Possibilities of achieving the nZEB building standard (nearly zero energy building) and the passive building standard for newly designed buildings in Poland

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Abstract. For some time, a trend has been noticeable in the construction sector to reduce energy consumption. It is manifested by the tightening regulations of thermal protection of buildings, an increasing number of low-energy and even passive buildings, new technologies available on the construction market, or the new name of the "nearly zero energy" (NZEB) building standard. It is true that the definition of NZEB buildings appeared already ten years ago in the Energy Performance Directive No. 2010/31/EU, but despite the fact that to some extent this type of buildings should already be the standard of construction, very few people know what is meant by NZEB and how it differs from the passive standard. The nZEB standard for newly designed buildings applies from January 1, 2021, to all European countries. Parameters for nZEB buildings are determined individually by each European country. In Poland, the requirements specifying the standard for nearly zero-energy buildings are included in the Technical and Construction Conditions. These requirements are very difficult to meet. The requirements apply to the thermal insulation of the external casing of buildings. This can be achieved by using appropriate materials and construction technologies, as well as by minimizing thermal bridges. The second requirement for nZEB buildings in Polish regulations concerns the Primary Energy indicator. This requirement can only be achieved through the use of appropriate energy sources, a very large extent Renewable Energy Sources. The article presents the possibilities of achieving the standard of newly designed buildings with "almost zero energy consumption" thanks to the use of appropriate materials, technologies, installations as well as heat and cold sources. The article also describes the standard of passive buildings, as well as the standard of passive buildings, which has been compared with the Polish standard of buildings "nearly zero energy building" (NZEB).

1. Introduction

Energy saving in the construction sector is linked to the idea of Sustainable Development [1], which involves reducing the use of non-renewable resources (coal, oil, gas, water) so that meeting the needs of the current generation will not reduce the chances of meeting the needs of future generations [2]. This idea is also related to the development of renewable energy technologies (solar, wind, geothermal, ground heat). Construction is a very energy-intensive sector (about 40% of total energy consumption). With this in mind, the construction sector needs to undergo a transformation to radically reduce energy demand. Actions taken in this sector are visible, for example through the development of energy-efficient technologies [3][4][5][6]. An example is the first passive single-family house in Poland built...
in 2007 by Biuro Projektowe Lipińscy Domy. Passive house was an expression of the author's fascination with the idea of energy efficiency and the search for the direction of development for single-family housing in Poland. Over the following years, several new constructions of passive buildings, both residential and public utility, were built in Poland. In addition to passive buildings, there is growing talk of 'nearly zero energy' buildings (nZEB) [2,7–9]. Both passive building standard and "nearly zero energy" building standard (nZEB) are parametrically defined standards (they have precise numerical energy efficiency requirements). The nZEB building standard appeared for the first time in the Energy Performance of Buildings Directive 2010/31/UE [10], as an announcement of a new building standard in Europe. All Member States have committed themselves to align their legislation with the nZEB standard and to define parameters, based on a number of national analyses. The nZEB building parameters had to be determined on the basis of a methodology for calculating cost-optimal levels of minimum energy performance requirements for buildings [11]. The nZEB standard does not only apply to newly designed buildings, but also to requirements for thermo-modernized buildings, for which it is sometimes much more challenging than for new buildings, [12,13]. Both standards: passive and nZEB are characterized by very low energy consumption. Both designers and contractors must learn how to design such buildings. Many authors have already taken up the topic [13–16]. The market for building materials and technologies must also adapt to such strict energy requirements [17–19]. In recent years, there has been a high level of activity of building materials manufacturers, who invest in innovative techniques that allow the construction of passive and nZEB buildings. These technologies, in addition to high energy efficiency, are often recycled products [20–22]. The aim of this article is to provide a way to set cost-optimal levels of minimum energy performance requirements for buildings using the example of a single-family building. The second objective is to compare the requirements defined for both standards: a passive building and a 'nearly zero energy' building (nZEB).

2. Near-zero energy buildings (nZEB)
As mentioned in the introduction, the definition of a nZEB building appeared in the Energy Performance Directive 2010/31/EU [1] ('nearly zero-energy building'). NZEB buildings are a mandatory standard in the European Union Member States. nZEB buildings, as defined in the Directive, „should have very good energy performance”. The energy performance of a building reflects its energy needs for heating, cooling, ventilation and domestic hot water supply. Low energy demand should come as much as possible from renewable energy sources, produced on site or near the building. The Directive has not imposed the same nZEB building parameters on the EU Member States, leaving it to each country to decide individually on the basis of an optimal cost analysis.

Article 9 obliges Member States to:
- After 31 December 2020, all new buildings shall be nearly zero energy buildings,
- After 31 December 2018, all new buildings occupied and owned by public authorities will be nearly zero energy buildings'.

Experts in each EU Member State have determined the level of minimum thermal insulation requirements for the building envelope, determined by U-values [W/(m²K)] and the level of non-renewable primary energy EP [kWh/(m²year)]. In Poland, the requirements for nZEB buildings are contained in the Technical Conditions in section X and in the second annex. [23].

The maximum value of the annual non-renewable primary energy demand indicator EP is calculated according to the following formula:

\[ EP = EP_{H+W} + \Delta EP_C + \Delta EP_L [kWh/(m² rok)] \]  

(1)

where:
EPH=W – partial EP value for heating, ventilation and domestic hot water preparation,
ΔEPC – the partial value of the EP cooling,
ΔEPL – the partial value of the EP indicator for lighting.

The partial values of EP index for Polish RES buildings for heating, ventilation and domestic hot water preparation are presented in Table 1.

Table 1. Partial coefficients from EP values for heating, ventilation and domestic hot water preparation

| No | Type of building             | Partial EP values for heating, ventilation and domestic hot water preparation [kWh/(m² rok)] |
|----|------------------------------|-------------------------------------------------------------------------------------------------|
|    |                              | Od 1.01.2021                                                                                   |
| 1  | Residential building:  
a) One family | 70                                                                                             |
|    |                              |                                                   |
| 2  | Collective residence building | 75                                                                                             |
| 3  | Public utility building:  
a) healthcare | 190                                                                                           |
|    |                              |                                                   |
| 4  | Farm, warehouse and production building | 70                                                    |

Primary energy (EP), is a parameter that characterises the heat/cooling power sources of a building more than the energy efficiency level of the building itself.

The requirements for thermal protection of the building envelope expressed in terms of thermal transmittance U [W/(m²K)] are contained in Annex 2, while the most important building envelope elements have been selected for comparison (Table 2) [23].

Table 2. Heat transfer coefficients U[W/(m²K)] for selected building elements

| Lp  | Part of building | U[W/(m²K)] |
|-----|------------------|------------|
| 1   | external wall t ≥ 16°C | 0.20       |
| 2   | floor            | 0.30       |
| 3   | roof t ≥ 16°C    | 0.15       |
| 4   | window t ≥ 16°C  | 0.90       |
| 5   | door             | 1.30       |

2.3. Passive buildings
In 1988 a passive building standard was developed at Lund University in Germany. The aim was that the building could function without heating and consume a minimum amount of energy. The first experimental passive building was built in Darmstadt, Germany in 1991.

In 1996, on the initiative of F. Weista, the Passivhaus Institut was founded in Darmstadt in 1996. It is a commercially operating company that implements the idea of passive houses and certifies buildings according to their standards. The cost of building the first passive building in the Passivhaus Institut standard was very high, so it did not initially favour the development of passive buildings. Passive buildings must have a compact body and very good thermal protection of the exterior enclosure. The name of the standard - passive building - indicates the passive use of solar energy (large glazing facing
south). The institute also recommends preheating the ventilation air, using GWC (heat exchange with the ground causes the fresh air to preheat above 5°C, even during the cold days of the winter season). The ventilation system should be equipped with a recuperator with efficiency above 80%. The building must show high tightness. The tightness coefficient n50 must not be greater than 0.6 [1/h] replacements per hour.

Originally, the requirements for passive buildings assumed the same parameters, regardless of the location of the building. Proof of meeting the criteria is provided by the "PHPP Passive Building Design Package" computer program (Table 3). Originally, passive buildings were defined as one class, characterised by a final energy demand for heating not exceeding 15 kWh/m2year. Currently, an assessment according to renewable primary energy (PER) has been introduced, which was developed by the Passive Building Institute. Depending on the amount of renewable primary energy demand (PER) and the generation of renewable energy, it is now possible to achieve one of three classes: Classic, Plus and Premium.

| Table 3. Energy parameters for a passive building by PassivhausInstitut [24] |
|---------------------------------|-----------------|-----------------|
| Heating                         | Criteria        | Alternative criteria |
| Heat demand for heating         | [kWh/(m²a)] ≤ 15 | - |
| Heating load                    | [W/m²] ≤ -      | 10 |
| Cooling                         | The need for coolness and dehumidification | [kWh/(m²a)] ≤ 15+ permissible additive for dehumidification |
| Cooling load                    | [W/m²] ≤ -      | 10 |
| Air-tightness                   | Air exchange multiplication factor n50 when measuring the pressure air tightness of the building | [1/h] ≤ 0.6 |
| Renewable primary energy (PER)  | Criteria        | Classic Plus Premium |
| Renewable primary energy demand (PER) | [kWh/(m²a)] ≤ 60 45 30 | Deviation from criteria by value +/- 15 kWh/(m²a) |
| Production of renewable energy (reference to built-up area) | [kWh/(m²a)] ≥ - 60 120 | If the above deviation is compensated for by means of altered production |

2.4. Building nZEB vs. passive building.
Nearly zero energy demand (NZEB) and passive buildings are two different standards. Both have a very good insulation performance (Table 4). Passive buildings in the Passivhaus Institut standard are characterised by extremely low final energy. The requirements of the Passivhaus Institut are associated with considerable investment outlays. Lowering the value of EKH to 15 [kWh/(m²year)], compared to the average value of new buildings in Poland at the level of 40 ÷ 70 [kWh/(m²year)], means that every detail of design and workmanship must be done with the greatest care. At the same time, Polish standard of nZEB buildings does not impose any restrictions on Final Energy. On the other hand, there is a requirement for Primary Energy in Polish requirements for nZEB buildings.
Table 4 shows the basic differences between the German passive building standard and the Polish nZEB standard.

Table 4. Comparison of selected parameters of the nZEB standard (Poland) and the passive standard wg Passivhaus Institut.

| No | Compared parameter                  | Passive standard          | The nZEB standard in Poland |
|----|-------------------------------------|---------------------------|-----------------------------|
| 1  | U[W/(m²K)] External wall t ≥ 16°C   | U ≤ 0.15                  | U ≤ 0.20                    |
| 2  | U[W/(m²K)] Floor                    | U ≤ 0.15                  | U ≤ 0.30                    |
| 3  | U[W/(m²K)] roof t ≥ 16°C            | U ≤ 0.15                  | U ≤ 0.15                    |
| 4  | U[W/(m²K)] Window t ≥ 16°C          | U ≤ 0.80                  | U ≤ 0.90                    |
| 5  | U[W/(m²K)] door                      | No requirements           | U ≤ 1.30                    |
| 6  | EK (heating)                        | EK ≤ 15 kWh/m²rok         | No requirements             |
| 7  | Design                              | Only with the PHPP package| Anything compatible with the engineering |
| 8  | Materials, installations, technologies | Only certified by the Passivhaus Institut | Anyone |
| 9  | Certification requirement           | Yes                       | No                          |
| 10 | Energy performance requirement      | Yes                       | Yes                         |
| 11 | Valid in Poland                     | No                        | Yes                         |

To summarize, designing and construction of a building in passive standard is certainly connected with higher investment costs (design in PHPP package, technological and material solutions necessary to achieve EK value ≤ 15 kWh/m²-year, expensive certification) and with lack of freedom of choice of materials and technologies for building a house. On the other hand, excessive reduction of final energy will translate into low costs of building use. When deciding whether or not to invest in a passive standard according to the Passivhaus Institut, it is also important to remember that from the beginning of 2021 the mandatory nZEB standard comes into force. A separate issue in the design of both passive and nZEB buildings is the issue of ensuring optimum comfort for users. Both standards are characterized by a very tight housing and very high thermal insulation of the partitions. Additionally, in passive buildings, very large glazing is designed on the southern side, in accordance with the principle of maximizing passive solar energy generation. This can lead to unfavourable overheating of rooms. Of course, it is necessary to take care not only of thermal comfort but also of other aspects of the comfort of using the rooms [25][26]. In addition to adapting the building to high energy standards, the provision of user comfort should be the subject of research work on the design of passive and nZEB buildings.

3. Results and discussions

3.1. Calculation of cost-optimal levels of minimum energy performance requirements for buildings using the example of a single-family building

The analysis was performed in accordance with the methodology set out in the European Commission document "Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings and establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements" [11]. The analysis is
to show whether the assumed values for the Polish RES standard can be achieved as a starting point. In the article, the authors focused on the analysis performed for single-family residential buildings.

The analyzed reference building is a typical example of single-family buildings under construction in Poland. The selection of a typical building geometry was based on expert opinions and available statistical data.

This analysis was conducted for a climate station located in Krakow. Different types of heating and domestic hot water preparation have been adopted for calculations.

- Coal boiler room
- Gas boiler (condensing boiler)
- Heating oil boiler (condensing boiler)
- Biomass (pellet) boiler room
- Electrical heating
- Air-to-water heat pump
- Ground source heat pump
- District heating

Domestic hot water preparation
- Sources like heating
- Gas flow heater
- Electric boiler

The building under analysis is a single-family, detached single-storey house with a usable attic with an A/Ve > 0.5 m-1 (Figure 1, Table 5, 6).

![A single-family house, example photograph of a building (source of authors' contributions)](image)

**Figure 1.** A single-family house, example photograph of a building (source of authors' contributions)

**Table 5.** Parameters of a detached house accepted for analysis

| No. | Size                  | Value | Unit   |
|-----|-----------------------|-------|--------|
| 1.  | Area $A_f$            | 116.70 | m$^2$   |
| 2.  | Cube                  | 422.37 | m$^3$   |
| 3.  | Average temperature   | 19.6  | °C      |
| 4.  | A/V                   | 0.80  | 1/m     |
Table 6. Overview of the surface of external partitions

| L.p. | Type            | Area [m²] |
|------|-----------------|-----------|
| 1.   | External walls  | 157.34    |
| 2.   | Ceiling         | 111.15    |
| 4.   | External door   | 9.14      |
| 5.   | Windows         | 24.23     |

The calculation of energy characteristics was performed in accordance with the methodology contained in [27]. For the analyzed building model, the following results of usable energy for heating and ventilation were obtained (Table 7).

Table 7. Usable energy demand for heating and ventilation (U-values for partitions according to WT have been assumed in the models)

| Usable energy demand | Weather station | WT 2021 |
|----------------------|-----------------|---------|
| Total [kWh]          | Cracow          | 7 500.06|
| For the heated area [kWh/m²] |                   | 64.27   |

It is also necessary to take into account the usable energy associated with domestic hot water preparation (Table 8).

Table 8. Domestic hot water demand

| No | Wielkość | Value | Unit |
|----|----------|-------|------|
| 1. | kₖ - Correction factor for interruptions in the use of domestic hot water | 0.9   | -    |
| 2. | Vₜₜ - Unitary daily hot water demand | 1.4 [dm³/(m² day)] |
| 3. | Daily hot water demand | 0.15 m³ |
| 4. | Annual domestic hot water demand | 53.67 m³ |
| 5. | Domestic hot water demand | 2 810.98 kWh |
| 6. | Domestic hot water demand per m² | 24.09 [kWh/m²] |

The next step of the analysis was to calculate primary energy for ventilation heating and domestic hot water. The following efficiency values were adopted for the source and installation for central heating and ventilation purposes included in Table 9.

Table 9. Efficiency values for the source and installation for central heating and ventilation

| Type of source                  | Source efficiency | The product of transmission, regulation and accumulation efficiency |
|---------------------------------|-------------------|---------------------------------------------------------------|
| Coal boiler room                | 0.82              | 0.88                                                         |
| Gas boiler (condensing boiler)  | 0.95              | 0.88                                                         |
| Heating oil boiler (condensing boiler) | 0.95            | 0.88                                                         |
| Biomass (pellet) boiler room    | 0.70              | 0.88                                                         |
| Electrical heating              | 0.99              | 0.90                                                         |
| Air-to-water heat pump          | 3.20              | 0.88                                                         |
| Ground source heat pump         | 3.80              | 0.88                                                         |
| District heating                | 0.98              | 0.88                                                         |
Table 10 presents the obtained values of the non-renewable primary energy index for the analysed cases, with the assumption that the U-value for partitions adopted for the calculation has been assumed for the nZEB requirements, valid since 2021 (WT2021) [28]. The calculations were based on meteorological data from the station located in Kraków. The green colour was used to distinguish cases for which EP requirements were met.

| Heating                              | Domestic hot water          | WT2021 [kWh/m²] |
|--------------------------------------|-----------------------------|-----------------|
| Coal boiler room                     | just like central heating   | 157.83          |
|                                      | gas-fired instantaneous water heater | 154.86        |
|                                      | electric instantaneous water heater | 225.14        |
| Gas boiler (condensing boiler)       | just like central heating   | 136.99          |
|                                      | gas-fired instantaneous water heater | 141.45        |
|                                      | electric instantaneous water heater | 211.74        |
| Heating oil boiler (condensing boiler) | just like central heating | 136.99          |
|                                      | gas-fired instantaneous water heater | 141.45        |
|                                      | electric instantaneous water heater | 211.74        |
| Biomass (pellet) boiler room         | just like central heating   | 32.43           |
|                                      | gas-fired instantaneous water heater | 69.76         |
|                                      | electric instantaneous water heater | 148.04        |
| Electrical heating                   | just like central heating   | 339.07          |
|                                      | gas-fired instantaneous water heater | 273.28        |
|                                      | electric instantaneous water heater | 339.07        |
| Air-to-water heat pump               | just like central heating   | 111.97          |
|                                      | gas-fired instantaneous water heater | 125.36        |
|                                      | electric instantaneous water heater | 195.64        |
| Ground source heat pump powered by electricity | just like central heating | 95.17          |
|                                      | gas-fired instantaneous water heater | 114.55        |
|                                      | electric instantaneous water heater | 184.83        |
| PV-powered ground source heat pump (50%) | just like central heating | 47.59          |
|                                      | gas-fired instantaneous water heater | 57.27         |
|                                      | electric instantaneous water heater (power supply for photovoltaic panels) | 92.42         |
| District heating                     | just like central heating   | 98.22           |
|                                      | gas-fired instantaneous water heater | 116.51        |
|                                      | electric instantaneous water heater | 186.79        |
4. Conclusions

4.1. Analysis of requirements for the Polish standard of nZEB buildings

The analysis showed that for the adopted model of a typical single-family, residential building in Poland (with gravity ventilation), the requirements adopted for the Polish standard of nZEB buildings are met only for buildings powered by biomass and air heat pump, but powered by electricity from photovoltaic panels. Heat pumps powered by mains electricity cannot ensure that Polish requirements for nZEB buildings are met. The conclusions of the analysis show that in order to meet the stringent requirements set for the Primary Energy parameter, the electricity demand must be covered by photovoltaic panels. In order to meet the Polish standard for nZEB buildings it is necessary to design buildings powered by heat through biomass or heat pumps powered by electricity produced by photovoltaic panels. Also of great importance is the production of heat for domestic hot water, which can be seen in the case of supplying the building with heat for heating a biomass boiler room, but supplying heat production for domestic hot water through an electric flow heater (powered by mains electricity). This case does not meet the requirements of the Polish nZEB standard. The analysis showed that for the year in which it was completed (2016), it is very difficult and, in some cases, impossible for buildings to meet the conditions. Such applications were forwarded to the European Commission. However, at present we can observe a very large development of the photovoltaic and heat pump market. As the availability of these technologies’ increases, they are becoming more and more economically justified.

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