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Thermal modernization of building resources in line with the transformation towards a climate-neutral economy in Polish conditions

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Abstract

The search for opportunities to save and use energy efficiently should primarily focus on sectors of the economy with the highest energy consumption. One such sector is construction. Buildings built in Poland in different periods according to the introduced and successively tightened thermal protection requirements have different energy characteristics, which differ from contemporary standards and future expectations in this respect. This article presents guidelines for the energy transformation of building resources towards climate neutrality and the condition of these resources in Poland to an extent relevant for estimating the energy savings potential as a result of their thermal modernization. The economic aspect relating to the implementation of the energy policy is also presented. Over the last twenty years, there has been a nearly 37% increase in final energy consumption and a close to 34% decrease in final energy intensity of gross domestic product (GDP) recorded in Poland, which proves that energy efficiency is growing virtually without increasing energy demand. Significant potential for rationalizing energy consumption is found, as well as the need to incur high costs relating to the construction sector transformation. The problem is the lack of databases on the technical condition, age, and energy performance of various groups of buildings, which means it is difficult to determine the thermal modernization needs and the achievable effects of energy savings for the entire building stock. Some inconveniences relating to the implementation of zero-emission guidelines are also pointed out due to the fact that the Polish energy system is largely based on fossil fuels.

Introduction

To counteract negative climate changes, the European Union has undertaken measures relating to the energy transformation of the economy towards achieving zero greenhouse gas emissions by 2050 (European Commission, 2019b). Industry, energetics, and transport have the largest share in emissions (European Commission, 2022b). Compared to 1990, the decrease in emissions in the EU-27+UK countries is estimated at 34.4% (in Poland, 21% and 35% compared to the base year 1988) (EEA, 2022). The EU's share of global greenhouse gas emissions fell from 15.2% to 7.3%. In 2021, a close to 6% increase in emissions was recorded, caused by the economic recovery after the pandemic, the increase in gas prices, and the growth in the use of coal in the energy sector. However, the level of emissions in 2021 did not exceed the level of 2019. According to the IEA, in 2022, the upward trend remained at 0.9%. It is believed that for the main sectors, with the exception of buildings, emissions will remain below 2019 levels, and an analysis shows a clear, long-term trend of reducing emissions (European Commission, 2022b; IEA, 2022).

A significant increase in the pace of emission reductions would be necessary to achieve the required targets. Within individual sectors, research is conducted on methods to reduce the level of emissions (Godin, Sapinski & Dupuis, 2021; Wójcik-Jurkiewicz et al., 2021; Fabbri et al., 2022; Kuzior, Vyshnevskyi & Trushkina, 2022; Kysiak, 2022). To reduce air pollution from energetics and industry, the EU introduced the emissions trading scheme (ETS). Intensive work is underway to reduce transport emissions (Szczepanek, 2015; Szaruga, 2020; Oniszczuk-Jastrząbek, Czermański & Kowalik, 2021; Sulik-Górecka & Strojek-Filus, 2022; Gucma, Deja & Szymonowicz, 2023). Air and sea transport are included in the ETS, and, in land transport, the transition to zero-emission vehicles and the development of sustainable fuel infrastructure is preferred. The next step is to gradually increase the share of renewable sources (European Parliament, 2018b; Gorás, Vranayová & Vranay, 2021; Idzikowski & Cierlicki, 2021; Lew et al., 2021; Ahmed et al., 2022; Lis & Savchenko, 2022; Voznyak et al., 2023). In 2021, renewable energy accounts for 21.8% of the energy consumed in the EU. Work has been undertaken, including increasing the consumption of renewable hydrogen and energy from renewable marine sources such as wave energy (Chybowski & Kuźniewski, 2016; Statistics Poland, 2022). In the building sector, the focus was on thermal modernization and improvement of energy efficiency (Lis, 2019; Pales et al., 2021; Wu & Skye, 2021; Attia et al., 2022; González-Torres et al., 2022; Pawłowski, 2023b).

The transformation of the construction sector is one of the essential elements of the vision of a decarbonized EU economy. The goal by 2050 is to achieve a zero-emission standard for all new and existing buildings (D'Agostino & Mazzarella, 2019; Cabeza & Ürge-Vorsatz, 2020; Holck et al., 2021; Jankovic et al., 2022; Maduta et al., 2022; Szymańska et al., 2022). A zero-emission building is a building with high energy performance. The remaining small energy demand is to originate from renewable sources and be produced on-site by its own installation or a nearby one and supplied via a direct grid. The building should be able to dynamically adjust energy consumption to the current production profile, enabling the largest amount of generated energy to be consumed in real time. The ability to store energy is also important (Lützkendorf & Frischknecht, 2020; European Parliament, 2023; Savin & Zhelykh, 2023). The construction of buildings with zero emissions but also zero energy consumption, as well as thermal modernization of the existing building stock towards their zero-emission performance, are considered very important for progress in achieving the objectives of the EPBD Directive (European Parliament, 2010; 2018a). The scope of comprehensive thermal modernization should include both improvements in the building structure and technical infrastructure (Kizyeyev et al., 2020; Vranay & Vranayova, 2020; Pawłowski, 2021; 2023a; Savchenko et al., 2021; Zhelykh et al., 2021a; 2021b).

The main role in the energy transformation of the construction sector will involve not only improving energy efficiency in the area relating to the operation of buildings, but also minimizing energy consumption corresponding to the production of materials used in construction and their disposal or optimizing the amount of materials necessary to erect and use buildings. Measures to improve the energy performance of buildings should also consider the quality of the indoor environment, the thermal comfort of occupants, sufficiency and closed loop, or green infrastructure. The idea of a green city fits perfectly into the concept of a decarbonized economy (Ukić et al., 2021; Bohdan, 2022; Bochenek, Klemm & Woźna, 2021; Čákyová et al., 2023). Achieving climate neutrality will have a positive impact not only on the environment but also on human health.

Scope and method of analysis

The aim of this study is to estimate the potential for energy savings as a result of the thermal modernization of buildings in Polish conditions. Issues relevant to the subject of this article are presented, i.e., strategies relating to the adaptation of the construction sector to the zero-emission standard, as well as data on the state of building stock to the extent relevant to achieving adequate energy efficiency. Next, the achievable level of energy savings and the costs of implementing the zero-emission policy are analyzed. The material is prepared on the basis of selection, ordering, analysis, and synthesis of available statistical data from various databases and the author's own research, as well as the selection and calculation of values relating to the topic of the study.

Policy assumptions regarding climate neutrality and strategies towards the energy transformation of building stock

The basis for promoting the improvement of the energy performance of buildings is the Energy Performance of Buildings Directive (European

Parliament, 2010; 2018a). The adopted recast version of EPBD will increase the rate of renovation of energy-inefficient buildings to the zero-emission standard. New buildings occupied, operated, or owned by public authorities from 2026, all new buildings from 2028, buildings undergoing deep renovation from 2032 and, by the end of 2050, all existing buildings should have such a standard with some exceptions, e.g., for heritage or temporary buildings (European Parliament, 2023). In addition, 24 months after the date of entry into force of the directive, it is recommended to equip, if it is technically suitable and economically and functionally feasible, solar energy installations in all new public and new non-residential buildings, all existing public and non-residential buildings by 2027, all new residential buildings by 2029 and, by 2033, all buildings undergoing major renovation. Moreover, from the date of entry into force of the directive, it will not be possible to use fossil fuel heating systems in new buildings and buildings undergoing a major renovation, deep renovation, or renovation of the heating system; they should be gradually phased out by 2040. The directive assumes the introduction of unification of the energy class system from A to G. All non-residential buildings should achieve class E by 2027 and class D by 2030, while residential buildings should achieve class E by 2030 and class D by 2033. The recommendations of the Commission on building renovation point to actions to develop a low-emission energy system and emphasize the importance of energy efficiency and the role of the buildings sector in achieving the EU's goals in the field of energy and climate. The strategy is the starting point for accelerating the cost-effectiveness of renovating groups of buildings with a low renovation rate (European Commission, 2019a).

The European Green Deal is a strategy for the transformation of the EU economy aiming at achieving climate neutrality in 2050. The goals set for 2030 are to reduce greenhouse gas emissions by 40% and increase the share of RES to 32% and energy efficiency by 32% compared to 1990, as well as to provide clean, secure, and affordable energy while constructing and renovating buildings in a resource and energy-efficient way. To meet the increase in energy efficiency, member states should launch a wave of building renovation (European Commission, 2019b). A Renovation Wave for Europe, announced in the European Green Deal, provides an action plan with specific regulatory, financial, and supporting measures that will at least double the annual rate of energy renovation of buildings, enabling the energy transition of 35 million buildings by 2030 and the creation of 160,000 additional jobs. To achieve the 55% emissions reduction target by 2030 of Stepping up Europe's 2030 climate ambition, greenhouse gas emissions from buildings should be reduced by 60%, final energy consumption by 14%, and energy consumption for heating and cooling by 18% (European Commission, 2020).

The Fit for 55 strategy is a set of acts amending or updating the regulations and establishing new initiatives to maintain compliance of the EU policy with the set climate goals, assuming the reduction of greenhouse gas emissions by 55%, increasing the share of RES to 40% and energy efficiency by 36–39% compared to 1990. It is proposed that the construction industry should be included in the emission allowance trading system, which is to contribute to the use of ecological fuels and shorten the period of return on investment (European Commission, 2021). In the REPowerEU Plan, the Fit for 55 acts were updated to increase energy efficiency by another 13% and the share of RES to 45% by 2030 and increase energy sovereignty, while moving away from fossil fuels. The introduction of financial instruments stimulating energy saving and reducing fossil fuel consumption was also encouraged (European Commission, 2022a). According to the European Commission, the Emissions Trading System (ETS) is the basic tool for reducing greenhouse gas emissions in a cost-effective way. It is a system of caps and trade with a fixed limit of greenhouse gas emissions by the installations covered by it. Under the ceiling, companies receive, buy, or can trade emission allowances (European Commission, 2019a; 2021).

In Poland, the long-term building renovation strategy adopted by the government in 2021 defines actions to achieve high energy efficiency and low-emission buildings in the perspective of 2050. The presented renovation and support scenario is intended to help cost-effective transformation of the domestic building stock. A key aspect of the renovation is the reduction of energy consumption and emissions linked to an improvement in the standard of buildings and the health and safety of occupants. The renovation path combining a rapid increase in the scale of shallow thermal modernization with the gradual dissemination of deep thermal modernization by 2030 was indicated as the recommended one (Council of Ministers, 2022). The Act on supporting thermal modernization and repairs defines the rules for financing part of the costs of thermal modernization and renovation projects as well as low-emission projects from the Thermal Modernization and Renovation Fund (Journal of Laws, 2008). On the other hand, the energy policy of Poland until 2040 sets the framework for energy transformation. It contains guidelines on the selection of technologies for the construction of a low-emission energy system (Statistics Poland, 2021).

Basic data on the construction sector and buildings

According to the EPBD, the share of buildings in the final energy consumption in the EU is 40% (European Parliament, 2023). In Poland, the largest energy consumers are transport and buildings. The structure of final energy consumption in Poland by sector is presented in Table 1 (Statistics Poland, 2023a).

Table 1. Structure of final energy consumption in Poland by sector (Statistics Poland, 2023a)

Economy sector	2001 (%)	2011 (%)	2021 (%)
Transport	17.0	26.9	31.3
Households	35.0	31.1	29.4
Industry	28.0	23.3	23.0
Services	11.0	13.0	11.3
Agriculture	9.0	5.7	5.0

All sectors, with the exception of transport, are recording a decline in energy consumption. Final energy consumption increased in the presented period from 55.0 Mtoe in 2021 to 64.7 Mtoe in 2011 to 75.2 Mtoe in 2021, i.e., by 36.7%. On the other hand, the value of the final energy intensity of GDP (with climatic correction) clearly decreased, which better illustrates the actual efficiency of energy management (Table 2) (Statistics Poland, 2023a).

Table 2. Final intensity of GDP with climatic correction 2000–2020 (based on data from Statistics Poland, 2023a)

Area name	2000	2010	2020
	(kgoe/euro2015p)		
European Union	0.091	0.081	0.071
Poland	0.125	0.099	0.083

kgoe – a kilogram of oil equivalent, euro2015p – the value of euro expressed in the market exchange rate in 2015.

The cumulative annual rate of improvement in the final energy intensity of GDP in the years 2000–2020 amounted to 2.0% per year for Poland and 1.2% per year for the EU in the presented period. The issues of energy efficiency of buildings should be treated as a priority because it is within this sector that the achieved effects in terms of energy savings can be greatest.

According to Eurostat, in 2021, there were over 131 million buildings in the EU, the vast majority of which were residential buildings. There are over 14.5 million buildings in Poland, of which nearly 6.5 million are residential buildings. Table 3 summarizes the estimated number of buildings in particular groups and divisions belonging to the section buildings within construction structures. The data from the Council of Ministers (Council of Ministers, 2022) was taken as the basis, which was supplemented with data from Statistics Poland (Statistics Poland, 2011–2022) and, in the case of collective housing buildings, from Statistics Poland (Statistics Poland, 2023b).

The energy quality of buildings depends on the period of construction and the thermal protection requirements applicable at that time and, of course, on their current technical condition. According to Eurostat, 42% of non-residential buildings and 38% of residential buildings in the EU were built before

Table 3. Number of buildings in Poland, January 1, 2023 (based on data from Statistics Poland, 2011–2022; Statistics Poland, 2023b; Council of Ministers, 2022)

SECTION/DEPARTMENT (– group)	Number	Percentage share in DEPARTMENT	Percentage share in *SECTION*
BUILDINGS	14,569,529	–	100
RESIDENTIAL BUILDINGS	6,474,793	100	44.44
– single-family residential buildings	5,908,858	91.26	40.56
– multi-apartment buildings	561,884	8.68	3.86
– collective residence buildings	4,051	0.06	0.03
NON-RESIDENTIAL BUILDINGS	8,094,736	100	55.56
– public utility buildings	437,425	5.40	3.00
– industrial and warehouse buildings	5,149,360	63.61	35.34
– other non-residential buildings	2,507,951	30.98	17.21

Table 4. Residential buildings in Poland by year of construction, January 1, 2023 (based on data from Statistics Poland, 2011–2022; 2013; the Council of Ministers, 2022; National, 2013)

Period	Number of buildings	Percentage of buildings	Number of apartments	Percentage of apartments	Area of apartments (m^2)	Percentage of area
before 1918	404,610	6.3	1,114,761	7.8	68,276,277	6.4
1918–1944	809,220	12.5	1,390,319	9.7	93,990,719	8.7
1945–1970	1,363,480	21.1	3,018,621	21.1	182,661,209	17.0
1971–1978	654,027	10.1	2,029,115	14.2	127,685,506	11.9
1979–1988	753,794	11.6	2,116,793	14.8	160,493,587	14.9
1989–2002	670,655	10.4	1,465,472	10.2	134,779,145	12.5
2003–2007	321,471	5.0	551,118	3.8	59,409,228	5.5
2008–2011	205,076	3.2	413,338	2.9	45,221,950	4.2
2012–2020	734,379	11.3	1,337,071	9.3	144,658,464	13.5
since 2021	221,479	3.4	473,500	3.3	43,800,000	4.1
(*)	332,556	5.1	425,864	3.0	14,187,278	1.3

(*) data of buildings (apartments) for which no information on the year of construction has been established.

1970, i.e., before the widespread introduction of energy efficiency measures. When analyzing the age of buildings in Poland, one can closely examine single-family and multi-apartment residential buildings due to the lack of statistical data on other groups. Table 4 presents the estimated number of these buildings built in subsequent years. Data from the National Census of Population and Housing 2011 (Statistics Poland, 2013) were taken as the basis, supplemented with data from Statistics Poland (Statistics Poland, 2011–2022) and the Council of Ministers (Council of Ministers, 2022).

Table 5. Requirements for thermal insulation of the building envelope in the following years (own elaboration based on standards and legal acts)

Period	Requirements based on	Refer to	k_{max}, $U_{k\,max}$, U_{max}, $U_{C\,max}$ (W/(m^2K))				k_{max}, U_{max} (W/(m^2K))	
			Wall	Floor above basement	Floor under attic	Flat roof	Window	Door
1953–1958	PN-B-02405:1953	k	1.45(1.15)[1]	1.16	1.16(1.05//0.93)[2]	0.87	no requirements	no req.
1958–1965	PN-B-02405:1957	k	1.45(1.16)[1]	1.16	1.16(1.05//0.93)[2]	0.87	no requirements	no req.
1966–1975	PN-B-03404:1964	k	1.45(1.16)[1]	1.16	1.16(1.05)[1]	0.87	no requirements	no req.
1976–1982	PN-B-03404:1974	k	1.16	1.16	0.93	0.70	2.8(2.9//3.3)[3]	2.9 (1.6)[4]
1983–1991	PN-B-02020:1982	k	0.75	1.00	0.40	0.45	2.6(2.0)[5]	3.0
1991–1999	PN-B-02020:1991	k	0.55(0.65)[6]	0.60 1.0 indust.	0.30	0.30	2.6(2.0)[5] 2.6 industrial	3.0 1.4 indus.
1998–2002	OJ 1997 No. 132, item 878	k	0.30(0.5) for single family 0.45(0.55)[6]	0.60 1.0 indust.	0.30	0.30	2.6(2.0)[5] sing. fam. 2.3 public 2.6 industrial	2.6 1.4 indus.
2002–2008	OJ 2002, No. 75, item 690	U_k	0.30(0.5) for single family 0.45(0.55)[6]	0.60 1.0 indust.	0.30	0.30	2.6(2.0)[5] sing. fam. 2.3 public 2.6 industrial	2.6 1.4 indus.
2009–2013	OJ 2008 No. 201, item 1238	U	0.30	0.45 0.8 indust.	0.25	0.25	1.8(1.7)[5] sing. fam. 1.8 public 1.9(1.7)[5] industrial	2.6
2014–2016	OJ 2013, item 926	U_C	0.25	0.25	0.20	0.20	1.3	1.7
2017–2020	OJ 2013, item 926	U_C	0.23	0.25	0.18	0.18	1.1	1.5
31.12.2020	OJ 2013, item 926	U_C	0.20	0.25	0.15	0.15	0.9	1.3

U – thermal transmittance (earlier k), U_C – corrected thermal transmittance with impact of air voids and mechanical fasteners in insulation layer, U_k – thermal transmittance with linear thermal bridges; [1]I, II climatic zone (zone III–VI); [2]I, II climatic zone (zone III–V//VI); [3]space between glass 20 mm (10//5); [4]single (double); [5]I–III climatic zone (zone IV, V); [6]full wall (with window and door openings).

The requirements for thermal protection of buildings have been significantly tightened over the years. In Poland, this initially involved limiting the maximum recommended value of the thermal transmittance for individual building envelope and then, from 1988, the energy intensity of buildings, initially expressed as the demand for final energy for heating and then, from 2013, as the demand for non-renewable primary energy for heating, cooling, hot water preparation, and lighting for non-residential buildings. Table 5 presents the requirements for thermal transmittance in subsequent years based on the standards and legal acts applicable in a given period. It is important to note that, in different periods, the requirements refer to different levels of thermal transmittance. The change in 2009 of the obligation concerning the maximum value of U_k to U did not, actually, fully tighten the requirements.

Potential for energy savings resulting from thermal modernization of buildings

Low thermal insulation of partitions generates significant heat losses, which are covered by the heating system. The energy demand for space heating and hot water preparation dominates the energy performance of buildings (Table 6).

According to the adopted recast version of EPBD, approximately 75% of buildings are energy inefficient (European Parliament, 2023). In Poland, over 70% of buildings were built before 2000, i.e., before Poland's accession to the EU and the period of tightening regulations on energy efficiency. The level of energy intensity of buildings is closely related to the construction of the building and the technical solutions employed, the location and surroundings of the building, as well as its intended use. Table 7 presents the level of energy intensity of buildings erected in different periods.

Table 6. Structure of energy consumption in households by end use (own elaboration and data from Statistics Poland, 2023a)

The method of energy use	Educational buildings (%)	Industrial buildings (%)	Households (%)
Space heating	87.0	80.0	65.4
Hot water preparation	2.0	2.0	17.1
Lighting and electrical appliances	10.0	18.0	9.2
Cooking	1.0	0	8.3

There is considerable potential for energy modernization of both residential and non-residential buildings. Since the Statistic Poland or Eurostat databases lack data on the energy performance of many groups of buildings in Poland, it is difficult to fully assess the potential for energy savings relating to the thermal modernization of the buildings sector. Therefore, an attempt to estimate the achievable energy savings was carried out in a median average calculational manner for a group of single-family and multi-apartment residential buildings. Data on

Table 7. Median value of the annual demand for non-renewable primary energy factor *EP* (Council of Ministers, 2022)

Period Buildings	<1994	1994–1998	1999–2008	2009–2013	2014–2016	2017–2018	2019–2020	Requirements EP_{max} (kWh/(m²year))		
RESIDENTIAL				EP (kWh/(m²year))				EP_{H+W}	ΔEP_C	ΔEP_L
Single-family	263.7	147.9	143.5	126.3	109.1	94.0	89.3	70	5	0
Multi-apartment	258.9	139.0	110.0	142.7	97.5	87.0	84.9	65	5	0
Dormitories	219.3	357.2	284.1	ND	145.6	121.7	143.6	75	25	25(50)
Boarding houses	286.7	272.3	201.3	ND	137.2	159.2	124.9	75	25	25(50)
NON-RESIDENTIAL				EP (kWh/(m²year))				EP_{H+W}	ΔEP_C	ΔEP_L
Hotels	334.8	351.9	277.1	302.6	193.2	213.2	184.3	45	25	25(50)
Touristic	383.0	393.2	206.8	299.5	173.5	174.3	181.2	45	25	25(50)
Office	272.8	268.3	236.9	210.3	155.9	155.2	152.2	45	25	25(50)
Justice	267.2	181.7	217.3	180.5	186.6	171.4	165.9	45	25	25(50)
Administrative	229.0	234.7	217.3	192.3	180.5	158.9	136.6	45	25	25(50)
Cultural	232.2	ND	182.7	200.8	250.7	109.2	164.0	45	25	25(50)
Educational	196.4	218.4	166.4	142.6	156.9	122.6	103.2	45	25	25(50)
Physical culture	370.4	214.8	232.1	165.9	164.2	132.8	146.5	45	25	25(50)
Healthcare	341.7	442.9	257.2	387.9	374.5	358.9	320.2	190	25	25(50)

EP_{H+W} – heating and ventilation, ΔEP_C – cooling, and ΔEP_L – lighting (for operation time $t_0 < 2500$ and $t_0 \geq 2500$).

buildings erected until 2011 were obtained from Statistics Poland (Statistics Poland, 2013), i.e., demand for energy, and from Statistics Poland (Statistics Poland, 2013), i.e., the area of flats. Data for buildings erected in 2012 were obtained on the basis of own research and from Statistics Poland (Statistics Poland, 2011–2022), i.e., the area of flats. The starting point was the average value of the final energy demand indicator (*EK*). The target value for the achieved savings was the currently applicable value of the non-renewable primary energy (*EP*) index for single-family buildings (i.e., 65 kWh/(m^{2}year)) reduced by approximately 10% (which results from the value of the input factor for coal, gas, and oil, i.e., 1.1 by which *EK* is multiplied to obtain *EP*) to a value of 58 kWh/(m^{2}year). Single-family buildings account for over 90% of all analyzed buildings. After multiplying the indicator of demand for final energy by the heated area of flats (Table 4), the value of demand for final energy (*EK*) was obtained, which is presented in Table 8, after converting kWh to PJ.

Research on the scale of thermal modernization of multi-apartment buildings, performed by Statistic Poland, was carried out for 189,289 out of 561,884, i.e., for about 33%. It was found that about 40% of buildings require thermal modernization to produce technical conditions that meet modern energy standards (Statistics Poland, 2018). Extrapolating the obtained results to the entire stock of buildings, it can be concluded that nearly 225,000 buildings should undergo thermal renovation, while according to the estimates of the National Energy Conservation Agency (KAPE), it may be as much as 307,000 (Council of Ministers, 2022). Thermal modernization of the building in previous years does not preclude the need to take further actions in this regard from the perspective of 2050. However, it seems that the owners of buildings that have undergone thermal modernization are unwilling to carry out further work to raise energy standards due to their economic unprofitability. The PKO Bank report indicates that, in 2012–2016, 17% of residential buildings and 12% of non-residential buildings underwent thermal modernization while, in 2017–2021, another 15% of residential buildings were modernized (PKO SA Bank, 2021). The most popular thermal modernization measure is insulating external walls, and the most popular chosen source of heat, if possible, is the heating network (65.9%) (Council of Ministers, 2022; Pawłowski, 2023b). Windows were replaced in 36.5% of buildings. Coal boilers were installed in 5.1% of buildings, and gas boilers were changed in 23.7% of buildings. Part of the work occurred without replacing the heat source. The average annual energy consumption for central heating before thermal modernization was 1295.1 GJ and after 973.5 GJ, while EP was 225.6 and 141.5 kWh/(m^{2}year), respectively. The achieved savings in annual energy consumption amounted to 24.8% and, in the case of EP, 37.3%. Buildings erected before 1945 have the smallest share in thermal modernization of the sector, only 9%, and the largest number of energy-modified buildings originated from the years 1967–1985 (Council of Ministers, 2022).

Reducing the energy demand for buildings automatically translates into a reduction in the emission of harmful substances into the atmosphere. According to the adopted recast version of EPBD, the share of buildings in greenhouse gas emissions in the EU is 36%. The energy carrier for heating in the EU residential sector is 42% natural gas, 14% oil, and only 3% coal (European Parliament, 2023). According to Statistics Poland data, about 40% of the energy consumed in Poland originates from coal

Table 8. Potential for energy savings (own elaboration based on output data from Council of Ministers, 2022)

Period	*EP*	*EK*	Average *EK* value	Target *EK* value	*EK* value difference	Average demand	Demand difference	Reduction %
	kWh/(m^{2}year)					PJ/year	PJ/year	
before 1918	> 350	> 300	360	58	302	88.5	74.2	83.9
1918–1944	300–350	260–300	280	58	222	94.7	75.1	79.3
1945–1970	250–300	220–260	240	58	182	157.8	119.7	75.8
1971–1978	210–250	190–220	205	58	147	94.2	67.6	71.7
1979–1988	160–210	140–190	165	58	107	95.3	61.8	64.8
1989–2002	140–180	125–160	143	58	85	69.4	41.2	59.4
2003–2011	100–140	90–120	105	58	47	39.6	17.7	44.8
2012–2020	85–120	75–110	93	58	35	48.4	18.2	37.6
(*)	–	–	199	58	141	10.2	7.2	70.8

(*) data of buildings (apartments) for which no information on the year of construction has been established.

and, in the total coal used in the EU to generate energy for households, the share of Poland is almost 90%, while in the case of natural gas only about 5% and biomass 10% (Statistics Poland, 2023a). It is believed that the economically viable thermal modernization of residential buildings enables the reduction of CO_2 emissions by over 37 million tonnes per year, which is about 10% of the total annual greenhouse gas emissions in Poland, and the reduction of particulate emissions by about 89,000 tonnes per year, which accounts for about 25% of the total particulate matter emissions in Poland (Council of Ministers, 2022). In the pursuit of climate neutrality, it is important to increase the share of energy from renewable sources. The share of RES in final energy consumption in 2020 was 16.1% (EU 22.1%), i.e., the target share in RES of 15% for Poland (20% for the EU) was achieved. In 2021, a slight decrease in the share of RES was recorded to 15.62% (Statistics Poland, 2022). The share of RES in Poland in 2001 was 6.8% (4.1% in the EU), i.e., the share of RES in the last 20 years increased by 8.8% (in the EU by 18%). The share of RES indicated in REPowerEU is to amount to 45% by 2030. This goal will be quite difficult to achieve.

Costs of implementing the decarbonization policy of the construction industry

The exceptional energy efficiency potential of the building sector is widely recognized, but the transition towards climate neutrality requires significant investment. Some studies showed that optimal solutions relating to deep thermal modernization to the level of (almost) zero energy consumption and emissions would not be able to be implemented on a large scale and to the full extent for financial reasons (Ferrara, Monetti & Fabrizio, 2018; Asdrubali et al., 2019; Savchenko & Lis, 2020; PKO SA Bank, 2021). The Fit for 55 package increases the emission reduction target to 55% in 2030, which is associated with an increase in ETS prices. This has a significant impact on the costs of functioning of the economy and the level of fuel and energy prices, but, at the same time, it increases the pressure on the decarbonization of the economy, i.e., thermal modernization activities and the development of RES. Although the buildings sector is expected to be covered by ETS from 2027, buildings connected to the grid are already covered by the climate policy since heating plants with a capacity of over 20 MW are already included in the ETS. This applies to, for example, about 37% of households in Poland. It is estimated that the cost that households will have to bear under the ETS will initially amount to around €0.5 billion and will increase to €2 billion in 2030 (PKO SA Bank, 2021). The estimated costs of implementing the Fit for 55 package by 2030 for the buildings sector are €152.2 billion. The values quoted include ETS costs and investment costs. The necessary investments relating to the implementation of Fit for 55 for the entire economy will also generate savings, for example, in the form of additional revenues to the state budget from the ETS and support from EU funds in the total amount of €253.5 billion, which can be used to increase energy efficiency (PKO SA Bank, 2021).

The scenario of thermal modernization of buildings in Poland, recommended under the long-term building renovation strategy, provides for a rapid increase in the scale of shallow thermal modernization, starting from the resources with the worst energy performance, with gradual dissemination of deep thermal modernization in the perspective of 2030, and then the dissemination of a high standard of renovation in the entire sector (Council of Ministers, 2022). Shallow thermal modernization is one of the stages of thermal modernization contributing to the achievement of deep thermal modernization in the future, after which the building will meet the requirements relating to energy saving and thermal insulation and will become a building with almost zero energy consumption. The expected cost of thermal modernization investments in buildings under the recommended scenario (Council of Ministers, 2022) in the years 2021–2050 is presented in Table 9.

Table 9. Planned cost of modernization investments in 2021–2050 (own elaboration based on data from Council of Ministers, 2022)

Period	Planned cost of thermal modernization investments for buildings (mln PLN)			
	Single-family residential	Multi-apartment	Non-residential	TOTAL
2021–2030	200,329	103,692	101,583	405,604
2031–2040	264,029	138,745	134,858	537,632
2041–2050	266,766	138,888	135,167	540,821
2021–2050	731,124	381,325	371,608	**1,484,057**

Table 10. Economic indicators of thermal modernization for selected buildings (Expertise, 2020; Council of Ministers, 2022)

Type of building	Energy cost savings (PLN/year)	SPBT (years)
Single-family residential	5,964.00	23
Multi-apartment	52,072.00	15
Boarding house	258,686.00	21.1
Social welfare home	205,764.00	17.5
Primary school (2 buildings)	(1) 83,070.00 and (2) 265,321.00	(1) 61.9 and (2) 45
Nursery school (2 buildings)	(1) 44,255.00 and (2) 21,359.00	(1) 2.6 and (2) 32.6
Nursery (2 buildings)	(1) 108,783.00 and (2) 38,321.00	(1) 8.1 and (2) 34.8
Hospital	303,579.00	47
Rehabilitation and care facility	695,458.00	27.3
Economic and industrial	55,410.00	15
Warehouse	22,311.00	13

KAPE estimated cost savings and the simple payback time (SPBT), which is the most commonly used measure of investment cost effectiveness for many thermal modernization investments (Expertise, 2020; Council of Ministers, 2022). Table 10 presents data for selected buildings.

A thermal modernization investment can be considered economically effective if the cost of saving 1 GJ of final energy, assuming a fifteen-year durability period of its effects and stability of prices as at the date of its completion, is lower than the cost of 1 GJ of final energy before modernization (Council of Ministers, 2022). If the price of energy before thermal modernization is low and after it is high, despite achieving high energy and ecological efficiency, the investment may not be cost-effective. The data presented in Table 10 and our own audit analysis indicate long payback periods for many investments, which may cause serious resistance to lending to them by banks. Considering the high costs of thermal modernization works, as well as their not entirely rational increase in the recent period, an indispensable element of actions aimed at improving the energy efficiency of buildings will be the use of various financial support schemes by the state to encourage building owners to modernize them. For the investor, such activities are profitable and directly cost-effective, while economic efficiency on a national scale considers a broader context, such as social or environmental costs. It seems that due to the achievement of the desired environmental and energy goals, some investments should be performed regardless of their cost effectiveness.

Conclusions

The European Union wants to lead the fight against global warming. The transformation towards climate neutrality is one of its priorities. The developed strategies are to help achieve this goal by 2050. In the coming decades, EU countries want to jointly reduce greenhouse gas emissions to a minimum and compensate for existing emissions. Building a zero-emission economy is not only counteracting negative climate change but also an opportunity to create a sustainable economy and energy independence. EU countries generate slightly more than 7% of global greenhouse gas emissions; therefore, without implementing similar actions on other continents, the EU climate policy will not stop the increase in global emissions. However, determination in this area may be a driving force for the translocation of climate neutrality to other parts of the globe. Poland joined the implementation of the goals indicated by the European Commission and focuses on improving energy efficiency in all sectors. The priority is for it to occur in a manner safe for society and, at the same time, beneficial for the economy. Although the consumption of final energy in Poland is growing, the energy intensity of GDP is decreasing, which proves that energy efficiency is growing without increasing the demand for energy. The EU energy and climate policy assumptions are particularly important for Poland, whose energy system is largely based on fossil fuels, particularly coal.

The construction sector in Poland is one of the major consumers of energy and, at the same time, one of the key emitters of harmful substances into the atmosphere. Reducing energy consumption by thermal modernization of energy-inefficient building resources and the use of RES are directions that will contribute to achieving the zero-emission goal in the set time perspective. The distribution of the age structure and the related energy intensity of buildings indicates a significant need for thermal modernization of the building stock in Poland.

In the case of the residential buildings sector, it is economically viable to implement thermal modernization that will reduce the demand for final energy by 75% and reduce total annual greenhouse gas emissions by 10% and total dust emissions by 25%. Direct pressure on the thermal renovation of buildings is imposed by the requirements regarding energy performance, which will eliminate the most energy-intensive building resources. The method of presenting energy performance in the form of classes, as proposed in the draft EPBD directive, as well as the requirement to systematically increase them, will strengthen the role of the certificate as a tool for assessing the effectiveness of thermal modernization measures. The extension of the emission allowances trading system will be a factor that generates an increase in the costs of using buildings but, at the same time, a motivation for changes towards their decarbonization.

Thermal modernization investments require high expenditures, which may exceed the financial capabilities of investors or be ineffective for them. The pace of the thorough renovation of buildings resulting in the transformation of the existing building stock will, therefore, depend to a large extent on the involvement of the financial sector in terms of the active participation of banks and financial institutions. A long payback period for investments in thermal modernization may be a demotivator for banks to grant loans. The use of appropriate supporting tools by the state may result in investors being more willing to undertake actions desirable from the point of view of the economy. Moreover, the growth in public awareness of zero-energy and zero-emission buildings can significantly contribute to the intensification of activities that increase the decarbonization of buildings. The lack of databases on the technical condition, age, and energy performance for many categories of buildings means it is difficult to accurately determine the needs for thermal modernization and the effects of energy savings that can be achieved. The launch of the Central Register of Emissions of Buildings in 2021 is an excellent opportunity to collect information on the condition and energy consumption of buildings; unfortunately, it currently contains only a small amount of data.

Reducing the global warming index will become a new optimization criterion not only for the construction of buildings with high energy performance and renovation of existing resources to increase their energy efficiency, but also for affecting the type of materials and devices used in the building structure, which will contribute to the promotion of products with low carbon footprints. The potential market for thermal modernization is vast, which means the emergence of a high demand for construction materials and works, and the possibility of creating new jobs in the construction, materials, and equipment industries.

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