Assessment of the Energy Characteristic of the Terrace House

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Abstract. In the article, the energy characteristics of a terraced house located in Kielce were assessed. The analyzed house was put into use in 1982. Due to the old manufacturing technology, mainly in the area of the materials used, to limit significant heat losses, it has been thermally renewed many times. The aim of the calculations was to indicate the financial benefits, in example to reduce the costs of maintaining the house and to provide its residents with the proper comfort of use of the building, also taking into account the health aspects. The analysis of the object was made in several stages. Proposed are changes reducing the demand for non-renewable primary energy Ep, using modern thermal insulation materials, joinery with low heat transfer coefficient and renewable energy sources. As a result, an energy-efficient building that meets WT 2017 was obtained. The annual demand for non-renewable primary energy EP was determined using the Certo 2015 program in educational version 1.3.3.0.

1. Introduction

Energy is a widely understood concept, extremely trendy in the last twenty years. Energy occurs everywhere and in various forms, technological and industrial development and live would not be possible without it. It obtains from two sources, which really come from the Sun - non-renewable (fossil) and renewable. Ending deposits of hard coal, oil and natural gas, as well as resulting from their use of the contamination of the environment, enforce the use of alternative energy sources in every area of life, including construction, at the design stage, the executive and utilitarian buildings residential, public, warehouse. That is why energy certification was introduced, legally approved by Directive 2002/91/WE [1] on a pan-European level, in Poland the Energy Ordinance of the Minister of Infrastructure of November 6, 2008 [2, 3, 4, 5, 6] and December 20, 2016 was added [7]. At present, each newly created building must meet not only the conditions of safety, durability, reliability [8, 9], but in the area of energy efficiency and building materials and the method of obtaining energy to everyday life. Existing buildings are subjected to thermal modernization process with the aim of improving the quality and comfort of living [10].

Rating the energy performance of the building, is an estimate of the demand for energy necessary to meet the needs associated with the use of the building or its parts. Energy consumption for heating, obtaining domestic hot water, air conditioning, ventilation and room lighting has a direct impact on the cost of home maintenance and the quality and hygiene of life of people living in it.
The paper attempts to estimate the rate of EP (annual demand for non-primary energy, which is the important parameter needed to determine the energy consumption of the house compliance with the requirements laid down by WT [11]) of a single-family terraced house located in the center of Kielce. The building was commissioned at the beginning of the 1980s, built in the technology of a large slab, i.e. at a time when energy efficiency was not important due to "cheap energy". To ensure thermal comfort and reduce maintenance costs, the facility has been thermo-modernized many times.

2. A few words about energy standards in construction

XXI century in the construction industry is the development of modern technologies in the field of construction materials, methods of preparation of individual components and entire structures, which are often called intelligent. Today, the comfort of living is the smallest expenses incurred for everyday use of the surrounding "world", that is, getting rid of unnecessary losses, but also the quality of the air we breathe. Unnecessary losses in the buildings in which we live, shown in figure 1, are mainly connected with energy consumption, as well as with devices and fuel type, suitable for heating them.

Elimination of losses takes place directly at the level of the structure by providing appropriate insulation partitions separating the interior of the building from the outside world in new and existing buildings. Examples of values of the heat transfer coefficient $U_{(\text{max})}$ are presented in table 1.

![Figure 1. Heat loss in the building [12]](image)

| No. | The type of partition and temperature in the room | Heat transfer coefficient $U_{(\text{max})}$ [W/(m²·K)] |
|-----|--------------------------------------------------|------------------------------------------------------|
|     | from 01.01.2014 | from 01.01.2017 | from 01.01.2021 |
| 1.  | External walls at $t_i \geq 16^\circ$C           | 0.25  | 0.23  | 0.20  |
| 2.  | Roofs, flat roofs and ceilings under unheated attics or over entrances, at $t_i \geq 16^\circ$C | 0.20  | 0.18  | 0.15  |
| 3.  | Floors on the ground, at $t_i \geq 16^\circ$C     | 0.30  | 0.30  | 0.30  |
| 4.  | Ceilings over unheated rooms and closed underfloor spaces, at $t_i \geq 16^\circ$C | 0.25  | 0.25  | 0.25  |
| 5.  | Ceilings over heated underground rooms and inter-story floors, at $t_i \geq 8^\circ$C | 1.00  | 1.00  | 1.00  |
Figure 2. Maximum values of the EP index for heating, ventilation and preparation of hot utility water according to WT 2014, 2017 and 2021 in a single-family building [14]

The current energy requirement by WT 2017 [11] according to EP index (figure 2) also affect the choice of energy sources for heating, ventilation and hot water. It is possible to meet their mainly involving devices using renewable energy sources, i.e.: the energy of sun, wind, water, geothermal, tidal. Keep in mind that these devices must have a high efficiency in converting energy, constantly working on what scientists and engineers [15, 16, 17].

3. Methodology of research

The assessment of the energy performance of the existing terraced house was made in accordance with WT 2017 [11] based on the EP index, i.e. the annual requirement for non-renewable primary energy to be used for the needs of the building. This ratio is determined from the formula:

\[
\text{EP} = \text{EP}_{H+W} + \Delta \text{EP}_C + \Delta \text{EP}_L \left(\frac{kWh}{m^2 \cdot \text{year}}\right)
\]

where: \(\text{EP}_{H+W}\) – partial maximum value of the EP index for the needs of central heating, ventilation and domestic hot water, \(\Delta \text{EP}_C\) – partial maximum value of the EP index for cooling, \(\Delta \text{EP}_L\) – partial maximum value of the EP index for lighting.

The low EP value is a financial saving for the home owner in the form of lower heating bills, greater thermal comfort in the premises, higher efficiency of the installation, energy-efficient lighting, building protection against overheating in the summer and cold in winter, protection of the natural environment resulting from the use of renewable energy sources and higher property value in the case of sales.

At work, the EP indicator was determined using the Certo 2015 program, educational version 1.3.3.0, meeting the requirements of the Regulation of the Minister of Infrastructure on the methodology for calculating the energy performance of a building [5] and WT 2017 [11].

4. Analyzed object, results and discussions

In the work, the analysis consisting in the determination of the EP index was a terraced house, located in the city center of Kielce, in the third zone, north-south, with an entrance from the north and a large number of windows on the south side. The building was built at the end of the 70s of the last century, it was put into use in 1982. Usable area 175.55 m\(^2\), cubic capacity 465.69 m\(^3\), foundation: clay and loam, construction of a large W70 slab, 3-storey building (basement, ground floor and first floor) with flat-ventilated roof, fully heated, gravity ventilation.

4.1. Basic data on the installations and partitions of the analyzed house

4.1.1. Condition for 1982:

- heat source for central heating and ventilation – Kielce heat and power plant,
- heat source for domestic hot water - water heated in a gas stove produced by Termet,
- woodwork: windows and external doors with a heat transfer coefficient \(U = 2.9\) [W/(m\(^2\)-K)],
- partition:
  - external wall N cellar: cement-sand plaster 0.015 m, block Siporex on cement and lime mortar 0.24 m, foamed polystyrene 0.08 m, lime-sand plaster 0.015 m, \(U = 0.345\) [W/(m\(^2\)-K)],
4.1.2. EP index for the building in the year of its commissioning. The indicator of annual demand for non-renewable primary energy necessary to meet the needs related to the use of the building was obtained from the Certo educational program 1.3.3.0 according to the methodology contained in the applicable regulations [11]. The EP index for the building in the year of its commissioning - 1982 amounted to 476.98 [kWh/(m²·year)] (figure 3).

Figure 3. EP index for the building in the year of putting it into use in 1982
4.2. Stages of thermo-modernization of the analyzed building

4.2.1. The first thermo-modernization year. In 2000, due to the lack of tightness and warping, the owner of the building exchanged windows with wooden, technologically new PVC with a low, for contemporary times, heat transfer coefficient \( U = 1.1 \text{ [W/(m}^2\cdot\text{K}]} \). According to WT 2008, the EP ratio for a normalized modernized building is \(-141.37 \text{ [W/(m}^2\cdot\text{K}]}\), and for the analyzed presented in figure 4.

![Figure 4. EP index for the building modernized in 2000](image)

4.2.2. The second thermo-modernization year 2000. Until 2001, the heat source for heating was Kielce heat and power plant, however, due to the huge transmission losses, the fees for central heating increased to 700.00 PLN for each month of the year, that is 8400.00 PLN per year. Therefore, in order to reduce costs, the owner carried out a second thermo-modernization consisting in changing the heat source for heating and domestic hot water, a single-function boiler for Viessmann's Vitopend 100 WHE gas was installed without a storage tank, the rest of the installation was unchanged. According to WT 2008, the EP ratio for a normalized modernized building is \(-141.37 \text{ [W/(m}^2\cdot\text{K}]}\), and for the analyzed shown in figure 5.

![Figure 5. EP index for the building modernized in 2001](image)

4.2.3. The third thermo-modernization year 2009. In the years 2008-2009, the analyzed building underwent a major renovation, and a comprehensive modernization was carried out:

- replacement of heat source for central heating, ventilation and domestic hot water - single-function boiler Viessmann Vitopend 100 W with closed combustion chamber and Vitocell 100 W container,
- construction and assembly of a new central heating installation, domestic hot water installation and plumbing installation,
- replacement of the garage door for a well-insulated by \( U = 1.0 \text{ [W/(m}^2\cdot\text{K}]}\) and external doors for well-insulated by \( U = 1.2 \text{ [W/(m}^2\cdot\text{K}]}\),
- replacement of windows in the staircase and basement for new PVC by \( U = 1.0 \text{ [W/(m}^2\cdot\text{K}]}\),
- elongation of the chimney, new flat roof over part of the clinker bricks - improvement of ventilation, i.e. more fresh air,
- partitions - external insulated and internal new:
  - external wall N cellar: gypsum plaster 0.015 m, block Siporex on cement and lime mortar 0.24 m, foamed polystyrene 0.08 m, lime-sand plaster 0.015 m, foamed polystyrene 0.1 m, silicate plaster 0.015 m, \( U = 0.17 \text{ [W/(m}^2\cdot\text{K}]}\),
  - external wall S and E cellar: gypsum plaster 0.015 m, reinforced concrete 0.18 m, twice an asphalt paper on a glue, foamed polystyrene 0.05 m, lime-sand plaster 0.015 m, foamed polystyrene 0.15 m, silicate plaster 0.015 m, \( U = 0.165 \text{ [W/(m}^2\cdot\text{K}]}\),
o internal supporting wall cellar: gypsum plaster 0.015 m, reinforced concrete 0.18 m, gypsum plaster 0.015 m, \( U = 2.146 \, \text{[W/(m}^2\cdot\text{K}]} \),

- internal dividing wall cellar: gypsum plaster 0.015 m, wall of cellular concrete blocks 500 0.18/0.12 m, gypsum plaster 0.015 m, \( U = 0.926 \, \text{[W/(m}^2\cdot\text{K}]} \),

- floor on the ground: terrazzo 0.01 m, concrete foundation under the floor 0.06 m, foamed polystyrene 0.12 m, polyethylene sheeting 0.0002 m, terrazzo 0.04 m, concrete foundation under the floor 0.04 m, polyethylene sheeting 0.0002 m, foamed polystyrene 0.05 m, twice an asphalt paper on a glue, lean concrete foundation 0.05 m, medium sand 0.10 m, ground under the building 0.14 m, \( U = 0.19 \, \text{[W/(m}^2\cdot\text{K}]} \),

- basement ceiling: gypsum plaster 0.015 m, ceiling from Żerań plate 0.24 m, twice an asphalt paper on a glue, polyethylene sheeting 0.0002 m, foamed polystyrene 0.05 m, concrete foundation under the floor 0.04 m, terracotta/beech parquet, \( U = 0.505/0.476 \, \text{[W/(m}^2\cdot\text{K}]} \),

- external wall N and S ground floor and first floor: gypsum plaster 0.015 m, block Siporex on cement and lime mortar 0.24 m, foamed polystyrene 0.08 m, lime-sand plaster 0.015 m, foamed polystyrene 0.1 m, silicate plaster 0.015 m, \( U = 0.17 \, \text{[W/(m}^2\cdot\text{K}]} \),

- external wall E ground floor and first floor: gypsum plaster 0.015 m, reinforced concrete 0.18 m, foamed polystyrene 0.05 m, lime-sand plaster 0.015 m, foamed polystyrene 0.1 m, \( U = 0.212 \, \text{[W/(m}^2\cdot\text{K}]} \),

- internal supporting wall ground floor and first floor: gypsum plaster 0.015 m, reinforced concrete 0.15/0.18 m, gypsum plaster 0.015 m, glaze, \( U = 2.261/2.185/2.216 \, \text{[W/(m}^2\cdot\text{K}]} \),

- internal dividing wall ground floor and first floor: glaze, gypsum plaster 0.015 m, wall made of YTONG cellular concrete blocks 0.1 m, gypsum plaster 0.015 m, glaze, \( U = 0.680/0.673 \, \text{[W/(m}^2\cdot\text{K}]} \),

- ground floor: gypsum plaster 0.015 m, ceiling from Żerań plate 0.24 m, twice an asphalt paper on a glue, polyethylene sheeting 0.0002 m, foamed polystyrene 0.05 m, concrete foundation under the floor 0.04 m, terracotta/beech parquet, \( U = 0.505/0.473 \, \text{[W/(m}^2\cdot\text{K}]} \),

- flat roof (ceiling floor): gypsum plaster 0.015 m, ceiling from Żerań plate 0.24 m, lean concrete foundation 0.015 m, twice an asphalt paper on a glue, foamed polystyrene 0.06 m, concrete foundation under the floor 0.05 m, warming with synthetic fleece 0.35 m, \( U = 0.103 \, \text{[W/(m}^2\cdot\text{K}]} \).

According to WT 2008, the EP ratio for a normative modernized building is 141.37 [kWh/(m²·year)], and for the analyzed is shown in figure 6.

**Figure 6.** EP index for the building being modernized in 2009

4.2.4. *The fourth thermos-modernization year 2014.* In 2014, the owner of the building used the co-financing the Kielce City Hall and set up photovoltaic panels using the renewable energy of the Sun for the needs of domestic hot water. According to WT 2014, the EP index for the new building is 120 [kWh/(m²·year)], and for the analyzed shown in figure 7.
4.2.5. The fifth thermo-modernization year 2016. The fifth thermost-modernization covered the replacement of windows with a new, eight-chamber, three-pane on PVC by $U = 0.7$ [W/(m²·K)]. The owner decided to replace the woodwork because of its poor condition, increased the humidity and the appearance of mold. According to WT 2014, the EP pointer for the new building is 120 [kWh/(m²·year)], and for the analyzed shown in figure 8.

4.3. Analysis results
The results of the analysis after all stages of thermo-modernization are summarized in table 2.
5. Conclusions

The results of the single-family terraced house, summarized in table 2 show the enormous benefits of the subsequent stages of thermal modernization of the building:

- the EP index decreases in the following years, since the 3rd modernization it meets the applicable WT,
- heat transfer coefficients for windows, doors and all partitions, except internal supporting walls, meet the legal requirements of WT, until 2021,
- insulation of the partitions separating the building from the external environment, in particular external walls and flat roof, provided protection of the building protecting the building against overheating in summer and cold in the winter,
- lower heating bills along with the modernization stages, but also in relation to the owner's earnings (table 2), in 2000, almost seven monthly salaries were needed to settle the heating bill, in 2009 almost two, and in 2016 not more than one,
- the use of photovoltaic panels for the purpose of domestic hot water reduces CO₂ emissions to the atmosphere.

Thermo-modernization carried out in the analyzed facility significantly improved the comfort of the building (financial benefits), its insulation, reduced the humidity level from 80% to approx. 50% in the heating season (no mold, clean air) despite high costs incurred for the renovation of the house, which so it was necessary for everyday functioning.

Another energy classification of buildings is proposed by the Association for Sustainable Development, where the indicator is the EU, i.e. the energy that needs to be used for the needs of the building without taking into account the efficiency of the heating system (table 3). The usable energy is therefore part of the primary energy.

Table 3. Energy classification of buildings according to the Association for Sustainable Development [18].

| Energy class | Type of building       | EU indicator kWh/(m²·year) |
|--------------|------------------------|---------------------------|
| A++          | zero energy            | to 10                     |
| A+           | passive                | 10-15                     |
| A            | a low energy           | 15-45                     |
| B            | energetic              | 45-80                     |
| C            | medium energy          | 80-100                    |
| D            | minimum legal (meet current WT) | 100-150                |
| E            | energy consuming       | 150-200                   |
| F            | highly energy consuming| over 250                  |

Bearing in mind the above classification, it is possible to propose to the building owner a change of the heat source for heating and domestic hot water to improve the energy of the house:

- installation of a gas condensing boiler with high efficiency up to 98% (Hs) / 109% (Hi) with a solar coverage > 50%, the Viessmann Vitodens 242F boiler was used in the calculation of the EP index. EP=85.16 [kWh/(m²·year)] (Figure 9).

Figure 9. EP index for a building with a new condensing gas boiler
installation of a heat pump using renewable geothermal energy. EP=11.64 [kWh/(m²·year)] (Figure 10).

![Figure 10. EP index for a building with a heat pump using renewable energy](image)

installation of a biomass boiler with high efficiency up to 94%, which can be combined with photovoltaic panels. EP=32.24 [kWh/(m²·year)] (Figure 11).

![Figure 11. EP index for a building with a biomass boiler](image)

The proposed improvements indicate different energy classifications of the analyzed building. The installation of a gas condensing boiler preserves the building in the medium energy building class and uses non-renewable (depleted or dependent on other energy powers) natural gas deposits. This investment financially corresponds to the installation of a biomass boiler. However, the use of a biomass boiler ensures no pollution of the environment, because it is a device using a renewable energy source. The drawback of this improvement is its serviceability, while the house is in the low energy class. The most beneficial change is the installation of a heat pump; whose final energy carrier is geothermal energy. The building becomes passive, but such modernization requires a large financial outlay (about 40 thousand zlotys, the need to use a ground pump due to the location of the object), for which return is needed 15 to 20 years, with the low price of traditional fuels.

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