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## Energy and Cost Analysis of Adapting an Existing Building to 2017 Technical Requirements and Requirements for NZEB

To cite this article: Malgorzata Fedorczak-Cisak *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 112094

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# Energy and Cost Analysis of Adapting an Existing Building to 2017 Technical Requirements and Requirements for NZEB

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**Abstract.** Energy efficiency is a very important factor in the Building sector. Building sector consumes about 40% of the world total energy. At present, new buildings in Poland and other European countries are designed according to very strict requirements. The problem arises when we take into consideration large number of the existing buildings. These buildings, especially the ones built in the last century, consume a lot of heating energy. Thermal protection requirements for the existing buildings subjected to thermo-modernization are specified in the technical regulations. Thermal protection requirements for thermo-modernized buildings in different countries are different. In Poland, a thermos-modernized building must meet the requirements for thermal protection of external partitions. In Ukraine, the requirements of thermal protection are modelled on European regulations. In Ukraine's, thermos-modernized buildings must meet the requirements for thermal protection of external partitions and primary energy requirements. However, in Poland thermo-modernized buildings do not have to meet the requirement for a non-renewable primary energy factor – EP. [kWh/(m<sup>2</sup>y)]. The existing buildings do not always have the option of converting a non-renewable heat source into renewable heat sources. In the article, the authors presented the energy analysis of adapting an existing building to the current technical requirements in Poland (WT 2017) and to the level of requirements for buildings of "almost zero energy consumption NZEB" (WT 2021) and adapting an existing building to the current technical requirements in Ukraine. The analysis was carried out based on thermo-modernization audits carried out for a single-family residential building. The analysed building was built in 80's in traditional technology. It is a two-story building located in Krakow. The audits considered various options for improving energy efficiency. Financial outlays for each variant will be determined. The authors of the article pointed out that comfort in buildings subjected to thermo-modernization a very important issue. On the example of an existing residential building, the authors analysed how to improve the vibration comfort of use in the rooms of a building.

## 1. Introduction

The improvement of energy efficiency in the municipal and household sector is a fundamental task of the European Union member states. This is a requirement of Directive 2010/31 / EU of the European Parliament and of the Council of 19.05.2010 on the energy performance of buildings (EPBD). The implementation of the directive mandates the construction of nearly zero-energy buildings (NZEB). In Poland and other EU countries, amendments to the legislative and executive provisions are being made, tightening the regulations for the thermal protection of buildings.



In Poland, amendments to technical and construction regulations regarding thermal protection and energy consumption of buildings are currently binding requirements for the energy performance of buildings. These requirements can be found in section X and Annex 2 to the "Regulation of the Minister of Infrastructure of 12 April 2002 on technical conditions that should be met by buildings and their location" (Dz.U.2015, point 1442).

From January 1, 2021, all newly designed buildings should be ones with almost zero energy consumption. Changes in the technical conditions for new buildings concern supply and exhaust ventilation as well as parameters to be achieved by the non-renewable primary energy coefficient EP for buildings. The coefficient EP determines the annual demand for non-renewable primary energy intended for heating, ventilation and hot water preparation in a building. In addition, newly designed buildings must simultaneously meet the requirements of the maximum primary energy demand (EP coefficient [kWh / (m<sup>2</sup>a)]) and the minimum thermal insulation of partitions (U [W / (m<sup>2</sup>K)]).

For existing thermo-modernized buildings, the Polish technical standards only require compliance with the requirements for thermal insulation of external partitions (U [W / (m<sup>2</sup>K)]).

The Act on Supporting force for Thermo-modernization Poland and renovations in Poland from November 21, 2008 defines the principles of financing from the resources of the Thermo-modernization and renovation funds part. According to the regulation implementing the Act, the maximum values of heat coefficients for thermo-modernized partitions are adopted in accordance with technical and construction regulations, i.e. according to Annex 2 to the "Regulation of the Minister of Infrastructure of 12 April 2002 on technical conditions that buildings should meet and their location" (Dz.U.2015, item 1422). Apart from this case and regulations of regional programs in Poland, there are no requirements for buildings subject to thermo-modernization, including the need to meet the requirement in terms of the EP coefficient.

Regulations regarding the energy efficiency of buildings in force in Ukraine are modelled on European regulations. Ukrainian regulations, unlike Polish regulations, include requirements for both external building partitions (U-value) and Primary Energy (EP coefficient).

In the further part of the article, conclusions from the energy assessment of a residential building built in 1985 in Krakow, will be presented. In the heated underground of a four-story building, there is a garage, a solid fuel boiler (coal, wood). For the building, calculations of energy demand for the current state and the state after thermo-modernization were carried out. Thermo-modernization of the building includes activities that allow to meet the limit conditions by:

- WT2017 (Polish current requirements for thermal protection of buildings)
- WT2021(Polish requirements for thermal protection of buildings from 1.01.2021)

In addition, analysis of thermo-modernization activities was carried out, allowing to meet the requirements in force in Ukraine, including the requirements of the EP. In the last part of the article the authors carried out the analysis of the building in order to ensure vibratory comfort, taking into account the location of the building and the technology of its erection.

## 2. Requirements for construction standards of standardized indicators of energy efficiency

In Poland, the legal basis for calculation of energy saving and insulation is Division X in Journal of laws POS. 926 from day 13.08.2013 year. [Regulation of the Minister of Transport, Construction and Maritime Economy of 5 July 2013. on amendments to the Ordinance on technical conditions to be met by buildings and their location]. In accordance with § 328 of this law the minimum requirements referred to in paragraph 1 is satisfied for a building to be reconstructed if the partitions and technical equipment of the building to be restored, meet at least the requirements of thermal insulation, specified in Annex 2 to the Regulation (table 1).

**Table 1.** Requirements for 1.01.2017

| Country        | Coefficient U [ $\text{W}/\text{m}^2\text{K}$ ] |              |      |         |       | Coefficient EP [ $\text{kWh}/\text{m}^2\text{a}$ ] |
|----------------|---|--------------|------|---------|-------|--|
|                | External Wall                                   | Floor        | Roof | Windows | Doors |  |
| <b>Poland</b>  | 0.23  | 0.30         | 0.18 | 1.10    | 1.50  | Not specified for the modernized building          |
| <b>Ukraine</b> | 0.30  | 0.20 (0.27*) | 0.17 | 1.33    | 1.67  | 150  |

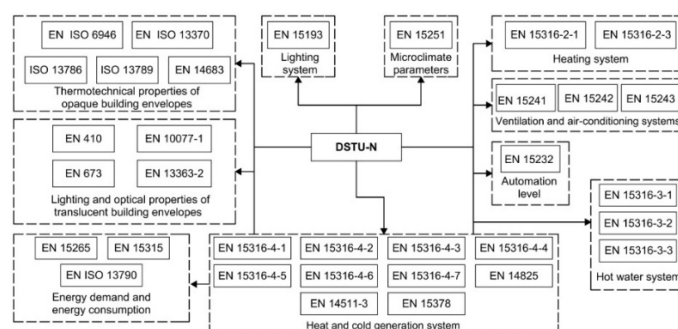
\* - the indicator for the ceilings of unheated cellars

According to the Polish legal regulations, until January 1, 2021, all buildings should be brought to a low level of energy consumption. The building should be modernized in such a way as to minimize the risk of overheating the building in the summer and the energy consumption for heating and preparation of hot water (table 2).

**Table 2.** Requirements for 1.01.2021

| Country        | Coefficient U [ $\text{W}/\text{m}^2\text{K}$ ] |              |      |         |       | Coefficient EP [ $\text{kWh}/\text{m}^2\text{a}$ ] |
|----------------|---|--------------|------|---------|-------|--|
|                | External Wall                                   | Floor        | Roof | Windows | Doors |  |
| <b>Poland</b>  | 0.20  | 0.3          | 0.15 | 0.9     | 1.3   | Not specified for the modernized building          |
| <b>Ukraine</b> | 0.30  | 0.20 (0.27*) | 0.17 | 1.33    | 1.67  | 150  |

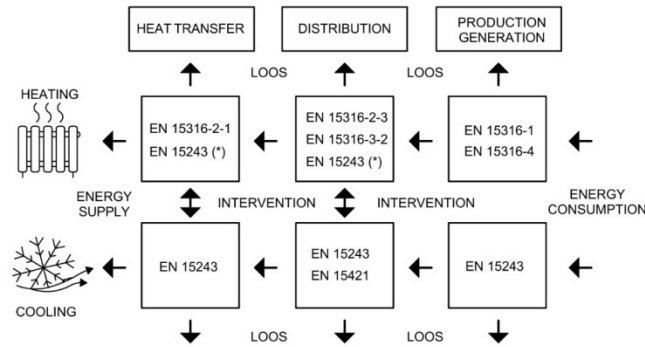
The concept of "energy efficiency of the building" was appeared in the terminology of normative documents of Ukraine with the adoption of DBN V.2.6-31:2006 (state building standards), which entered into force on 01.04.2007. In December 2010, Ukraine joined the European Energy Community and pledged the implementation of article 3 Directive 2010/31/EU on the energy performance of buildings regarding the adoption of a methodology for calculating the energy efficiency of buildings. Then a national standard DSTU B EN ISO 13790 was developed, which has a degree of compliance with the international standard. Today, Ukraine has a system of current norms and standards in the field of energy efficiency of buildings, which are interconnected with the international standards (figure 1).



**Figure 1.** Scheme of interconnection of the project DSTU-N with international standards

For determination of the energy efficiency of buildings was developed by the state building codes DBN V.1.2-11: 2008 "Basic requirements for buildings and structures. Energy saving ", by the order of Ministry for Regional Development, Building and Housing of Ukraine of January 26, 2008 No. 36; DBN V.2.6-31: 2016 "Thermal insulation of buildings", which establish requirements for thermal engineering indicators of protective structures of buildings and structures and the procedure for their calculation, and

DBN V.2.5-64: 2012 "Engineering equipment of buildings and structures. Internal plumbing and sewerage. Part I. Design. Part II Construction."; DBN V.2.5-67: 2013 "Heating, ventilation and air conditioning", which provide the requirements for engineering systems of new buildings and buildings under reconstruction. Ukraine has approved standards for ventilation, air conditioning, heating and metering methods for energy indicators (figure 2).



**Figure 2.** Energy Consumption and Energy Estimation of Buildings in accordance with DSTU

Normalized indicators of energy efficiency of buildings in Ukraine are defined by DBN V.2.6-31:2016 according to which minimum requirements to resistance to heat transfer of the protecting design of residential buildings, are established (table 1).

According to DBN V.2.6-31:2016 the basic requirement for energy efficiency of buildings in Ukraine can be represented as:

$$EP \leq EP_{\max}, \quad (1)$$

where  $EP$  -the estimated or actual specific heat consumption of the building;  $EP_{\max}$  - the maximum permissible value of specific heat consumption for heating the building for the heating period, kWh/m<sup>2</sup>.

$EP_{\max}$  depending on the purpose of the building, its height and temperature zones of operation. The territory of Ukraine is divided into two temperature zones (figure 3). For this research were collected indicators I climate zone, as the climatic conditions of this zone correspond to the climatic conditions of Poland. **For buildings subject to thermos-modernization, it is allowed to accept increased values of the maximum annual specific energy demand with a coefficient of 1÷1.25 to  $EP_{\max}$ .**



**Figure 3.** Map of the temperature zones of Ukraine

Normative maximum specific energy demand EP max for residential buildings with 1-3 floors, which are located in the first temperature zone is  $120 \text{ kWh/m}^2$ . Since the calculation is made for the conditions of modernization, therefore accept the value of EP max equal  $150 \text{ kWh/m}^2$ .

The degree of thermal insulation of structures characterizes the resistance of heat transfer R. Than the larger this value, the lower the heat loss due to the construction.

According to DBN define the minimum value of resistance to heat transfer of opaque surrounding structures, external walling and doors of residential building  $R_{q\min}$ . For existent building that implements thermo-modernization, application of lowering coefficient R is assumed 0.75 for opaque parts of external walls and 0.8 for other building envelopes. For reference, the index  $R_{q\min}$  changes to U (table 1).

### 3. Energy analysis on the example of an existing building.

The energy assessment was carried out for a residential building built in 1985 in Krakow. In the heated underground of a four-story building, there is a garage, a solid fuel boiler (coal, wood). For the building, calculations of energy demand for the current state and the state after thermo-modernization, were carried out.

As a result of the local inspection, structural partitions with the following structure were inventoried:

- a) external walls made of checker brick 25 cm, foam polystyrene 2.0 cm, ceramic block brick 18.8 cm walls at the ground with concrete 24 cm,
- b) PVC window joinery after thermo-modernization
- c) galvanized steel door with thermal insulation,  $U = 2.60 \text{ W / m}^2\text{K}$
- d) wooden truss, roof covered with sheet metal
- e) FERT floors, non-insulated floors

The building has gravity ventilation - the number of exchanges has been assumed  $n = 1.0 \text{ l / h}$ . The source of heat for a central heating installation from steel pipes with cast iron radiators is a solid fuel boiler. Average fuel consumption from the last five heating seasons was about 20 tons.

#### 3.1. Energy analysis on the example of an existing building

The conducted analysis for the existing state showed that the consumption of Primary Energy is very high, significantly exceeding the requirements for the reference building (Figure 4). In Polish law, there are no regulations requiring that buildings subjected to thermo-modernization meet the requirements for EP, but for the purposes of the analysis, such a comparison was made.

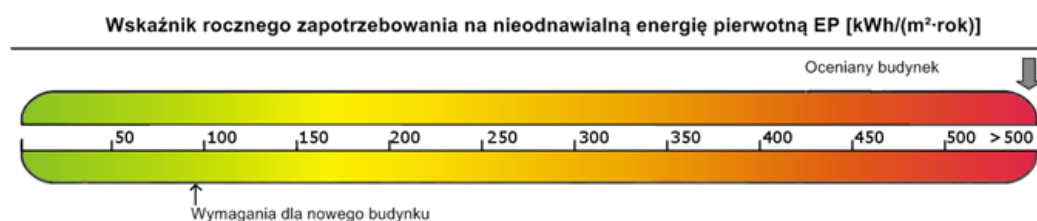


Figure 4. EP factor for the existing state

**Table 3.** WT2017 requirements for the reference building**The reference building according to WT2017**

|   |            |        |                     |
|---|------------|--------|---------------------|
| The heating area in analysed building   | $A_f$      | 211.46 | $m^2$               |
| Partial maximum value of the EP indicator for heating, ventilation and hot water preparation  | $EP_{H+W}$ | 95.00  | $kWh/(m^2 \cdot a)$ |
| The maximum value of the EP indicator defining the annual design demand of the building for non-renewable primary energy for heating, ventilation, cooling, domestic hot water preparation and lighting | $EP_{max}$ | 95.00  | $kWh/(m^2 \cdot a)$ |

**Table 4.**  $EP_{max}$  requirements according to WT2017 for the reference building**Checking the requirement for EP**

| EP $kWh/(m^2 \cdot a)$ |   | $EP_{max}$<br>$kWh/(m^2 \cdot a)$ | Comments            |
|------------------------|---|-----------------------------------|---------------------|
| 575.26                 | < | 95.00                             | Requirement not met |

**Table 5.** Summary table of heating and ventilation system efficiency in the existing state

Existing state

|   |  |         |
|---|--|---------|
| Type of energy carrier                          | Local energy production in the building - Coal |         |
| Usable energy $Q_{H,nd}$                        | 56076.71                                       | $kWh/a$ |
| Selected production variant                     | Coal boilers produced after 2000.              |         |
| Energy for auxiliary equipment $E_{el,pom,H\%}$ | 361.60   | $kWh/a$ |

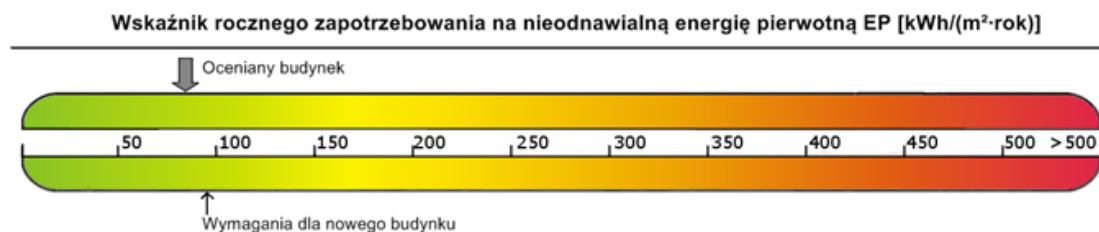
**Table 6.** Summary table of the efficiency of the hot water preparation system in the existing state

Existing state

|   |  |         |
|---|--|---------|
| Type of energy carrier                          | Local energy production in the building - Coal |         |
| Usable energy $Q_{W,nd}$                        | 5093.49  | $kWh/a$ |
| Energy for auxiliary equipment $E_{el,pom,W\%}$ | 14.27  | $kWh/a$ |

### 3.2. Checking the boundary conditions according to WT2017 for the state after thermal modernization

After the analysis of the building's lead to the level of WT2017 requirements, the following values of Primary Energy were obtained (fig)



**Figure 5.** EP factor requirement until 2017

**Table 7.** WT2017 requirements for the reference building

**Checking the requirement for EP**

| EP kWh/(m <sup>2</sup> •a) |   | EP <sub>max</sub><br>kWh/(m <sup>2</sup> •a) | Comments              |
|----------------------------|---|--|-----------------------|
| 84.48                      | < | 95.00  | Requirement fulfilled |

**Table 8.** Table summarizing the efficiency of the heating and ventilation system for the state after thermal modernization according to WT2017 and WT2021

Condition after thermo-modernization - option 1

| Type of energy carrier                                | Local energy production in the building - Biomass |       |
|---|---|-------|
| Usable energy Q <sub>H,nd</sub>                       | 42369.41  | kWh/a |
| Energy for auxiliary equipment E <sub>el,pom,H%</sub> | 361.60  | kWh/a |

Condition after thermo-modernization - option 2

| Type of energy carrier                                | Local energy production in the building - Biomass |       |
|---|---|-------|
| Usable energy Q <sub>H,nd</sub>                       | 20276.57  | kWh/a |
| Energy for auxiliary equipment E <sub>el,pom,H%</sub> | 361.60  | kWh/a |

**Table 9.** Table summarizing the efficiency of the hot water preparation system for the state after thermal modernization according to WT2017 and WT2021

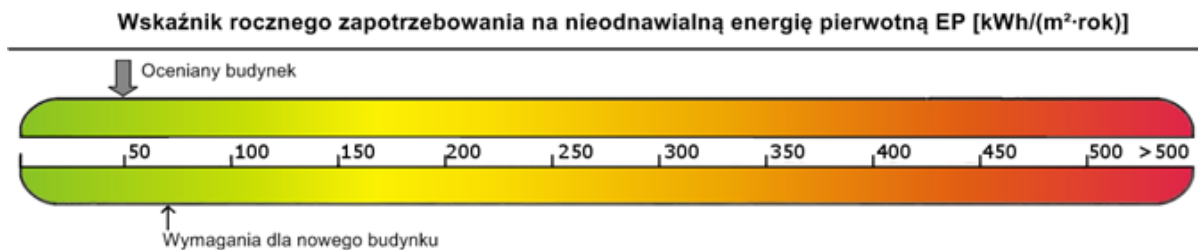
Condition after thermo-modernization - option 1 and 2

| Type of energy carrier                                | Local energy production in the building - Biomass |       |
|---|---|-------|
| Usable energy Q <sub>H,nd</sub>                       | 5093.49   | kWh/a |
| Energy for auxiliary equipment E <sub>el,pom,H%</sub> | 14.27   | kWh/a |



### 3.3. Checking the boundary conditions in accordance with WT2021 and for requirements compliant with the requirements applicable to the condition after thermal modernization

After analysing the building's lead to the level of WT2021 requirements, the following values of Primary Energy were obtained (fig)



**Figure 6.** EP factor requirement in accordance with WT2021

**Table 10.** Requirements of WT2021 for the reference building

#### Checking the requirement for EP

| EP kWh/(m <sup>2</sup> •a) |   | EP <sub>max</sub><br>kWh/(m <sup>2</sup> •a) | Comments              |
|----------------------------|---|--|-----------------------|
| 49.14                      | < | 70.00  | Requirement fulfilled |

### 3.4. Checking the boundary conditions according to DBN V.2.6-31: 2016 "Thermal insulation of buildings", for the state after thermo-modernization

**Table 11.** Requirements for the reference building in Ukraine

#### Checking the requirement for EP

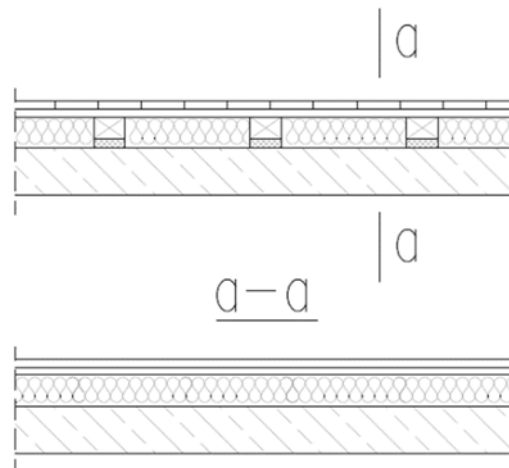
| EP kWh/(m <sup>2</sup> •a) |   | EP <sub>max</sub><br>kWh/(m <sup>2</sup> •a) | Comments              |
|----------------------------|---|--|-----------------------|
| 72,56                      | < | 150.00                                       | Requirement fulfilled |

**Table 12.** Summary table of the efficiency of the heating and ventilation system and the preparation of hot utility water for the state after thermal modernization of the guidelines in force in Ukraine

| Type of energy carrier                                | Local energy production in the building - Biomass |       |
|---|---|-------|
| Usable energy Q <sub>H,nd</sub>                       | 34920.06  | kWh/a |
| Energy for auxiliary equipment E <sub>el,pom,H%</sub> | 361.60  | kWh/a |
| Usable energy Q <sub>W,nd</sub>                       | 5093.49   | kWh/a |
| Energy for auxiliary equipment E <sub>el,pom,W%</sub> | 14.27   | kWh/a |

#### 4. Vibrational comfort

One of aspect of comfort in rooms is vibrational comfort often neglected by designers. Detailed information about requirements for vibrational comfort could be found in [8-9]. Analysed building is localized in Krakow in Wzgórza Krzesławickie district. The district was very quiet and free of transport excitation and it was called green zone of Krakow. Nowadays, when Krakow is growing up Wzgórza Krzesławickie are “construction site”. That is why although there is no need today to protect residents of analysed building against vibration, during renovation, it is recommended to install floating floor. Proposal of that kind of floor is shown in Figure 7.



**Figure 7.** Cross sections of floating floor

Cost of that kind of floating floor is about 18 EUR/m<sup>2</sup> with vibro-insulation mat used pointwise. Now this type of mat is ne needed and mineral wool is enough to protect residents of building from vibrations, so cost of floating floor only with wool is about 11 EUR/m<sup>2</sup>.

#### 5. Conclusions

The following statement should be presented:

- In the above two options, the EP value was calculated based on the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on the methodology for determining the energy performance of a building or part of a building and energy performance certificates. In the third variant, the PN-EN 13790: 2009 standard was used. To obtain the required value of the EP index according to WT 2017, it was necessary to change the type of heating installation in the building and to heat the roof, whereas in the case of WT 2021, window carpentry with a heat transfer coefficient of 0.9 W / m<sup>2</sup>K had to be replaced. In the third variant, replacement of windows and installations was assumed to obtain an EP value lower than 150 kWh / m<sup>2</sup> (value for thermos-modern buildings in Ukraine).
- By thermos-modernization of the building in question for WT 2017, we receive 24% saving of seasonal heat demand, in the case of WT 2021, savings amounted to 64%, while with thermo-modernization, according to the guidelines in Ukraine, this saving was 37% compared to the existing state.
- Level of transport vibrations in localization of analysed building is very low (local road) that is why there is no need to protect residents of that building against vibrations. Because district in which building is localized, is fashionable for Krakow residents (green zone) installing of floating floor is recommended.

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