WHAT KIND OF HEAT LOSS REQUIREMENTS NZEB AND DEEP RENOVATION SETS FOR BUILDING ENVELOPE?

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Abstract

In most of countries the energy performance of buildings is defined as (primary) energy use of whole building's (heating, cooling, ventilation, DHW, lighting, HVAC auxiliary, appliances), not as specific requirements for building envelope. For construction companies of production of modular renovation panels it in necessary to know heat loss properties of building envelope (U, W/(m^2·K); Ψ, W/(m·K); χ, W/K; q_{50}, m^3/(h·m^2)).

In this study it is analyzed what kind of heat loss requirements exists for building envelope to meet on annual basis to following targets: nZEB i.e. national nearly zero energy definition; deep energy renovation with 80 % reduction of primary energy; ZEB i.e. net Zero Energy Building = the annual primary energy use = 0 kWh/(m² a).

Indoor climate and energy calculations were made based on national energy calculation methodologies in six countries: Denmark, Estonia, Latvia, Czech Republic, Portugal, and Netherland.

Requirements for heat loss of building envelope vary depending on requirements on indoor climate and energy performance in specific country, outdoor climate, availability of renewable energy, and building typology. The thermal transmittance of the modular wall panels for nZEB was ≈5% from pre-renovation thermal transmittance in Latvia, ≈10% in Estonia and up to 50% in Portugal. For roof the decrease of thermal transmittance was smaller mainly due to smaller thermal transmittance before renovation.

Results show the difficulties to reach ZEB with multi-story apartment buildings in cold climate. There are not enough places to install renewables for energy production on site.

Keywords: *nZEB, Deep energy renovation, ZEB, Modular renovation panels, energy performance of buildings.*

1 Introduction

The Energy Performance of Buildings Directive recast (EPBD) [1] gives ambitious goals for the building sector to reduce energy use as well as greenhouse gas emissions. In energy efficiency targets, the existing building stock and its energy performance improvements play a major role. The EPBD defines nearly Zero Energy Building (nZEB) is a building that has a very high energy performance and requires the calculation of primary energy indicator.

Nemry et al. [2] modelled building stock for the EU-25 and reported that heat losses due to ventilation, through roofs and external walls are important for a majority of dwellings and most cases bear a significant potential for economically efficient environmental improvements, especially for additional roof and façade insulation. Kuusk [3,4], Arumägi [5], and Alev et al. [6] have shown that additional thermal insulation of building envelope have important role in improving of energy performance of existing building stock in cold climate.

The European building sector has not been able yet to devise a structural, large-scale retrofitting process and systematic approach. The use of prefabricated multifunctional modular renovation elements could help to fulfill all these points. IEA ECBCS Annex 50 demonstrated prefabricated systems for low energy renovation of residential buildings and proved this concept in six demonstration sites in Austria, the Netherlands and Switzerland by reducing energy consumption of all renovated buildings by 80% to 90% [7]. Silva et al [8] presented a prefabricated retrofit modules for the facades and showed the implementation of the retrofit module within an integrated retrofit approach, whose final goal was to obtain a building with the minimum possible energy consumption and greenhouse gas emissions.

The Horizon 2020 MORE-CONNECT project [9] developes prefabricated, multifunctional renovation elements for the total building envelope (façade and roof) and installation/building services. These elements can be combined, selected and configured by the end-user, based on his specific needs. For construction companies and producers of modular renovation panels it is necessary to know heat loss properties of building envelope:

- thermal transmittance (U, W/(m^2·K)) of exterior wall, roof, floor, windows, doors, etc;
- linear thermal transmittance (Ψ, W/(m·K)) of connections, details and thermal bridges;
- air leakages (q_{50}, m^3/(h·m^2)) of building envelope.

In this study indoor climate and energy calculations were made based on national energy calculation methodologies in six countries to determine what kind of heat loss requirements nZEB and deep energy renovation sets for building envelope.

2 Methods

The selection and development of prefabricated and multifunctional building envelope elements for modular retrofitting started with an inventory of the initial performance criteria and requirements in five geo-clusters in Europe:

- Northern focuses on solutions for the Scandinavian market (represented by Denmark),
- Continental Northern East focuses on a collaboration between Baltic States but also in other former East-European countries (represented by Estonia and Latvia);
- Continental Centre focuses on solutions for continental climates (Czech Republic);
- Mediterranean focuses on solutions for mild and warmer climates (Portugal);
- Western Central focuses on the Dutch/Belgium markets (represented by Netherland).

Indoor climate before renovation represented indoor climate category (ICC) III (an acceptable, moderate level of expectation) and after renovation ICC II (normal level of expectation).

The indoor climate and energy calculations were made to six reference buildings Fig. 1 and Tab. 1, correspondingly on national energy calculation methodologies and requirements. All input data used in energy calculations represent the typical case of that country.

Fig. 1 *Reference buildings used for indoor climate and energy calculations to see the influence of nZEB definitions to requirements of modular building envelope retrofitting elements.*

Tab. 1 *Information about studied buildings before renovation and requirements on indoor climate.*

Properties of building	Countries that national energy calculation methods were used					
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Netherland
Construction time	1967	1986		~1950	1997	1963
Number of floors	4	5		3	3	2
Net area, m^2	1836	3519		1194	1414	84
Heated area, m^2	1836	2968		1107	1279	84
Compactness, m^2 / m^3, m^{-1}	0.38	0.35		0.47	0.23	0.48
Number of apartments	24	80		24	18	1
Thermal transmittance W/(m^2·K) U_{wall}	0.5	1.1	1.80	1.35	0.92	1.9
U_{roof}	0.4	1.0	1.25	0.9	0.94	2.8
U_{floor}	0.5	0.6	0.49	1.53	0.78	2.0
$U_{window\ (glass/\ frame)}$	3.1	1.6	2.56	1.2	3.10	2.8
U_{door}	3.1	1.6	2.56	1.4	3.10	2.5
Airtightness of building envelope q_{50}, $m^3/(hm^2)$	14.4	4.2	5	Included in ventilation rates	12	9
The use of DHW l/(m^2·a)	250	520				175
l/(pers. day)			36	40	40	40
Heating with its efficiency	1	Rad. 0.97	Rad. 0.97	Rad. 0.88	Rad. 1.0	Radiator 1.0
Energy performance value, kWh/(m^2·a)	112	225	139	245	179	216
Indoor climate targets						
Minimum temperature for heating, °C, ~1.0 clo, ~1.2 met	20	21	18	20	18	20
Maximum temperature for cooling, °C, ~0.5 clo, ~1,2 met		27	28	27	25	25
General air change rate, h^{-1}	0.5	0.6	0.6	0.5	0.5	0.26

Indoor climate and energy calculations are made for four different cases:

- nZEB i.e. national nearly zero energy definition (if available in specific country);
- DER i.e. deep energy renovation with 80 % reduction of primary energy for:
  - space heating (+ pumps);
  - space cooling;
  - ventilation (heating, cooling, fans);
  - domestic hot water (DHW).
- ZEB i.e. net Zero Energy Building = the primary energy use = 0 kWh/(m² a) (on annual basis) for:
  - space heating (+ pumps) and space cooling;
  - ventilation (heating, cooling, fans);
  - DHW.

3 Results and discussions

3.1 National nZEB requirements

Due to the diversity of the European buildings sector and climate, each state have to define national nZEB approaches reflecting national, regional or local conditions. In most of countries the energy performance of buildings is defined as (primary) energy use of whole buildings. In Denmark the nZEB is referred to BR2020 which calls for a total primary energy use of 20 kWh/m²/year (primary energy factor for district heating=0.6 and for electricity=1.8). Portuguese regulations define that the nZEB solution corresponds to the cost-optimal renovation solution of the envelope.

Tab. 2 presents results of indoor climate and energy calculations for national nZEB requirements.

Differences in climate and nZEB regulations cause also different requirements for heat loss of modular prefabricated insulation panels in different countries. In the northernmost country, Estonia, the strictest requirements exists on thermal transmittance of building envelope. Even adjoining state countries Estonia and Latvia with almost similar climates, differences in energy regulations cause stricter requirements on thermal transmittance of building envelope in Estonia. Similarly, stricter requirements on energy performance of buildings in Denmark [10] causes stricter requirements on thermal transmittance of building envelope than in Czech Republic. In warmest country, Portugal, requirements on thermal transmittance of building envelope are the lowest for nZEB.

Minimizing heat loss of building envelope is not enough for nZEB in Estonia and Latvia. On site heat and electricity production is need in both countries: ~7% of solar collectors for DHW per heated area and in Estonia additionally ~5% of solar panels per heated area for producing electricity. As in Portugal the use of district heating is not popular, the heat pump (COP=4.1) was used there as renewable energy source.

Tab. 2 *Results of indoor climate and energy calculations for* ***national nZEB*** *requirements.*

Properties of building	Countries that national energy calculation methods were used					
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Netherland[1)]
Buildings need (net energy use (without losses of technical systems), kWh/(m²·a)						
Space heating	2.2-7	11.7	11.8	37	16.1	22.7
Space cooling				-	3.2	(9.4)
Ventilation	in heating	5.6	15.5	incl. in heating	15.0	incl. in heating
Domestic hot water	14	30	56	20.7	29.3	21.4
Appliances, lighting	-	29.5	16.7	8.2 lighting	-	12.8 (lighting)
Fans, pumps	1.59	6.2	10.8	-	-	1.91
Produced heat and electricity on site, kWh/(m²·a)						
Solar collectors (heat)	0	21	21	0	10.4	In DHW
PV panels (electricity)	0	5.5	0	0	0	56.9
Heat pump	0	0	0	0	25.8	0
Collectors for DHW, m²	0	180	200	0	69	4
PVpanels for electricity, m²	0	150	0	0	0	26
Primary energy use, kWh/(m²·a)						
Energy performance value	20	91	85	92	35	11.4
Building envelope						
Thermal transmittance U_{wall} W/(m²·K)/ $\Psi_{wall/wall}$	0.14/n.a	0.11/0.15	0.19/0.1	0.25 (total influence of thermal bridges/ couplings ΔU=0.02 W/(m²K))	0.47/0.50	0.16
U_{roof} W/(m²·K)/ $\Psi_{roof/wall}$	0.11/n.a	0.08/0.17	0.16/0.1	0.2	0.32/1.00	0.16
U_{floor} W/(m²·K)/ $\Psi_{floor/wall}$	0.34/0.3	0.22/0.02	0.19/0.05	0.4	0.86/0.50	0.16
U_{window} W/(m²·K)/ $\Psi_{window/wall}$	0.7/0.1	0.8/0.02	1.2/0.03	1.1	2.40/0.25	1.1
U_{door} W/(m²·K)/ $\Psi_{door/wall}$	0.7/0.1	1.0/0.02	1.2/0.03	1.1	2.40/0.25	1.1
Airtightness of building envelope q_{50}, m³/(h·m²)	2.4	3.0	1.5	1.5	8	1.5

[1)] A national legal definition for nZEB renovation was currently missing for Netherland, data is an example for ‘zero-on –the-meter’ renovation level

3.2 Deep energy renovation with 80 % reduction of primary energy for space heating and cooling, ventilation, and domestic hot water

Tab. 3 presents results of indoor climate and energy calculations for basic reduction of the primary energy consumption for space heating and cooling, ventilation, and domestic hot water by at least 80 % compared to the original consumption before renovation.

To decrease the energy consumption for space heating and cooling, ventilation, and domestic hot water by at least 80 % compared to the original consumption depends strongly on energy performance of the building before renovation. Depending on country’s climate, regulations and energy use of building before renovations, 80 % of energy reduction may cause stricter or weaker requirements on energy performance than national nZEB requirement.

The production of heat and electricity on site is unavoidable in all countries except Denmark. In Estonia the share of renewable energy is the largest, because energy performance value includes also energy used for appliances and lighting that cannot be decreased by modular insulation panels. Almost the total area of the roof is covered with solar collectors and PV panels in Estonia to degrease the primary energy for space heating and cooling, ventilation, and domestic hot water by 80 %.

Tab. 3 *Results of indoor climate and energy calculations for basic reduction of the primary energy consumption for space heating and cooling, ventilation, and domestic hot water by at least* ***80 %*** *compared to the original consumption before renovation.*

Properties of building	Countries that national energy calculation methods were used					
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Netherland
Buildings need (net energy use (without losses of technical systems), kWh/(m^2·a)						
Space heating	2.2-7	2.9	13.1	37	16.1	36.6
Space cooling			-	-	3.2	-
Ventilation	in heating	4.3	15.5	in heating	15.0	6.8
Domestic hot water	14	30	56	20.7	29.3	24.9
Appliances, lighting	-	29.5	16.7	8.2 lighting	-	12.8
Fans, pumps	1.6	6.5	10.8	0.4	-	9.7
Produced heat and electricity on site, kWh/(m^2·a)						
Solar collectors (heat)	0	21	21	0	10.4	
PV panels (electricity)	0	23.3	0	14.3	0	114
Heat pump	0		0	0	25.8	60.1
Collectors for DHW, m^2	0	180	200	130	69	0
PVpanels for electricity, m^2	0	630	0	0	0	39
Primary energy use, kWh/(m^2·a)						
Energy performance value	20	45	95	49	35	82
Building envelope						
Thermal transmittance				total influence of thermal bridges/ couplings ΔU=0.02 W/(m^{2}K)		
U_{wall} W/(m^2·K)/ $\Psi_{wall/wall}$	0.14/n.a	0.08/0.08	0.19/0.1	0.25	0.47/0.50	0.18/0.1
U_{roof} W/(m^2·K)/ $\Psi_{roof/wall}$	0.11/n.a	0.06/0.17	0.16/0.1	0.2	0.32/1.00	0.15/0.1
U_{floor} W/(m^2·K)/ $\Psi_{floor/wall}$	0.34/0.3	0.22/0.02	0.19/0.05	0.4	0.86/0.50	0.29/0.24
U_{window} W/(m^2·K)/ $\Psi_{window/wall}$	0.7/0.1	0.8/0.02	1.4/0.03	1.1	2.40/0.25	1.6/0.06
U_{door} W/(m^2·K)/ $\Psi_{door/wall}$	0.7/0.1	1.0/0.02	1.3/0.03	1.1	2.40/0.25	2.0/0.24
Airtightness of building envelope q_{50}, m^3/(h·m^2)	2.4	1.5	1.5	1.5	8	

3.3 ZEB, net Zero Energy Building

To eliminate different requirements on energy performance in different countries the last calculations were made for **ZEB** (net Zero Energy Building = the use of primary energy on annual basis = 0 kWh/(m^{2}a) for space heating and cooling, ventilation, and DHW), Tab. 4. Similarly to previous cases, it was possible to reach the goal by: minimizing the energy use and maximizing the energy production on site form renewable sources.

Similarly to previous cases, each country found the optimal solution themselves.

In Central European milder climatic conditions the ZEB is possible in practice. In theory, also in colder climate (In Estonia and Latvia) the ZEB is possible, when there is place to install solar collectors and PV panels 57% of heated area of the building. Therefore for multistory apartment buildings ZEB is extremely difficult if not impossible in cold climate.

Tables 2, 3, 4 present requirements on thermal transmittance on building envelope to reach different energy efficiency levels (nZEB, DER, ZEB). Inside the specific climate and energy performance calculation principles there requirements are building specific. Other possibilities are to present requirements on building envelope as average thermal transmittance of building envelope (U_{mean}, W/(m^2·K)) or specific heat loss on heated area of the building ($H/A_{heating}$, W/(m^2·K). For construction companies and producers of modular renovation panels is usually necessary to know specific properties of specific building envelope parts. Usually production techology sets limits for thermal transmittance. For example insulation in roof panel could be thicker than in walls because load bearing structures are thinker in roof due to longer span. Therefore we presented requirements as thermal transmittance. We agree that thermal transmittance in Tables 2, 3, 4 are not irreversible fixed values but rather the guiding values for designer for the first selection in the early stage of design and manufacturer for technology determination in factory.

All of the presented requirements of prefabricated elements are related to heat losses, because this influences most strongly the modular panel's solution. Are there also other requirements on building envelope like durability, structural stability, fire safety, moisture safety, acoustic price etc. In addition to heat loss of building envelope also other parameters influence the energy performance of building, like heat gains, use of renewable materials within the element etc. All these requirements need to be fulfilled and factors to be taken into account during design process in the final optimization of modular panel solution.

Tab. 4 *Results of indoor climate and energy calculations for* ***ZEB*** *(net Zero Energy Building = the use of primary energy on annual basis = 0 kWh/(m²a) for space heating and cooling, ventilation, and DHW).*

Properties of building	Countries that national energy calculation methods were used					
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Netherland
Buildings need (net energy use (without losses of technical systems), kWh/(m^2·a)						
Space heating	2.2-7	2.9	4.0	37	16.1	36.6
Space cooling				–	3.2	-
Ventilation	in heating	4.3	5.3	in heating	15.0	6.8
Domestic hot water	14	30	56	20.7	29.3	24.9
Appliances, lighting	-	29.5	16.7	8.2 lighting	-	12.8
Fans, pumps	1.59	6.5	9	0.2	-	9.7
Produced heat and electricity on site, kWh/(m^2·a)						
Solar collectors (heat)	9.5	21	29.3	0	10.4	
PV panels (electricity)	7.2	55.4	39.5	30.8	14.3	114
Heat pump		12.1		0	25.8	60.1
Collectors for DHW, m^2	2	180	285	0	69	0
PVpanels for electricity, m^2	4	1500	1200	280	135	39
Primary energy use, kWh/(m^2·a)						
Energy performance value	0	0	0	0	0	0
Building envelope						
Thermal transmittance						
U_{wall} W/(m^2·K)/ $\Psi_{wall/wall}$	0.14/n.a	0.08/0.08	0.08/0.08	0.25 (total influence of thermal bridges/ couplings ΔU=0.02 W/(m^2K))	0.47/0.50	0.18/0.1
U_{roof} W/(m^2·K)/ $\Psi_{roof/wall}$	0.11/n.a	0.06/0.17	0.08/0.1	0.2	0.32/1.00	0.15/0.1
U_{floor} W/(m^2·K)/ $\Psi_{floor/wall}$	0.34/0.3	0.15/0.02	0.15/0.1	0.4	0.86/0.50	0.29/0.24
U_{window} W/(m^2·K)/ $\Psi_{window/wall}$	0.7/0.1	0.6/0.02	0.8/0.05	1.1	2.40/0.25	1.6/0.06
U_{door} W/(m^2·K)/ $\Psi_{door/wall}$	0.7/0.1	0.8/0.02	0.8/0.05	1.1	2.40/0.25	2.0/0.24
Airtightness of building envelope q_{50}, m^3/(h·m^2)	2.4	1.5		1.5	8	

4 Conclusions

Requirements for building envelope vary depending on requirements on indoor climate and energy performance in specific country, outdoor climate, availability of renewable energy, and building typology.

The thermal transmittance of the modular wall panels for nZEB was ≈5% from pre-renovation thermal transmittance in Latvia ($U_{w.nZEB}$≤0.19 W/(m^2·K)), ≈10% in Estonia ($U_{w.nZEB}$≤0.11 W/(m^2·K)) and up to 50% in Portugal ($U_{w.nZEB}$≤0.47 W/(m^2·K)). This shows that panel's manufacturer may have difficulties to develop a single product for the whole Europe. Differences in climates and national regulations cause different requirements on thermal transmittance of building envelope. The strictest requirement on transmittance of building envelope is in Denmark and in Portugal, requirements on thermal transmittance of building envelope are the lowest for nZEB. For roof the decrease of thermal transmittance was smaller mainly due to smaller thermal transmittance before renovation.

Results show the difficulties to reach ZEB in multistory apartment buildings in cold climate. There is not enough space to install renewables for energy production on site.

Results will be in future optimized in development of innovative, multifunctional building envelope elements for modular renovation in H2020 MORE-CONNECT project.

Acknowledgement

The study has been conducted in the projects H2020 MoreConnect, TK146 the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, IUT1−15 Nearly-zero energy solutions and their implementation on deep renovation of buildings.

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