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Improving the Energy Efficiency of Public Utility Buildings in Poland through Thermomodernization and Renewable Energy Sources—A Case Study

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Abstract: Economical and efficient use of energy is promoted around the world as a model of conscious care for the environment in which we live. A mere change of habits in the use of energy can reduce its costs by 5% to 15%, and investments in energy-saving technologies can pay for themselves after just a few years. This case study shows how significant steps can be taken in saving energy in the building of public utility buildings through deep thermomodernization using renewable energy sources—compressor heat pumps and photovoltaics. The article presents a comprehensive thermomodernization of a school building made according to Polish regulations. A detailed description of the tested object is given, and the calculation procedure is described. Next, the optimal investment variant and ex post analysis are described. The implementation of these projects significantly improved the energy efficiency of the building and generated final energy savings of 80%, which will significantly reduce the school's operating costs. Thanks to the applied improvements, it was possible to save 72.30% of thermal energy in the building, which directly translates into lowering the building's operating costs. The improvement of energy efficiency indicators ranges from 66% for usable energy to almost 85% for non-renewable primary energy. Furthermore, by reducing the demand for energy used in the building by nearly 74%, we see a reduction in CO_2 emissions. The methods used were desk research and an extended case study of Poland, a country facing a number of problems related to energy prices during the energy crisis. In this article, we identify the challenges faced by Poland due to its geopolitical situation, and the solutions introduced to the difficult situation in the energy market come in the form of the thermomodernization of buildings. It was on this basis that Poland was selected as a case study.

Keywords: thermomodernization; energy efficiency; renewable energy sources; desk research; case study

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1. Introduction

The rising costs of obtaining electricity and heat are beginning to have an increasingly strong impact on the choice of technology and the profitability of investments. Environmental protection requirements and the increase in conventional energy prices encourage potential investors to use renewable energy sources. It is becoming more and more essential to use clean energy sources such as solar radiation, wind, water, or geothermal energy. In buildings undergoing thermomodernization, in order to reduce the costs of heating and heating domestic hot water, the amount of heat energy consumed should be reduced. However, this involves introducing changes in the central heating system and hot water installation, as well as improving the thermal insulation of partitions. The insulation of the building has a huge impact on reducing energy demand and only to this state should the heating system modernization plan be adjusted. The point is that the boiler power should not be too high in relation to the needs, which is associated with large losses, achieving the opposite effect to the intended one. Saving energy is key to fighting climate change and energy dependency. Energy efficiency is about using less energy to obtain the same result. It allows you to save energy and reduce the emissions of harmful compounds into the atmosphere.

The aim of the thermomodernization of the School building in Piwniczna-Zdrój was to reduce the amount of thermal energy consumed from conventional sources of electricity for the needs of the building. A deep thermomodernization was carried out in the building—external walls below and above the ground, flat roofs, old external window, and door joinery were replaced and the old oil boiler was replaced with a new heat source: compressor heat pumps with a capacity of 160 kW. The efficiency of central heating and hot water installations was increased, and the lighting installation was modernized. A photovoltaic installation with a capacity of 41.4 kW was also made.

Thanks to comprehensive thermomodernization, it was possible to save 72.30% of thermal energy in the building, which directly translates into a reduction in the operating costs of the building. The improvement of energy efficiency indicators ranges from 66% for usable energy to almost 85% for non-renewable primary energy. Furthermore, by reducing the energy demand consumed in the building by nearly 74%, we see a reduction in CO_2 emissions.

The use of renewable energy sources to power a hotel facility is a rational solution from the point of view of energy management, the impact of the installation, and the facility on the environment. The obtained energy, ecological, and economic effects lead us to believe that the thermomodernization of the building, as well as the modernization of the heat source, central heating installation, and hot water, are fully justified. The rationalization of the structure, covering the final energy demand (EK) in a building in the field of heating and ventilation through an increase in the use of RES, has a fundamental impact on the value of the EP indicator of the unit consumption of non-renewable primary energy. This is due to the share of these needs (approx. 75–80%) in the overall final energy balance in all areas of its consumption in the building. Thus, the substitution of conventional installations using fossil fuels with installations based on local RES resources in a synergistic effect improves the energy efficiency of buildings and reduces greenhouse gas emissions and other environmental pollutants.

Utility buildings, by their nature, take measures to improve their energy efficiency by reducing energy consumption, reducing carbon dioxide emissions and improving the comfort level of their users. Key benefits include a reduced operating cost, which is influenced by, among other things, the insulation of walls, roofs, windows, but also the wide-ranging modernization of heating systems. An important issue that has become increasingly important over the past few years is the reduction of carbon dioxide emissions, thus reducing global emissions of greenhouse gases. Thermomodernization contributes to reducing the carbon footprint of a utility building by reducing energy consumption and using renewable energy sources. It is also important to improve indoor comfort by minimizing temperature fluctuations and significantly improving ventilation. This is undoubtedly important for improving the well-being of users [1]. Every country in the European Union abides by legislation in accordance with European Union directives that regulate and standardize the requirements for the thermomodernization of utility buildings to meet certain energy efficiency requirements, as well as national programmes that financially support the process of thermomodernization. In summarizing, thermomodernization of utility buildings is important for a sustainable future and can bring significant benefits to building managers and users, but most importantly to the environment.

The energy audit was carried out in accordance with the Regulation of the Minister of Development of 29 April 2020 [2] in order to carry out the energy balance of the school building. The audit includes the performance of a full energy balance of the facility, equipment, and installations, and the project aimed at improving energy efficiency. The preparation of a detailed energy balance, together with the school's energy performance, made it possible to define and propose modernizations which, when completed, will bring the greatest improvement in energy efficiency along with the possibility of assessing the level of energy savings, which, in turn, will translate directly into the operating costs of maintaining the school's thermal comfort, along with the implementation of renewable energy sources. Energy auditing is not only related to thermomodernization or renovation; an energy audit is an assessment of the existing state of energy use in a given facility, and it determines the possibilities and measures for its improvement. It also includes an economic and energy analysis of improvements in the building along with the selection of the optimal scope of modernization works. Therefore, the audit is the basis for the correct decision to undertake measures to improve the energy efficiency of the facility. It is also an analysis and assessment of the current state of energy acquisition and its use in the tested facility, as well as an indication of ways to improve the current state. The analysis of the impact of individual modernizations was carried out with the goal of primarily improving the energy efficiency of the building by reducing heat losses with the use of thermomodernization, but it also considered the economic and ecological consequences of the proposed solutions.

The main purpose of the article is to present, through thermomodernization with the use of renewable energy sources, both the means and effects of energy saving in public buildings in Poland. The practical solutions presented were embedded in the theoretical framework.

2. Literature Review

Energy efficiency can be defined in a variety of ways [3,4] depending on a specific research need, scientific discipline [5–7], research context, etc. [8,9]. The literature on the subject offers broader or narrower interpretations of this conceptual category. In general terms, energy efficiency can be defined as the relationship between energy gained and energy supplied through the prism of benefits gained relative to energy consumed [10]. In more specific terms, following the principle of economic rationality [11], it can be indicated that energy efficiency consists in delivering more outputs and services using the same energy input, or delivering the same outputs with less energy input.

Thus, energy efficiency usually means using less energy to perform the same task by eliminating energy waste [12]. It helps to reduce greenhouse gas emissions, the demand for energy imports, and dependence on fossil fuel suppliers. It reduces individual household energy bills and economy-wide costs [13]. The higher the energy efficiency (achieved for example through eco-innovations, technical, organizational, institutional, and structural changes [14], sustainable and responsible management of resources [15]), the greater the energy savings and, consequently, the lower the greenhouse gas and pollutant emissions.

In the literature, one can also find a number of related (often closely synonymous) terms and whole phrases referring to this conceptual category; for example: "energy efficiency policy" [16], "energy conservation/saving" [17], "reduction of energy consumption", "energy efficiency resources", "efficient/sustainable use of resources", "rational use of energy/energy resources" [18], "reverse energy consumption", "effective useful life", „energy management" [19], "ratio of useful outputs to physical energy inputs", energy conservation [20]", "choice of lower energy consumption", "reduction of energy intensity of industrial processes" [21], "reverse energy consumption", "effective useful life", etc. [22–24].

Measures to reduce energy losses and thus to improve energy efficiency bring about significant benefits in terms of not only saving energy and combating climate change, but also improved human health and new job creation. This is why it is important to take various measures in this area, including solutions such as the thermal upgrading of buildings and the use of renewable energy sources, as discussed in this article.

Thermal upgrading is one of the very important measures aimed at reducing the consumption of primary energy (i.e., energy embodied in fuels and carriers) needed to satisfy demand for final energy. It can consist in the renovation of an entire building or its part, and its scope depends very much on the needs and the capital of the project owner. It is worth remembering that the vast majority of existing buildings were constructed before the introduction of modern formal energy performance requirements. Consequently, such buildings require an upgrade of their technical features aimed at reducing energy demand. Nowadays, the term thermal upgrading is mostly associated with thorough energy retrofitting; this is because it is necessary to undertake a series of measures that cover a much broader scope than simple construction work related to insulating building envelopes, walls and roofs, or improving the thermal characteristics of window joinery and glazing. Such work must also include the installation of energy management systems, the modernization/replacement of HVAC systems (responsible for the efficient exchange of indoor air and thus regulating temperature and humidity levels), the modernization/replacement of obsolete heating and cooling sources with high-efficiency systems utilizing renewable energy sources, and the use of "nature-based solutions" such as green walls [21,25].

Thermal upgrading measures lead to reductions in heat loss and energy use costs, as well as improvements in building operating conditions [26]. It is the heating and cooling of buildings, which account for 40% of the EU's total energy consumption (of which about 75% is energy used inefficiently), that are currently the targets of modernization efforts [27].

There are computer programmes on the market that significantly accelerate the performance of thermal calculations of buildings along with the calculations of the energy performance of buildings; therefore, it remains to choose the right application from the range of products offered by IT companies. In Poland, the main programmes that meet the requirements of current legislation are as follows: Audytor OZC; BuildDesk Energy; Certo; and Arcadia TermoCAD. The Audytor OZC allows you to perform thermal calculations of buildings in accordance with applicable regulations, as well as freeing designers from the need to thoroughly study often complicated and unclear regulations. BuildDesk Energy Certificate Professional is software for analyzing the energy performance of buildings and preparing energy performance certificates, as well as the designed energy performance of the building. The Certo programme, offered by the Lower Silesian Energy and Environment Agency from Wrocław, is intended for the preparation of energy performance certificates and the energy performance of buildings and residential premises, non-residential buildings (e.g., public utility buildings, schools, hospitals, offices), parts of buildings constituting an independent technical and functional whole, production buildings, halls, freezers, and commercial buildings. ArCADia-TERMOCAD is a programme designed to draw up energy performance certificates required for lease and sale transactions of buildings or premises, and to calculate the demand for heat in rooms. It can also perform energy renovation and energy efficiency audits, e.g., for the purpose of receiving a modernization bonus. Moreover, it is used for certified BREEAM calculations.

In pursuit of energy efficiency improvements based on thermal upgrading, a number of initiatives and activities are being undertaken. ZEBRA2020 (Nearly Zero-Energy Building Strategy 2020) can be mentioned as an example of such projects. It focuses on monitoring the transition of the market to nearly Zero Energy Buildings (nZEBs) with the aim of developing recommendations and strategies for the construction industry and policy makers to accelerate the introduction of the nZEBs idea to the market [28].

Another extremely important factor influencing the improvement of energy efficiency is the use of renewable energy sources. Renewable energy is the use of solar, geothermal, hydro, ocean, wind, and biomass energy to provide electricity and heat to end users. It is also the use of biomass sources to provide fuels for various activities such as transport, telecommunication, cooking, etc. [29]. When analyzing the possibilities of replacing energy sources with renewables, it is worth bearing in mind their most important features: the possibility of obtaining "free" energy in the long term and the significant reduction of greenhouse gas emissions due to the lower consumption of fossil fuels. Growing public awareness of the beneficial environmental impact of renewable energy systems and financial support for the installation of new systems based on RESs mean that renewable energy generation is becoming increasingly popular in many parts of the world. The increasing share of renewable energy in energy systems translates into reduced consumption of the aforementioned primary energy, which, in turn, leads to reduced exploitation of fossil fuel resources [30]. There is a high correlation between fossil fuel consumption and environmental pollution, which constitutes one of the important management issues for energy-intensive enterprises [31]. Research results show that renewable energy sources have the potential to reduce energy costs by 10 to 26% and carbon dioxide emissions by 5 to 13% compared to fossil energy sources [32,33]. In this context, it is worth mentioning that many governments and international organisations (mainly in the US and EU) have developed a number of specific regulations aimed at improving the energy efficiency of buildings and reducing the environmental impact of excessive energy consumption. This allows for the promotion of solutions that involve the widespread use of renewable energy sources [34]. In this regard, the aforementioned Zero-Energy Building programme has become an important point of reference for planned measures in this field [35]. The EU Renewable Energy Directive has also recently been strengthened. The EU's binding renewable energy share target for 2030 has been raised to a minimum of 42.5%, compared to the current target of 32% [36]. An example of a measure developed outside Europe is the ECLAC initiative aimed at strengthening the capacity of policy makers and technical experts in the Caribbean region to access and use new concepts, strategies, and mechanisms relating to energy efficiency and renewable energy [37].

In view of the complexity and multifaceted nature of the relationships among energy efficiency improvements, thermal upgrading of buildings, and the use of renewable energy sources, the theoretical section is limited to indicating what the authors consider to be the most important themes relevant to the issues addressed in the article.

3. Review of the State Policy

Energy efficiency is the degree to which a building is prepared to provide thermal comfort during use with the lowest possible energy consumption for heating or cooling [38]. According to the Energy Efficiency Law of 20 May 2016 (implementing the Directive of the European Parliament and of the Council of 25 October 2012, as amended by the Law of 20 April 2021), it is the ratio of the achieved magnitude of the utility effect of a given object, technical device, or installation, under typical conditions of its use or operation, to the amount of energy consumed by that object, device, or installation [39–41].

The fundamental of the EU's energy efficiency policy was the Directive of 2012 (2012/27/EU), which established a set of binding measures to help the EU achieve its goal of improving energy efficiency by 20% by 2020. It also introduced energy savings targets and a number of energy efficiency guidelines, including energy-efficient renovations, mandatory energy certificates for buildings, minimum energy efficiency standards for various products, energy efficiency labels, and smart meters. In December 2018, the revised directive (2018/2002/EU) increased the EU's overall energy efficiency target for 2030 to at least 32.5% (from 2007 forecasts) [42].

Currently, the basic EU document that regulates energy efficiency issues (among other issues) and enables the member states of the community to achieve energy neutrality is the Green Deal strategy of December 2019. Its most important assumption is the intention to achieve climate neutrality by 2050, i.e., the transition to clean energy and to achieve zero gas emissions net greenhouse. This goal is to be achieved, i.a., by [43] the following:

- Ensuring affordable and secure energy supplies in the EU;
- Creating an integrated, interconnected, and digital EU energy market;
- Giving priority to energy efficiency, improving the energy performance of buildings, and developing an energy sector based mainly on renewable sources (RES).

In 2021, the European Commission suggested a revision of the existing directive, setting an ambitious target for increasing energy efficiency. It stipulated that between 2021 and 2030, each EU member state would develop a 10-year integrated national energy and climate plan outlining how it intends to achieve its 2030 energy efficiency targets.

The Energy Performance of Buildings Directive (EU/2018/844) introduced mandatory long-term guidelines to promote the renovation of the country's construction stock, both public and private, to ensure a highly energy-efficient and low-carbon building stock by 2050 [44]. It accelerated the transformation of existing buildings into near-zero energy buildings by 2050. The 2022 edition includes another update, following the publication of the "Fit for 55" climate regulation package, which enshrines the EU's mandatory climate target of reducing greenhouse gas emissions by at least 55% by 2030. It includes 13 pieces of legislation, leading to a green transformation through the use of new initiatives, amending key regulations and legislation relating to European Green Deal issues. The documents included in the package focus on reducing greenhouse gas emissions, promoting the use of renewable energy, and increasing the energy efficiency of EU countries [13,45].

According to EU estimates, buildings are the largest individual energy consumer in Europe. They currently account for around 40% of the EU's total energy consumption and 36% of greenhouse gas emissions. Around 35% of buildings in the EU are over 50 years old, and almost 75% are energy inefficient. Therefore, it is a very important aspect of EU policy to support the renovation of the residential and non-residential building stock, both public and private, to ensure a highly energy efficient and low carbon building stock by 2050 (EU/2018/844) [13,46]. In October 2020, the Commission published the Renovation Wave Strategy (COM/2020/0662), whose purpose was to double the annual energy renovation rate over the next ten years. In July 2021, another revised Directive on the Energy Performance of Buildings (COM/2021/802) was implemented, where the renovation rate was increased, in particular for the worst-performing buildings [2]. On 14 March 2023, the European Parliament adopted the proposal for a new directive on the energy efficiency of buildings (EPBD—Energy Performance of Buildings Directive). Its main goals are to significantly reduce greenhouse gas emissions and energy consumption in the EU construction sector by 2030 and to make it climate-neutral by 2050. The timeline of changes provided for in the directive is as follows [47]:

- From 2026, all new buildings occupied, operated, or owned by public authorities should be zero-emission;
- From 2028, all new private buildings should be zero-emission (should be equipped with solar technologies);
- From 2032, thoroughly renovated residential buildings should be zero-emission;
- From 2027, non-residential and public buildings must achieve energy class E, and from 2030 class D;
- From 2030, residential buildings will have to achieve at least energy class E, and from 2033 energy class D.

An excellent way to increase energy efficiency is to use renewable, non-fossil energy sources. In 2020, RES energy accounted for only 17.4% of total energy used in the EU. Oil and petroleum products were the largest source of energy at 34.9%, followed by natural gas at 23.7%. Renewable energy sources not only benefit the climate, but also result in lower costs for the use of electricity and heat. They are seen as a huge opportunity and source of benefits for overcoming the development crisis (especially the aspects of economic, social, and environmental disorder) [48] and the current energy crisis. RES, therefore, have become an integral part of international climate and energy policy, being one of the pillars of the implementation of the European Green Deal. Examples of RES include wind turbines, solar panels, photovoltaic panels, biomass, heat boilers, or thermal power generation. They are an excellent alternative to fossil fuels, contributing to the reduction of greenhouse gas emissions and the diversification of energy sources, as well as reducing dependence on volatile fossil fuel markets, especially oil and gas markets [49].

The energy crisis related to the war in Ukraine has further increased the need for energy conservation. It has intensified political discussions on the diversification of sources of energy supplies to EU countries, as well as pressure to modify the structure of the energy balance [50]. In March 2022, in the wake of the war in Ukraine and an attempt to become independent of gas supplies from Russia, the REPowerEU programme (COM/2022/0230) was introduced, which proposed another revision of energy efficiency targets. This is aimed at accelerating the uptake of renewable gas and replacing it with other energy carriers, also phasing out Russian fossil fuel imports by reducing energy consumption by at least 13% in 2030 as measured against 2007 projections [13,43,46]. This creates opportunities to modernize and expand energy infrastructure to diversify energy sources and enter into new contracts with new suppliers [50]. It is also expected to accelerate Europe's transition to clean, renewable energy not so much because of the conflict in Ukraine, but also because of the need to implement the European Green Deal.

4. Use of External Funding to Improve the Energy Efficiency of Public Buildings

The aim of external funding from, for example, national or EU sources is to create the conditions for sustainable development [51–53], taking into account aspects of a modern energy sector, and ensuring energy security for all residents while respecting environmental protection principles. The main objective of the government programme to support renovation and retrofitting of buildings financed from the state budget is to improve the technical condition of existing properties, with particular emphasis on their thermal upgrading. There are a few special purpose programmes to help promote and at the same time to co-finance the implementation of energy saving measures, for example:

- The Thermal Upgrading and Renovation Fund;
- The Infrastructure and Environment Operational Programme;
- The Regional Operational Programme;
- The Clean Air Programme;
- The STOP SMOG Programme.

The Thermal Upgrading and Renovation Fund operates under the Act on support for thermal upgrading and renovation as well as the central register of building emissions of 21 November 2008 [54]. This Act aims to regulate the financing of part of the costs of thermal upgrading and renovation projects, low-carbon projects, the construction or modernization of renewable energy source systems, and the operation of the central building emissions register. Within the scope of the financial support provided by the programme, project owners can obtain funds from the thermal upgrading bonus. The thermal upgrading bonus is a subsidy for, among other things, public buildings owned by local government units and used by them for the performance of their public tasks. The bonus can be granted to entities that have undertaken thermal upgrading projects and constitutes repayment of a loan taken out for this purpose. The amount of the bonus is 26% of the total cost of a thermal upgrading project.

Concerning the Infrastructure and Environment Operational Programme [55]—whose objective stems from one of the three priorities of the Europe 2020 Strategy [56], namely, sustainable growth understood as supporting a more resource-efficient, environment-friendly, and competitive economy, environmental objectives, as well as economic, social, and territorial cohesion—the programme aims to subsidize a low-carbon economy, where the most cost-effective way to reduce emissions is to use existing energy resources efficiently. In the case of Poland, the areas with the greatest potential for energy efficiency improvements are public and residential buildings. Under the programme, co-financing will be provided for multi-family residential buildings and public buildings (i.e., public buildings subject to energy upgrading obligations under Article 5 Clause 1 of Directive 2012/27/EU [57] on energy efficiency). The role of EU funds should be to promote energy efficiency through the implementation of the most energy-efficient technologies. One of the directions of such activities could include thorough energy modernization of buildings understood as their comprehensive thermal upgrading, which means projects aimed at improving the energy efficiency of a public building and reducing its annual demand for usable energy, final energy, and non-renewable primary energy.

The Regional Operational Programme [58] is financed by the European Regional Development Fund (ERDF) and the European Social Fund (ESF). Classified as a less developed region, the Małopolskie Province is an active programme participant. The financial allocation of the Małopolskie Province Regional Operational Programme for the years 2014–2020 was EUR 2,924,481,149, including an ERDF allocation of EUR 2,071,582,510 (70.84%), an ESF allocation of EUR 806,633,462 (27.85%), and EUR 46,265,177 from the REACT-EU instrument. The Regional Operational Programme is divided into 16 priority axes. This article focuses on axis 4 called regional energy policy. Under this priority axis, support will be provided to energy efficiency improvement projects with significant potential in terms of not only reducing CO_2 emissions, but also increasing the competitiveness of the economy. It should also be emphasized that support for a low-carbon economy takes place on many levels and with the involvement of various sectors. Energy efficiency improvement projects in the sector of public and residential buildings are implemented in line with the adopted energy and climate package, which aims to reduce energy consumption by 20%. The areas with the greatest potential include public buildings. Thorough energy modernization of public buildings will consist of their insulation, the replacement of windows and external doors, the use of energy-efficient lighting bulbs, and the reconstruction of heating systems (along with the replacement of a heat source, the connection to a new heat source, the modernization of a service connection, and the connection to a district heating network). A prerequisite for the implementation of such projects will be the performance of energy audits. Beneficiaries of the programme may be local government units. The budget for the implementation of thermal upgrading measures is EUR 57,467,094.

The Clean Air Programme [59,60] is addressed to owners and co-owners of single-family houses, or separate residential premises in single-family buildings with independent land and mortgage registers. Grants for thermal upgrading and replacement of heat sources: PLN 66,000 (approx. EUR 14,000) for the basic co-financing level; PLN 99,000 (approx. EUR 21,000) for the higher co-financing level; or PLN 135,000 (approx. EUR 28,600) for the highest co-financing level. The programme aims to dramatically change air quality and reduce greenhouse gas emissions by replacing heat sources and improving energy efficiency of residential buildings. The tool facilitating the achievement of these objectives is funds provided to beneficiaries eligible for the basic, higher, or highest level of co-financing. The programme was launched in 2018 and is to continue until 2029. The amount of co-financing in the case of a grant for partial repayment of the capital of a credit is determined with reference to the eligible costs of a particular project factually incurred by the project owner using their own funds and credits, with the proviso that the amount of the grant must be lower than the capital of the credit used for the eligible costs of the project.

The STOP SMOG programme [61] aims to eliminate or replace heat sources with low-emission ones and to finance thermal upgrading projects in buildings inhabited by people suffering from energy poverty. Applications for funding under this programme can be submitted by communes or districts. The maximum level of co-financing is 70% of eligible costs. At the time of its launch, the Thermal Upgrading and Renovation Fund offered its future beneficiaries PLN 142,087,300 (approx. EUR 30,103,242). Projects financed from this fund are executed on the basis of an agreement entered into between a commune and the National Fund for Environmental Protection and Water Management. Cost eligibility is determined in accordance with the applicable catalogue of costs [8]. The legal basis for the STOP SMOG Programme is the Act on support for thermal upgrading and renovation as well as the central register of building emissions [62].

5. Case Study

The analyzed case study shows the impact of comprehensive thermomodernization on the energy efficiency indicators of the school building in Piwniczna-Zdrój, which translates directly into energy savings and reduced operating costs of the building.

Energy savings are generated through thermomodernization, i.e., greater use of renewable energy sources (RES). Special requirements are imposed on investors by the Act on RES, energy performance, and energy efficiency. These requirements are also included in the regulation on the technical conditions to be met by buildings and their location, which, from 2021, sets out the requirements for buildings with nearly zero energy consumption [63–65]. The requirements and recommendations for new buildings contained in the draft amendment to the EPBD [63] concern not only the lack of emissions at the location of the building, but also the following:

- High intelligent building readiness index (SRI);
- High share of renewable energy;
- Higher level of self-consumption of energy;
- Improvement of air quality through the use of mechanical ventilation with heat recovery;
- Low operating costs.

For the construction sector to become climate-neutral by 2050, all new buildings should be zero-carbon by 2028. Existing residential buildings would have to be rated at least E for their energy performance by 2030 and D by 2033 on a scale from A to G, where G corresponds to the 15% worst energy performing buildings in a Member State's national stock. Non-residential and public buildings would have to reach the same level by 2027 and 2030, respectively. According to the European Commission, buildings in the EU are responsible for 40% of our energy consumption and 36% of greenhouse gas emissions. On 15 December 2021, the European Commission adopted a legislative proposal to amend the Energy Performance of Buildings Directive (EPBD) as part of the so-called "Ready for 55" package. The new European climate law (July 2021) enshrined both the 2030 and 2050 targets in binding European law [63–65].

5.1. The Analyzed Building

The considered building is located in Piwniczna-Zdrój. It is a school building. The nearest weather station for which long-term observations and a typical meteorological year are available is located in Zakopane, 100 km south-east of Piwniczna-Zdrój (Figure 1). The average annual outdoor temperature in the period 1971–2000 was 6.9 °C, and the design outdoor temperature for this climate zone is −22 °C [54,64].

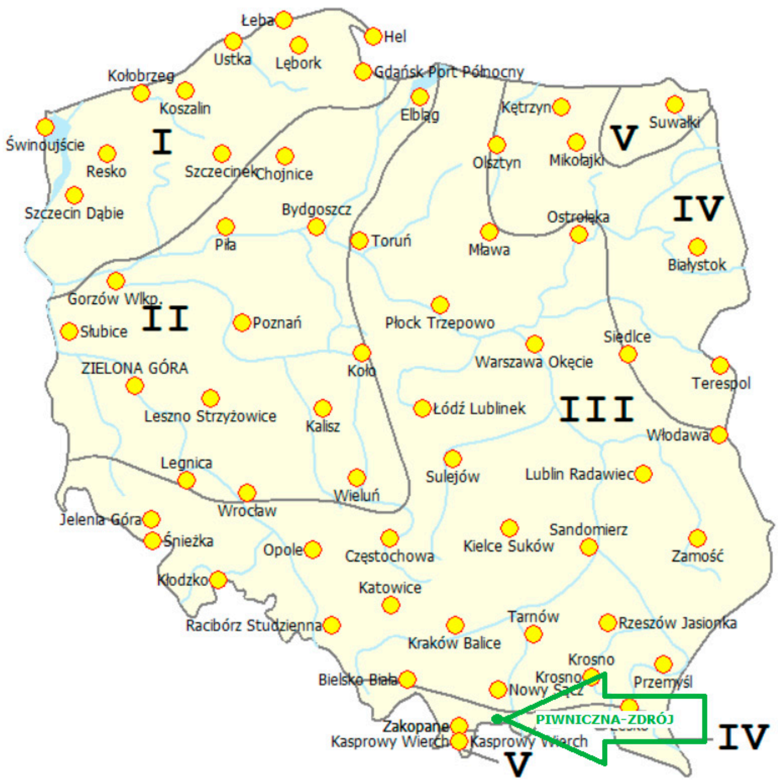


Figure 1. Polish climatic zones according to PN-EN 12831 and the location of the school in Piwniczna-Zdrój [54,64].

According to the PN-EN 12831 standard, Piwniczna-Zdrój lies in the IV climate zone. Guided by its provisions and legal requirements, design conditions for the site under consideration were adopted (Table 1) [66–68].

Table 1. Design thermal conditions for the considered location [66,67].

Parameter	Value	Unit
Design outdoor temperature	−22.0	°C
Indoor air temperature-usable premises	20.0	°C
Indoor air temperature-staircase	16.0	°C
Indoor air temperature-cellar	12.0	°C
Heating degree days-external partitions (20.0 °C)	4538.3	K·d
Heating degree days-external partitions (16.0 °C)	3078.3	K·d

The building is located on a plot in the north–south direction. It is a two-story building with a partial basement. The school building was built in the 1960s as a typical building. It consists of three two-story pavilions (constructively independent), a connector, and a kitchen part, forming one block. On the western side of the School building, a new sports hall was built in 2015, which is heated by a separate 400 kW oil boiler located in the School's boiler room. The school building is made of traditional brick technology. The external walls 45 cm thick made of full ceramic and silicate facing bricks. The school building is heated by an oil boiler room (2 × heating oil boilers with a capacity of 230 + 260 kW). The radiators were partly replaced with aluminum ones equipped with thermostatic valves. The larger part is made of ribbed cast iron without thermostatic valves. Domestic hot water (DHW) is provided locally with the use of electric capacitive accumulation heaters. It was built in 1960 with a total volume of heating and heated area of 10,482.3 m^3 and 3716.7 m^2, respectively (Figure 2).

Figure 2. External view of the school before modernization.

Due to the high operating costs of the School's building, the Director decided to prepare the necessary technical and design documentation in order to carry out a comprehensive thermomodernization. The first document is an energy audit in the order of executive designs of individual modernizations in the scope of specific installation industries. The developed documents showed places of large heat escape from the building and elements that absolutely needed to be modernized. The key turned out to be the modernization and insulation of the building's external partitions, the replacement of windows and external doors, and the modernization of the central heating and hot water installations using renewable energy sources.

5.2. Energy Audit

As to the external partitions of the building, the external walls below and above the ground and ventilated roofs are not insulated and do not meet the current Technical Conditions of 2021. Windows and exterior doors also do not meet WT2021; it is necessary to replace them with new ones with better heat transfer coefficients. The table below presents the thermal parameters of external partitions before modernization against the background of technical requirements (Table 2).

Table 2. Thermal parameters of external partitions before modernization against technical requirements for buildings from the year 2017 (WT2017) and the year 2021 (WT2021) [67,68].

Partition	U_{actual} (W/m^2·K)	U_{2017} (W/m^2·K)	U_{2021} (W/m^2·K)
External Walls, $t_i \geq 16$ °C			
External wall	1.176	0.230	0.200
External Walls, $t_i < 16$ °C			
Wall by the ground	0.510	0.300	0.300
Roof, $t_i \geq 16$ °C			
Ventilated flat roof	2.343	0.180	0.150
External Doors			
External doors	3.000	1.500	1.300
External Windows			
External windows	2.500	1.100	0.900

The energy audit revealed several significant drawbacks and sources of losses and indicated ways to improve [2].

The main elements to improve are as follows:

- External walls below and above the ground—limiting heat loss through external partitions—recommended additional insulation;
- Ventilated roof—limiting heat loss through external partitions—recommended additional insulation;
- Desirable replacement of windows and external doors with more airtight ones with a heat transfer coefficient U corresponding to WT2021;
- Modernization of the heat source (hybrid CO system: existing condensing oil boiler house with a capacity of 230 kW + compressor reversible air–water heat pumps with a capacity of approx. + modernization of the central heating system; replacement of 55/45 °C radiators + installation of thermostatic valves—210 pcs., heat meter);
- Photovoltaic installation is planned for assembly around 41.40 kW (92 pcs. × 450 W)—supplying compressor heat pumps in central heating system and electric heaters in the DHW system;
- Modernization of the lighting installation is planned—replacement of internal and external light sources as well as emergency ones with energy-saving ones, e.g., LED type (243 lamps), and modernization of the internal electricity installation along with reconstruction of the lightning protection system.

5.3. Modernization of External Partitions

In the next stage, an assessment of the cost-effectiveness of improvements in reducing heat loss through external partitions and the possibilities of improving energy performance through the implementation of these improvements were carried out [2]. The scope of the planned thermomodernization activities was as follows:

1. Insulation of all walls below the ground with thermal insulation material with a thermal conductivity coefficient $\lambda = 0.032$ W/mK with a thickness of at least 10 cm;

2. Insulation of walls above the ground with thermal insulation material with a thermal conductivity coefficient λ = 0.032 W/mK with a thickness of at least 15 cm;
3. Insulation of the base ventilated with thermal insulation material with a thermal conductivity coefficient λ = 0.038 W/mK with a thickness of at least 25 cm;
4. Replacement of external windows (heat transfer coefficient min; U = 0.9 W/m^{2}K—235 pcs.);
5. Replacement of external doors (heat transfer coefficient min; U = 1.3 W/m^{2}K—16 pcs.);
6. Modernization of the heat source (hybrid central heating system: existing 230 kW condensing oil boiler house + 160 kW air-to-water compressor reversible heat pumps, approx. 160 kW + buffer tank 1000 dm^3 + HUW tank 600 dm^3) with full automation and control. Modernization of the central heating system (replacement of 55/45 °C radiators + installation of thermostatic valves—210 pcs., heat meter);
7. A photovoltaic installation of approx. 41.40 kW (92 × 450 W) is planned for installation—powering compressor heat pumps in the central heating system and electric heaters in the hot water system;
8. Modernization of the lighting installation is planned—replacement of internal and external light sources as well as emergency ones with energy-saving ones, e.g., LED type (243 lamps) and modernization of the internal electricity installation along with reconstruction of the lightning protection system.

In the case of external walls, extruded polystyrene was used, and in the case of the flat roof, mineral wool boards with a very good thermal conductivity coefficient were used, which translates into very good thermal insulation properties.

5.4. Energy Consumption for Heating

To assess the energy effects, the heat consumption in the current state was calculated in the Audytor OZC program (version 7.0 Pro, Sankom, Warsaw, Poland), using the monthly method PN-EN ISO 13790. A building model was created (Figure 3), and all partitions were determined in accordance with documentation and verification during the site visit.

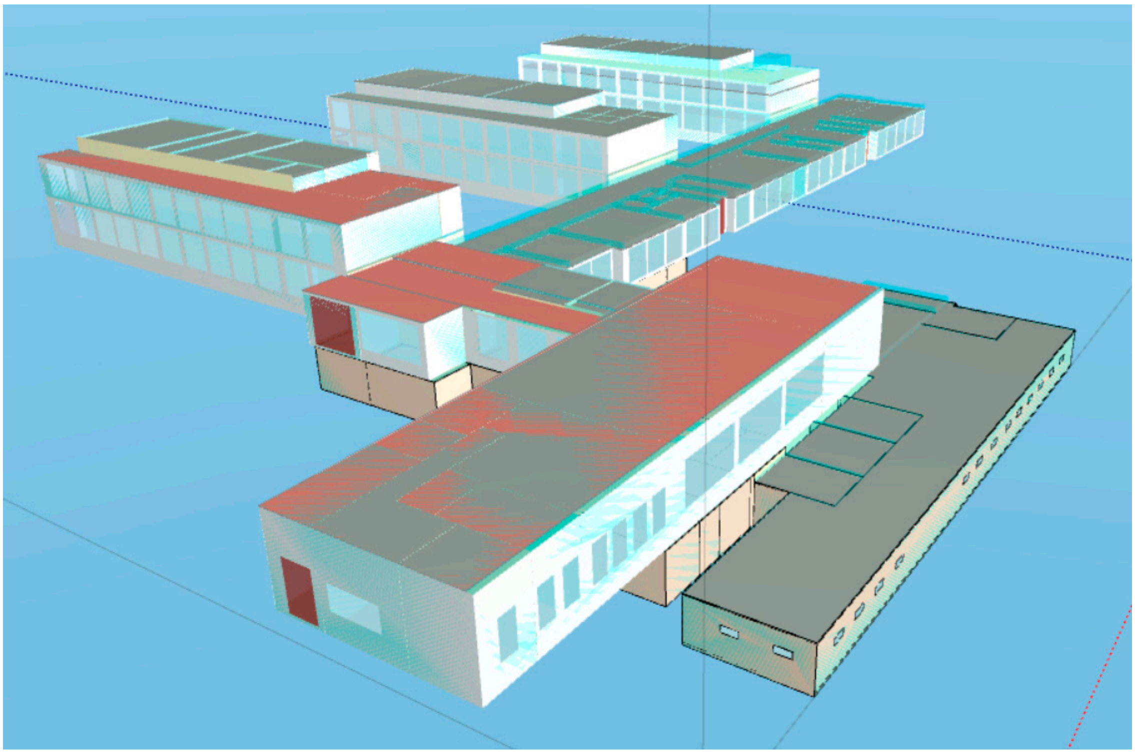


Figure 3. View of the building in the Audytor OZC program.

The annual demand for heat amounted to 3814.27 GJ and ranged, excluding the non-heating period from June to August, from 125.87 GJ in July to 514.58 GJ in January. The largest annual losses occurred through the external walls and amounted to 1429.53 GJ, followed by the ventilated flat roof—1390.25 GJ.

The above information and detailed calculations of the energy balance for the building, having at its disposal its energy performance, make it possible to estimate which elements in the building are to be modernized and improved with thermal insulation. You can locate any leaks and thermal bridges and determine what treatments can improve the efficiency of energy production in heating and hot water systems. The assumptions for generating the optimal modernization variant are always to meet the requirements contained in the technical conditions that buildings should meet. They determine the appropriate heat transfer coefficients for all homogeneous and heterogeneous external partitions. They indicate the possibilities and the need to use renewable energy sources to improve the energy performance of the building.

Table 3 presents the achieved thermal conductivity coefficients for the key and modernized building envelope against the technical conditions for 2017 and 2021 in Poland.

Table 3. Thermal parameters of external partitions after modernization against technical requirements for buildings from the year 2017 (WT2017) and the year 2021 (WT2021) [1,54,64].

Partition	U_{actual} (W/m^2·K)	U_{2017} (W/m^2·K)	U_{2021} (W/m^2·K)
External Walls, $t_i \geq 16$ °C			
External wall	0.191	0.230	0.200
External Walls, $t_i < 16$ °C			
Wall by the ground	0.189	0.300	0.300
Roof, $t_i \geq 16$ °C			
Ventilated flat roof	0.148	0.180	0.150
External Doors			
External doors	1.300	1.500	1.300
External Windows			
External windows	0.900	1.100	0.900

The annual demand for heat after the introduction of the thermal insulation of external partitions amounted to 1018.51 GJ and ranged, excluding the non-heating period from June to August, from 34.04 GJ in July to 137.10 GJ in January.

5.5. Improved Energy Efficiency

The most important part of determining the energy efficiency of a building is defining three key indicators in the classification of the energy efficiency of a building. They can be unambiguously subjected to analysis by calculating individual coefficients of energy demand: primary EP, usable EU, and final EK.

When calculating the annual final energy demand, it is worth emphasizing the fact that it should be expressed as the ratio of the usable energy demand, which is determined by the heat balance of the building to the average seasonal efficiency of the heating system. The calculations are aimed at determining the demand for heating purposes and are given in the equation below [1,64]:

$$Q_{K,H} = \frac{Q_{H,nd}}{\eta_{H,tot}} \left[\frac{\text{kWh}}{\text{year}}\right], \tag{1}$$

where:

$Q_{H,nd}$—useful energy demand to heat a residential building (useful heat);
$\eta_{H,tot}$—average seasonal efficiency of the building's heating system.

An important element that is taken into account, apart from the energy intended to heat the building, is also that used to prepare domestic hot water, and the energy demand for it is defined by the formula given below [1,64]:

$$Q_{K,W} = \frac{Q_{W,nd}}{\eta_{W,tot}} \left[\frac{\text{kWh}}{\text{year}}\right], \tag{2}$$

where:

$Q_{W,nd}$—demand for preparation of domestic hot water;
$\eta_{W,tot}$—average annual efficiency of devices preparing domestic hot water.

The above two equations allow us to determine the final energy factor (EK) of which they are components. It is important for both the auditor and the user that the EK, EU, and EP coefficients are given as the number of necessary kilowatts used to heat a square meter of the building's surface throughout the year. The following equation shows us the method of calculating the required final energy EK to supply the building [1,64]:

$$EK = \frac{Q_{K,H} + Q_{K,W}}{A_f} \left[\frac{\text{kWh}}{\text{year} \times \text{m}^2}\right], \tag{3}$$

where:

A_f—heated or cooled space in the building with a specific temperature, expressed in [m^2].

The primary energy demand factor is calculated on the basis of the annual energy needs for heating and domestic hot water preparation and, where applicable, cooling or ventilation of the premises and lighting in specific cases. The aforementioned EP coefficient is calculated from the dependence:

$$EP = \frac{Q_P}{A_f} \left[\frac{\text{kWh}}{\text{year} \times \text{m}^2}\right], \tag{4}$$

where:

Q_p—annual demand for primary energy [kWh/year].

Of which the annual primary energy demand is calculated according to the formula:

$$Q_P = Q_{P,H} + Q_{P,W} + Q_{P,C} + Q_{P,L} \left[\frac{\text{kWh}}{\text{year}}\right], \tag{5}$$

where:

$Q_{P,H}$—annual primary energy demand through the heating and ventilation system for heating and ventilation;
$Q_{P,W}$—annual primary energy demand by the domestic hot water preparation system;
$Q_{P,C}$—annual primary energy demand for the space ventilation and cooling system;
$Q_{P,L}$—annual demand for a lighting system (calculated only for public buildings).

In the existing state, the building is characterized by the following energy efficiency indicators (Table 4).

The building after thermomodernization is characterized by the following energy efficiency indicators (Table 5).

Table 4. Summary list of energy efficiency indicators for the condition of the existing building (own elaboration]).

Assessment of the Energy Characteristics of the Building		
Energy Performance Index	**Building Being Assessed**	**Requirements According to Technical and Construction Regulations 2021**
Annual useful energy demand indicator	EU = 260.4 [kWh/m^2 year]	
Annual final energy demand indicator	EK = 453.5 [kWh/m^2 year]	
Annual demand for non-renewable primary energy	EP = 574.8 [kWh/m^2 year]	EP = 70.0 [kWh/m^2 year]
Unit amount of CO_2 emissions	E_{CO2} = 0.157 [$MgCO_2$/m^2 year]	
Share of renewable energy sources in the annual final energy demand	U_{OZE} = 0.0 [%]	
Heat demand indicator for heating	$Q_{H,nd}$ = 3814.27 [GJ]	

Table 5. Summary list of energy efficiency indicators for the state after modernization of the building (own elaboration).

Assessment of the Energy Characteristics of the Building		
Energy Performance Index	**Building Being Assessed**	**Requirements According to Technical and Construction Regulations 2021**
Annual useful energy demand indicator	EU = 86.2 [kWh/m^2 year]	
Annual final energy demand indicator	EK = 91.1 [kWh/m^2 year]	
Annual demand for non-renewable primary energy	EP = 84.4 [kWh/m^2 year]	EP = 70.0 [kWh/m^2 year]
Unit amount of CO_2 emissions	E_{CO2} = 0.041 [$MgCO_2$/m^2 year]	
Share of renewable energy sources in the annual final energy demand	U_{OZE} = 57.7 [%]	
Heat demand indicator for heating	$Q_{H,nd}$ = 1018.51 [GJ]	

6. Discussion

A well-executed thermomodernization of the facility includes a number of elements. The basis is considered to be insulation or insulation of the building, including external walls, roofs or flat roofs, floors, and, if possible, the foundations of the building and the entire foundation slabs. Traditional materials such as mineral wool and polystyrene are used for this purpose, but investors are increasingly willing to use modern materials, such as sprayed polyurethane foams or extruded polystyrene boards. For the thermomodernization of the building to make sense, it is also necessary to replace façade and roof windows, as well as external doors and garage doors with those with a low thermal conductivity coefficient if absolutely necessary. It is worth thinking about the fact that the windows should be three panes and equipped with a coating which hinders the penetration of infrared radiation. On the one hand, this will reduce heat loss in winter; on the other hand, it will reduce the heating of the house through the windows during the summer.

Thermal insulation is about more than just reducing energy consumption. It is the protection of the building against damage and destruction, and thus the care for its technical condition in the long term. In addition, the fully insulated building with energy-saving windows is simply a comfortable place to stay every day, one in which the perfect temperature is easily achieved, even when there is a harsh winter outside. In a properly insulated house, we will certainly feel comfortable, but only if we take care of something else, i.e., the quality of the air. This is the complexity of the relevant activities.

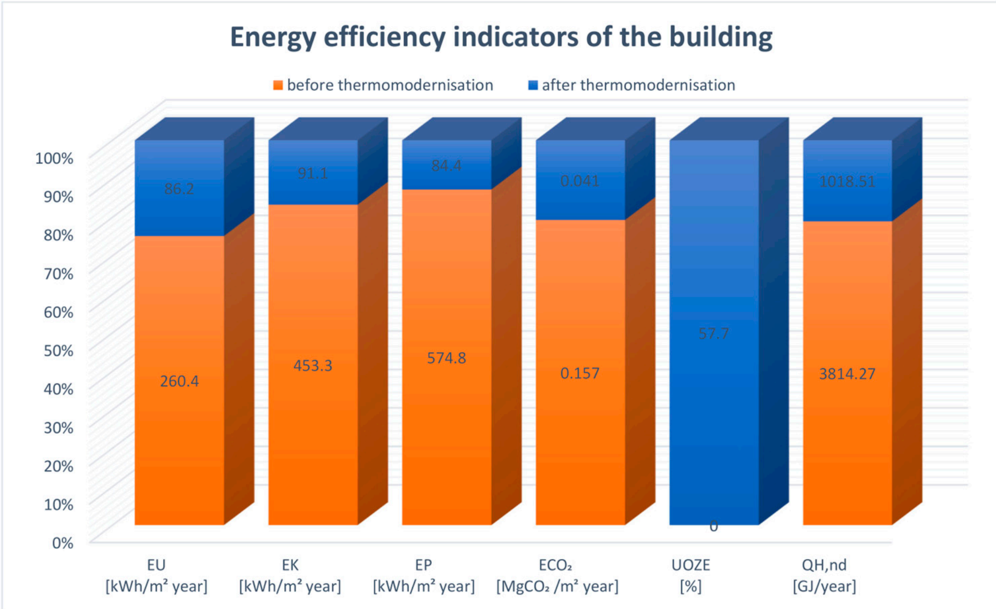
Energy efficiency is extremely important and a priority in order to achieve the goals set by the EU in this area. Energy efficiency, or simply saving energy, is not only a way to reduce harmful greenhouse gas emissions by reducing energy production, but also a real source of savings. Nearly 70% of the energy used in buildings is used for heating, so it is worth taking care of tight doors and windows as well as sufficiently thick walls. It should be remembered, however, that these activities cannot take place at the expense comfort or the loss of ventilation in the rooms. Saving energy should primarily consist in its rational or optimal use and not in denying yourself basic comforts such as warmth at home, lighting, or cooking dishes. The need to increase energy efficiency results from the growing energy needs with simultaneous climate change and growing customer preferences for energy-saving products. Social and environmental changes are reflected in EU and national regulations. The market perspective emphasizes the importance of maximizing utility and minimizing costs with regard to energy efficiency. In 2021, the Commission presented a proposal to amend the Energy Efficiency Directive to bring it in line with the EU's new ambitious climate targets of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and reaching climate neutrality by 2050. The proposal includes an increased energy efficiency target of 9% by 2030 (compared to the 2020 baseline scenario), which was subsequently increased to 13%. In the REPowerEU plan, published in May 2022, it also highlights the role of the energy efficiency first principle in moving from the traditional model of fossil fuel-based energy production and consumption towards a more flexible system incorporating renewable technologies and focusing on actively engaged energy consumers.

In the presented analysis of energy efficiency indicators, they have a very significant impact on the energy performance of the building. Differences in the levels before and after thermomodernization, along with the percentage savings, are presented in Table 6 and Scheme 1.

From the table and scheme below, we can conclude that thanks to the thermomodernization of external partitions—the most sensitive and leaky in the facility, i.e., external walls below and above ground with a ventilated roof—and through the use of renewable energy sources such as heat pumps and photovoltaic installation, it was possible to save 72.30% of thermal energy in the building, which directly translates into a reduction in the operating costs of the building. The improvement of energy efficiency indicators ranges from 66% for usable energy to almost 85% for non-renewable primary energy. Furthermore, by reducing the energy demand consumed in the building by nearly 74%, we see a reduction of CO_2 emissions.

Table 6. Summary list of energy efficiency indicators for the state after modernization of the building (own elaboration).

Assessment of the Energy Characteristics of the Building		
Energy Performance Index	**Differences in the Group before and after Thermomodernization**	**Percentage Saving of Individual Indicators**
Annual useful energy demand indicator	EU = 174.2 [kWh/m^2 year]	66.90 [%]
Annual final energy demand indicator	EK = 362.4 [kWh/m^2 year]	79.91 [%]
Annual demand for non-renewable primary energy	EP = 490.4 [kWh/m^2 year]	85.32 [%]
Unit amount of CO_2 emissions	E_{CO2} = 0.116 [MgCO_2/m^2 year]	73.89 [%]
Heat demand indicator for heating	$Q_{H,nd}$ = 2795.76 [GJ]	72.30 [%]



Scheme 1. Summary list of energy efficiency indicators for the state after modernization of the building (own elaboration).

7. Conclusions

Thermomodernization is a step in the right direction, especially when it includes a number of coherent activities planned by an expert. Ad hoc projects conducted "quickly" and on your own will not bring the same effects as a comprehensive renovation of individual elements, including improvements such as central heating installation, hot water, thermal insulation, replacement of window joinery, and ventilation, as well as adding systems based on renewable energy sources to the building. Thermomodernization is mainly associated with the installation of insulation and the replacement of obsolete heat sources. However, this is not enough to actually reduce energy consumption and create a completely healthy environment at home. Many building owners focus on thermal insulation (mainly external walls) alone, forgetting, for example, about improving the ventilation or air conditioning system. It is also worth remembering that thermomodernization also includes activities such as drying the walls or installing sun visors and protecting against overheating (which is becoming an increasing problem).

Installations using renewable energy sources (RES) have already settled on the Polish market for good, and their popularity will certainly continue to grow. On the one hand, the use of RES is dictated by the applicable legal regulations, namely, in accordance with the technical conditions to be met by buildings and their location, the indicator of the annual demand for non-renewable primary energy EP; on the other hand, the growing competition in the RES market translates into a wider choice of product solutions and lower prices of devices. Failure to include RES in the design of a building means that it has little chance of obtaining a building permit. The benefits of using renewable energy sources (RES) are indisputable. Thanks to them, the building can have a less negative impact on the environment, which, in turn, will make life in the area more pleasant and healthier. An effective way to eliminate smog, but also to save the Earth's natural resources, is to replace solid-burning boilers with renewable energy sources.

An important stage is the energy audit and design, but so is the execution. Incorrect installation of even a thermal insulation system can turn out to be a waste of money, and insulation repairs can be expensive. Therefore, thermomodernization is profitable when it is based on a reliable analysis of profits and incurred costs and, at the same time, correctly implemented. Then, it fulfills its basic goal, i.e., improving the quality of life and functioning of individual households.

Important benefits of thermomodernization include the fight against smog, the reduction of carbon dioxide emissions, and clean air. To achieve this, it is not enough to replace the heat source; as experts indicate, it must be preceded by the installation of insulation and windows that meet current standards regarding the heat transfer coefficient. Thermomodernization is also closely related to care for the technical condition of the building, which becomes better protected against the occurrence of such phenomena as, for example, freezing or dampness. A comprehensively thermomodernized house remains warm and stable for a long time; it does not require costly repairs and renovations. As a result, it has a higher market value. In addition, it looks much better. The aesthetic effects of thermomodernization can be seen with the naked eye. Often, even old buildings become difficult to recognize thanks to the work carried out; they change their appearance dramatically—new facades, windows, and external doors, combined with, for example, the modernization of balconies, give spectacular effects.

Improving energy efficiency and the rational use of existing energy resources, in view of the growing demand for energy, are areas to which Poland attaches great importance. The fight against climate change begins at home and now, in modern society, it is buildings that are the main consumers of energy. Saving energy by switching off lights and using energy-saving appliances and light bulbs saves on annual energy costs and lowers CO_2 emissions, while good insulation and modern windows are among the many measures which can be undertaken to reduce emissions and heating/cooling bills.

Energy-saving construction and renewable energy sources are directions that allow us to reduce the demand for fossil fuels, and thus protect the climate. They should also be of particular interest to investors planning to build or modernize a building as they enable a significant reduction in the costs associated with the operation of the building. Out of concern for the natural environment and our future, it is necessary to strive to minimize the non-renewable energy used for this purpose, i.e., that derived from fossil fuels. It should be replaced as much as possible with renewable energy (solar radiation, wind, and energy accumulated in the ground, water, or air). The use of renewable energy sources (RES) is not only associated with a significant reduction in air pollution, but also provides savings for the users of systems and devices based on it. The greater the share of renewable energy in the energy balance, the greater the savings in costs related to heating, cooling, utility water heating, and electricity consumption.

In the socioenergy transformation and the correlation of social, economic, and ecological systems, the system of ethical and social principles, together with the principle of sustainable development, serves to properly evaluate the categories of social life. Taking into account properly selected and specific indicators from the socioeconomic area, the application of the principle of sustainable development can be used to study energy efficiency while fully satisfying human needs in all dimensions of life.

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