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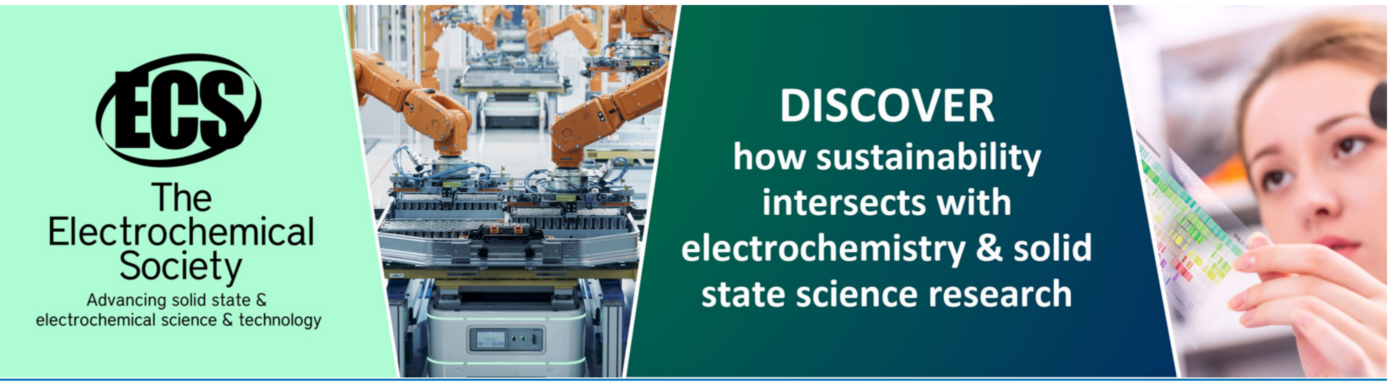

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Defining the Polish nearly Zero Energy Building (nZEB) renovation standard

S Firląg, A Chmielewski

The Faculty of Civil Engineering, Warsaw University of Technology, Lecha Kaczyńskiego 16, 00-637 Warszawa, Poland

s.firlag@il.pw.edu.pl

Abstract. The paper describes the process of defining the requirements for renovation of single-family residential buildings to the nZEB standard in Polish conditions. According to the survey results the nZEB renovation standard should include only two indicators: energy need for heating Q_H expressed in kWh/(m²year) and percentage reduction of the primary, non-renewable energy Q_P demand. Process of defining the requirements was divided into two stages: calculation of cost-optimal heat transfer coefficients for renovated elements of building envelope, calculation of cost-optimal renovation standard of the two single-family model houses. The analysis was made for three Polish cities (coldest, medium and warmest) and for 5 different energy prices. As an optimizing criterion the minimum cumulative cost was used, calculated for the 30-year time-scale for different variants of renovation.

1. Introduction

Poles live in homes that are inadequately insulated against heat loss. Heating technology is outdated and the most popular fuel is highly polluting coal, burned in old coal-fired boilers. It is estimated that more than 70% of detached single-family houses in Poland (3.6 million) have no, or inadequate, thermal insulation [1]. Only 1% of all houses in Poland can be considered energy efficient, primarily those that have been built in the last few years [1, 2]. Most of the buildings without thermal insulation had been built before 1989 [3].

In order to support deep renovation of single family-houses, it is crucial to determine the requirements for cost-effective renovation. The method and principles of support should give the investors the incentive to self-incur the costs of carrying out economically viable activities. For example, there should be no support for energy efficiency projects with short payback time, as these can be financed by building owners or by using external capital. It is necessary to introduce a definition for the nZEB renovation standard and define technical requirements for individual energy efficiency measures (e.g. the insulation of external building elements). These must be formulated in a way that in the near future there will be no need for renovation of the currently modernized buildings.

2. Potential indicators of an nZEB renovation standard for Poland

A survey was carried out among 17 experts during a meeting within the Efficient Poland Initiative on potential approaches and indicators that could be used for the nZEB definition of existing single-family houses in Poland. The list of the indicators was created on basis of European nZEB definitions [4]. The results of the survey were the starting point for the definition of nZEB renovation for single family buildings (Table 1.). The results show that 7 of the indicators have scored 10 or more votes –

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should be included in the definition. At the same time many indicators have received negative votes. In order to state which of them are most important the number of "No" votes was subtracted for the "Yes" votes. The results are presented in the last column of the table, in order of net score.

It can be seen that the first two indicators scored the highest number of "YES" votes, and among the lowest number of "NO" votes and accordingly can be considered the most important indicators to be used in specifying a nZEB renovation definition.

Table 1. Results of the survey on the potential indicators of nZEB renovation definition.

Should the nZEB definition of renovation include requirements for?	Yes	No	Importance (Yes-No)
Index of non-renewable, primary energy demand Q_P	12	5	7
Index of final (delivered) energy demand Q_F	10	6	4
Index of energy need for heating Q_H	15	2	**13**
CO_2 emission index	10	5	5
Share of renewable energy sources	10	7	3
Thermal transmittance (U-value) of different building elements	12	4	8
Air tightness	7	7	0
Ventilation systems including the efficiencies of heat recovery	9	6	3
Efficiencies of heating and domestic hot water systems	9	6	3
Summertime comfort – risk of overheating	5	9	-4
Energy demand of auxiliary systems	6	8	-2
Energy efficiency of renovation improvement - percentage reduction of the primary, non-renewable energy Q_P demand	13	3	**10**
Index of final (delivered) energy demand Q_F for cooling	1	0	1

According to the findings of the survey, the definition of nZEB renovation should only include two indicators:

- The energy need for heating Q_H, expressed in kWh/(m²year), and
- The percentage of reduction of primary non-renewable energy demand Q_P, (including heating, ventilation, domestic hot water (DHW), cooling and auxiliary systems for the case of residential buildings), determined in relation to the energy demand of building before renovation.

These two indicators would make the definition very flexible (reduction of Q_P can be achieved in many ways, e.g. use of RES, increase of systems energy efficiency, reduction of energy need for DHW, cooling) but at the same time very demanding. The energy need for heating (Q_H) depends among others, on the thermal transmittance of the building elements, the thermal bridges, the air tightness and the ventilation system's type. A low value of the energy need can be achieved in different ways depending on the building's condition. For example, in case it is not possible to insulate the ground floor, other elements of the building's envelope, e.g. external walls, roof, windows or doors, can have a better thermal transmittance. In addition, ventilation with heat recovery can be applied in order to reduce the ventilation heat loss and energy need. The energy need for heating (Q_H) as an indicator gives flexibility and provides the opportunity to choose the best renovation measures.

The indicator referring to the reduction of primary energy demand (Q_P) includes aspects like efficiencies of the heating and DHW system, energy source type and use of Renewable Energy Sources (RES). Depending on the building's conditions, different solutions can be chosen. Additional use of first indicator - the energy need for heating (Q_H), prevents against situation in which only RES (with low primary energy factor PEF) will be implemented in order to reduce the primary, non-renewable energy demand. In Poland value of PEF for biomass is 0,2 and for coal 1,1, so change from coal to biomass will reduce the primary, non-renewable energy demand by about 82% where the energy demand for heating can stay at the same level.

3. NZEB standard based on cost optimal calculations

The process of determining requirements for the nZEB renovation definition was divided in two stages. The cost optimal U-value of the building's envelope is initially calculated and based on this, the energy demand for heating and the reduction of non-renewable primary energy demand are then estimated:

- Stage I – Cost-optimal heat transfer coefficients for renovated elements of the building envelope

The aim of the calculation was to determine the cost optimal U-values for the elements of the building's fabric (e.g. structural material, insulation, windows etc.) for single-family houses to be renovated. The results depend on the type of the building element (external wall, roof, etc.), its initial U-value and the cost of energy. As an optimizing criterion, the minimum cumulative cost (investment + cost of energy losses) was used, calculated over 30-year period. Based on literature review [5, 6, 7] a discount rate of 4.0% was assumed, the energy price increase rate equal to 1.6% above the year-on-year inflation level that was 1.8%. All the values were constant during the analyzed period.

- Stage II – Cost-optimal renovation definition for single-family houses

In the second part of the analysis the cost optimal scenario for renovation of two reference buildings was determined. As an optimizing criterion, the minimum cumulative cost (investment + energy cost of heating, DHW and auxiliary electricity) was used, calculated over 30-year period. 12 scenarios of renovation were defined based on the heat transfer coefficient of the building elements, the ventilation, the central heating and domestic hot water solutions. For each scenario the energy need for heating and ventilation was calculated according the ISO 13790 standard. The reduction of primary non-renewable energy demand for heating, ventilation, domestic hot water and auxiliary systems was also determined following the polish regulations.

4. Building models

Two reference building models were used to determine the requirements for renovation to the nZEB definition (Figure 1):

- a typical two-storey building with a flat roof,
- a one-storey building with an attic.


Figure 1. Reference single family houses: (left) two-storey building with flat roof, (right) one-storey building with an attic [8].

5. Cost-optimal U-values of renovated building envelope

Table 2 shows the calculation results of the discounted cumulative cost depending on the energy cost and U-values for a renovated external wall of U-value 0.82 W/(m^{2}K). Depending on the heating energy cost per 1 GJ the cost-optimal thermal transmittance (characterised with lowest discounted, cumulative cost), is between 0.12 to 0.20 W/(m^{2}K) (Table 2., bold).

Table 2. The discounted, cumulative cost (k_{Rd}) per m^2 including the cost of energy loss and the unit cost of renovation with tax (k_{VAT}), depending on the renovation variant and the cost of 1 GJ of energy. Insulation of external walls with ETICS using EPS with λ = 0.033 W/(mK).

U-value, insulation cost and energy loss per m^2 of external wall depending on insulation thickness					Heating energy cost in PLN per 1 GJ				
					20	30	40	50	60
d	U-value	*K*	K_{VAT}	Energy loss	Discounted, cumulative cost in PLN per m^2				
cm	W/(m^{2}K)	zł/m^2	zł/m^2	GJ/(m^{2}year)	K_{Rd_20}	K_{Rd_30}	K_{Rd_40}	K_{Rd_50}	K_{Rd_60}
0	0,820	0,00	0,00	0,262	132	199	265	331	397
10	0,231	99,93	107,92	0,074	145	164	182	201	220
12	0,202	103,56	111,84	0,065	145	161	177	194	210
14	0,180	107,19	115,76	0,058	145	159	174	189	203
16	0,163	110,81	119,68	0,052	146	159	172	185	198
18	0,148	114,44	123,60	0,047	147	159	171	183	195
20	0,136	118,07	127,52	0,043	149	160	171	182	193
22	0,125	122,04	131,80	0,040	152	162	172	182	193
24	0,117	125,58	135,63	0,037	154	164	173	183	192
26	0,109	129,99	140,38	0,035	158	167	176	184	193
28	0,102	133,53	144,21	0,033	161	169	177	185	194
30	0,096	137,07	148,03	0,031	164	171	179	187	195

Figure 2 shows the change of discounted cumulative cost depending on the energy cost and U-values for a renovated external wall. The cost optimal U-vale is characterized with lowest discounted, cumulative cost. Increasing trends at the ends of the chart show that either renovation cost or energy loss cost is starting to dominate in cumulative cost.

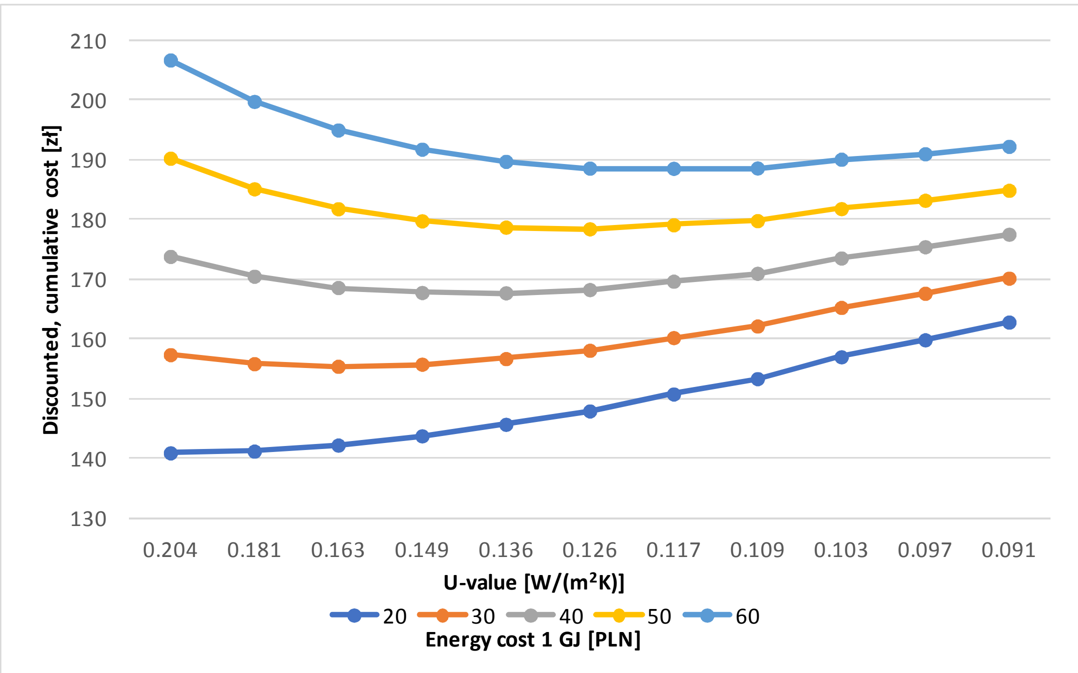

Figure 2. The discounted, cumulative cost (k_{Rd}) per m^2 for renovated external wall depending on the thermal transmittance and the energy cost.

The cost-optimal thermal transmittance for the renovated building elements is presented in Table 3. For each building element the thickness of the additional insulation d, and the cost of renovation is given. The optimal thermal transmittance strongly depends on the energy price. The table shows the values for the lowest and the highest energy price per GJ. The minimum and maximum U-values were used for defining the renovation variants used in the second part of the analysis:

- First variant (W1) – the building envelope was renovated according to the cost-optimal thermal transmittance specified for energy price of 20 PLN per GJ,
- Second variant (W2) – the building envelope was renovated according to the cost-optimal thermal transmittance specified for energy price of 60 PLN per GJ.

Table 3. The cost-optimal renovation variants (depending on the energy price) for the building envelope used in stage II of the analysis.

Building element	W1 - 20 PLN per 1 GJ				W2 - 60 PLN per 1 GJ			
	d	U-value	renovation cost	unit	d	U-value	renovation cost	unit
	cm	W/(m^{2}K)			cm	W/(m^{2}K)		
External wall	12	0.21	112	PLN/m^2	24	0.12	136	PLN/m^2
Floor above an unheated cellar	7	0.25	53	PLN/m^2	10	0.19	76	PLN/m^2
Floor on a ground	14	0.24	129	PLN/m^2	26	0.14	154	PLN/m^2
Flat roof	12	0.22	86	PLN/m^2	26	0.12	111	PLN/m^2
Pitched roof	20	0.18	142	PLN/m^2	35	0.10	164	PLN/m^2
Windows	-	0.9	562	PLN/m^2	-	0.9	562	PLN/m^2
External doors	-	1.3	4088	PLN/door	-	0.9	4347	PLN/door

6. Cost-optimal building renovation standard

On the basis of defining U-values of building elements and solutions referring to the upgrading of the ventilation system and the use of RES, different renovation variants were identified. All of them include upgrading of the existing heating and domestic hot water system together with replacement of the heating source. The symbols used to distinguish the variants are explained below:

- W0: baseline variant, existing reference building before renovation,
- W1: variant I of building’s envelope renovation, energy price 20 PLN per 1 GJ,
- W2: variant II of building’s envelope renovation, energy price 60 PLN per 1 GJ,
- G: natural ventilation, base case before renovation,
- H: hybrid ventilation, it was assumed that the energy loss through ventilation will be reduced by 20%
- R: balanced ventilation with heat recovery, efficiency of heat recovery: 90%,
- S: solar system used for DHW heating, assumed coverage between 50-60% of DHW energy demand.

The optimal variants of renovation of the two reference buildings are presented in Table 4 (two-storey building) and Table 5 (one-storey building). The choice of the variant depends on a decisive extent on two factors: the price of energy per 1 GJ and the building location (climate).

Table 4. Cost-optimum renovation variants of the two-storey building with flat roof

location	energy price per 1 GJ		
	20 PLN	40 PLN	60 PLN
	cost-optimum renovation variants		
Warszawa	W1/G	W2/G	W2/G/S
Szczecin	W1/G	W2/G	W2/G/S
Suwałki	W1/G	W2/G	W2/R/S

Table 5. Cost-optimum renovation variants of the one-storey building with an attic

location	energy price per 1 GJ		
	20 PLN	40 PLN	60 PLN
	cost-optimum renovation variants		
Warszawa	W1/G	W2/G	W2/H/S
Szczecin	W1/G	W2/G	W2/H/S
Suwałki	W1/G	W2/G	W2/H/S

The calculations show that:

- for both building types at a low energy cost of PLN 20 per GJ, the renovation variant W1/G, was optimal. It is a variant including natural ventilation and the following heat transfer coefficients (U) of external buildings elements: external walls 0.19-0.21 W/m^{2}K, floor on the ground 0.24 W/m^{2}K, flat roof 0.22 W/m^{2}K, pitched roof 0.18 W/m^{2}K, floor above unheated basement 0.25 W/m^{2}K, windows 0.9 W/m^{2}K and external door 1.3 W/m^{2}K.
- At the energy cost of PLN 40 per GJ, the renovation variant W2/G was optimal for both building types. In this case the variant involves natural ventilation and the following heat transfer coefficients (U) of external buildings elements: external walls 0.12 W/m^{2}K, floor on the ground 0.14 W/m^{2}K, flat roof 0.12 W/m^{2}K, pitched roof 0.10 W/m^{2}K, floor above unheated basement 0.19 W/m^{2}K, windows 0.9 W/m^{2}K and external door 0.9 W/m^{2}K.
- In the case of PLN 60 per GJ, for both building types the optimal variant is W2/S, which takes into account solar collector installations supporting the preparation of domestic hot water. Some differences can be seen in regard to ventilation. In the case of the two-storey building with flat roof, the mechanical ventilation with heat recovery is cost-effective in Suwałki (the coldest location), whereas for the second building the use the hybrid ventilation is optimal for all locations.

Table 6 and Table 7 show the energy need for heating (Q_H) (including heating and ventilation) for the cost-optimal variants of renovation of the two reference buildings respectively. It can be seen that the energy need ranges from 30.9 to 91.1 kWh/m2year, corresponding to the optimal variants. The high range of values is a result differences in climate (different locations), energy prices and building types. It corresponds well to the reality in which energy consumption can vary strongly even for the same buildings.

Table 6. Energy need for heating for the two-storey building with flat roof for cost-optimum renovation variants

location	energy price per 1 GJ		
	20 PLN	40 PLN	60 PLN
	Q_H kWh/m^{2}year		
Warszawa	72,9	55,6	55,6
Szczecin	67,6	51,4	51,4
Suwałki	91,1	70,9	30,9

Table 7. Energy need for heating for the one-storey building with an attic for cost-optimum renovation variants

location	energy price per 1 GJ		
	20 PLN	40 PLN	60 PLN
	Q_H kWh/m^{2}year		
Warszawa	66,0	48,5	41,7
Szczecin	60,9	44,5	38,2
Suwałki	83,8	63,6	55,7

Based on calculated energy need for heating primary non-renewable energy demand was calculated for the buildings. At this point renovation of heating and DHW system, auxiliary equipment was included as well as use of solar collectors for DHW. The obtained reduction of the primary energy demand for heating, ventilation, hot water production and the work of auxiliary equipment (this includes energy for fans, pumps, electronics, etc.) ranges from 69% to 86% (Table 8 and Table 9). The higher reduction in primary non-renewable energy can be achieved by using RES and better insulated building envelope. The location does not have a significant effect in this case.

Table 8. Change of primary, non-renewable energy index after renovation to the cost-optimum variant for two-storey building with flat roof

localization	Q_P index for base variant	energy price per 1 GJ		
		20 PLN	40 PLN	60 PLN
		Q_P index for renovation variants (percentage reduction in regard to base variant)		
	kWh/m^{2}year	kWh/m^{2}year	kWh/m^{2}year	kWh/m^{2}year
Warszawa	448	137 (69%)	116 (74%)	96 (79%)
Szczecin	425	130 (69%)	110 (74%)	90 (79%)
Suwałki	527	160 (70%)	135 (74 %)	74 (86%)

Table 9. Change of primary, non-renewable energy index after renovation to the cost-optimum variant for one-storey building with an attic

localization	Q_P index for base variant	energy price per 1 GJ		
		20 PLN	40 PLN	60 PLN
		Q_P index for renovation variants (percentage reduction in regard to base variant)		
	kWh/m^{2}year	kWh/m^{2}year	kWh/m^{2}year	kWh/m^{2}year
Warszawa	574	138 (75%)	117 (79%)	88 (84%)
Szczecin	546	132 (75%)	112 (78%)	84 (84%)
Suwałki	669	160 (75%)	135 (79%)	105 (83%)

7. Conclusions

Based on the above analysis and considering received results the Polish definition of nZEB renovation of single-family house was proposed. Because large range of values, especially in regard to energy need for heating, was obtained, it was assumed that averages will be used for the indicators.

The requirements for nZEB renovation of single-family residential buildings are following:

- The energy need for heating $Q_H \leq 60$ kWh/(m² year),
- The percentage of reduction of the primary, non-renewable energy Q_P demand (including in case of residential buildings heating, ventilation, domestic hot water and auxiliary systems) ≥ 75%.

Defined requirement for energy need for heating can be compared with indicator for low-energy residential buildings in NF40 standard $Q_H \leq 40$ kWh/(m² year) [9] or passive buildings $Q_H \leq 15$ kWh/(m² year) [10]. It is lower, and it should be because reaching low-energy standard in case of existing buildings can be technically complicated (e.g. implementation of mechanical ventilation with heat recovery) and very expensive. Meanwhile, the second requirement, referring to the percentage reduction of the primary, non-renewable energy Q_P demand, is similar as for deep renovation, commonly understood as one that focuses on the building envelope and achieves an energy reduction of 75% or more compared to the situation before the renovation. The absolute values of Q_P are higher than required for new nZEB houses in Poland - primary, non-renewable energy demand ≤ 70 kWh/(m² year) [9].

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