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Original Research Article

EVOLUTION OF ENERGY EFFICIENCY OF BUILDINGS USING THE GUIDELINES OF THE EUROPEAN GREEN DEAL PLAN

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Abstract

In contemporary literature, there are not many analyses taking into account changing heat transfer coefficients over the years and examining and comparing the variability of insulation thickness in different thermal standards. The article presents the evolution of energy demand taking into account the requirements of the Green Deal. The analysis was carried out using two materials, showing how their thickness changed in relation to the evolving energy requirements. The research was illustrated with an example of thermal modernization for a building in specific time periods. The analysis was carried out using a numerical program, comparing warming variants for individual years using the Index of annual primary energy demand. Following the requirements contained in the EPDB directive, a comprehensive reduction of the penetration coefficients for building partitions was proposed and requirements for the mandatory use of mechanical ventilation and photovoltaics were introduced.

Keywords: energy efficiency, green deal, building insulation, heat transfer coefficient, thermal standards, energy performance

1. EVOLUTION OF THERMAL STANDARD REQUIREMENTS SINCE 1950

Regulations on the thermal protection of buildings in Poland were introduced in the 1950s. It was at this time that provisions regarding thermal insulation of building partitions first appeared in Polish standards. These regulations were motivated by the need to ensure the durability of external partitions and the comfort of use of rooms exposed to moisture accumulation on the internal surfaces of the partitions. This phenomenon was caused by the low thermal resistance of the partitions and the occurrence of

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critical humidity and even dew point temperature on the internal surfaces. This phenomenon occurred in partitions that were in contact with the external environment at low external temperatures[1-5].

When the first thermal standards began to be introduced, the main goal was to ensure minimum standards for the thermal insulation of buildings. Achieving these standards was important to reduce heat loss and lower energy consumption for heating and cooling buildings. At that time, increasing air pollution and the use of non-renewable energy sources were not yet as common as today, so the main goal was simply to save building operating costs [6,7].

However, over the years, our knowledge of climate change and the impact of greenhouse gas emissions on our planet has expanded significantly. As a result, thermal standards have had to evolve to accommodate these new challenges [8,9]. Many countries have introduced stricter energy efficiency regulations, imposing stricter requirements on insulation, ventilation, heating and cooling systems, and energy sources [10].

The energy efficiency of a building is a key aspect from the point of view of sustainable development and environmental protection. Good thermal insulation of building partitions contributes to a significant reduction in energy consumption needed to heat the building, which in turn leads to reduced emissions of greenhouse gases and other atmospheric pollutants. Therefore, in addition to the introduction of advanced insulation technologies, more and more countries around the world are introducing requirements regarding the minimum heat transfer coefficient for building envelopes [11]. Heat transfer coefficients are also important in the design of heating and cooling installations. The lower the heat transfer coefficient, the less power required to maintain the appropriate temperature in rooms, which leads to lower energy consumption and lower operating costs [12]. Therefore, when designing heating and cooling installations, the values of the heat transfer coefficient for building partitions should be taken into account and heating and cooling devices and systems should be selected in accordance with energy and ecological requirements.

As building energy efficiency requirements have evolved since the 1980s, there are several key milestones in the classification of thermal standards that reflect advances in our approach to property design and construction.

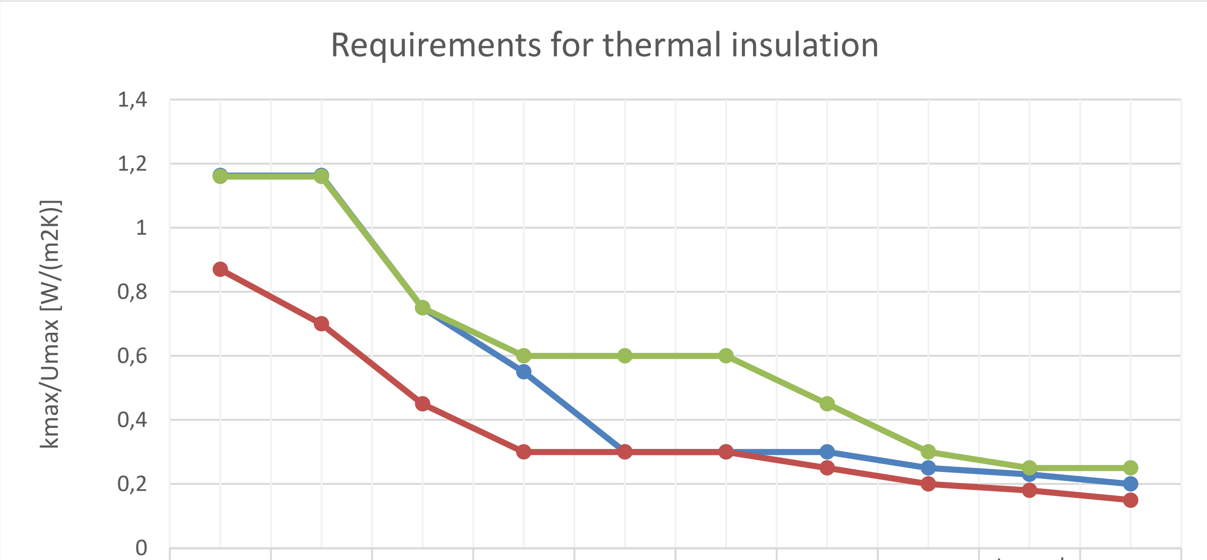
Heat transfer coefficients depend on heat losses related to the temperature difference between the interior and exterior. The lowest coefficients occur for roofs, then for walls and floors [13]. These rates have also changed significantly over recent decades as a result of the introduction of more advanced insulation technologies.

The initial regulations that appeared in the 1980s and 1990s focused primarily on defining the minimum requirements for thermal insulation of buildings. These standards determined how much heat could escape from a building and set minimum insulation requirements for roofs, walls, floors and windows. While these were steps in the right direction, these standards did not take into account many other factors that affect energy efficiency [14].

In the 1990s and early 21st century, thermal standards also began to take into account issues related to ventilation and heating systems. Heating buildings has become more efficient, resulting in lower energy consumption for heating. These regulations also promoted solutions such as ventilation heat recovery systems, which further increased energy efficiency [15].

As our awareness of climate change grew, more stringent standards emerged in the 2010s, such as "low-energy" and "zero-emissions" standards [16]. These regulations aim to minimize energy consumption in buildings and even produce energy in a sustainable manner. Zero-emission buildings use solar, wind or other renewable energy to meet their energy needs [17,18].

As the problem of climate change has become global, there has been a need to harmonize thermal standards at an international level. Organizations such as the International Sustainable Building Council (USGBC) and the International Organization for Standardization (ISO) have developed international standards and certificates that promote sustainable and energy-efficient construction around the world [19].
On the figure below [Fig.1] it is shown how requirements for thermal insulation has changed over time.



	PN-64/B-03404 1966-1975	PN-74/B-03404 1976-1982	PN-82/B-02020 1983-1991	PN-91/B-02020 1992-1997	Journal of Law no. 132 30.06.97 1998-2001	Journal of Law no. 75 12.04.02 2002-2008	Journal of Law no. 201 06.11.08 2009-2013	Journal of Law of 2013 pos. 926 2014-2016	Journal of Law of 2015 pos. 1422 2017-2020	WT-2021 2021-present
Walls	1,163	1,163	0,75	0,55	0,3	0,3	0,3	0,25	0,23	0,2
Roof	0,87	0,7	0,45	0,3	0,3	0,3	0,25	0,2	0,18	0,15
Floor	1,16	1,16	0,75	0,6	0,6	0,6	0,45	0,3	0,25	0,25

Fig. 1. A chart showing heat transfer coefficient requirements over the years

2. BUILDING ANALYSIS IN THE CONTEXT OF THE GREEN DEAL PLAN

2.1. The context of the Green Deal

The European Green Deal was published at the end of 2019 and is the EU's largest action to achieve climate neutrality. Ursula von der Leyen, shortly after taking over as President of the European Commission, presented a new European development strategy called the European Green Deal (EGD). As a result of this initiative, the European economy is to achieve climate neutrality by 2050, as well as increase the efficiency of resource use, reduce pollution levels and protect biodiversity on the continent while ensuring social justice. Unlike other energy strategies, e.g. in the Energy Union, and previous climate goals, e.g. 20-20-20, EGD is characterized by a holistic approach. According to the accompanying EGD roadmap, a legal framework and guidelines will be implemented after reviewing and adapting European legislation [20,21].

2.2. The role of the Green Deal in promoting energy efficiency in buildings

In the face of the challenges of climate change and growing energy demand, energy efficiency of buildings is becoming an extremely important element of efforts towards a sustainable future [22]. In this context, the European Union's Green Deal plays a key role in promoting and accelerating action to increase the energy efficiency of buildings [23]. By improving the energy efficiency of buildings, the Green Deal plan contributes to reducing CO_2 emissions from the construction sector, which is one of the main sources of greenhouse gas emissions [24]. The plan promotes the retrofitting of existing buildings to increase their energy efficiency through better insulation, more efficient heating and cooling systems and the use of renewable energy sources. By increasing energy efficiency, the use of fossil fuels in the heating sector will be reduced, which will contribute to improving air quality and public health [25].

The key legislative tool supporting the goals of the Green Deal is the EPDB directive. Pursuant to Directive 2010/31/EU of the European Parliament and of the Council (EU) of 19 May 2010 on the energy performance of buildings (EPBD), the improvement of the energy performance of buildings (if economically justified) is promoted to an almost zero-energy level. In accordance with the EE Energy Efficiency Directive, energy efficiency is improved through deep, comprehensive thermal modernization of the building, which allows for energy savings of over 60%.

Thermal modernization is intended to transform buildings into almost zero-energy buildings, i.e. buildings with zero net energy consumption and zero carbon dioxide emissions annually. The energy should come largely from renewable energy generated on-site or nearby, including: wind, biomass, solar energy. It was agreed that from 1 January 2019 all new buildings owned by the public sector must be nearly zero energy buildings, and by 31 December 2020 all other new buildings. The Association for Sustainable Development characterizes the building with the EU index (Use Energy Index), which should be less than or equal to 10kWh/m^2 per year and with the best energy class A++.

3. CASE STUDY

The analyzed building[Fig. 2] is a single-family, detached, one-story house with an attic and a flat roof. Building characteristics:

- Location of the building: Poznań
- Ground freezing zone: I
- Building area: 200 m^2
- Groundfloor area: 100 m^2
- Attic area: 100 m^2
- Building height: 5 m
- Roof angle: 2°
- Building length: 10 m
- Building width: 10 m

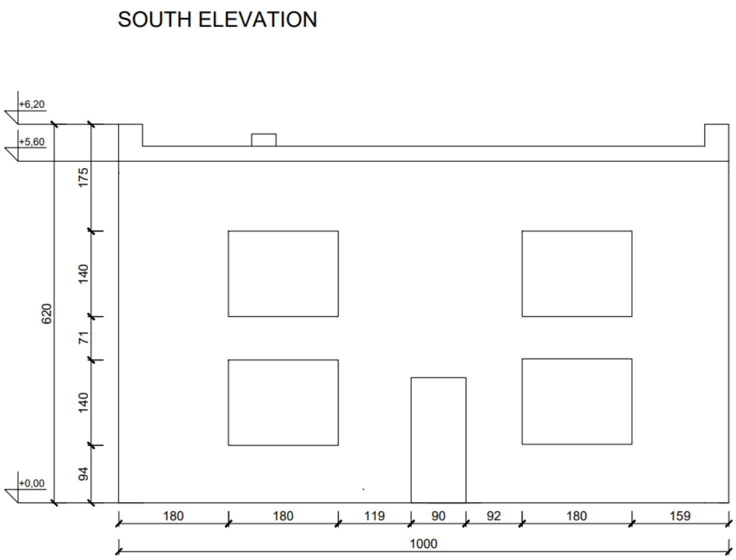


Fig. 2. South elevation of the building

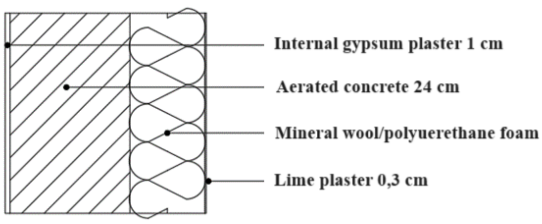


Fig. 3. Layering of the partition – external wall

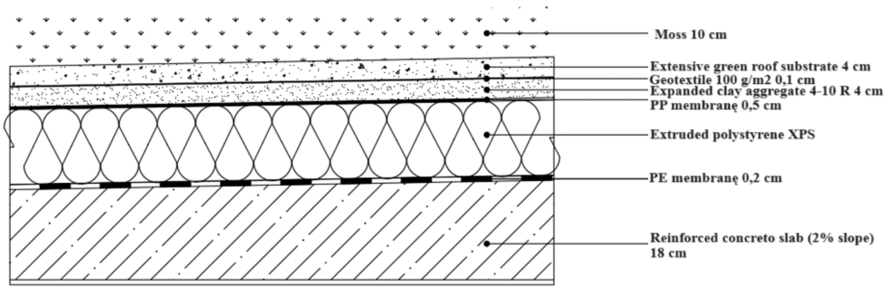


Fig. 4. Roof envelope layers – bisolar green roof system

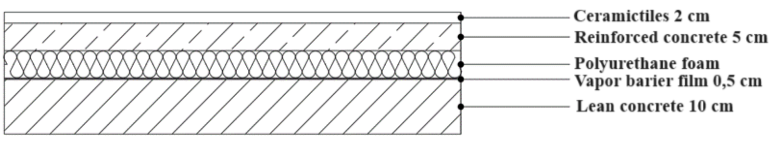


Fig. 5. Layers of the building envelope – ground floor

The analysis adopted seven different thermal standards for the building in question. These standards refer to thermal insulation requirements for buildings in Poland in various historical periods, in particular in the 1980s, 1990s and today. Below is a brief description of each of these standards [26].

- 1983 Standard - This thermal standard reflects the minimum building requirements that were in effect from 1983 to 1991. The respective thermal transmittance values for this standard are: for external walls - 0.75 W/m^2·K, roofs - 0.45 W/m^2·K, ground floors - 1.16 W/m^2·K, based on the PN-82/B-02020 norm „Thermal insulation of buildings".
- 1992 Standard - This thermal standard reflects the minimum building requirements that were in effect from 1992 to 1997. The respective thermal transmittance values for this standard are: for external walls - 0.55 W/m^2·K, roofs - 0.3 W/m^2·K, ground floors - 0.6 W/m^2·K, based on the PN-B-02020:1991 norm „Thermal Insulation of Buildings – Requirements and Calculations".
- 2008 Standard - This thermal standard reflects the minimum building requirements that were in effect from 2008 to 2013. The respective thermal transmittance values for this standard are: for external walls - 0.30 W/m^2·K, roofs - 0.25 W/m^2·K, ground floors - 0.45 W/m^2·K based on the following regulations or guidelines "Regulation of the Minister of Infrastructure of November 6, 2008, amending the regulation regarding the technical conditions that buildings and their location should meet".
- 2013 Standard - This thermal standard reflects the minimum building requirements that were in effect from 2013 to 2016. The respective thermal transmittance values for this standard are: for external walls - 0.25 W/m^2·K, roofs - 0.20 W/m^2·K, ground floors - 0.30 W/m^2·K based on the following regulations or guidelines "Regulation of the Minister of Transport, Construction, and Maritime Economy of July 5, 2013, amending the regulation regarding the technical conditions that buildings and their location should meet".
- 2017 Standard - This thermal standard reflects the minimum building re-quirements that were in effect from 2017 to 2020. The respective thermal transmittance values for this standard are: for external walls - 0.23 W/m^2·K, roofs - 0.18 W/m^2·K, ground floors - ~~0.25~~0.30W/m^2·K based on the following regulations or guidelines "Announcement of the Minister of Infrastructure and Development dated July 17, 2015, regarding the publication of the consolidated text of the Regulation of the Minister of Infrastructure on the technical conditions that buildings and their location should meet".
- Current Standard - This thermal standard reflects the minimum building requirements in effect from 2021 to the present day. The respective thermal transmittance values for this standard are: for external walls - 0.20 W/m^2·K, roof - 0.15 W/m^2·K, ground floors - ~~0.25~~0.30W/m^2·K based on the following regulations or guidelines WT-2021
- Green Deal Standard. The analysis adopted conditions implementing calculations made for mandatory guidelines for passive houses, i.e. the value of the heat transfer coefficient for external walls - 0.10 W/m^2·K, roof - 0.15 W/m^2·K, ground floor - 0.15 W /m^2·K

Two types of insulation were adopted for analysis: the most popular type of insulation (λ=0,032 [W/(m·K)]) and the more advantageous one (λ=0,025 [W/(m·K)]).

For all assumed external wall scenarios, 24 cm thick concrete blocks with two types of insulation of different thicknesses were selected for different variants. The heat transfer coefficient U was calculated using the URSA-TERMO program[27].

The basic layers of an external wall are shown below:

Table 1. List of external wall structure layers with their thickness and thermal conductivity coefficient

Wall layers (inside to outside)	Thickness [cm]	λ [W/(m·K)]
1. Internal gypsum plaster	1	0,40
2. Aerated concrete	24	0,25
3. Insulating material	variable	0,032/0,025
4. Lime plaster	0,3	0,70

For all assumed roof cases, a bisolar green roof was adopted [28]. It is a green roof integrated with a photovoltaic panel installation system, where the green roof serves as ballast. To calculate the heat transfer coefficient U, the online green roof calculator from Leca was used: https://leca.pl/dla-projektanta/kalkulatory/kalkulator-dachy-zdrowie/. A green roof with an inverted layer arrangement was designed, with extensive greenery according to the Leca system. Extruded polystyrene (XPS) was chosen as the insulating material.
The layers of the roof partition are presented below:

Table 2. List of roof structure layers with their thickness and thermal conductivity coefficient

Roof layers (from top)	Thickness [cm]	λ [W/(m·K)]
1. Extensive green roof substrate	4	1,00
2. Geotextile 100 g/m2	0,1	-
3. Expanded clay aggregate 4-10 R	4	0,16
4. PP membrane	0,5	0,16
5. Extruded polystyrene XPS	variable	0,038
6. PE membrane	0,2	0,2
7. Reinforced concrete slab (2% slope)	18	1,64

In all accepted cases, the ground floor insulated with polyurethane foam was taken into account.
The floor layers on the ground are shown below:

Table 3. List of floor structure layers along with their thickness and thermal conductivity coefficient

Floor layers (from top)	Thickness [cm]	λ [W/(m·K)]
1. Ceramictiles	2	1,30
2. Reinforced concrete	5	2,30
3. Polyurethane foam	variable	0,025
4. Vapor barier film	0,5	1,00
5.Lean concrete	10	1,05

Below is a list of the required insulation thicknesses and heat transfer coefficients for all analyzed standards.
External wall specifications:

Table 4. Specification for external walls

Standard	Required heat transfer coefficient U [W/(m^2K]	Insulating material λ=0,032 [W/(m·K)]		Insulating material λ=0,025 [W/(m·K)]	
		Thickness [cm]	Heat transfer coefficient [W/(m2K]	Thickness [cm]	Heat transfer coefficient [W/(m2K]
Standard in 1983	0,75	0,8	0,71	0,6	0,715
Standard in 1992	0,55	2,5	0,515	2	0,510
Standard in 2008	0,30	7	0,299	5,5	0,298
Standard in 2013	0,25	9,5	0,242	7,5	0,240
Standard in 2017	0,23	10,5	0,225	8,5	0,219
Standard in 2021	0,20	12,5	0,197	10	0,194
Green Deal Standard	0,10	30	0,095	23	0,097

Roof specifications:

Table 5. Specification for roof

Standard	Required heat transfer coefficient U [W/(m2K]	Extruded polystyrene XPS	
		Thickness [cm]	Heat transfer coefficient [W/(m2K]
Standard in 1983	0,45	6,5	0,442
Standard in 1992	0,30	11	0,290
Standard in 2008	0,25	13,5	0,244
Standard in 2013	0,20	17	0,199
Standard in 2017	0,18	19	0,180
Standard in 2021	0,15	23,5	0,148
Green Deal Standard	0,15	23,5	0,148

Ground floor specification:

Table 6. Specification for the floor on the ground

Standard	Required heat transfer coefficient U [W/(m2K]	Polyurethane foam	
		Thickness [cm]	Heat transfer coefficient [W/(m2K]
Standard in 1983	0,75	1,5	0,715
Standard in 1992	0,60	3,5	0,587
Standard in 2008	0,45	5	0,434
Standard in 2013	0,30	8	0,286
Standard in 2017	0,25	9,5	0,244
Standard in 2021	0,25	9,5	0,244
Green Deal Standard	0,15	15	0,147

3.1. Compatibility of energy sources with the assumptions of the Green Deal plan

Compliance of power sources with the assumptions of the European Union's Green Deal Plan is key to achieving goals related to climate neutrality and sustainable development. The Green Deal Plan places strong emphasis on increasing the share of renewable energy in the energy mix [29,30]. To be consistent with this agenda, countries and companies must increase investment in solar, wind, hydropower and other sources. Conventional energy sources, especially those based on fossil fuels, should be gradually eliminated [31,32]. Heat pumps are known for their high energy efficiency. Compared to traditional gas or oil-based heating systems, heat pumps can significantly reduce energy consumption for heating buildings [33]. To ensure optimal solution, the analysis considered the installation of an air-water heat pump connected to solar collectors. This is optimal choice. The efficiency of such a system depends on external conditions. To choose optimal heat pump, you need to estimate the building's heating power demand. Calculation of such demand is possible using the calculator available on the "Specific Heat" website: https://cieplo.app/start [34].

To compare different types of energy carriers for heating purposes, Table 7 shows the amounts of CO_2 emitted per unit of energy. The presented data show that from the point of view of greenhouse gas emissions, the worst is heating with electricity, and the best - with heat from thermal power plants and biofuels.

Table 7. CO_2 emissions from the use of various energy carriers [kg CO2/kWh fuel]

fuel	CO_2
lignite	0,40
coal	0,33
heavy fuel oil	0,28
light fuel oil	0,26
natural gas	0,20
electricity	1,10
heat from coal-fired EC	0,07
biomass	0*

The chart below, Fig. 6, shows the daily consumption of thermal energy for heating for each of the six standards in two variants, and the chart Fig. 7 shows the peak heating power (C.O.) on the "frostiest" day of winter, i.e. with an average daily outdoor temperature of -18 °C. Electric heating (air-to-water heat pump) was taken into account as the heating source in cases 1-6 and gravity ventilation was adopted. In case 7 (Green Deal Standard), biomass and mechanical ventilation were obligatory.

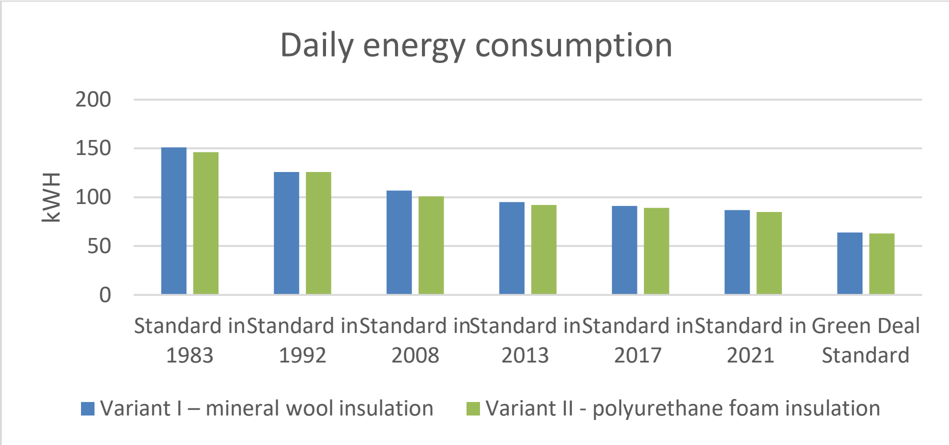


Fig. 6. Average daily consumption of thermal energy for heating - energy needed for heating

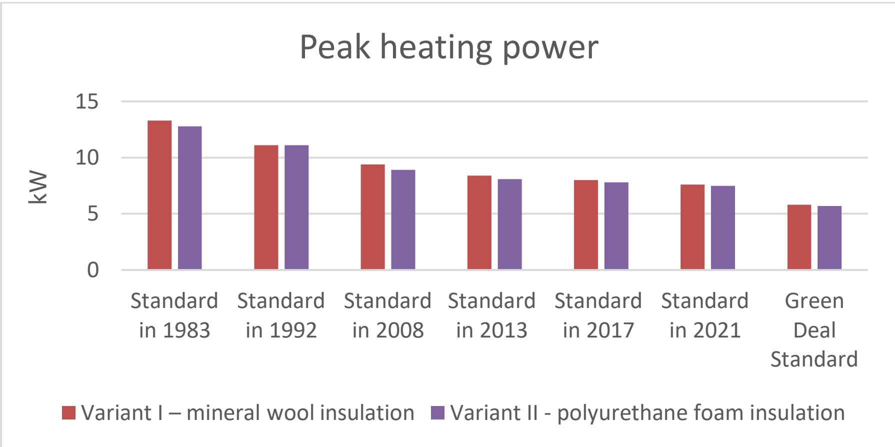


Fig. 7. Peak heating power

The chart below, Fig. 8, shows the results of needed energy consumption and production for photovoltaic panels. To calculate, the monthly energy usage has been estimated considering the presence of the heat pump.

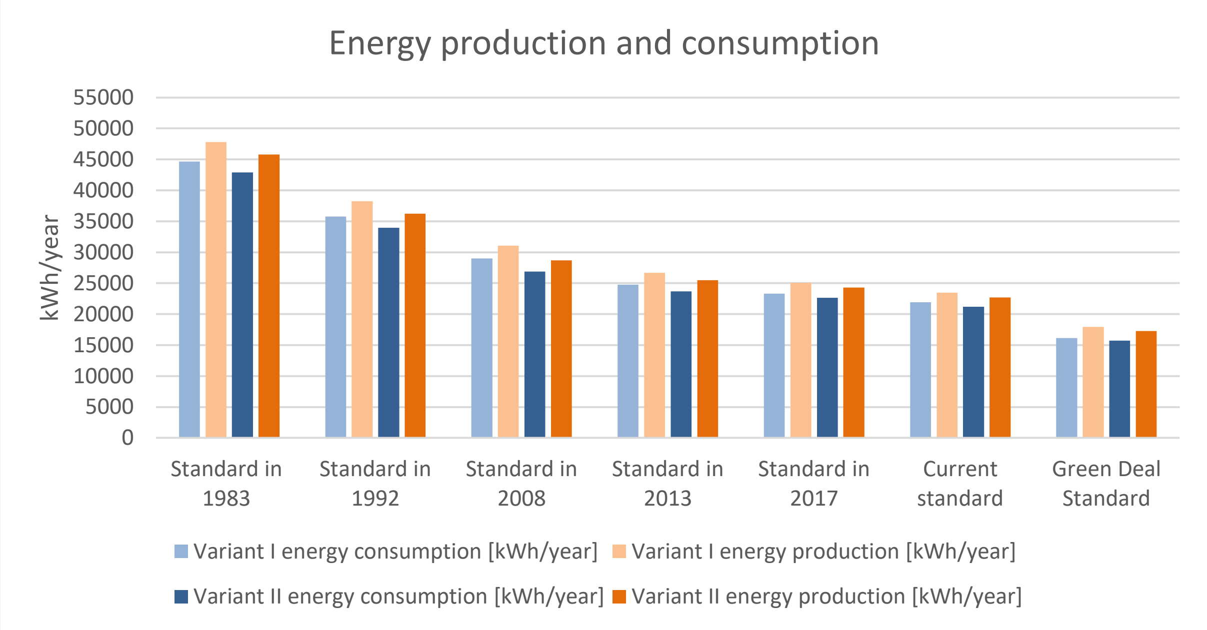


Fig. 8. Energy production and consumption

4. ANALYSIS OF ENERGY PERFORMANCE CERTIFICATES

The energy performance certificate for buildings specifies the amount of energy necessary to meet the needs related to the use of the facility [35]. This rating takes into account the useful, final and primary energy required for heating, ventilation, domestic hot water, cooling and interior lighting[40]. It provides users with information on energy consumption and carbon dioxide emissions related to the operation of a given facility [36,37].

The ArCADia-TERMOCAD program was used to carry out energy performance certificates [38]. It was assumed that all rooms were located in one temperature zone, and an air/water heat pump was used as the heating system [39].

Figure 9 presents a summary and comparison of all standards and variants of primary energy demand considered for the heat transfer coefficient required in a given year for two different insulating materials.

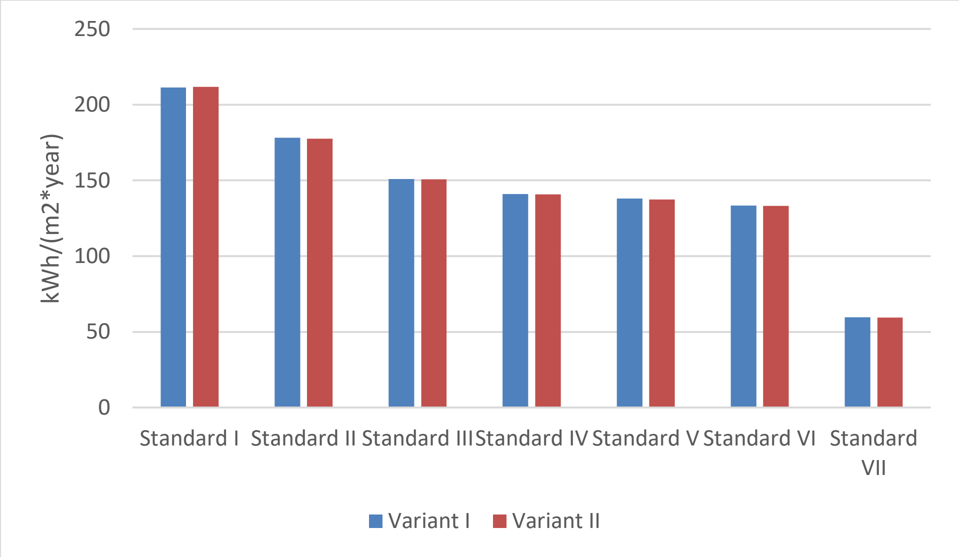


Fig. 9 Index of annual primary energy demand

5. FINAL CONCLUSION

The European Green Deal sets ambitious goals for the European Union to achieve climate neutrality by 2050. In the context of thermal modernization of buildings and thermal conductivity, the Green Deal emphasizes the need to increase energy efficiency in buildings as a key element in reducing greenhouse gas emissions. The Energy Performance of Buildings Directive (EPBD) is a key legislative tool under the Green Deal. This directive sets requirements for the energy efficiency of buildings and aims to promote cost-effective measures to improve energy efficiency. The Green Deal indirectly addresses thermal conductivity, emphasizing the importance of improving the thermal performance of building envelopes. The U-value, or thermal conductivity coefficient, is a key parameter in assessing the effectiveness of insulating materials in preventing heat loss. The Green Deal encourages the use of materials and technologies that contribute to lower U-values, which translates into reduced energy demand for heating and cooling.

The requirements regarding the heat transfer coefficient U, which have been changing dynamically since 1983, have resulted in an increase in the thickness of insulation meeting these requirements for external walls by 93.6%, for roofs by 72% and for ground floors by 84% (tables 4,5,6). The average daily consumption of thermal energy for heating, as expected - due to better insulation and lower heat transfer coefficient, decreased by 42.38% in the first insulating material and by 41.78% in the second one. The peak heating power for first insulating material decreased by 42.86% and for the second one - 41.41%.

The energy performance analysis showed that buildings in the years 1983-2013 were characterized by limited economic energy savings. For both insulating materials, the most energy-efficient variant is the 2021 standard, and the least favorable is the 1983 standard. Primary energy between the first analyzed standard in 1983 and the last one in 2021 for first insulating material decreased by 36.87%, and for the second one 37.19%.

As expected, variant VII turned out to be the most beneficial, as it adopted mandatory assumptions that were adjusted to the Green Deal plan. The demand for primary energy in Standard VII was reduced by as much as 55.25% compared to Standard VI (currently applicable conditions). Daily energy consumption decreased by 26.44% and peak heating power by 23.68%

To sum up, this article highlights the dynamic nature of the transformation of building power sources and their impact on energy efficiency and operating costs. Technological progress and ecological awareness have contributed to the increasing importance of renewable energy sources. At the same time, government regulations play a key role in driving this process. The analysis also shows that insulating material characterized by a lower thermal conductivity coefficient has better insulating abilities. Thanks to its lower thermal conductivity coefficient, it can achieve equivalent insulating effects at a lower thickness. Material with a lower thermal conductivity coefficient is also more energy efficient, which means that buildings insulated with this material may require less energy to maintain appropriate temperature conditions.

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