Nearly zero energy buildings with air-source heat pumps across Europe

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Abstract. Buildings are one of the most significant energy consumers and carbon emitters. As a result, their energy efficiency is a focal subject of European legislation, including the regulation of nearly zero energy building (NZEB) constructions. NZEB definition, however, differs significantly when it comes to the national level. Consequently, residential NZEBs can be characterised with altering building physical characteristics and various energy demands, according to the location of the buildings. More than that, not only the construction, but also heating, ventilation and air conditioning (HVAC) systems can be highly dependent on the geographic, especially weather conditions. With the help of dynamic building energy performance simulation (BEPS), this study reveals how the location of a single-family house affects the operational energy consumption of heating and cooling, once from the perspective of the different national NZEB regulations and also as a result of diverse climatic conditions influencing the performance of the technical building system. For the latter, we focus on one of the most expanding heat supply solution, the air-source heat pumps. To adequately address the reduction of the environmental impacts of the building sector, besides energy consumption the study analyses operational carbon emissions as well. Results highlight that though there are differences in the requirements of the specific NZEBs, some remain to produce similar indicators in all aspects, while other Member States (MS) are appealing from certain indicators, yet much worse in carbon emission. Conclusions of the paper can be considered to improve operational energy or emission management through the legislation of the building stock, MS specifically.

Keywords. nearly zero energy building, energy consumption, carbon emission, regulation, thermal transmittance, building energy performance simulation, TRNSYS, heat pump
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1. Introduction

Buildings contribute a major part of global energy consumption and carbon emission. Residential buildings account for an approximate of 22% of final energy consumption, and 17% of the CO_2 emission [1]. As the European Union targeted minimizing its environmental impact on these fields, the recast of the Energy Performance of Buildings Directive (EPBD) made it mandatory for new residential buildings to fulfil the criteria of Nearly Zero Energy Building (NZEB) level, from 2021 [2]. Though, the definition is to provide energy performance requirements and renewable measures to be implemented, the specific requirements are to be defined by the Member States (MS) [3]. Hence on one hand, MSs regulate different performance indicators to form their definition of NZEB and on the other hand, even the same indicators have various limits depending on the MS. Consequently, under the same definition of NZEB, buildings could appear on a wide range of energy consumption or carbon emission.

Certain researchers have aimed to investigate the problem. Simson et al. contrasted the same residential buildings for Denmark, Estonia and Finland with the specific climatic conditions and legislations regarding the energy-related calculations [4]. The report of Garzia et al. compared the primary energy demand of NZEBs in Austria, Germany, France, Italy and Sweden with the help of the Passive House Planning Package tool [5]. It is also worth mentioning that Guillén-Lambea et al., highlighted that differences in the energy demand could appear within a single country as well [6].

A conclusion of the mentioned studies and the regulation trend is that there is a lack of research that reflects the difference of energy consumption and carbon emission emerging from the varying measures and altering climatic conditions of the Member States, while eliminating certain limitations. Most often these are using steady state calculations, considering the same level of insulation for a building in different countries, neglecting weather change effects on the efficiency of the technical building system or using country-specific suggestions when calculating the energy demand.

The goal of this paper, therefore, is comparing the energy consumption and carbon emission of a case study residential building in different MSs of the EU highlighting the effect of altering climatic conditions and country specific regulations on the building physical parameters while applying the same calculation principles. The paper is organized as follows: Research Methods provides the method of the calculation, explaining how the limits are resolved or minimized. Section 3 presents the results of the calculation, while conclusions are drawn in Section 4.

2. Research Methods

The method of the study was developed to minimize the limitations found in other studies. The main pillars that had to be considered were the selection of:

- the countries to examine,
- the building to study,
- the technical building system to approach and
- the method of the calculation.

2.1 countries and requirements

Specifying the thermal insulation level of the studied building is challenging when examining under different conditions. However, as more and more countries implement requirements on the thermal transmittance (U-value) of the specific building structures, using the minimum values that fulfil the criteria eases comparison. For this consideration, some of the countries were selected that have published threshold levels of building structure U-values, namely Belgium, Cyprus, Hungary, Ireland, Italy, Poland, Slovakia and Slovenia [7].

It is notable, that countries from various climate are included in the further calculations. The tendencies of thermal transmittance values of the building structures of the specific countries somewhat align with the climatic characteristics. Generally, colder climate countries appear with lower U-value limits, while warmer climate Member States have higher values. Consequently, Cyprus is the most permissive, with 2.25 W/m^{2}K regarding the openings, and 0.4 W/m^{2}K for the other structures [8]. The strictest is Slovakia with a maximum of 0.6 W/m^{2}K for glazed openings, 0.15 W/m^{2}K for external walls and 0.1 W/m^{2}K for both the ground and roof slabs [9]. Other transmittance values are represented in **Tab. 1**.

Italy is separated for many climate zones depending on the number of heating degree days. In the calculations, zone E is considered later.

Tab. 1 – Thermal transmittance requirements of the specific building structures in the selected countries.

U-values [W/m^{2}K]	BEL [10]	CYP [8]	HUN [11]	IRL [12]
External wall	0.24	0.40	0.24	0.21
Glazed opening	1.50	2.25	1.15	1.60
Ground slab	0.24	0.40	0.26	0.21
Roof slab	0.24	0.40	0.17	0.16
U-values [W/m^{2}K]	**ITA_E [13]**	**POL [14]**	**SVK [9]**	**SLO [15]**
External wall	0.24	0.20	0.15	0.20
Glazed opening	1.40	0.90	0.60	1.00
Ground slab	0.26	0.30	0.10	0.18
Roof slab	0.22	0.15	0.10	0.18

2.2 reference building

The reference building for the analysis was selected with the assumption of a geometry that could be realistic for all the countries of the study. The case study single-family house (SFH) can be characterised with standard design, without particular energy awareness concept of compactness or glazed surface ratio. The net floor area of the building is 98 m^2, heated volume of 283 m^3, thermal envelope surface of 337 m^2 and a glazed opening area of 36 m^2. The geometry of the SFH was modelled with SketchUp software.

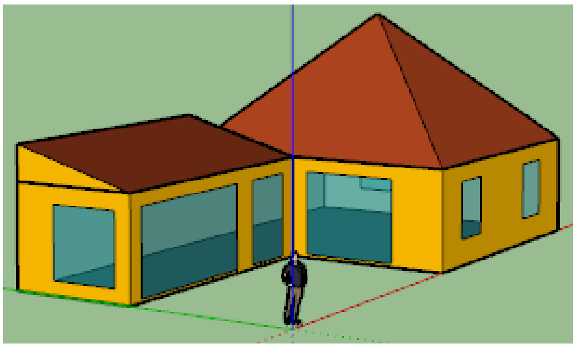

Fig. 1 – SketchUp model of the reference building.

An air-to-water heat pump was considered as heat supplier, because it meets the requirements of a highly efficient, renewable source system and is likely to spread in most of the countries NZE buildings [3]. As heat emitter floor heating and slab cooling were considered. In the calculations we focused only on heating and cooling, although such a system is capable of covering domestic hot water needs as well. As the objective was to highlight the differences of the space heating and cooling energy performance indicators as a result of various climatic conditions and regulations, domestic hot water production was excluded from the calculations.

2.3 calculation specifications

The modelled geometry was imported to TRNBuild, where the layers, thermal bridges, infiltration and ventilation and internal gains were specified.

The thermal transmittance of the building structures was adjusted to exactly the threshold value of each country, with only modifying the insulation thickness, no other elements of the layer order. Similarly, glazed elements were selected to meet the exact value of the national requirements.

Regarding the internal gains, 5 W/m^2 was considered in the calculations. Ventilation and infiltration were considered as a minimum of 0.5 1/h. This was increased at warm nights to reduce net energy need for cooling: in case when the mean temperature of a day exceeded 23 °C, windows were opened for a night-time period of 10 pm to 6 am, providing a more intensive ventilation, 9 1/h for the night period [11].

2.4 loads and demands

The parameters specified in TRNBuild were imported into TRNSYS v18 dynamic building energy performance simulation (BEPS) tool. Both loads and demand were calculated with a 5 minute timestep, external weather data of each locations, and a heating setpoint of 20°C and cooling setpoint of 26°C [16].

2.5 system specifications

As the heat pump is considered in a monovalent use, heating and cooling performance of the unit are sized to meet the loads during the coldest and warmest periods. Regarding the efficiency of the heat pump, TRNSYS component Type941 air-to-water heat pump performance map was used, that accounts the ambient temperature and humidity ratio. Both floor heating and slab cooling were assumed with a temperature difference of 5°C between the supply and return water temperature. Circulating pumps were sized to meet the exact heating and cooling loads with this temperature difference under the most extreme conditions. The overall pump efficiencies are considered as 0.7.

3. Results

3.1 heating and cooling load

Heating and cooling loads of the reference building are represented on **Fig. 2** in a plot, with the associated external temperatures. Heat loads appear to be proportional to external design temperature for most of the countries. Exception to this are Slovakia and Ireland. Both appear to be the effect of their relatively strict regulations, as temperature data fits in the range of the other cases. From **Tab. 1** this is more obvious for Slovakia, though comparing Ireland's requirements with the much colder Poland, threshold levels of structural thermal transmittance values are relatively strict for Ireland as well.

The heating load of Poland and Cyprus quite fit the trend of the remaining countries, though it can be highlighted that the minimum temperatures and loads alter significantly, resulting in the highest heating load, 5.2 kW for the former, and the lowest, 3.3 kW for Cyprus.

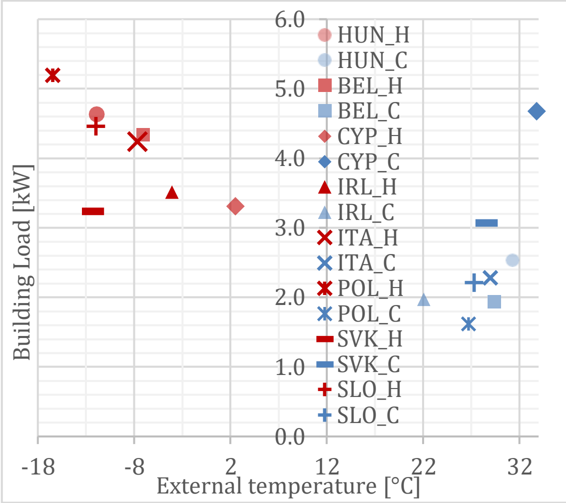

Fig. 2 – Net energy demands and loads of the reference building in different Member States.

In case of the cooling load, it is hard to find any regularities. Cyprus, with by far the highest temperature and solar radiation loads, scores the highest cooling load, even higher than its heating load as anticipated. Surprisingly, the second highest cooling load appears in case of Slovakia. A possible explanation can be that high insulation level enhances the risk of overheating [17].

3.2 net energy demands

Results of the net energy demands are resembling to the loads as **Fig. 4** reveals. Hungary, Italy and Slovenia represent similar net energy demands for the SFH with their certain conditions. Despite the lower heating load, net energy demand for heating in Ireland is close to these countries, which is the result of longer heating season (**Fig. 3**).

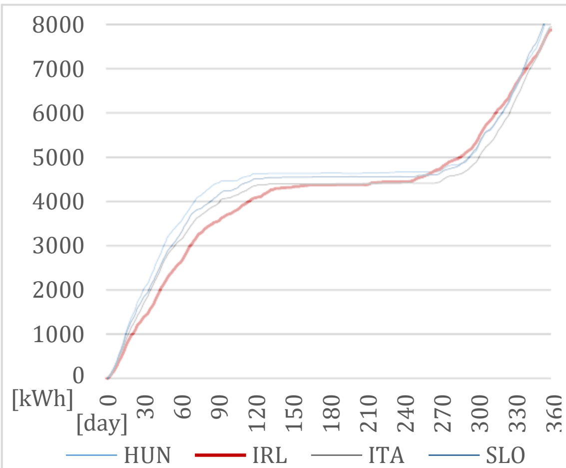

Fig. 3 – Accumulated heat loads of the countries with similar heating demand.

Belgium at first might seem a bit off these countries, however, its 9,434 kWh/year demand is just 12% higher than the average of the above-noted four countries.

Opposingly, MSs highlighted for their mismatching loads are dissimilar in this comparison again. The SFH has by far the lowest net energy demand, 5,171 kWh/year in Cyprus, which is 40% less than the average demand of the above-mentioned five countries (8,634 kWh/year). Furthermore, unsurprisingly, Cyprus is the only country that has a higher share of net energy needed for cooling than heating.

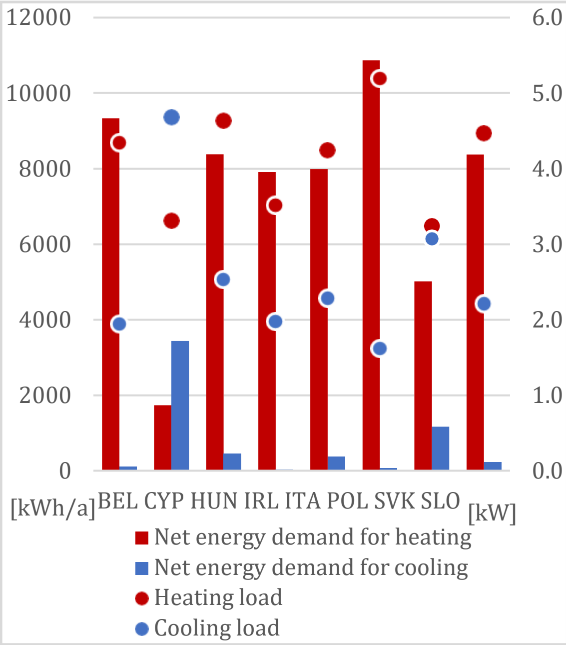

Fig. 4 – Net energy demands of the reference house for the test reference year of each countries.

Slovakia has not only the lowest heating load, but strictest U-value criteria also provides the second lowest net energy demand for heating 5,014 kWh/year and the second lowest sum of net energy need, 6,178 kWh/year. Relatively high share of the energy demand for cooling presumably appears for the previously (section 3.1) mentioned reasons.

When adapting the Polish weather conditions and requirements, the demand is more than the double of the Cyprus case, namely 10,938 kWh/year. This suggests that despite the rather strict regulation, extremely low temperatures (compared to the other countries) not only result in the highest demand but also the highest, 27% higher net energy demand than the average of Belgium, Hungary, Ireland, Italy and Slovenia.

Though the simulations result in cooling needs in all of the cases, in many countries this seems to be logically avoidable and therefore excluded in the further analysis.

3.3 operational energy consumption

Besides the differences caused by altering climates and regulations, efficiencies of the heating and cooling systems also affect energy consumption. This is especially true in case of appliances highly relying on external weather parameters, just like air-to-water heat pumps.

In case of the present study, Seasonal Performance Factor of Heating (SPFH) and Seasonal Performance Factor of Cooling (SPFC) values (including the energy consumption of the circulating pumps) show 30% and 11%, difference, respectively, among the countries. As expected, SPFH is the lowest in case of the coldest climate (Poland) and SPFC is the lowest in the warmest Member State (Cyprus). This implicitly widens the gap of indicators based on operational energy consumptions of the technical building system, like primary energy consumption or carbon emission.

Furthermore, other factors, such as the poor control due to the high thermal inertia and the slowly reacting system could cause losses and increase the energy consumption.

Fig.5represents the operational energy consumption of the analysed SFH in the different MSs. It is clearly notable, that while net energy need of the SFH in Ireland was close to the Hungarian, or the Italian cases, the much better SPFH results in a significantly lower operational energy consumption in Ireland.

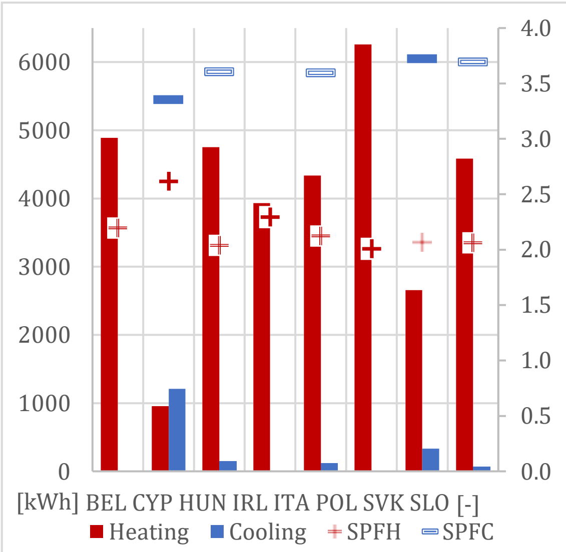

Fig. 5 – Seasonal performance factors of heating and cooling and energy consumptions

For the same reason, the SFH in Poland is even more energy consuming, having the worst SPFH of all the presented examples.

It is to mention that SPFs were calculated with on-off heat pumps as momentarily, no inverter-driven option is available in TRNSYS, though the trend of the SPF values of these appliances is similar as a function of external weather parameters [18].

3.4 operational carbon emission

Though one of the most significant indicators of NZEBs is the primary energy consumption of the building, conversion factors could mislead the results when comparing the countries, as they are also at the discretion of the MSs [19]. To avoid this effect, operational carbon emission of the SFHs are represented in the study. An advantage of this approach is that carbon intensity factors are not declared by the MSs but calculated, usually, based on life cycle assessment.

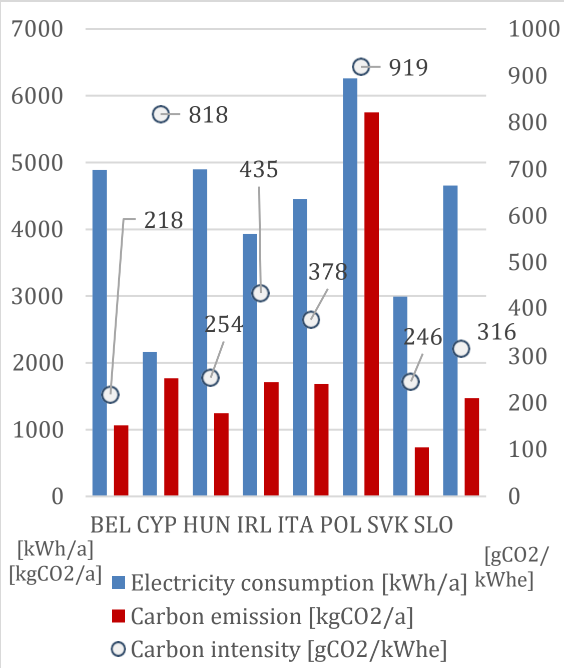

Fig. 6 – Annual carbon emission of the heating and cooling system of the reference building in different Member States

The deviation of the carbon intensity factors of the studied Member States though is significant [20]. On the top of that, Poland, consuming the most electricity for heating and cooling has way the worst carbon intensity factor, 919 g/kWh$_e$ which is almost 4 times of the second least consuming Slovakia's 246 g/kWh$_e$. This obviously widens the gap amongst the environmental impact of the SFH in these countries. The reference building located in Slovakia only emits 13% of the Polish extremely high level of 5,753 kgCO$_2$eq/year.

In case of Cyprus, similarly, the high carbon intensity factor boosts the emissions of the SFH and as a result, the least consuming location is the same time the second most emitting however it is to note that with 1,768 kgCO$_2$eq/year it is still only 31% of the Polish carbon emission level.

Interestingly, countries that were highlighted for their similar net energy needs, carbon intensity factor represents a decisive factor from the perspective of greenhouse gas emissions. In the end, among of those the Belgian case has the lowest annual emission, 1066, as a result of the lowest carbon intensity factor, while Ireland has the highest, 1710 kgCO$_2$eq/year, with the highest carbon intensity factor of the focused countries.

4. Conclusion

Residential buildings have a lot to offer in climate change mitigation for their huge share of energy consumption and carbon emission. The European Union aimed to have impact this sector with the mandatory implementation of Nearly Zero Energy Building definition, nevertheless the development of the requirements are to be determined by the Member States individually.

This is a source of not only various indicators for NZEB characterization, but also leaves room for different threshold levels on the same ones, like in case of the thermal transmittance regulation of specific building structures. Comparing eight Member States have revealed that the maximum of thermal transmittance values vary between 0.90-2.25 W/m^{2}K for the glazed openings, 0.15-0.40 W/m^{2}K for external walls and 0.10–0.40 W/m^{2}K for the ground and roof slabs.

Building energy performance simulation of a reference single family house has shown that despite these alternating values, heating loads are consistent compared with the minimum temperatures of each country. An exception to this is the Slovakian heating load, which appears to be significantly lower than the others. Regarding the cooling load, there are no general trends, nevertheless it is interesting that Slovakia scores the second highest cooling load, which is attributed to the risk of overheating as a result of the combined effect of hight level insulation and high thermal inertia.

Net energy needs appear as anticipated by the heat loads. The case of Ireland well represents the importance of climatic conditions. Despite the much lower heating load, net energy needed for heating is approximately the same in Ireland as in Italy, Hungary or Slovakia, as a consequence of longer heating season. Unsurprisingly, Poland has by far the highest net energy need for heating and Slovakia has the second lowest (after Cyprus).

When served with a modern, renewable energy source-based technical building system, such as air-to-water heat pump with surface heating, altering seasonal performances of the appliance have a visible impact on energy consumption. In case of Poland, the high net energy need for heating is further enhanced with the lowest seasonal performance factor for heating. On the contrary, Irelands second highest SPFH reduces its energy consumption notably, compared to the other countries.

What Ireland gains on high efficiency, loses it on high carbon intensity factor. An indicator to highlight is the operational carbon emission, in which aspect

Ireland worsens its relatively good position of energy-based indicators. Slovakia, opposingly, is even more appealing in the context of operational carbon emission, with far the lowest 735 $kgCO_2eq$/year due to the low electricity-consumption and the second least carbon intensity factor of 246 g/kWh_e. On the other end comes Poland, with an extremely high 5,753 $kgCO_2eq$/year, a combined result of worst energy consumption and carbon intensity factor.

Consequently, nearly zero energy buildings are the most similar in their heating load trends. Energy-consumption related indicators of the reference building differ a lot depending on its location for the specific climatic conditions. This is a bit controversial as this leads to the same naming, NZEB, meaning "nearly zero" to largely different extents. Seeing the results, it is advised to either perform similar investigations that could properly suggest thermal transmittance requirement values, balancing the specific target indicators (like net energy needs), or to highlight in communication that NZEB indicators could have huge variations depending on the exact location. For the latter it could be added that for further harmonization of the indicators, some Member States would need to invest disproportionately much money.

It is also suggested that operational carbon emission indicators shall appear in the definition as a flagship of environmental awareness. This would also provide room in differentiating the support schemes of renewable energy sources.

4.1 limitations and future work

Recently, more and more countries announce requirements on the specific thermal transmittance of the specific building structures. As the present study is limited to eight Member States, it is planned to expand scope with other countries. Furthermore, other building types must be included to clarify the extent the reference building selection influenced the results.

5. Acknowledgement

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6. Appendices

For the weather specifications Test Reference Year weather files of Brussels, Larnaca, Budapest, Dublin, Milan, Warsaw, Bratislava and Ljubljana were used. For shading, default settings of TRNBuid were applied.

Complete result tables of the mentioned indicators are presented in further tables. For more information see the link below.

Tab. 2 - Simulation results of the reference building for the eight specified locations

	Heating load [kW]	temp. [°C]	Cooling load [kW]	temp. [°C]
BEL	4.341	-7.08	1.940	29.38
CYP	3.312	2.53	4.682	33.79
HUN	4.632	-11.88	2.534	31.30
IRL	3.513	-4.08	1.974	22.08
ITA	4.244	-7.66	2.281	28.98
POL	5.194	-16.48	1.618	26.71
SVK	3.238	-12.28	3.071	28.59
SLO	4.465	-11.98	2.212	27.28
Net energy	Heating [kWh]	Cooling [kWh]	Sum [kWh]	
BEL	9331	103	9434	
CYP	1735	3436	5171	
HUN	8379	458	8837	
IRL	7910	27	7936	
ITA	7986	375	8361	
POL	10871	68	10938	
SVK	5014	1163	6178	
SLO	8374	229	8603	
HVAC	SCOP [-]	SPFH [-]	SEER [-]	SPFC [-]
BEL	2.85	2.20		
CYP	3.37	2.62	4.57	3.35
HUN	2.65	2.04	4.95	3.61
IRL	2.98	2.29		
ITA	2.76	2.12	4.93	3.60
POL	2.61	2.01		
SVK	2.71	2.07	5.17	3.72
SLO	2.68	2.06	5.09	3.70
Elect-ricity	Heating [kWh_e]	Cooling [kWh_e]	Sum [kWh_e]	CO_2 [kg/a]
BEL	4890		4890	1066
CYP	955	1207	2162	1768
HUN	4753	148	4901	1244
IRL	3931		3931	1710
ITA	4334	119	4454	1684
POL	6260		6260	5763
SVK	2657	334	2991	736
SLO	4584	70	4654	1471

The datasets generated during and/or analysed during the current study are not available because at the moment of publishing but the authors will make every reasonable effort to publish them at https://epget.bme.hu/oktatoi_oldal.php?lepes=4&oid=151 in near future.

7. References

[1] International Energy Agency, “2019 Global Status report for Buildings and Construction,” 2019.

[2] EPBD, Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. 2018.

[3] D. D’Agostino, S. T. Tzeiranaki, P. Zangheri, and P. Bertoldi, “Assessing Nearly Zero Energy Buildings (NZEBs) development in Europe,” Energy Strateg. Rev., vol. 36, no. July, p. 100680, 2021, doi: 10.1016/j.esr.2021.100680.

[4] R. Simson, K. E. Thomsen, K. B. Wittchen, and J. Kurnitski, “A Comparative Analysis of NZEB Energy Performance Requirements for Residential Buildings in Denmark, Estonia and Finland,” E3S Web Conf., vol. 246, no. April, 2021, doi: 10.1051/e3sconf/202124614001.

[5] F. Garzia et al., “Report on EU implementation of nZEBs,” 2018. [Online]. Available: http://www.cravezero.eu/wp-content/uploads/2018/07/CRAVEzero_D21_Report-of-EU-implementation-of-nZEBs.pdf.

[6] S. Guillén-Lambea, B. Rodríguez-Soria, and J. M. Marín, “Comfort settings and energy demand for residential nZEB in warm climates,” Appl. Energy, vol. 202, pp. 471–486, 2017, doi: 10.1016/j.apenergy.2017.05.163.

[7] Concentrated Action, “Energy Performance of Buildings Database.” https://epbd-ca.eu/database-of-outputs.

[8] C. Ministry of Commerce Industry and Energy Tourism, “2nd National plan fo increasing the number of Nearly Zero-Energy Buildings (NZEBs),” Press Inf. Off., 2017.

[9] Z. Sternova and J. Magyar, “EPBD implementation in the Slovak Republic,” 2018. [Online]. Available: https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-Slovak-Republic-2018.pdf.

[10] M. De Meulenaer and T. Kristien, “Belgium Flemish 2016 - Implementing the Energy Performance of Buildings Directive 2018,” 2018. [Online]. Available: https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-Belgium-Flemish-Region-2018.pdf.

[11] Ministry Without Portfolio of Hungary, “Regulation 7/2006 determining the energy performance of buildings,” 2020. https://net.jogtar.hu/jogszabaly?docid=a0600007.tnm (accessed Jun. 17, 2021).

[12] I. Department of Housing, Local Government and Heritage, Building Regulations - Technical Guidance Document L- Conservation of Fuel and Energy – Buildings other than Dwellings. 2021, pp. 1–100.

[13] C. Ezilda, A. Federici, A. Martino, M. Antinucci, and G. Varalda, “EPBD implementation in Italy,” 2018. [Online]. Available: https://www.buildup.eu/sites/default/files/content/ca-epbd-iv-italy-2018.pdf.

[14] D. Bekierski, R. Geryło, and D. Kaczorek, “EPBD implementation in Poland - status 2016,” 2018. [Online]. Available: https://www.buildup.eu/sites/default/files/content/ca-epbd-iv-poland-2018.pdf.

[15] M. Š. Zavrl, M. Tomšič, A. Rakuščcek, and E. Potočar, “EPBD Implementation in Slovenia,” 2018. [Online]. Available: https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-Slovenia-2018.pdf.

[16] E. C. for S. CEN, EN 15251 (2012) - Indoor environmental input parameters for design and assessment of energy performance of buildingsaddressing indoor air quality, thermal environment, lighting and acoustics, vol. 44. 2012, pp. 0–9.

[17] S. Verbeke and A. Audenaert, “Thermal inertia in buildings: A review of impacts across climate and building use,” Renew. Sustain. Energy Rev., vol. 82, no. August 2017, pp. 2300–2318, 2018, doi: 10.1016/j.rser.2017.08.083.

[18] G. Bagarella, R. Lazzarin, and M. Noro, “Sizing strategy of on-off and modulating heat pump systems based on annual energy analysis,” Int. J. Refrig., vol. 65, pp. 183–193, 2016, doi: 10.1016/j.ijrefrig.2016.02.015.

[19] R. Hitchin, K. E. Thomsen, and K. B. Wittchen, “Primary Energy Factors and Members States Energy Regulations - Primary factors and the EPBD,” no. 692447, p. 4, 2018, [Online]. Available: https://www.epbd-ca.eu/wp-content/uploads/2018/04/05-CCT1-Factsheet-PEF.pdf.

[20] European Joint Research Centre, “Reporting guidelines,” Covenant of Mayors for Climate and Energy, 2020. https://data.jrc.ec.europa.eu/dataset/919df040-0252-4e4e-ad82-c054896e1641.