A PROPOSAL FOR DEFINING NEARLY ZERO ENERGY BUILDING (NZEB) REQUIREMENTS FOR RENOVATION OF SINGLE-FAMILY HOUSES IN POLAND

Briefing

A significant percentage of houses in Poland are inadequately insulated. Heating technology is outdated and the most frequently used fuel is coal, burned in old coal-fired boilers, largely contributing to air pollution. It is estimated that more than 70% of the detached single-family houses in Poland (3.6 million) have no, or inadequate, thermal insulation.

Only 1% of all houses in Poland can be considered as energy efficient and were mainly built in the last few years[1]. Most of the buildings without thermal insulation were built before 1989. Data from the Central Statistical Office[2] indicate that about 50% of the residential buildings in Poland have been insulated, but in the vast majority of cases, to a sub-optimal level. Given that the economic case for improving the insulation of these partially insulated buildings is not favourable, it can be concluded that the remaining 50% of buildings should be prioritized for renovation. Acceleration of the cost-effective renovation of existing buildings can improve the energy efficiency in Poland. At the same time this is the easiest and fastest way of gaining energy savings. The main objective of this report is to present possible nZEB requirements for renovation of single family houses in Poland.

POTENTIAL INDICATORS OF AN NZEB RENOVATION DEFINITION FOR POLAND

During 2017, BPIE carried out a survey under the auspices of the Efficient Poland initiative, on potential approaches and indicators that could be used for the nZEB definition of existing single-family houses in Poland.

According to the findings of the experts' survey, it is proposed that the definition of nZEB renovation should be comprised of two main indicators:

- The energy need for heating QH, expressed in kWh/(m² year), and
- The percentage reduction of primary non-renewable energy demand QP, for heating, ventilation, domestic hot water (DHW), cooling and auxiliary systems (this includes energy for fans, pumps, electronics, etc.) relative to the energy demand of the building before renovation.

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 type of ventilation system. 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, could be retrofitted to improve its thermal performance.

[1] Energy Efficiency in Poland 2013 Review
[2] Inhabited buildings, the National Census of Population and Housing 2011, Central Statistical Office, 2013

In addition, ventilation with heat recovery can be applied in order to reduce the ventilation heat loss and energy need. The indicator referring to the reduction of primary energy demand (Q_P) includes aspects like improving the efficiency of the heating and DHW system, changing the energy source type and using renewable energy sources (RES). In both cases, different combinations of solutions can be applied, given the specific conditions and the location of the building. It is intended that the nZEB definition is non-prescriptive for particular measures in order to allow flexibility in determining the best solution for a particular building.

By considering both indicators within the nZEB definition, ensures that the requirements cannot be met solely through the installation of RES. This is particularly important in Poland, since the primary energy factor (PEF) for biomass is 0.2 and for coal 1.1. This means that a change from coal to biomass, while desirable from an air quality perspective, would reduce the primary, non-renewable energy demand by about 82% without reducing the energy demand for heating. This is an unacceptable way of achieving nZEB.

NZEB DEFINITION 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 1

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 materials, windows etc.). The results depend on the type of building element, its initial U-value and the cost of energy. As an optimising criterion, the minimum cumulative cost (investment + cost of energy) was used, calculated over a 30-year period.

Stage 2

COST-OPTIMAL RENOVATION DEFINITION FOR REFERENCE BUILDINGS

In the second part of the analysis, the cost optimal scenario for the renovation of two reference building types, was determined. As an optimising criterion, the minimum cumulative cost (investment + energy cost of heating, DHW and auxiliary electricity) was used, calculated over a 30-year period.

Twelve scenarios of renovation were defined based on the heat transfer coefficient of the building elements, the ventilation, and the central heating and domestic hot water systems. For each scenario, the energy need for heating and ventilation was calculated through the Audytor OZC software, consistent with 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.

REFERENCE BUILDING TYPES

Two reference building types for single-family houses were used to determine the optimal variants for renovation (Figure 1):

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

Figure 1-Reference building types (a) two-storey building with flat roof (b) one-storey building with an attic (source: KAPE)

(a) (b)

COST-OPTIMAL U-VALUES OF RENOVATED BUILDING ENVELOPE

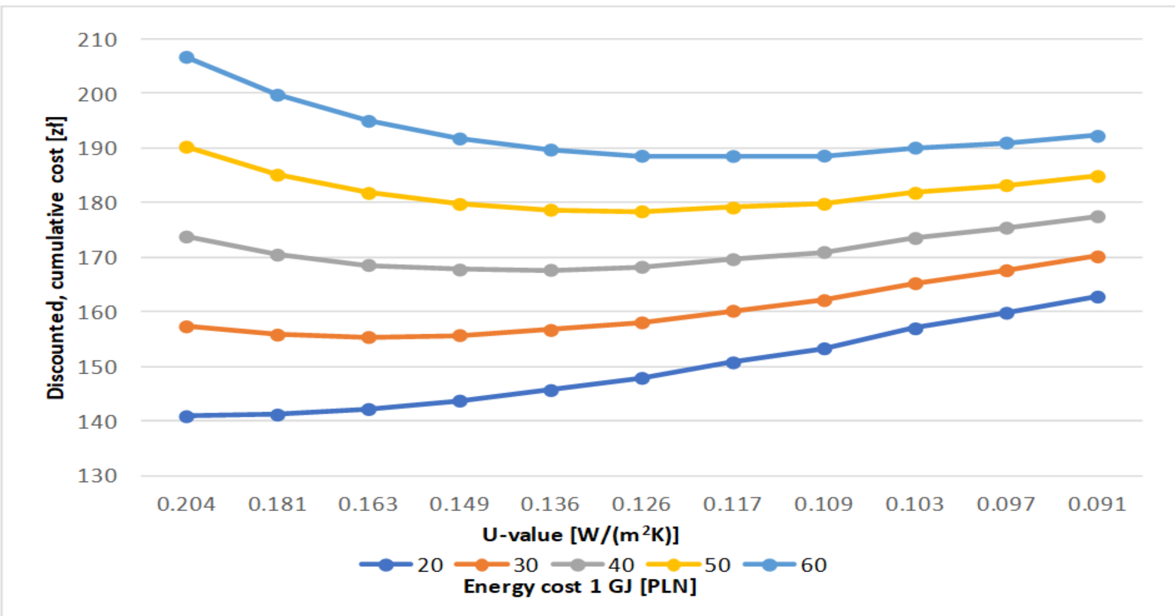
Table 1 shows the calculation results of the discounted cumulative cost in relation to the energy cost and the U-values for a renovated external wall of U-value=0.82 W/(m^2K). Depending on the heating energy cost per GJ, the cost-optimal thermal transmittance (corresponding to the lowest discounted cumulative cost-highlighted), is between 0.12 and 0.20 W/(m^2K) (Figure 2).

Table 1 - The discounted, cumulative cost (KRd) per m^2 including energy cost and the cost of renovation inclusive of tax (KVAT), in relation to the renovation variant cost (K) and the cost of 1 GJ of energy (1 EUR=4.2PLN). Insulation of external walls with ETICS[3] using EPS with λ = 0.033 W/(mK). The highlighted cells have the lowest cumulative cost for a given energy cost

U-value, insulation cost and energy cost 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^2K)	zł/m^2	zł/m^2	GJ/(m^2year)	K_{Rd_20}	K_{Rd_30}	K_{Rd_40}	K_{Rd_50}	K_{Rd_60}
0	0.820	0.00	0.00	0.262	132.4	198.6	264.8	331.0	397.2
10	0.231	99.93	107.92	0.074	145.9	164.9	183.9	202.9	221.9
12	0.202	103.56	111.84	0.065	145.1	161.7	178.4	195.0	211.6
14	0.180	107.19	115.76	0.058	145.3	160.1	174.9	189.7	204.5
16	0.163	110.81	119.68	0.052	146.3	159.6	172.9	186.2	199.5
18	0.148	114.44	123.60	0.047	147.8	159.9	172.0	184.1	196.2
20	0.136	118.07	127.52	0.043	149.7	160.8	171.9	183.0	194.1
22	0.125	122.04	131.80	0.040	152.3	162.5	172.8	183.0	193.2
24	0.117	125.58	135.63	0.037	154.6	164.2	173.7	183.2	192.7
26	0.109	129.99	140.38	0.035	158.1	167.0	175.9	184.8	193.6
28	0.102	133.53	144.21	0.033	160.9	169.2	177.5	185.8	194.1
30	0.096	137.07	148.03	0.031	163.7	171.5	179.4	187.2	195.0

Figure 2 shows the variation in the discounted cumulative cost depending on the energy cost and U-values for a renovated external wall. The cost optimal U-value has the lowest discounted, cumulative cost (lowest point of the curve). Higher overall costs at the left and right extremes of the curves show that either renovation cost or energy cost is starting to dominate in the 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



[3]External Thermal Insulation Composite System

The cost-optimal thermal transmittance for the renovated building elements is presented in Table 2. 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 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[4]
- Second variant (W2) – the building envelope was renovated according to the cost-optimal thermal transmittance specified for energy price of 60 PLN per GJ[5]

Table 2 - 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 per floor area	Unit	d	U-value	Renovation cost per floor area	Unit
	cm	W/(m²K)			cm	W/(m²K)		
External wall	12	0.206	111.84	PLN/m²	24	0.118	135.63	PLN/m²
Floor above an unheated cellar	7	0.247	52.92	PLN/m²	10	0.187	75.60	PLN/m²
Floor on a ground	14	0.235	129.44	PLN/m²	26	0.144	154.29	PLN/m²
Flat roof	12	0.217	85.76	PLN/m²	26	0.121	111.30	PLN/m²
Pitched roof	20	0.177	141.65	PLN/m²	35	0.097	163.88	PLN/m²
Windows	-	0.9	562.36	PLN/m²	-	0.9	562.36	PLN/m²
External doors	-	1.3	4087.73	PLN/door	-	0.9	4347.35	PLN/door

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 these variants include upgrading of the existing heating and domestic hot water system together with the 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 envelope renovation, energy price 20 PLN per GJ,
- W2: variant II of building envelope renovation, energy price 60 PLN per 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 3 (two-storey building) and Table 4 (one-storey building). The choice of the variant depends to a significant degree on two factors: the price of energy and the building location (climate).

[4]The current average price of energy from firewood
[5]The current average price of energy from heating oil

Table 3 - 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 (warmest)	W1/G	W2/G	W2/G/S
Suwałki (coldest)	W1/G	W2/G	W2/R/S

Table 4 - Cost-optimum renovation variants of 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 building elements:
  - ⇒ External walls: 0.19-0.21 W/m^{2}K,
  - ⇒ Ground floor: 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,
  - ⇒ ground floor: 0.14 W/m2K,
  - ⇒ 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 domestic hot water systems. Some differences can be seen in regard to ventilation. In the case of the two-story building with a flat roof, the mechanical ventilation with heat recovery is cost-effective in Suwałki (the coldest location), whereas for the one story building with attic (second building type), the use of hybrid ventilation is optimal for all locations.

Table 5 and Table 6 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/m^{2}year, corresponding to the optimal variants. The high range of values is a result of differences in climate (different locations), energy prices and building types. There is a good correspondence with the reality where energy consumption can strongly vary even for the same building.

Table 5 - Energy need for heating for 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/m²year	kWh/m²year	kWh/m²year
Warszawa	72.9	55.6	55.6
Szczecin	67.6	51.4	51.4
Suwałki	91.1	70.9	30.9

Table 6 - Energy need for heating for 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/m²year	kWh/m²year	kWh/m²year
Warszawa	66.0	48.5	41.7
Szczecin	60.9	44.5	38.2
Suwałki	83.8	63.6	55.7

Based on the calculated energy need for heating, the primary non-renewable energy demand was calculated for the two building types. The primary non-renewable energy demand depends from efficiencies of the systems, hot water demand, use of RES, auxiliary equipment and PEF factors. The process of renovation includes modernization of heating, and DHW system and 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 ranges from 69% to 86% (Table 7 and Table 8). 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 7 - Change of primary, non-renewable energy index after renovation to the cost-optimum variant for two-storey building with flat roof

Location	Q_P index for base variant	Energy price per 1 GJ		
		Q_p index for renovation variants (percentage reduction in regard to base variant)		
	kWh/m²year	kWh/m²year		
		20 PLN	40 PLN	60 PLN
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 8: Change of primary, non-renewable energy index after renovation to the cost-optimum variant for one-storey building with an attic

Location	Q_P index for base variant kWh/m²year	Energy price per 1 GJ Q_P index for renovation variants (percentage reduction in regard to base variant) kWh/m²year		
		20 PLN	40 PLN	60 PLN
Warszawa	574	138 (75%)	117 (79%)	88 (79%)
Szczecin	546	132 (75%)	112 (78%)	84 (84%)
Suwałki	669	160 (75%)	135 (79%)	105 (83%)

CONCLUSIONS

Based on the above analysis and taking into consideration the collective views of the building experts, a definition of nZEB renovation of single-family houses was proposed. Due to a large range of values, especially in regard to energy need for heating, average values were used for the indicators.

The requirements for nZEB renovation of single-family residential buildings Cost-optimal renovation definition for reference buildings are:

- **The energy need for heating $Q_H \leq 60$ kWh/(m² year),**
- **The percentage 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%.**

The defined requirement for energy need for heating is higher than the unofficial indicator for new-build low-energy residential buildings in Poland of $Q_H \leq 40$ kWh/(m² year). This is expected since reaching a low-energy standard in the case of existing buildings can be technically complicated (e.g. implementation of mechanical ventilation with heat recovery) and expensive. The second requirement referring to the percentage reduction of the primary, non-renewable energy Q_P demand, is similar for deep renovation. This is commonly understood as one that focuses on the building envelope and achieves an energy reduction of 75% or more compared to the conditions prior renovation. Cost-effectiveness of renovation process deepens strongly on energy price. Implementation of anti-smog regulations in Poland, referring to quality of fuel and boilers, will increase the energy price and stimulate the renovation process.

BPIE

June 2018

The Buildings Performance Institute Europe is a European not-for-profit think-tank with a focus on independent analysis and knowledge dissemination, supporting evidence-based policy making in the field of energy performance in buildings. It delivers policy analysis, policy advice and implementation support.

Buildings Performance Institute Europe
Rue de la Science / Wetenschapsstraat 23, B-1040 Brussels
info@bpie.eu / www.bpie.eu / @BPIE_eu