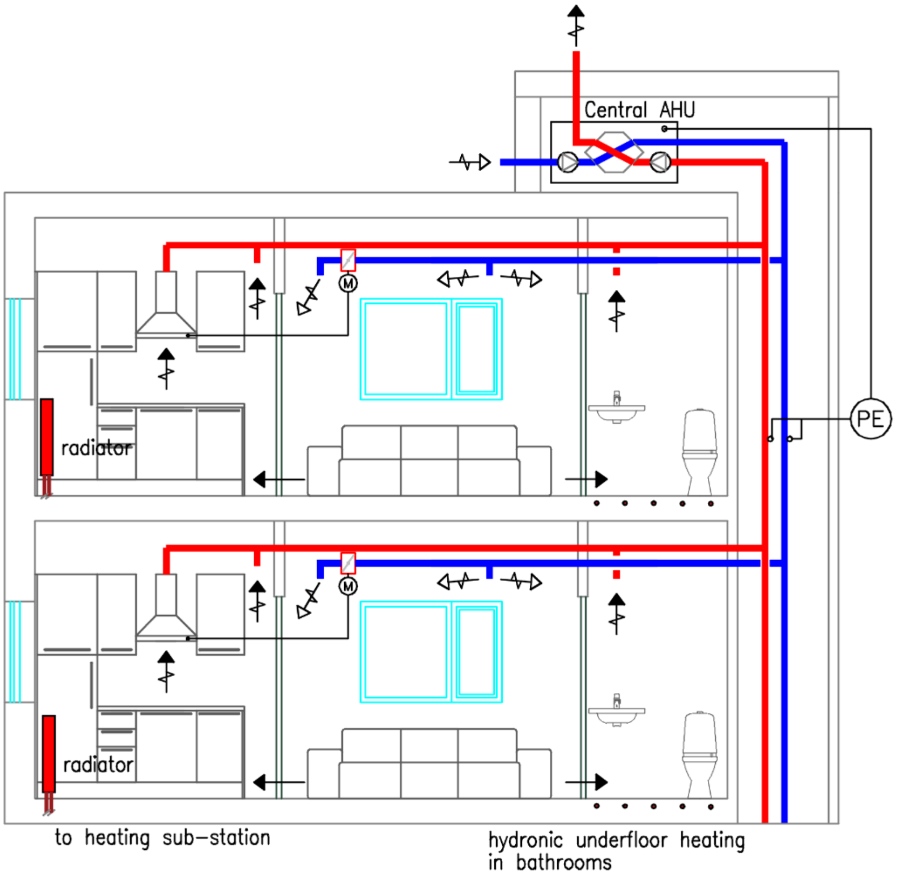


Figure 21. Apartment building mechanical supply-exhaust ventilation with central air handling unit.

The most common heat source for apartment building is district heating (DH). In this case hot water for both heating and domestic hot water (DHW) creation is heated in a central sub-station (Figure 22). Water flow from the DH side through plate HEXs is regulated with motorized valves according to the heating supply water characteristic and DHW temperature set-point. To decrease the return water temperature in the DH circuit, two HEXs are used – one for pre heating the cold water with return water from heating system HEX and the other to achieve the required set-point for DHW. Energy consumption is measured separately for each system.

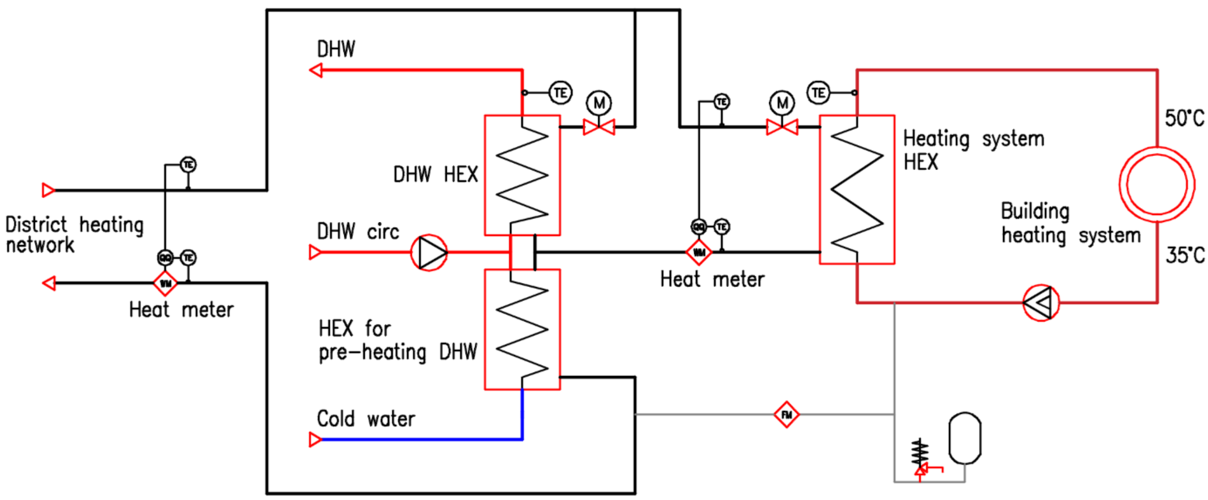


Figure 22. Typical district heating sub-station for heating and domestic hot water.

Other commonly used heat sources for apartment buildings are heat-pump (HP) based systems. In this case accumulation tanks for both heating system and DHW are usually used to cope with peak power demand (Figure 23). Low temperature heating curve is required to achieve high performance and low electricity consumption for the HP.

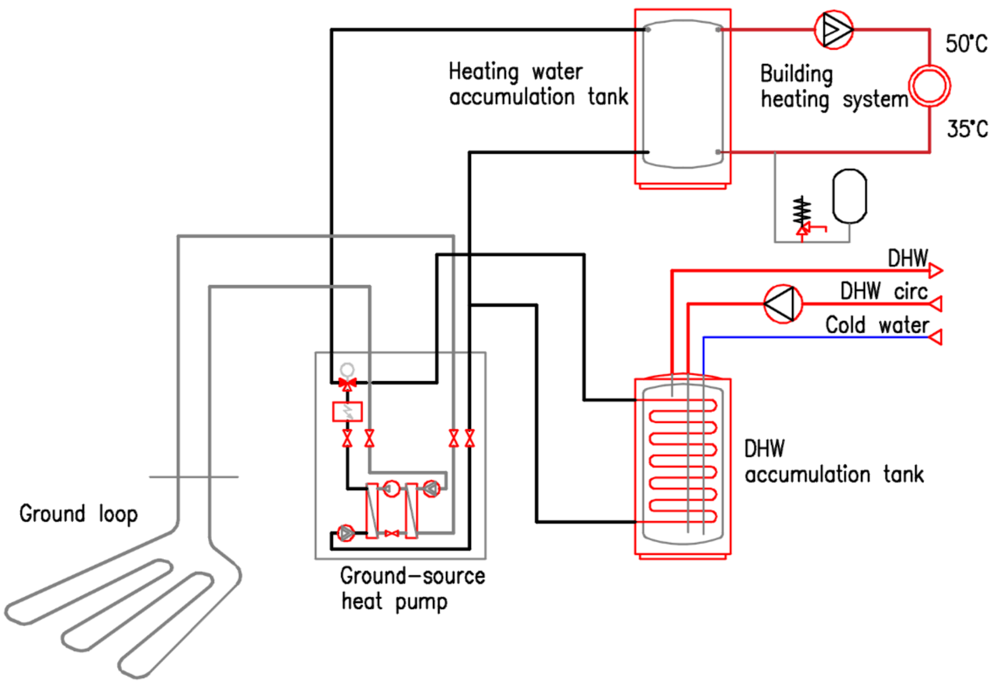


Figure 23. Typical ground-source heat pump based-sub-station for heating and domestic hot water.

6.2.2 Heating cooling and ventilation systems in office buildings

Most commonly heating for office buildings is provided with district heating network and distributed to the building with water radiators (Figure 24). Due to low heating demand, low temperature heating curve can be used in the radiator network. Also heating provided for ventilation system is district heating based and designed with larger heating coil to be used also with lower heating curve. The latter designs enable futureproof energy efficient district heating networks with low temperature supply water. Cooling systems in modern new buildings are based on efficient chillers and coupled with free cooling option bypassing the chiller and enabling cooling water production with lower outdoor temperatures. Usually, active chilled beams are used to utilise high temperature cooling supply water and a condensation free system. This solution is one of the most energy efficient and assures good indoor climate with low draught risk. Ventilation is provided with high efficiency air handling units containing EC or PM fans, low leakage insulated casing and typically with hygroscopic rotary heat exchanger for effective frost control and low energy consumption. The heating, cooling and ventilation systems are connected via intelligent building automation system which optimizes energy consumption to provide good indoor environment. Supplied energy is measured in all major circuits to ensure efficient operation of the systems and provide feedback on energy use.

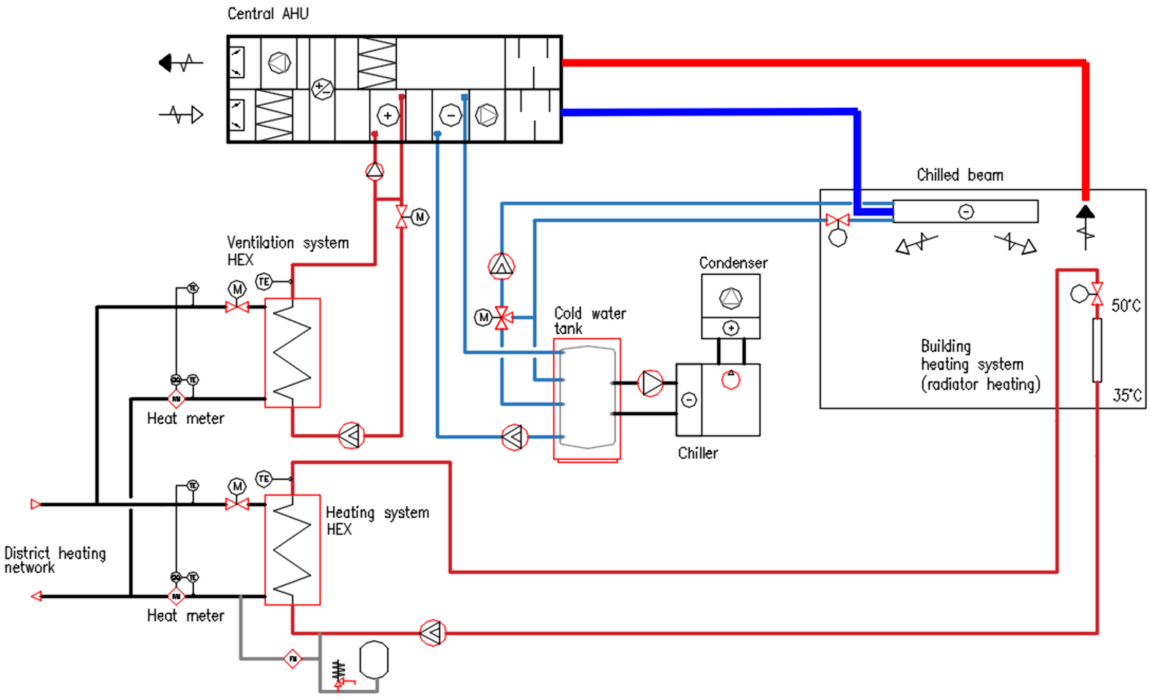


Figure 24. District heating and chiller based-sub-station for heating and cooling.

The state-of-the-art design for modern office buildings utilises geothermal heat and heat exchange with 'activated' structural foundation by integrating heat exchanger pipes to 'energy piles' allowing heating and cooling through heat pump systems (Figure 25). Utilising low temperature heating and high temperature cooling for high heat pump performance is achieved with radiant heating and cooling panels or thermally activated floor slabs. The latter solutions allow to provide high thermal comfort for the building occupants.

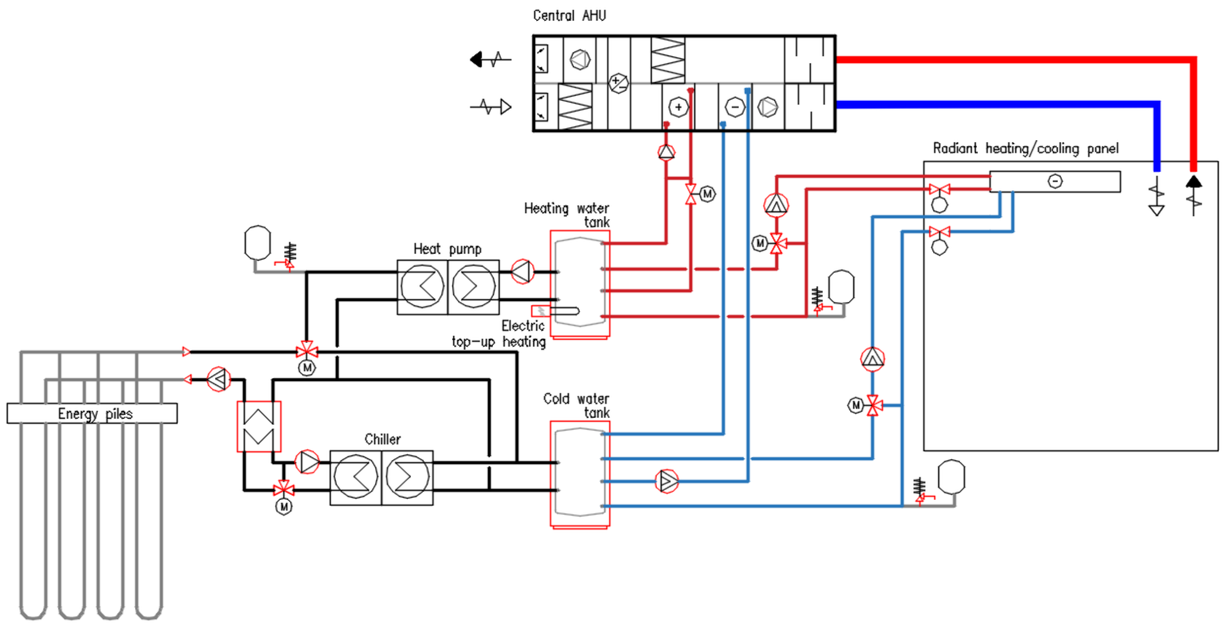


Figure 25. Ground-source heat pump and chiller with energy piles based-sub-station for heating and cooling.

6.2.3 Heating and ventilation systems in single family buildings

Typical single-family buildings use either heat pumps (Figure 26, Figure 27), gas boilers (Figure 28) or wood (pellet) boilers as a heat source for space heating and domestic hot water heating. In case of heat pump system, with high building envelope performance in terms of low heat losses, airtight constructions and heat recovery ventilation, space heating is provided via underfloor heating to achieve high coefficient of performance for the heat pump.

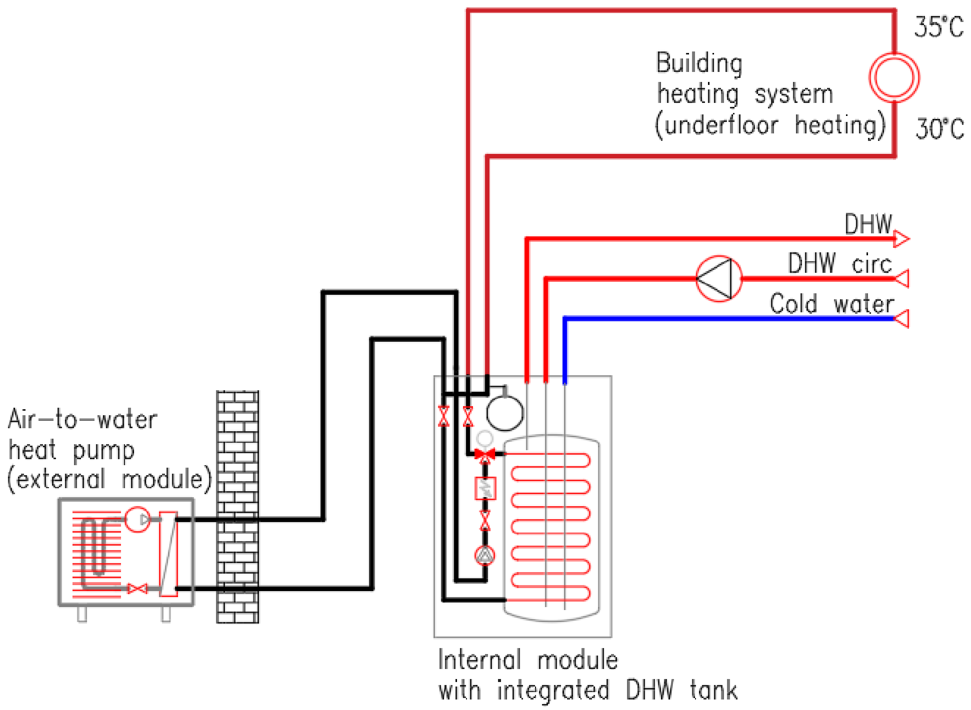


Figure 26. Typical air-source heat pump based-sub-station for heating and domestic hot water.

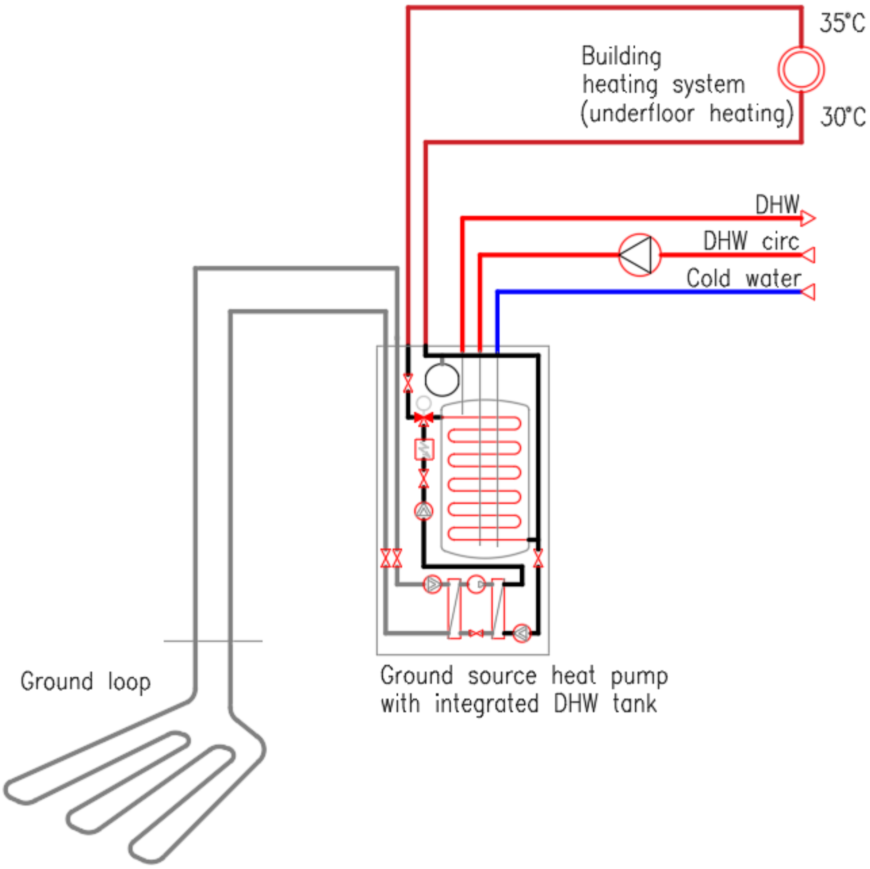


Figure 27. Typical ground-source heat pump based-sub-station for heating and domestic hot water.

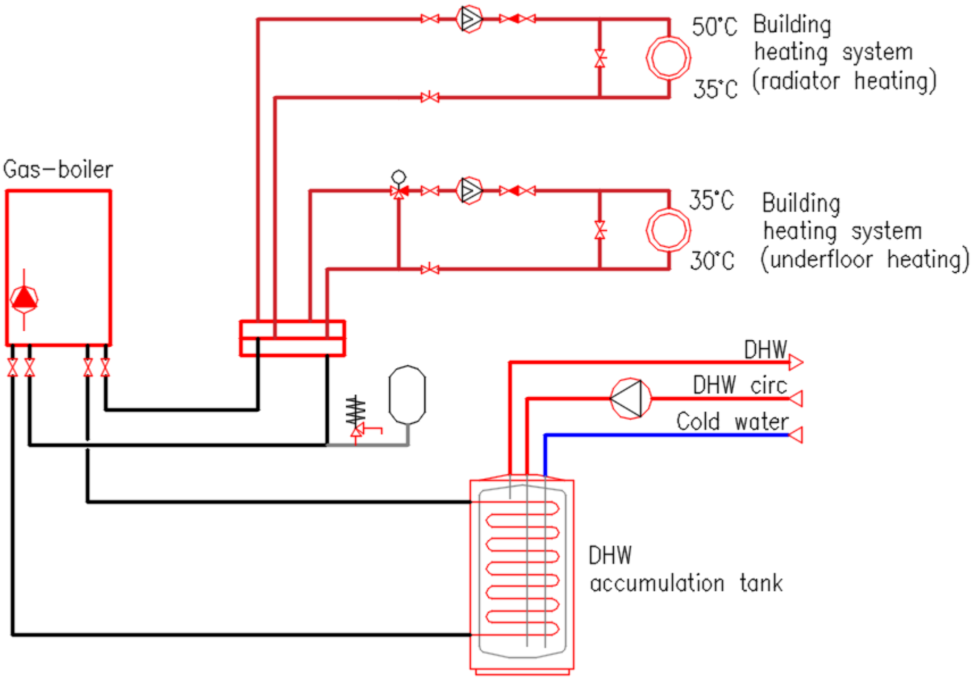


Figure 28. Gas-boiler based-sub-station for heating and domestic hot water.

6.3 Renewable energy systems

Renewable energy systems will play an increasing role in future energy supply, both for conditioning our buildings and as general energy supply in the society. From this will follow a need for buildings to become resilient and flexible regarding their uptake of energy to match it as closely as possible with the availability of renewable energy production and the amount of energy in the supply grids. This issue will be touched further in the next section.

This section describes the most used renewable energy systems used on or nearby buildings supplied the renewable energy source. More detailed descriptions and more technologies can be found in a report from IEA Annex 75 "Cost-effective Building Renovation at District Level - Combining Energy Efficiency & Renewables - Subtask A: Technology overview" – [Mørck et al – May2020].

6.3.1 **Photo voltaic (PV)**

Photovoltaic solar (PV) cells produce electricity from sunlight and come in many shapes or forms. The most common technologies are crystalline structures and thin film. The most efficient PV-panels today have a test efficiency of 24 %, but efficiencies up to 46 % for single cells have been observed in laboratory testing. It is expected that the efficiency of solar cells and solar cell products will increase in the following years. The increased efficiency will make solar panel technologies more profitable. Combined with the reduction of raw material usage and overall costs in the production, this is expected to be a driver for increased profitability for PV-panels, which will boost the introduction of more PV panels worldwide. Building integrated photovoltaics are used to replace conventional building parts such as roofs and facades. The focus in the market development seen today is on installation, performance, aesthetic integration, and maintenance challenges

Using prefabricated building elements with technical solutions is another trend that is likely to reduce construction time and cut installation cost of building façades with solar panels in the future. A prefabricated building is constructed using factory made building elements that are transported to the construction lot. Using prefabricated building elements (prefab) is often a cheaper and faster solution than on-site construction of buildings, and prefab elements are often more dimensionally stable than on-site constructions.

Due to the current cost of PV systems compared to possible solutions for reducing the energy demand of a building, PV is one of the cheapest solutions to make a building meet the primary energy target embedded in the national NZEB requirements.

6.3.2 Ground Source Heat Pumps

The market for small ground-source heat pumps (GSHP) has stabilised during the last years, but there is a steady market growth for larger systems for residential buildings as well as in the commercial and institutional sector**.** Systems with increasing size, deeper boreholes and higher capabilities are investigated. The distribution and technology development of the GSHP are therefore progressing actively. Research related to heat pumps and geothermal energy is carried out to include energy storage.

Areas of interest concerning the district heating network includes large cavern thermal energy systems for high-temperature storage and cold networks with distributed heat pumps.

Another application of ground-source heat pumps is ectogrid™[1], a system, which will circulate, reuse, and share the energy within a district. This will decrease the need for supplied

[1] https://www.eon.se/foeretag/vaerme-och-kyla/ectogrid2

energy and save costs. The innovation is not in the components of the system, but in the new and novel way they are put together. Only one thermal grid is needed, but it serves several purposes – thermal distribution for both heating and cooling as well as storage and flexibility. A basic principle is that one should harvest all thermal energy flows (heating and cooling) and balance them against each other. This flexible grid connects the city that distributes thermal energy flows between neighbours. Each building connected to the system uses heat pumps and cooling machines. The buildings make energy "deposits or withdrawals" from the grid, which means that the energy demands from all the buildings are balanced against each other.

6.3.3 Solar thermal

Solar installation supporting district heating systems, as well as heating and cooling applications in commercial and industrial settings have gained interest and scale in recent years**.** Even though it is quite developed in some parts of Europe, there are research indicating that the cost of a large-scale district solar heating system can be significantly reduced in relation to individual systems and that for that reason is being considered as a future development in coming years, in conjunction with seasonal storage.

This trend should be also placed in context with the continuous development of solar technologies. For example, polymeric collectors are a different approach with significant weight and cost reduction. In addition, recycled polymeric materials can be used. Another significant advance is the introduction of different filling gases in solar collectors. Experiments considering gases such as Xenon and Argon suggest that flat plate collectors can obtain higher thermal performance with a thinner collector design and reduced weight.

In terms of technology, there are indications that some novel concepts can improve substantially solar thermal cooling systems, both for adsorption chillers and for absorption chiller, using system optimization for an improved balance between solar thermal energy input and cooling output. In the past, this technology was expensive, however there some prospects regarding cost reduction that can help further developments in the future**,** which can be significant for wider implementation in e.g., Southern Europe.

6.4 Future solutions

This section describes some solutions that are expected to become solutions for future NZEB, either as emerging technologies or as technologies that will be required to make buildings an active player in an energy system with fluctuating production due to the transition to utilisation of primary renewable energy sources.

6.4.1 Low temperature thermal grid (LTTG)

Third generation heating networks (conventional district heating <100 °C supply temperature) are the current state of the art. Low temperature (LT) 4th generation heating networks (with supply 35-65 °C) are increasingly establishing themselves on the market, being planned and implemented. Local low-temperature thermal grids (LTTG+) or 5th gen DH represents a complete innovation in district heating and cooling and goes far beyond previous approaches. In this type of system, significantly lower system temperatures are available and efficient heat pumps are used to raise system temperatures to those specifically required (avoidance of exergy losses) and innovative network topologies and operating modes (e.g., non-directional systems without central network pumps) are used in combination with seasonal storage systems. The innovative elements of LTTG+ to be further developed are in detail, but there is a large potential for significant reduction in primary energy consumption.

6.4.2 Ventilation

Research for more energy efficient HVAC systems is going on which include nano-technological coatings and surface treatments for improved heat transfer; new nano- and micro-materials for improved efficiency of the refrigerants, and improved efficiency and heat transfer capabilities of coolants via new nano-technological additives. Furthermore, research is going on to integrate heat recovery technology into passive ventilation systems.

Another research topic concentrates on a new residential ventilation system with a balanced, constant air volume system with heat recovery, which enables regulation of the supply air temperature in each individual room in a house. The novelty of the new system is based on a component, called a manifold (i.e., a junction box from which several smaller ducts branch off), which contains a built-in water heating coil and temperature dampers on each of the outlets. The primary function of the manifold is to distribute the total supply airflow rate into different rooms. The supply air is then delivered to the rooms via several separate ducts connected to the manifold. A centralized heating coil is installed in the manifold to integrate individual space heating in the ventilation system. Thus, heating of the ventilated zones can be handled solely by the ventilation system. The system enables supplying air with various temperatures to different rooms and can cover different heating demands in rooms at the same time. Heating and ventilation system is automatically controlled based on wireless technology.

Demand controlled ventilation is another kind of ventilation that could be more and more used in the future. Though it must be mentioned that the use of demand-controlled ventilation doesn’t reduce the energy demand in countries, where the requirements have a certain minimum ventilation rate.

Mechanical ventilation is often a requirement in offices and schools, but not in dwellings. Although e.g., in Denmark, it is voluntary to use either natural or mechanical in dwellings, it is often necessary to enforce mechanical ventilation due to the strict energy requirements in the Building Regulation. The trend is that it will be more common to use mechanical ventilation in the future.

More use of air cleaners in schools, commercial buildings and dwellings could also be a future trend. The air cleanser can be used instead of increasing the air volume and is able to reduce the air pollution. Though, not all kind of pollution can be reduced, and the air cleaner can even produce some pollution itself.

COMPARATIVE CALCULATIONS OF EXAMPLE CASES

7 COMPARATIVE CALCULATIONS OF EXAMPLE CASES

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 countries. This section aims to give an overview of the differences and similarities in energy performance calculation methodology, “strictness” of performance requirements and compare the NZEB levels between Nordic and Oceanic countries.

To analyse the energy performance requirements and compare the methodological differences between Nordic, Oceanic countries, and EC recommendations on buildings energy efficiency the following steps are used:

- Comparing national requirements by the key numbers, energy performance calculation specifics and methodological differences.
- Simulating building performance as required by the national regulations of each country.
- Simulating building performance using national TRY weather and input data for standard use from EN 16798-1:2019 to fulfil the EC PE recommendation for NZEB.
- Comparing and analysing the results to quantify the strictness of the NZEB requirements.

7.1 Reference residential buildings

Two residential buildings were selected for the analysis: a single storey detached house and a multi storey apartment building. Both buildings were initially designed as NZEB according to its nation of origins: the single-family house in Denmark and the apartment building in Estonia. The buildings are representative examples of new NZEBs with modern designs and technical solutions (Figure 29). The main parameters of the buildings are described in Table 29.

Table 30. Building parameters.

Parameter	Single-family house	Apartment building
Net heated area, m²	138	4986
Ext. walls U-	0.29	0.12
Roof U-	0.09	0.08
Slab on ground U-	0.12	0.12
Windows U-	1.3…1.5	0.9
Building leakage rate q_{50}, m^3/h per m^2 of envelope	1.0	1.5
Ventilation heat recovery efficiency, -	0.88	0.80
Specific fan power of the ventilation system, $kW/(m^3/s)$	1.0	1.5
Installed PV system power (max PV whole roof covered), kW	3.6	65.4
Heat generation	Heat pump, SCOP=3.58	District heating

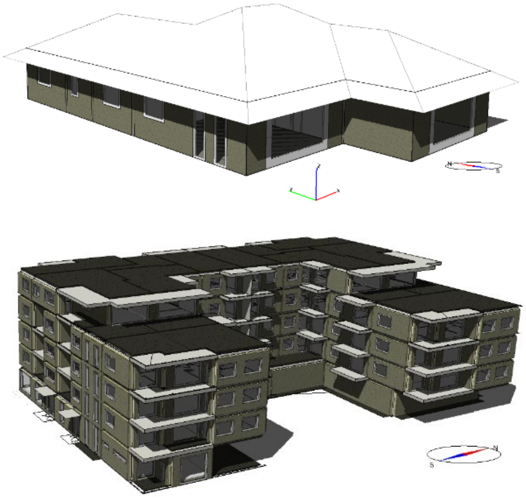


Figure 29. Simulation models of the reference single-family house and apartment building.

7.2 Reference office building

For the analysis we have selected a new office building located in Estonia. The building is designed and constructed to meet NZEB energy performance level requirement, EPC class “A”. This means that 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. The total net heated area of the building is 12 789 m^2, from which a 4 776 m^2 section of contains typical offices and thus only this part was used in the analysis. With changes made to the preliminary design regarding lighting and HVAC systems, the calculated primary energy consumption decreased from 99 to 82 kWh/(m^2 y). The latter value is achieved by accounting local energy production from PV-system installed on the roof. The 129 PV-panels, each with nominal power of 400W, yields 9.3 kWh/(m^2 y) of electricity (TRY-based calculation). Internal lighting system of the building is designed as fully automated with occupancy sensors and dimming based on available daylight using LED fixtures. The average installed lighting power to achieve >500 lx in occupied spaces is <8 W/m^2. The building’s air permeability rate at 50Pa of pressure difference q_{E50} is designed and measured after completion by air leakage test to be below 1.0 m^3/h per m^2 of building envelope area. The weighted average SFP of the ventilation systems is 1.44 kW/(m^3 s) and temperature efficiency of heat recovery is 0.85. The thermal transmittance of external walls is 0.15 W/(m^2 K); roof 0.10 W/(m^2 K); floor on ground 0.15 W/(m^2 K); and windows 1.0 W/(m^2 K) with glazing solar factor of 0.3.

The building is connected to a district heating network to which the heat is supplied from energy efficient heating plant utilizing renewable energy sources classifying the network as “energy efficient” and allowing for lower primary energy factor to be used in the energy performance calculation. The building’s heating system is designed to use low temperature supply water via radiator heating. Cooling is provided with energy efficient chillers and distributed to rooms with active chilled beams. High Energy Efficiency Ratio (EER) is achieved with high temperature supply water ensuring a condensation free system. The building is modelled according to design and commissioning documents. The constructed building model consists of 45 thermal zones (Figure 30).

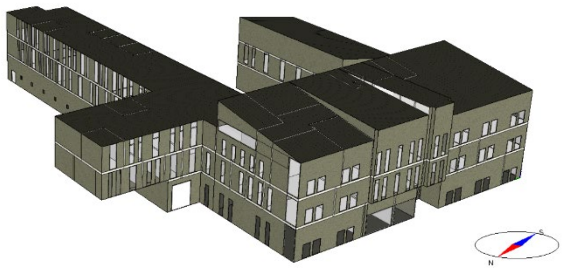


Figure 30 3D view of the reference office building simulation model in IDA ICE software.

7.3 National NZEB levels comparison – residential buildings

7.3.1 Single-family house

Following the Danish requirements, installation of 12 m² of PV (Figure 31, case 1) sets the building on the BR 2018 voluntary “low- 7 ² y)] that is more strict than mandatory NZEB. The NZEB 6 1 ² y), is achieved with 5 m² of PV panels (case 2). The initial design installation of the house with 24 m² of PV produces a surplus of 73% PV energy compared with the amount required for NZEB. However, when calculating the building with 5 m² of PV using the EU standardized input data while leaving technical systems, envelope, and other building parameters initial (case 3), the building does

kWh/(m² y), but is requiring additional 16 m² of PV panels (case 5). This means that even the amount of PV required for Danish low energy level is not sufficient to achieve EC level (case 4). In this case also the EC recommendation of PE without renewable energy production (Oceanic zone) is not fulfilled.

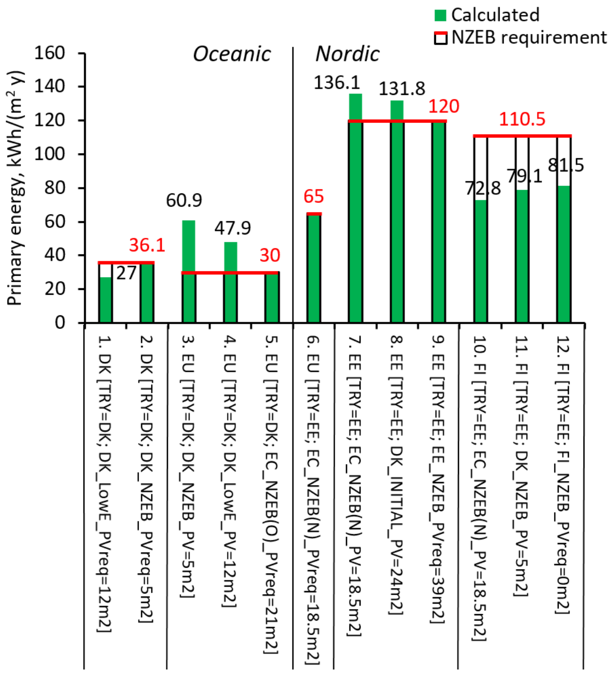


Figure 31. Annual PE consumption of the reference single-family house. PV energy production is added or removed to meet NZEB requirements. Code example: DK [TRY=DK; DK_LowE_PVreq=12 m²] – Danish methodology [Simulated with Danish TRY, meets Danish Low energy threshold with 12 m² of installed PV].

6 ^{2} y), is met with 18.5 m^2 of PV (case 6). This amount however is not sufficient to achieve the Estonian NZEB performance level (case 7). Even the initial installation of 24 m^2 PV panels (case 8) is not sufficient to 1 ^{2} y). It would require 39 m^2 of PV panels in total (case 9) for the building to qualify in Estonia as NZEB (energy performance class A). The higher need for PV electricity production in the Estonian cases at one hand is because only the fraction of produced energy that is used in the building is accounted in energy calculation.

Even with the added PV production, the building does not meet all Estonian requirements - it would need to comply with energy performance class B without accounting the on- 1 ^{2} y). This requirement however is not fulfilled, meaning that, for example, the thermal or technical systems performance of the building envelope should be improved. This is also expected when moving the initial Oceanic design to a colder climate. In contrast, the Finnish NZEB requirements were met even without local renewable energy production (case 12). It must be emphasised that besides methodological and climatic differences, the PE performance results are largely influenced by the national PE factors. As the reference building utilises heat pump system for space, ventilation air, and DHW heating, the PE consist of only electricity consumption, highlighting the impact of the nationally different electricity PE factors.

7.3.2 Apartment building

The reference apartment building (designed for Nordic climate and including RE production to meet Estonian NZEB requirement) calculated according to the Danish building regulations met the NZEB ^{2} y) quite easily with total PE of 9.9 kWh/(m^2 y) (Figure 32, case 1), which is also expected due to climatic differences. Even without PV production the building performance surpasses the required PE threshold by only 0.7 kWh/(m^2 y) (case 2).

The reference apartment building without PV production (case 3) is far to meet the EC Oceanic NZEB and exceeds the EC PE limit without on-site renewable energy production 6 ^{2} y). The reference building with PV does also not meet EC NZEB maximum value (case 4, calculated with EU standardised input data). This illustrates the relatively high-performance level for EC Oceanic zone, considering the building is initially designed for Nordic climate. Basically, the results show that EC Oceanic NZEB is not achievable with district heating with EU default primary energy factor because the roof of the reference building is fully covered with PV and it is practically impossible to further improve the energy performance.

Calculation results using the EU standardised input data for the Nordic climate show that the building exactly meets EC recommended level for PE without accounting RE production, ^{2} y) (case 5). Also, the EC PE recommendation with RES is fulfilled (case 6). As the building is designed as NZEB in Estonia, it is also designed to meet the national NZEB requirements with initial PV production (case 8) and the required low energy (energy class B) requirements (case 7) in Figure 25.

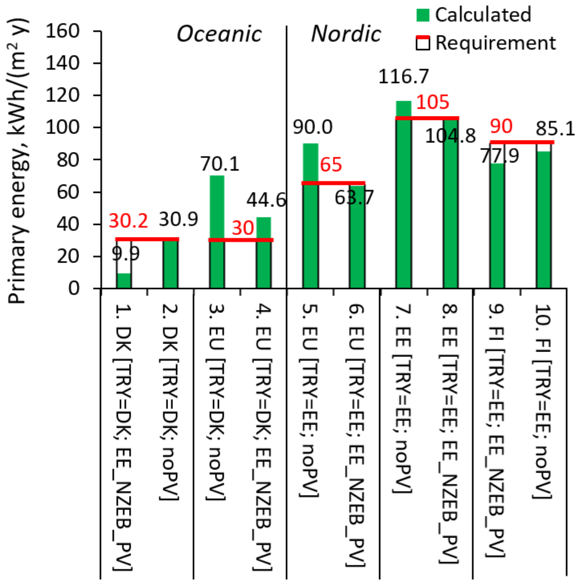


Figure 32. Annual PE consumption of the reference apartment building. PV energy production is added to meet NZEB requirements. Code example: DK [DK_LowE; TRY=DK; PV=24m2] – Danish methodology [Danish Low energy threshold; Danish TRY and 24m2 of installed PV].

As was the case with Finnish requirements for detached houses, the apartment building fulfils the requirements also without on-site renewable energy production as well (cases 9 and 10). The results indicate that the Estonian requirements match the EC recommendations if the building utilises district heating energy. It can also be stated that buildings designed to comply with Finnish building regulations, would not meet the EC PE recommended levels.

7.3.3 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. In order 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 Ahmed et al (2021) :

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

where U_{opt}^{ref} is the optimal thermal transmittance of the respective building element for a reference climate (W/(m^{2}K), U_{opt}^{j} is the optimal thermal transmittance of the building element for a respective climate (W/(m^{2}K), 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).

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 Figure 33. 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.

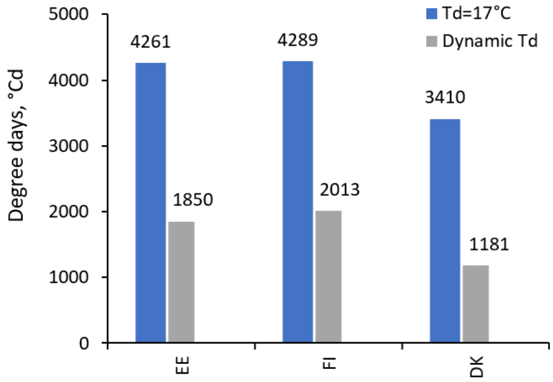


Figure 33 Degree days calculated from country specific TRYs: calculated with typical constant 17°C and dynamic base temperatures.

The correction factors and climate corrected thermal transmittances for envelope elements are shown in Table 30. The initial Estonian building values are used as a reference for transitioning from Estonian climate to Finnish and Danish climate. 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 Table 30.

Table 31 – 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

7.3.4 Office building energy performance

Although Finnish TRY ambient temperatures are slightly lower compared to Estonian TRY data, calculations following the Estonian methodology result in higher heating energy need (Figure 34 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.

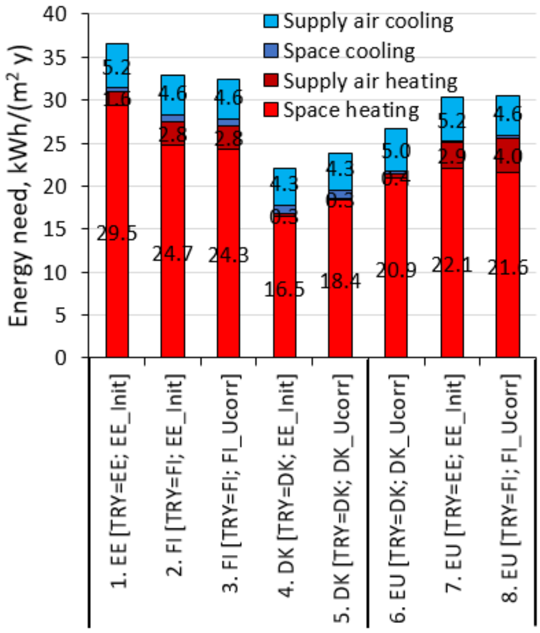


Figure 34 Comparison of annual energy need for heating and cooling using country specific climate data, methodologies, and climate corrected U-values. Calculated according to Estonian (EE), Finnish, (FI) and EU standardized (EU) methodology and input data.

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 (Figure 35, case 1).With the maximum PV installation of 284 m^2, 52 kW 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 42 kW of PV-panels to meet the NZEB PE requirement (case 3). For exact requirement level for the initial case, only 4 kW 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 39 kW 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/(m^2 y) of PE over the Danish NZEB requirement of 41.2 kWh/(m^2 y) (Figure 36, case 1). To achieve the required level, 14 kW 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/(m^2 y) above the requirement. To achieve the limit value, 49 kW 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/(m^2 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/(m^2 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.

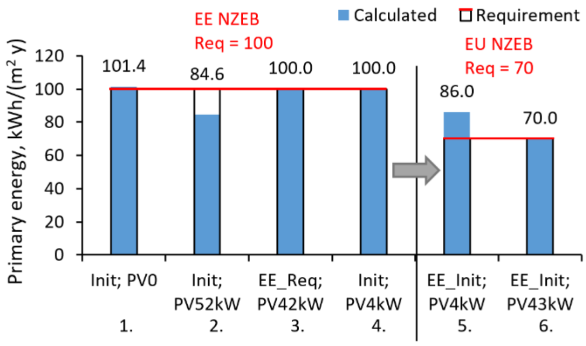


Figure 35. Annual PE consumption of the reference office building. Estonian cases calculated according to Estonian methodology (cases 1-4) and EU standardized methodology (cases 5-6), all cases with Estonian TRY. [Code: Init – Initial building parameters; EE_Req – reduced requirements for U-values; PV_42 – accounting for 42 kW of PV-panels].

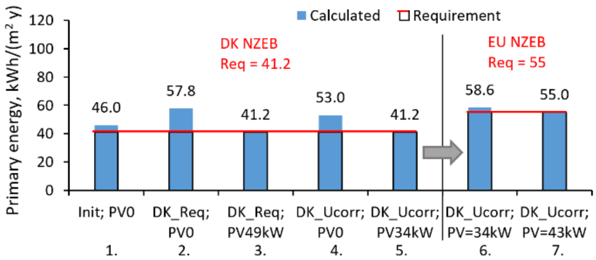


Figure 36. Annual PE consumption of the reference office building. Danish cases calculated according to Danish methodology (cases 1-5) and EU standardized methodology (cases 6-7), all cases with Danish TRY. [Code: Init – Initial building parameters; DK_Ucorr – Danish climate-corrected U-values; DK_Req – Danish minimum requirements for U-values; PV_49 – accounting for 49 kW of PV-panels].

The initial

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.

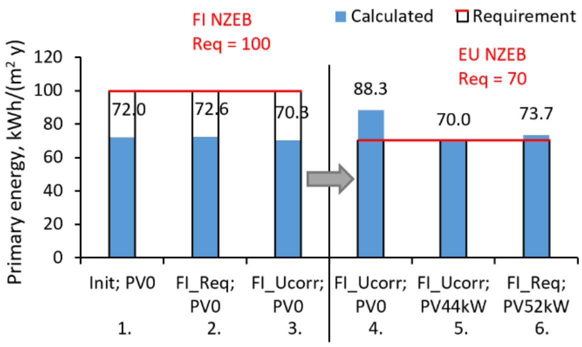


Figure 37. Annual PE consumption of the reference office building. Finnish cases calculated according to Finnish methodology (cases 1-3) and EU standardized methodology (cases 4-6), all cases with Finnish TRY. [Code: Init – Initial building parameters; FI_Ucorr – Finnish climate-corrected U-values; FI_Req – 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.

7.4 Conclusions

The study illustrates the strictness of EC NZEB recommendations in Oceanic and Nordic regions. 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.

In case of the Oceanic zone, the EC recommendations for residential NZEB PE appear to require relatively higher energy performance compared to the Nordic zone recommendations. This is illustrated with the case of Denmark, located in colder part of the Oceanic zone. A highly insulated reference apartment building with district heating and PV fulfilling EC Nordic NZEB recommendation exceeded EC Oceanic NZEB recommendation(!). At the same time, a reference detached house with ground source heat pump and extensive PV installation was capable to meet EC Oceanic NZEB recommendation. However, this performance level clearly exceeded Danish NZEB and Low Energy.

In the Nordic climate zone, Estonian NZEB requirements complied very closely to EC Nordic NZEB recommendation. Finnish NZEB requirements were less strict and did not fulfil EC Nordic NZEB recommendation.

The study illustrates the need of having two sets of requirements: with and without renewable energy production, as is the case for Denmark and Estonia and for EC benchmarks. Denmark has solved the issue by setting the maximum amount of RE allowed to account in the PE calculation, requiring the building to achieve a sufficient level of energy efficiency by means of thermal insulation and HVAC systems. In Estonia there are PE requirements for the building without accounting on-site RE production as well as for the building including RES. Finland with less strict requirements, however, has not followed the separation of requirements.

7.4.1 Recommendations

It is recommended that EC reconsider the recommended building energy performance levels for new NZEBs constructed in the “Oceanic climate zone” or alternatively reconsider definitions of the European climate zones.

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Simson R. Thomsen K.E. Wittchen K.B. and Kurnitski J. A Comparative Analysis of NZEB Energy Performance Requirements for Residential Buildings in Denmark, Estonia, and Finland. Cold Climate HVAC & Energy 2021, 10th International SCANVAC Cold Climate Conference. 20-21 April 2021, online (Tallinn).

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8.2 Project oral presentations without paper

Simson, R. Arumägi. NZEB Energy Performance Requirements for Residential Buildings in Denmark, Estonia, and Finland. Concerted Action EPBD V 5th online plenary meeting 26-28 May 2021.

Wittchen K.B. Results from Nordic-Baltic nearly zero energy buildings (NZEB) project (In Danish). Presented at “Danvak dagen”, Copenhagen, 6 April 2022.

8.3 Workshops

Kurnitski, J. Simson, R. NZEB Requirements in Nordic Countries. Workshop held in the Cold Climate HVAC & Energy 2021 conference. 21 April 2021.

Nordic-Baltic NZEBs

This report compares national requirements on Nearly Zero En-ergy buildings in the Nordic and Baltic regions. Additionally, it gives examples of typical buildings (residential, offices, and oth-ers) that comply with the national requirements and the building elements and installations typically found in these buildings. Fi-nally, it compares calculated energy performance of selected example buildings in the different schemes and climates to in-vestigate which requirements are stricter and how they comply with the EU recommendations.