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Thermomodernization as a Mechanism for Improving Energy Efficiency and Reducing Emissions of Pollutants into the Atmosphere in a Public Utility Building

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Abstract: Improving energy efficiency indicators and reasonable use of energy resources in the context of the increasing demand for energy are sectors that must definitely be paid attention to. The fight against climate change must start in the construction sector, as buildings are the main consumers of energy. Saving energy through the rational use of energy sources and good thermal insulation of buildings allows you to reduce the amount of heating and/or cooling bills as well as to care for the environment by reducing emissions. This article presents aspects of improving the energy efficiency of a health clinic building in Mszana Dolna through the use of comprehensive thermal modernization of the external envelope. Thermal modernization of the most energy-intensive and leaky external partitions in the building, i.e., the external walls below and above the ground and the ventilated flat roof, managed to save 53% of the building's thermal energy, which directly translates into lowering the building's operating costs. We managed to achieve an improvement in energy efficiency ratios from 37% to almost 60%, and a reduction in CO_2 emissions at a level of nearly 50%.

Keywords: energy efficiency; energy audit; thermal modernization; CO_2 emissions; non-renewable primary energy; final energy; usable energy

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Citation: Szczotka, K.; Barwińska-Małajowicz, A.; Szymiczek, J.; Pyrek, R. Thermomodernization as a Mechanism for Improving Energy Efficiency and Reducing Emissions of Pollutants into the Atmosphere in a Public Utility Building. *Energies* **2023**, *16*, 5026. https://doi.org/10.3390/en16135026

Academic Editor: Frede Blaabjerg

Received: 5 May 2023
Revised: 1 June 2023
Accepted: 26 June 2023
Published: 28 June 2023

1. Introduction

Improving energy efficiency indicators is sometimes referred to as a so-called "sixth fuel" (besides coal, oil, gas, nuclear energy and renewable energy) as it reduces the growth in demand for fuel and energy. This fuel does not need to be produced or extracted; it just needs to be saved. Improved energy efficiency reduces the adverse impacts of the processes related to the generation and consumption of energy on human well-being and health as well as on the environment (by reducing greenhouse gas emissions), and contributes to increasing energy security by helping to reduce import dependency. Furthermore, measures aimed at improving the energy efficiency of buildings form the basis for the development of a modern and innovative energy sector. They contribute, among other things, to improving air quality or reducing heating costs. In addition, they are part of fulfilling Poland's obligations to reduce carbon dioxide emissions and increase the share of renewable energy sources (RES) in energy generation. Investing in improving the energy efficiency of buildings brings large energy savings, comfort in the use of buildings and sustainable economic development. There are many programmes, tools and measures used to improve energy efficiency. Among the latter, thermal upgrading measures undoubtedly deserve special attention. In many countries, including Poland, widespread projects aimed at the thermal upgrading of residential buildings, in line with the European Union (EU) strategy, help to significantly reduce the consumption of energy for home heating [1].

"Energy efficiency first" is one of the three watchwords of the so-called "Winter Package"—a set of regulatory proposals presented in 2016 by the European Commission setting out the most important directions for the European Union's climate policy. The proposals currently under way in the EU particularly emphasise the energy-saving potential of energy consumption in buildings, which account for 40 per cent of final energy consumption and yet harbour large swathes of inefficiency [1].

The main reason for carrying out thermal modernisation in existing buildings is to reduce the heating costs incurred. However, it is also needed because of the changes expected in the next years, namely:

- energy prices will continue to rise, causing heating costs to increase, and with thermomodernization, the impact of energy prices on building charges can be significantly reduced;
- the introduction of the energy assessment of buildings (energy performance certificates) will create a situation in which the poor energy performance of a building, deviating from current requirements, will be associated with a lower market value of the building, the need for lower rents, etc.;
- legal requirements for thermal insulation will be continuously tightened and will gradually take the form of economic pressure to improve the existing condition of the building, e.g., by making tax rates, loans and charges dependent on the energy quality of the building.

Therefore, the thermal modernisation of buildings is necessary, and it is worth doing it now, as it is possible to obtain financial assistance for its realisation under the act on supporting thermal modernisation and renovation [2,3].

Thermomodernization can vary in scope, depending on the current state of the building and the owner's financial capabilities. Individual thermal modernisation projects bring different savings, and their profitability (payback time) is not the same either. Therefore, if funds do not allow you to carry out thermal modernisation to the full extent, you should perform, first and foremost, those improvements that are most cost-effective. One of the biggest problems that may occur during wall insulation is the formation of thermal bridges, i.e., places through which heat flow intensifies. Thermal bridges are very dangerous places in a building envelope, not only because these are places of increased heat escape, but, above all, because the increased heat escape leads to a decrease in the temperature of the partition surface, which, in turn, may lead to a risk of surface condensation and, in extreme cases, to the development of mould fungi on chilled surfaces. Therefore, it is very important to perform thermal insulation in a continuous manner, leaving no places that could cause heat to escape from the building. Insulation of the building envelope is essential. It should necessarily concern the roof (when the attic is heated) or the ceiling under the attic, as insulation of these parts of the building is particularly effective.

The main purpose of the current work is to understand the impact of thermal modernization on the energy efficiency of a building. This paper analyses a case study showing a specific variant of thermal modernization, what energy and cost savings can be expected in a public utility building after it is carried out correctly and in accordance with the art of engineering and how it affects the energy efficiency of the building. The case study as well as its summary and conclusions clearly show how properly conducted thermal modernization affects the specific energy efficiency indicators of the building under consideration. In our opinion, the contribution of the current state of the art is to show a good case study that allows for the replication of this scheme in other aspects of thermal modernization of various types of buildings.

2. Literature Review

Interpretation of the conceptual category of energy efficiency constitutes part of an interdisciplinary scientific discourse. Energy efficiency can be rather simplistically defined as the relationship between the result of an activity, a product manufactured or a service provided and the energy input consumed. It can be seen as the ratio of benefits acquired to energy spent, showing the relationship between energy gained and energy used [4]. In other words, it is the ratio of outputs, services, goods or energy obtained to energy input [5,6]. The literature on the subject distinguishes different levels of, and approaches to, the interpretation of energy efficiency. It also points to related terms concerning this conceptual category, such as "energy conservation", "reduction in energy consumption", "rational use of energy resources", "sustainable use of resources", "efficient use of resources", "rational use of energy", "reverse energy consumption", "ratio of useful results to physical energy inputs", "choice of lower energy consumption", etc. [7–11]. In the scientific literature, the term "energy efficiency" is not only accompanied by related or synonymous terms and phrases, but also different meanings are attributed to this category, depending on the scientific discipline, the context of an individual analysis, its type or scale [12–19]. Thus, with respect to scales and economic sciences, it should be noted that this conceptual category can be explained in terms of both macro and micro scales. For example, from the macroeconomic perspective of a conventional market economy, energy efficiency can, according to the aforementioned principle of rational management, be defined as energy intensity or, conversely, as energy productivity. In this sense, energy inputs are assigned specific monetary output parameters. At this point, it is still worth clarifying the concept of primary energy, which is understood as coal, natural gas, oil, nuclear energy and renewable energy sources. In the above context, energy intensity can, for example, be defined as primary energy consumption per gross domestic product (GDP) unit or primary energy consumption per citizen [20]. At the macro level, efficiency indicators of the economy are measured as gross domestic product per unit of energy used to produce it. [21]. However, the scientific literature also indicates that using the energy-to-GDP ratio to measure macroeconomic energy efficiency can be misleading [22]. Energy intensity can also be expressed in relation to certain physical parameters, e.g., electricity consumed by household appliances (fridges, induction hobs, ovens, TVs or washing machines), fuel consumption per 100 km and annual heat consumption per square metre of floor space, taking into account the ambient temperature. It is worth mentioning that various ways are currently being pursued to improve the energy efficiency of buildings. One important solution is thermal upgrading, which is discussed in this article. A slightly different approach to energy efficiency, related to thermal upgrading in the context of engineering and technical sciences, also belongs to the macro scale: energy efficiency in the context of energy conversion. In this sense, energy efficiency can be defined by efficiency indexes or conversion utilisation rates (e.g., energy efficiency index of a power plant, heating system or refinery). In this context, the focus is on usable energy, i.e., energy that is used by the end consumer (fuel oil, electricity, refined natural gas, petrol or diesel fuel) [20]. Energy efficiency can therefore also be defined as a measure of efficiency in economic activities [5], with different references used in different business sectors for both the interpretation and the measurement of energy efficiency itself. For example, in the construction industry, the energy efficiency of a building can be defined as the extent to which energy consumption per square metre of floor area of the building corresponds to the established energy consumption patterns for that particular building type under specific climatic conditions [23].

In view of the many possibilities of interpreting the term "energy efficiency", the theoretical section is limited only to the interpretations presented above, as those are the most relevant to the issues addressed in the article.

In publications on the impact of thermal modernization on energy savings in buildings of various types in the last 2–3 years, the results of energy efficiency improvements with the use of thermal modernization are most often presented in the works [24–26], along with the use of modernization of conventional heat sources with the use of renewable sources of energy, e.g., in hybrid systems [26–28]. An assessment of real energy effects was made on the basis of measurements carried out during the 4-year period of operation. They were compared with the results of theoretical calculations included in the energy audit, and an attempt was made to describe the reasons for the discrepancies. The planned and achieved economic efficiency indicators were assessed and the amount of pollutant emission reduction was determined [28]. In turn, other works in the field of thermal modernization concern the assessment of activities aimed at improving the energy efficiency of buildings made with prefabricated technology. One study assessed whether a change in the method of central heating control from a traditional one, taking into account only the change in the external temperature in relation to the weather, would contribute to an increase in the energy efficiency of buildings [29]. Another publication presented the results of research on the possible environmental benefits of thermal modernization of single-family houses in the area of southern Poland. The analysis was limited to determining the impact of actions limiting the emission of pollutants into the air by insulating the external partitions of single-family houses. The research was conducted for two voivodeships: Śląskie and Małopolskie. Its purpose was to determine the financial costs and possible environmental effects of thermal modernization of single-family buildings [29,30].

Over the last 5 years, issues related to energy efficiency have often been discussed in scientific publications, but they have been more cross-sectional. They are related to the legislation in the field of almost zero-energy and plus-energy construction. Rarely do foreign authors discuss aspects of thermal modernization similar to those in our publication, and in their examples as case studies. This is one of many that are thematically similar to our publication. These articles investigated the energy-saving potential of different types of buildings located in different climatic conditions through real-world energy consumption analysis and computer simulation. The building load was determined by linear regression from existing energy bills and was used to validate the computer simulation of energy consumption. The results also show that while the use of energy-saving solutions has a significant impact on energy consumption, even the most economical solutions will have a long payback period.

Referring to the scope of our publication, there are more publications by Polish authors in the citations because, in recent years, changes in legislation have been very frequent, which, in consequence, means that it is very important for people dealing with this subject to properly approach the modernization of a building, in order to raise its energy efficiency, together with the implementation of rapidly developing renewable energy sources.

3. Review of EU and National Policies

Directive 2002/91/EC [31] of the European Parliament and of the Council was the first Energy Efficiency Directive. It was implemented in 2009. Its aim is to promote the improvement of the energy performance of buildings. Directive 2002/91/EC regulates requirements [31] on the following issues:

(a) methodology and guidelines for calculating the energy performance of buildings;
(b) minimum energy performance requirements for new and refurbished buildings;
(c) energy certification of buildings;
(d) inspections of boilers and air-conditioning systems in buildings and assessment of heating systems where the boilers are more than 15 years old.

The next directive was Directive 2010/31/EU of the European Parliament and of the Council [32]. Similarly to its predecessor, it promotes the improvement of the energy performance of buildings in the EU, taking into account prevailing outdoor climatic and local conditions as well as indoor climate requirements and cost-effectiveness. It regulates requirements [32] applicable to the following areas:

(a) a common general framework for a methodology for calculating the integrated energy performance of buildings and building units;
(b) the application of minimum energy performance requirements for new buildings and new building units;
(c) the application of minimum energy performance requirements;
(d) national plans to increase the number of nearly zero-energy buildings;
(e) energy certification of buildings or building units;
(f) regular inspection of heating and air-conditioning systems in buildings;

(g) independent control systems for energy performance certificates and inspection reports.

These are minimum requirements, and member states can introduce more stringent measures. The most significant changes consisted of the introduction of a definition of a so-called nearly zero-energy building (nZEB). According to the directive on the energy performance of buildings (EPBD) [32], it is a building with very high energy performance in which a significant part of the energy should come from renewable sources. However, it became necessary to further modify the existing European guidelines on the energy performance of buildings. The result was the introduction of Directive 2018/844 [33] of the European Parliament and of the Council (EU) of 30 May 2018, amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU [5,34] on energy efficiency.

The new directive included the following new elements:

(a) a long-term renovation strategy;
(b) electromobility;
(c) a smart readiness indicator for buildings;
(d) a methodology for determining the energy performance of buildings.

The latest EPBD looks ahead to 2050, taking into account, in addition to the traditional thermal upgrading of buildings, many technological innovations and know-how that are still in their development and testing phases. On 15 March 2023, the European Parliament adopted draft legislation aimed at accelerating the pace of building renovation, reducing energy consumption and lowering greenhouse gas emissions. The directive on energy performance of buildings provides for many changes that will have a huge impact on the development of renewable energy sources and the modern construction industry. From 2028, all new buildings are to be zero-emission. New buildings occupied or operated by or belonging to public authorities will have to be zero-emission from 2026, while from 2028, all new buildings should be equipped with solar energy technology, if it is technically and economically feasible. In buildings undergoing renovation, these regulations will apply from 2032. National regulations must be in line with EU guidelines on thermal upgrading, energy efficiency, renewable energy sources and the energy performance of buildings. The energy consumption requirements that new and renovated buildings must meet are linked to global trends as well as the current geopolitical situation and fuel access issues [35]. In this regard, the basic legal act in Poland concerning support for the thermal modernization and renovation of buildings is the act of 21 November 2008 [36]. It regulates the issue of financing of some costs of thermal upgrading and renovation projects, low-emission projects, the purchase, assembly, construction or modernisation of renewable energy source systems, as well as the operation of the Central Building Emission Register by the Fund for Thermal Upgrading and Renovation of Buildings. This act was supplemented by an act amending the act regarding support for thermal upgrading and renovation of buildings of 23 January 2020 [37]. It provided for the establishment of the Central Building Emission Register. This is intended to be an IT tool for identifying sources of low emissions generated by buildings. The register collects key information on emission sources in the municipal-dwelling sector (households, local boiler houses, small service enterprises). It makes it possible to collect data on the energy status of buildings and information on various forms of public aid granted for thermal upgrading or boiler replacement projects. The main registration criterion is the power of a given building's energy source, regardless of the legal form of use of the building, i.e., for residential or business purposes. The register covers not only residential buildings but also public sector buildings (e.g., schools, offices), including small local heating plants or small manufacturing enterprises, provided that the nominal thermal power of the fuel combustion source used does not exceed 1 MW. Another piece of the relevant legislation in force in Poland is the Regulation of the Minister of Investment and Development [38] of 21 December 2018 regarding defining a list of types of building materials, equipment and services related to the implementation of thermal upgrading projects [38]. It came into force on 1 January 2019. The annex to the regulation lists the materials that can and should be used in the process of thermal upgrading in order for a building to achieve zero-emission status. New and renovated buildings are to be nearly zero-energy to have a lower environmental impact. Technical and building automation systems play a considerable role in increasing energy efficiency. Buildings can be assessed on the basis of their readiness to be connected to smart grids. Installations and equipment are intended to form a coherent whole supervised by an intelligent control system such as a Building Management System (BMS), which is a building automation system that provides the ability to monitor and manage all equipment and systems in and around a building. It is used to manage lighting, heating and air-conditioning installations, guaranteeing a healthy and comfortable indoor environment for residents and optimising energy consumption. As mentioned earlier, the Central Building Emission Register also provides information on public aid, such as grants or subsidies for thermal upgrading projects. One of the national programmes providing financial assistance for such projects is the clean air programme [39]. Its participants can get rid of an inefficient solid fuel heat source and replace it with a new and environmentally friendly heating device and receive a subsidy for this. The funds obtained can be used for the thermal upgrading of a building, the replacement of windows and doors as well as the installation of photovoltaic panels. The new edition of the clean air 3.0 programme was launched on 3 January 2023 [40]. It introduces additional measures to be used in the case of carrying out a comprehensive thermal upgrading project, which is intended to ensure a reduction in the consumption of usable energy for heating to no more than 80 kWh/m^2 per year, or by at least 40%. Both EU and Polish national regulations aim to define and clarify the rules that will contribute to increasing the energy efficiency of buildings, reducing pollution and ensuring the further development of renewable energy sources. It is expected that the achievement of these goals will contribute directly to the improvement of the well-being of all inhabitants of the European Union [35,36]. Thermal upgrading projects bring about various economic benefits, which can contribute to accelerating the country's economic growth, as well as reducing local air pollution and carbon dioxide emissions as a consequence of the gradual elimination of so-called low emission sources.

4. Case Studies

The proposed case study shows the positive impact of thermal modernization on the energy efficiency indicators of the health centre building in terms of energy savings and lower operating costs. Energy requirements drive users to save a lot of energy. One of the ways is to carry out comprehensive thermal modernization via greater use of renewable energy sources (RES). These requirements are also imposed by the act relating to energy performance and energy efficiency and the regulation on technical conditions to be met by buildings and their location, which, from 2021, sets out guidelines for nearly zero-energy buildings [32,41].

Achieving the zero-energy construction standard, applicable to all buildings erected after 2029, is easy to achieve and implement, and brings measurable operational benefits. The requirements and recommendations for new buildings contained in the draft amendment to the EPBD [32] concern:

(a) a higher smart readiness index (SRI);
(b) a high share of renewable energy;
(c) a higher level of self-consumption of energy;
(d) a healthy indoor climate thanks to effective and controlled ventilation;
(e) low energy costs for heating and hot water;
(f) the possibility of cooling rooms, improving comfort of use.

The most important part of EU and national legislation on the energy efficiency of buildings has recently changed. This applies, in particular, to the new EPBD on the energy performance of buildings, adopted by the European Parliament on 14 March 2023. It lays the foundations for the decarbonization of the building stock by 2050 and introduces a number of significant changes. Domestically, on 28 April 2023, the provisions of the amended Energy Performance of Buildings Act (EPBD) will come into force. Work is also underway to amend the regulation on the methodology of determining the energy performance of a building or part of a building and the preparation of energy performance certificates. This topic is of great interest to many communities and is widely discussed.

In order to ensure the decarbonization of the building sector, the EU's roadmap for achieving its climate targets emphasizes the need to phase out fossil fuels used for heating by 2040, when direct emissions from the building sector will need to decrease by around 80–89%. In the December 2021 draft EPBD itself, there was a proposal to introduce a higher residential building standard than the current nZEB (in Poland, this is the technical conditions TC2021 standard, i.e., non-renewable primary energy $EP_{max} \leq 70$ kWh/(m^2 year) for single-family houses, for example). In the original draft amendments to the directive, the maximum EP value for ZEBs was 65 kWh/(m^2 year) for a continental climate. The EP_{max} values proposed in the ZEB standard were protested by many organizations and individual countries, including Poland, and are now to be set by the member states themselves [32].

4.1. The Analysed Health Clinic Building

The considered building, located in Mszana Dolna, is a municipal health clinic. The nearest weather station for which long-term observations and a typical meteorological year are available is located in Nowy Sącz, 58 km southwest of Mszana Dolna (see Figure 1). The average annual outdoor temperature of the period 1971–2000 was 7.6 °C, and the design outdoor temperature for this climate zone is −20 °C [38,41].

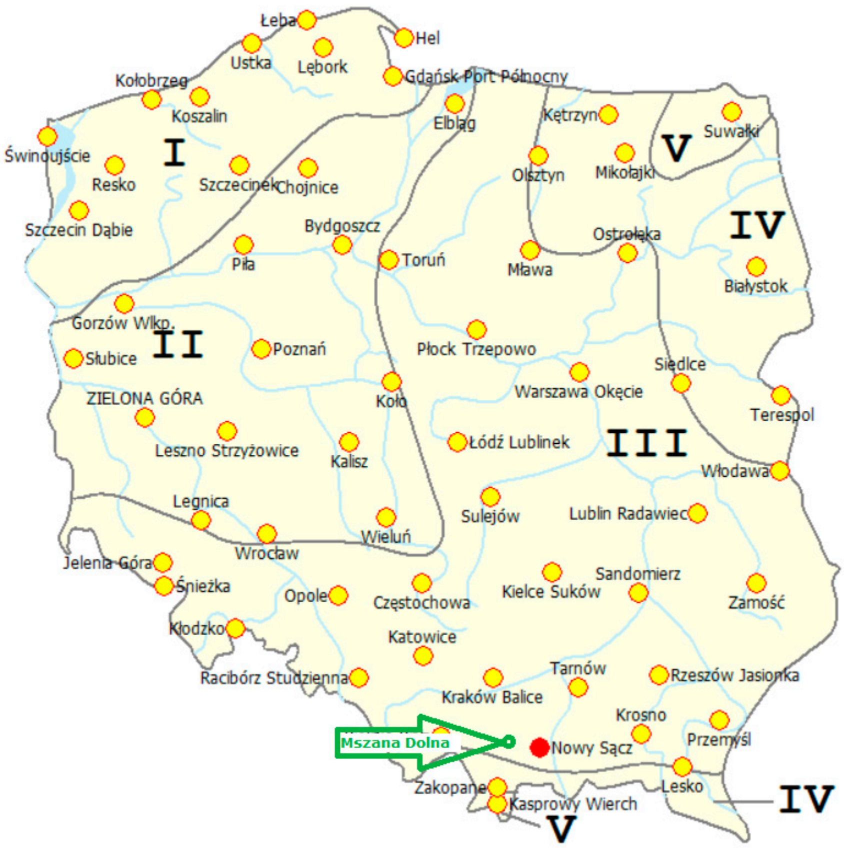

Figure 1. Polish climatic zones according to PN-EN 12831 and the location of Mszana Dolna (own elaboration based on [38,41,42]) Figure 1 shows the individual locations of climate zones against the background of the map of Poland with the marking of climate stations in individual cities.

According to the PN-EN 12831 standard [42], Mszana Dolna lies in climate zone III. Guided by its provisions and legal requirements, design conditions for the site under consideration were adopted (see Table 1)

Table 1. Design thermal conditions for the considered location (own elaboration based on [41–43]).

Parameter	Value	Unit
Design outdoor temperature	−20.0	°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 health clinic building, built with traditional brick technology, has 3 floors (basement and 2 above-ground floors), with a rectangular plan measuring 26.55 × 11.10 m (see Figure 2).

Figure 2. External view of the clinic before modernization (own archive).

Built in 1973, the building has a total volume of heating and heated area of 1746.4 m^3 and 690.1 m^2, respectively.

Characteristics of the building:

- External curtain walls made of aerated concrete, plastered on both sides, 28 cm thick (heat transfer coefficient U = 1.176 W/(m^2 K));
- gable walls made of solid brick on the inside and silicate brick on the outside, 53 cm thick (U = 1.280 W/(m^2 K));
- External basement walls of rendered solid brick, insulated with asphalt felt, with a total thickness 34 cm and 60 cm (U = 0.632 W/(m^2 K), U = 0.532 W/(m^2 K)—wall at ground level);
- Goose-ribbed roofs, insulated with 2 cm thick fibreboard, with an average air void of 60 cm (U = 1.628 W/(m^2 K);
- Roofing with asphalt felt laid on pan boards; 24 cm thick ribbed interstorey ceilings insulated with 2 cm of fibreboard (U = 1.285 W/(m^2 K));
- New windows made of PVC profiles and double glazing, with a heat transfer coefficient depending on the window size of U = 1.1 W/(m^2 K);
- Unplasticized polyvinyl chloride glazed entrance door with a heat transfer coefficient of U = 1.2 W/(m^2 K);
- Gravity ventilation system.

The building is heated by a condensing gas boiler room (two De Dietrich boilers, each with a capacity of 35 kW). There is a central installation with panel radiators, but the building mostly has finned cast iron radiators without thermostatic valves. Domestic hot water is prepared from a condensing gas boiler room in the central installation with circulation. The building is equipped with the following installations: central heating, domestic hot water, water and sewage, and -electric and lightning protection. The technical condition of the building is good; however, a comprehensive thermomodernization of the building envelope to technical conditions TC2021 is recommended.

The very high operating costs of the building resulted in a search for savings. An energy audit was carried out in order to diagnose the places enabling a reduction in building operating costs by reducing heat losses through the building's external partitions and improving energy efficiency indicators [41,42].

4.2. Energy Audit

An energy audit is a study aimed at determining the amount of energy used and its optimization. An energy audit is a multi-stage procedure for optimizing energy consumption and reducing its purchase costs. The audit can be carried out in terms of selected issues or in its entirety. The key element of the audit is consulting, which guides the development or possible modernization of the building. This also results in the synonymous name of the audit—thermomodernization. This activity is strictly legally conditioned, based on the act of 1998 and the regulation of the Minister of Infrastructure of 2008 regarding the energy audit.

According to the above documents, the basic elements of an audit are:

- an inventory of the building, including technical and construction tests;
- assessment and advice on the technical condition of the building;
- technical documentation necessary to undertake thermal modernization activities and improvements;
- cost estimates taking into account the costs of the above-mentioned activities.

The first step in performing an energy audit is to analyse the current condition of the building. Considering, e.g., site inspection and technical documentation, the efficiency of the installation and the demand for heat during the standard heating period are determined. The obtained parameters constitute a mathematical model that should be confronted by reality. If discrepancies arise, corrections and additional tests are made. The next step is crucial for a well-conducted audit. It is an analysis of possible improvements and modernization. The proposed actions concern not only technical aspects, but also organizational (e.g., staff training) and legal (e.g., changing the energy tariff) aspects. The next steps concern the return on investment. The first stage is to determine the investment outlays based on the current situation of the market. Then the savings that will be generated by the actions taken are calculated. Both of these values are components of the investment profitability analysis. An energy audit is the basis for making informed decisions in terms of optimizing the costs of energy consumption in a building. Often, the performance of the audit at the first level allows for simple changes without cost or at a low cost to achieve significant savings in energy consumption, which, in real terms, translates into lower building maintenance costs.

The energy audit for the building in question was carried out in accordance with applicable legal documents [38,42–44] and taking into account the guidelines contained in the regulation of the Minister of Development and Technology of 15 December 2022 amending the regulation on the detailed scope and forms of energy audits and partial renovation audits, templates of audit cards, as well as an algorithm for assessing the profitability of a thermomodernization project. The main purpose of the audit is to identify ways to reduce energy consumption, assess their costs and make recommendations on the selection and timing of changes that will bring the greatest benefits. The audit proposes specific solutions, selected on the basis of extensive knowledge of the market and professional knowledge. The scope of thermomodernization work analysed in the audit is determined together with the investor. In the case of thermal insulation, the optimal thickness of thermal insulation is calculated on the basis of cost-effectiveness criteria. After determining which activities are profitable, the optimal scope of the work is determined, i.e., a set of investments recommended for implementation. The selection of the scope of the work is based mainly on economic criteria, although other arguments are also taken into account, e.g., improvement of thermal comfort, elimination of wall freezing, increased safety and reliability of central heating, simplification of equipment operation and ecological benefits. Technical conditions and the need to combine some improvements, which will only bring the expected results, are also taken into account.

This International Standard (EN ISO 13790 [41]) is one of a series of calculation methods for the design and evaluation of the thermal and energy performance of buildings. It presents a coherent set of calculation methods at different levels of detail for the energy use of the space heating and cooling of a building and the influence of the recoverable thermal losses of technical building systems, such as the heating and cooling system.

The International Standard is used in combination with other energy-performance-related standards (see Figure 3, which gives an outline of the calculation procedure and its links with other energy-performance-related standards).

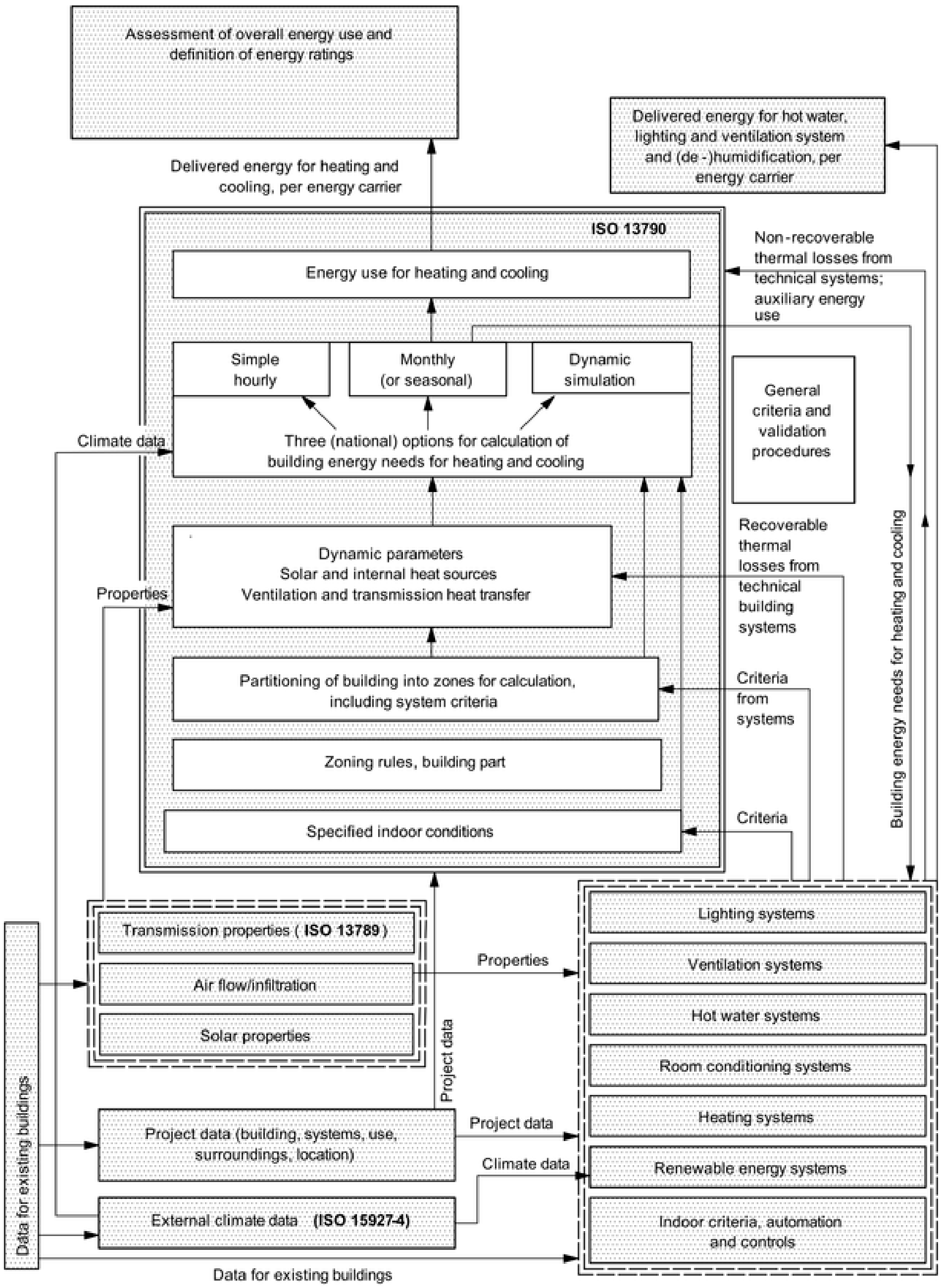

Figure 3. Flow chart of the calculation procedure and links with other standards [41–43].

The main input parameters are:

- ventilation properties;
- heat gains from internal sources and the sun;
- climatic data;
- description of building elements, systems and their use;
- comfort requirements;
- data on heating, cooling, domestic hot water, ventilation and lighting systems;
- division of the building into different zones;
- energy losses dissipated and recoverable or recovered in the building;
- air flow rate and temperature of the supplied ventilation air (in the case of centrally pre-heated or pre-cooled) and related energy consumption for air circulation and pre-heating or pre-cooling;

The output parameters are:

- annual energy demand for space heating and cooling;
- annual energy consumption for space heating and cooling;
- the length of the heating and cooling season (in terms of operating hours of the system) affecting the energy consumption and auxiliary energy of the season-dependent technical building systems for heating, cooling and ventilation.

Additional outputs are:

- monthly values of energy demand and energy consumption;
- monthly values of the main elements of the energy balance, e.g., permeability, ventilation, internal heat gains;
- passive solar gains;
- installation losses (from heating, cooling, domestic hot water, ventilation and lighting) recovered in the building.

This method includes the calculation of:

(a) heat transfer by transmission and ventilation;
(b) the share of internal and solar heat gains in the building's heat balance;
(c) the annual energy demand for heating and cooling;
(d) the annual energy consumption for heating and cooling the building, using input data from relevant system standards.

The building's external partitions—the external walls below and above the ground and ventilated flat roofs—are not thermally insulated and do not meet the current technical conditions of 2021. The windows and external doors are in good technical condition and do not require modernization.

The rules for calculating the value of the heat transfer coefficient U for partitions are specified in the PN-EN ISO 6946 standard [44]: "Building components and building elements. Thermal resistance and heat transfer coefficient. Calculation Method". This standard provides ways to assess the contribution of construction products and services to energy saving and to the overall energy performance of buildings. This standard provides a method for calculating the thermal resistance and heat transfer coefficient of building components and building elements, with the exception of doors, windows and other glass components, components through which heat transfer to the ground takes place, and components through which air is provided.

The heat transfer coefficient is calculated using the following formula (The relevant indicator values are shown in Table 2):

$$U = \frac{1}{R_T}\left[\frac{W}{m^2 \cdot K}\right] \tag{1}$$

where:

R_T—total thermal resistance of the partition $\left[\frac{m^2 \cdot K}{W}\right]$

The total thermal resistance of the partition (R_T) is calculated from the formula:

$$R_T = R_{si} + \sum_{i=1}^{n} \frac{d}{\lambda_i} + R_{se} \left[\frac{m^2 \cdot K}{W}\right] \quad (2)$$

where:

R_{si}—heat transfer resistance on the internal side of the partition $\left[\frac{m^2 \cdot K}{W}\right]$;

d—component thickness [m];

λ_i—thermal conductivity $\left[\frac{W}{m \cdot K}\right]$;

R_{se}—heat transfer resistance on the external side of the partition $\left[\frac{m^2 \cdot K}{W}\right]$.

Table 2. Values of heat transfer resistance coefficients on the inside and outside of the partition are adopted on the basis of the directions of heat flow through the partition according to PN-EN ISO 6946 [44].

$\left[\frac{m^2 \cdot K}{W}\right]$	Direction of the Heat Flux		
	Up	**Horizontal**	**Down**
R_{si}	0.10	0.13	0.17
R_{se}	0.04	0.04	0.04

The table below presents the thermal parameters of external partitions before modernization against the background of technical requirements (see Table 3).

Table 3. Thermal parameters of external partitions before modernization against the technical requirements for buildings from the 2017 year (TC2017) and 2021 year (TC2021) (own elaboration based on [25,35,44]).

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	1.280	0.230	0.200
External Walls, $t_i < 16$ °C			
Wall by the ground	0.632	0.300	0.300
Roof, $t_i \geq 16$ °C			
Ventilated flat roof	1.628	0.180	0.150
External Doors			
External doors	1.200	1.500	1.300
External Windows			
External windows	1.100	1.100	0.900

The calculations were made in accordance with the PN-EN ISO 13790 standard and the methodology contained in the regulation of the Minister of Development and Technology of 15 December 2022 amending the regulation on the detailed scope and forms of energy audits and partial renovation audits, templates of audit cards, as well as an algorithm for assessing the profitability of a thermomodernization project.

The energy audit performed clearly indicated which structural elements require the use of appropriate thermal insulation to improve the energy efficiency of the building (see Table 4, Figure 4).

Table 4. Summary of energy losses through partitions—heating (own elaboration).

Description	[GJ/year]	[kWh/year]	[%]
Interior doors	0.00	0.00	0.0
External doors	5.18	1 440	0.9
Exterior window	54.41	15 113	8.9
Basement floor	14.44	4 011	2.4
Ceiling heat down	0.00	0.00	0.0
Ventilated flat roof	159.84	44 401	26.2
Exterior wall at ground level	13.75	3 819	2.3
Interior wall	0.00	0.00	0.0
Exterior wall	201.24	55 900	33.0
Heat for ventilation	160.09	44 469	26.3
Total	608.95	169 153	100.0

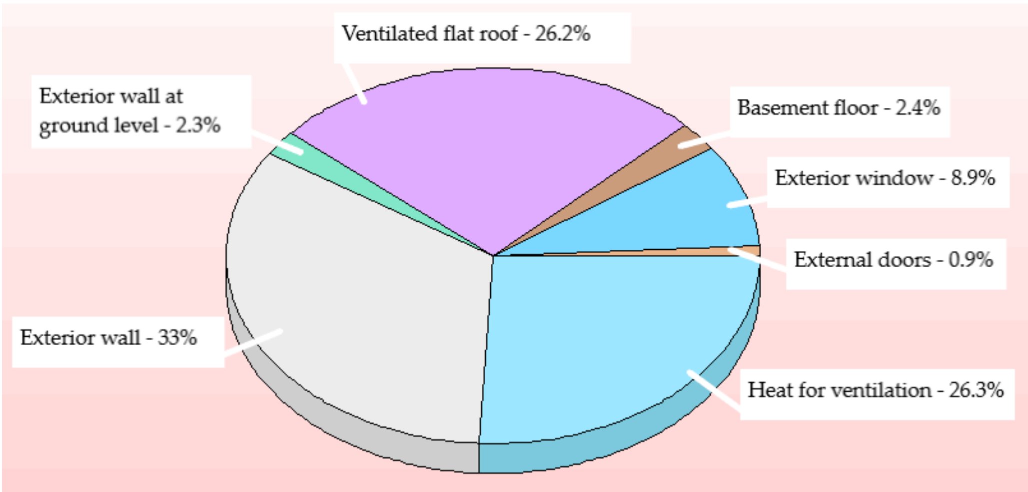

Figure 4. Graphical representation of energy losses through partitions—heating (own elaboration).

Due to the highest heat losses shown, the following partitions are subject to modernization:

- ✓ the external walls below and above the ground require the use of thermal insulation material;
- ✓ the ventilated flat roof requires the use of additional thermal insulation material.

4.3. Modernization of Multi-Layer External Partitions

In the next stage of the energy audit, calculations were made regarding the profitability of improvements in the reduction in heat loss through external partitions and the possibility of improving energy efficiency indicators through their implementation.

The planned thermal modernization will cover:

1. The walls below the ground level were insulated with thermal insulation material with a thermal conductivity coefficient $\lambda = 0.032$ W/mK and a minimum thickness of 12 cm.
2. The walls above the ground were insulated with thermal insulation material with a thermal conductivity coefficient $\lambda = 0.032$ W/mK and a minimum thickness of 15 cm.
3. The ventilated flat roof was insulated with thermal insulation material with a thermal conductivity coefficient $\lambda = 0.038$ W/mK and a minimum thickness of 25 cm.

In order to make the appropriate thermal insulation of partitions, the following were used: extruded polystyrene for the external walls and mineral wool for the flat roof.

4.4. Energy Consumption for Heating

In order to determine the design heat load of the building and determine its energy performance, a virtual 3D model of the building was built in the Audytor OZC program (version 7.0 Pro, by Sankom, Warsaw, Poland). A monthly method was used using the PN-EN ISO 13790 standard. A detailed 3D model of the building was created (see Figure 5), consistent with the design documentation and reality.

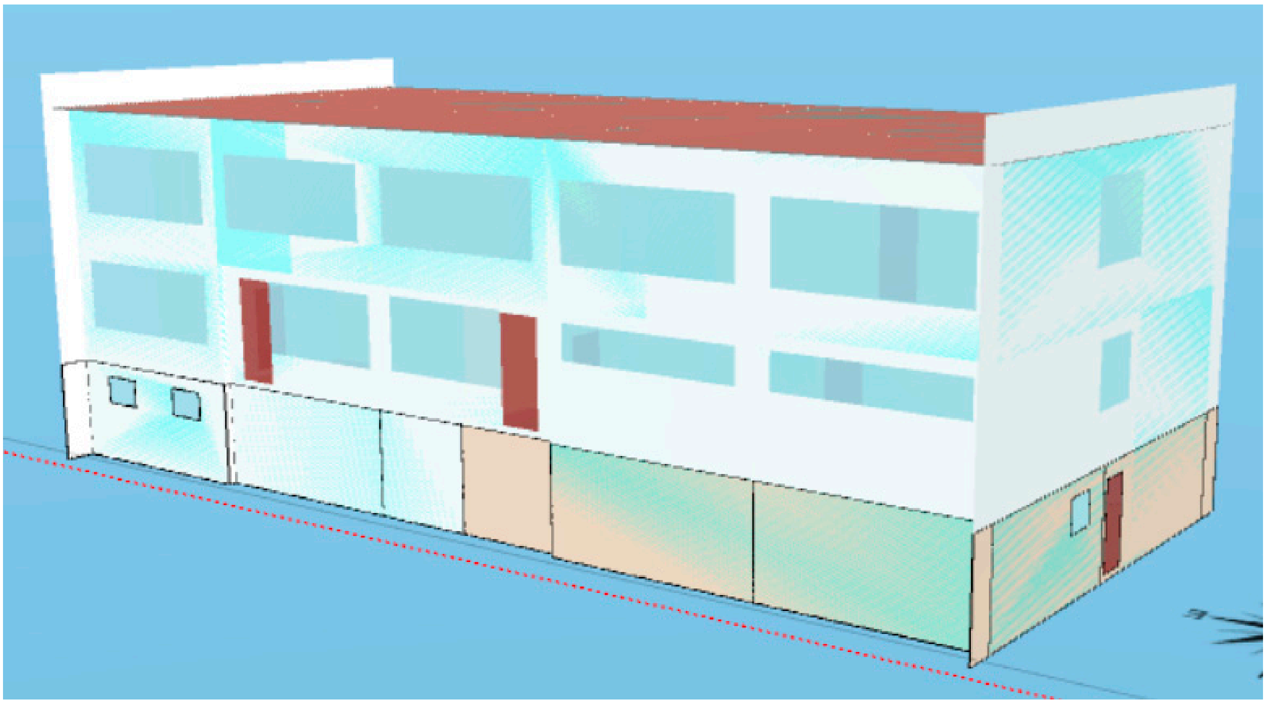

Figure 5. View of the building in the Audytor OZC program (own elaboration).

The annual design demand for heat amounted to 608.95 GJ/year (169.153 MWh/year). The largest heat losses occurred through the external walls and amounted to 201.24 GJ/year and, respectively, 159.84 GJ/year for the ventilated flat roof.

Having information about the relationships between individual indicators, we can easily assess the quality of the building, taking into account thermal modernization of partitions, elimination of thermal bridges and improvement of the tightness of the structure.

The main criterion for the energy assessment was the fulfilment of the requirements contained in the technical conditions of TC2021, meeting the requirements in terms of the building structure and the heat transfer coefficient of the external partitions. In fact, it turned out that the modernized partitions have coefficients much better than those required in the technical conditions of 2021 (see Table 5).

Table 5. Thermal parameters of external partitions after modernization against the technical requirements for buildings from the 2017 year (TC2017) and 2021 year (TC2021) (own elaboration).

	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	0.193	0.230	0.200
External Walls, $t_i < 16$ °C			
Wall by the ground	0.190	0.300	0.300
Roof, $t_i \geq 16$ °C			
Ventilated flat roof	0.147	0.180	0.150

The table below presents the thermal parameters of external partitions before and after thermal modernization with a percentage change (see Tables 6–8, Figure 6).

Table 6. Thermal parameters of external partitions before and after modernization with reduction in [%] against the background of technical requirements for buildings from 2021 (TC2021) (own elaboration).

Partition	U_{before} (W/m^2 K)	U_{after} (W/m^2 K)	U_{2021} (W/m^2 K)	Difference [%]
		External Walls, $t_i \geq 16$ °C		
External wall	1.280	0.193	0.200	84.92
		External Walls, $t_i < 16$ °C		
Wall by the ground	0.632	0.190	0.300	69.94
		Roof, $t_i \geq 16$ °C		
Ventilated flat roof	1.628	0.147	0.150	90.97

Table 7. Summary of energy losses through partitions—heating after thermal modernization (own elaboration).

Description	[GJ/year]	[kWh/year]	[%]
Interior doors	0.00	0.00	0.0
External doors	5.18	1 440	1.8
Exterior window	54.41	15 113	19.2
Basement floor	14.20	3 943	5.0
Ceiling heat down	0.00	0.00	0.0
Ventilated flat roof	15.02	4 173	5.3
Exterior wall at ground level	4.69	1 303	1.8
Interior wall	0.00	0.00	0.0
Exterior wall	29.15	8 098	10.3
Heat for ventilation	160.09	44 469	56.6
Total	282.74	78 539	100.0

Table 8. Summary of energy stats in the building envelope before and after modernization (own elaboration).

Description	Heat Losses before Modernization [GJ/year]	Heat Losses after Modernization [GJ/year]	Difference [%]
Interior doors	0.00	0.00	0.00
External doors	5.18	5.18	0.00
Exterior window	54.41	54.41	0.00
Basement floor	14.44	14.20	1.66
Ceiling heat down	0.00	0.00	0.00
Ventilated flat roof	159.84	15.02	90.60
Exterior wall at ground level	13.75	4.69	65.89
Interior wall	0.00	0.00	0.00
Exterior wall	201.24	29.15	85.51
Heat for ventilation	160.09	160.09	0.00
Total	608.95	282.74	53.57

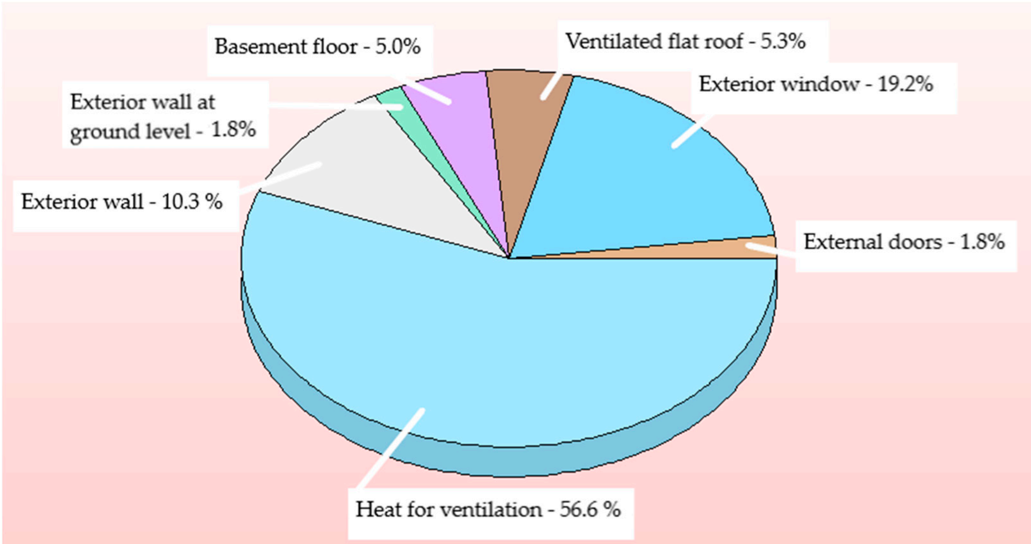

Figure 6. Graphical representation of energy losses through partitions—heating after thermal modernization (own elaboration).

The thermal parameters of the external partitions presented in the table clearly show that, after modernization, thanks to the implementation of thermal insulation, we can save nearly 70% to 90% as a reduction in energy escaping through the multi-layer partitions. The greatest savings, over 90%, occur for the ventilated flat roof; slightly smaller savings occur for external walls above the ground; and the smallest savings—nearly 70%—occur for external walls below the ground.

Table 8 shows exactly what impact thermal insulation has on energy losses in multi-layer partitions. Insulation of the flat roof made it possible to save 90% of the heat that escaped to the atmosphere through it, the insulation of external walls above the ground more than 85%, while the insulation of external walls below the ground resulted in savings of nearly 66%. In total, the proposed thermal insulation measures allowed for a reduction in heat loss from the building of 326.21 GJ, which gives 53.57%. The reduction in energy demand of 53.57% allowed for a simultaneous reduction in energy and operating costs of the building.

The annual demand for heat after the introduction of thermal insulation of external partitions amounted to 282.74 GJ/year (78.539 MWh/year). It has been possible to reduce consumption and heat loss through the building envelope very significantly, while the ventilation loss occurring in the building has remained constant due to the lack of modernization in this area. Upgrading the heating source together with upgrading the ventilation system would allow for further large energy savings and improve the energy efficiency of the building.

4.5. Improved Energy Efficiency

The most important element leading to a decision on the selection of the appropriate thermomodernization solution is the determination of the three key indicators in the energy efficiency classification, the energy demand coefficients: primary EP, usable EU and final EK.

When calculating the demand for final energy, we take into account the ratio of the annual demand for usable energy to the average seasonal efficiency of the heating system. The calculations determine the demand for heating purposes. We determine them from the relationship below [25,35,44]:

$$Q_{K,H} = \frac{Q_{H,nd}}{\eta_{H,tot}} \left[\frac{kWh}{year}\right] \tag{3}$$

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.

Another element is the energy used to prepare domestic hot water, and its demand is determined by the following formula [25,35,44]:

$$Q_{K,W} = \frac{Q_{W,nd}}{\eta_{W,tot}} \left[\frac{kWh}{year}\right] \quad (4)$$

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 coefficient of final energy demand (EK). It is important that the factors EK, EU and EP are given as the number of kilowatts needed to heat a square metre of building area during the year. The following equation shows us the method of calculating the required final energy EK to supply the building [25,35,44]:

$$EK = \frac{Q_{K,H} + Q_{K,W}}{A_f} \left[\frac{kWh}{m^2 \cdot year}\right] \quad (5)$$

where:

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

The demand for non-renewable primary energy is calculated on the basis of the annual demand for energy for heating and domestic hot water, cooling and the lighting system. The EP index is calculated from the relationship:

$$EP = \frac{Q_P}{A_f} \left[\frac{kWh}{m^2 \cdot year}\right] \quad (6)$$

where:

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

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

$$Q_P = Q_{P,H} + Q_{P,W} + Q_{P,C} + Q_{P,L} \left[\frac{kWh}{year}\right] \quad (7)$$

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 for 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 the lighting system (calculated only for public buildings).

The usable energy efficiency index is calculated from the following dependence:

$$EU = \frac{Q_U}{A_f} \left[\frac{kWh}{m^2 \cdot year}\right] \quad (8)$$

where:

Q_U—annual demand for usable energy [kWh/year].

$$Q_U = Q_{H,nd} + Q_{W,nd} + Q_{C,nd} \left[\frac{kWh}{year}\right] \quad (9)$$

where:

$Q_{H,nd}$—annual usable energy demand for heating and ventilation;
$Q_{W,nd}$—annual demand for usable energy for preparation of domestic hot water;
$Q_{C,nd}$—annual usable energy demand for cooling.

Determination of the unit value of CO_2 emissions in a building or part of a building equipped with technical systems is calculated as follows:

$$E_{CO_2} = \frac{E_{CO_2,H} + E_{CO_2,W} + E_{CO_2,C} + E_{CO_2,L} + E_{CO_2,P}}{A_f} \left[\frac{MgCO_2}{m^2 \cdot year}\right] \quad (10)$$

where:

$E_{CO_2,H}$—the amount of CO_2 emissions from the combustion of fuels by the heating system;
$E_{CO_2,W}$—the amount of CO_2 emissions from the fuel combustion process by the domestic hot water preparation system;
$E_{CO_2,C}$—the amount of CO_2 emissions from the combustion of fuels by the cooling system;
$E_{CO_2,L}$—the amount of CO_2 emissions from the combustion of fuels by the built-in lighting system;
$E_{CO_2,P}$—the amount of CO_2 emissions from the combustion of fuels by auxiliary devices in technical systems.

In the existing state, the building is characterized by the following energy efficiency indicators (see Table 9):

Table 9. 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 = 281.5 [kWh/m^2 year]	
Annual final energy demand indicator	EK = 467.3 [kWh/m^2 year]	
Annual demand for non-renewable primary energy	EP = 567.7 [kWh/m^2 year]	EP = 240.0 [kWh/m^2 year]
Unit amount of CO_2 emissions	E_{CO_2} = 0.119 [$MgCO_2$/m^2 year]	
Heat demand indicator for heating	$Q_{H,nd}$ = 608.95 [GJ/year]	

The health clinic building after thermomodernization is shown in the figure below (see Figure 7).

Figure 7. View of the building after thermal modernization (own elaboration).

The building after thermal modernization is characterized by the following energy efficiency indicators (see Table 10).

Table 10. Summary list of energy efficiency indicators for the state of the building after modernization (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 = 163.4 [kWh/m^2 year]	
Annual final energy demand indicator	EK = 292.1 [kWh/m^2 year]	
Annual demand for non-renewable primary energy	EP = 229.4 [kWh/m^2 year]	EP = 240.0 [kWh/m^2 year]
Unit amount of CO_2 emissions	E_{CO_2} = 0.060 [MgCO_2/m^2 year]	
Heat demand indicator for heating	$Q_{H,nd}$ = 282.74 [GJ/year]	

An example of the possibility of eliminating the influence of the weather on heat demand is the use of electronic controllers with weather control, which help to achieve such energy savings through intelligent heating control. In the building in question, the modernization measures consisted only of the use of thermal insulation in the external partitions, because the building has a new medium-temperature radiator heating system controlled semi-automatically with the use of regulators and electronic thermostatic valves.

4.6. Thermal Imaging Studies of the Building after Thermomodernization

Thermal imaging tests are designed to check the thermal insulation completed during the implementation of comprehensive thermomodernization. Thermovision tests can be carried out before a building is put to use, while living in a house and especially before a planned thermomodernization. These tests allow you to effectively locate any thermal bridges and carefully plan actions aimed at reducing heat energy losses. They make it possible to evaluate the construction work performed as well as design solutions. This, in turn, allows us to draw conclusions for the future and improve the quality of subsequent projects.

Thermographs of buildings show the thermal insulation of a building; the correctness of the insulation of the attic part of the building; the continuity and thermal insulation of tie beams; the correctness of the assembly and insulation of windows, doors and garage doors; insulation thickness, tightness and continuity; and correctness of the use of insulation material.

Examination with a thermal imaging camera allows you to locate pipes hidden in the walls, check the condition of their insulation and the tightness and insulation of chimneys. Thermal imaging tests can also be carried out when the building is inhabited and thermal modernization is planned. After the building audit, a report is written, which is the basis for the analysis, drawing conclusions and undertaking possible thermal modernization of the building.

The thermovision was performed after the thermal modernization of the health clinic building in Mszana Dolna. Thermal imaging tests were performed using a thermal imaging camera from Testo 883. The resolution is 320 × 240 pixels, expanded to 640 × 480 pixels with Super Resolution technology. In addition, thermal sensitivity of <40 mK makes even the smallest temperature differences visible. Measurements range from −30 °C to +650 °C, with a measurement accuracy reading of ±2 °C, ±2%.

The results and thermograms show how professionally and accurately the insulation of the building was carried out. The thermograms do not show any heat escapes or thermal bridges, and the insulation is continuous and energy-tight, which allows the appropriate energy efficiency indicators and energy savings to be achieved (see Figure 8).

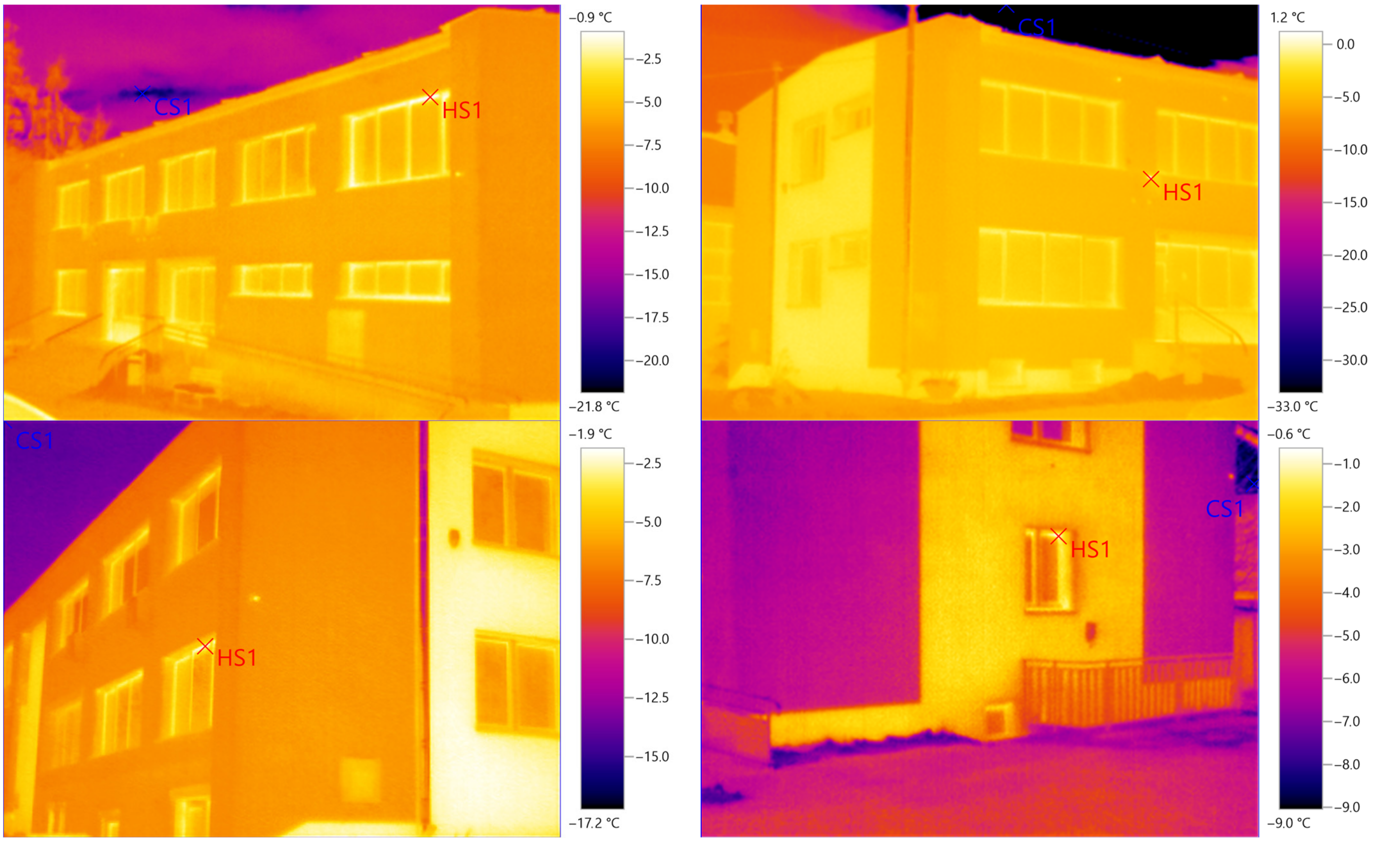

Figure 8. View of the building after thermal modernization. Images taken with the thermal imaging camera Testo 883 (own elaboration).

Differences in colours and irregularities in the shape of the image depend on the uniformity of the partition's thermal insulation. When identifying a fragment with a specific defect, a thermogram with an isotherm is made. The reference temperature is determined, and then the temperature difference between the characteristic fragments of the partition surface is determined.

A properly conducted thermovision examination of building partitions made it possible to conclude that the thermal insulation was carried out correctly. It is impossible to locate places with heat losses in the facility or places that pose a risk of surface condensation. The study helped to diagnose and evaluate the distribution of the temperature field of external surfaces for the purposes of the correct execution of the elements of the facade structure.

5. Discussion

In order for the thermal modernization of a facility to be effective, it must include a comprehensive approach to the issue. The basic element is thermomodernization of external partitions such as external walls, roofs, windows and external doors. Materials such as polystyrene foams, mineral wool in various forms as well as new materials such as polyurethane foams are most often used for this purpose. The most important feature of these materials is the heat transfer coefficient; the lower it is, the better the thermal insulation of the material. Thermal insulation is about more than just reducing energy consumption. Energy efficiency and its improvement in terms of energy savings is a key element of energy policies. The most important element is to achieve an appropriate reduction in energy consumption by 2030 in order to meet the relevant objectives of the European Union set for individual member states. All countries have an obligation to adapt their energy policies in such a way that legislation promotes the use of renewable sources and zero-energy and zero-emission buildings.

In the presented analysis of energy efficiency indicators, these indicators have a very significant impact on the energy performance of the building. Differences in the levels before and after thermal modernization along with the percentage savings are presented in Table 11.

Table 11. Summary list of energy efficiency indicators for the condition of the building before and after modernization, along with changes in the indicators in % (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 = 118.1 [kWh/m^2 year]	41.95 [%]
Annual final energy demand indicator	EK = 175.2 [kWh/m^2 year]	37.49 [%]
Annual demand for non-renewable primary energy	EP = 338.3 [kWh/m^2 year]	59.59 [%]
Unit amount of CO_2 emissions	E_{CO_2} = 0.059 [$MgCO_2/m^2$ year]	49.58 [%]
Heat demand indicator for heating	$Q_{H,nd}$ = 326.21 [GJ/year]	53.57 [%]

The presented table shows that the thermal modernization of the building's external partitions—the external walls above and below the ground and the ventilated flat roof—managed to save 53% of the thermal energy in the building. The improvement of energy efficiency indicators ranges from 37% to almost 60%, and the reduction in CO_2 emissions is nearly 50%.

6. Conclusions

An important role in this analysis is played by the energy audit, which shows which elements and their improvement improve the mentioned aspects the most.

The energy audit presents a thermal modernization project that is the most advantageous in terms of energy savings and costs. It presents and describes the total scope of work to be performed in order to minimize heat losses in the entire building. Such an audit should be carried out by an authorized person, i.e., an auditor or energy advisor. They must demonstrate knowledge in the field of construction, electrical installations and heating and ventilation, as well as move freely between the latest technologies and regulations. Their task is to identify the problems that exist in the building. They should also point out the right optimization path that will reduce energy consumption without compromising user comfort.

Thanks to the thermal modernization of the most sensitive and leaky external partitions in the building—i.e., the external walls above and below the ground and the ventilated roof—it was possible to save 53.57% (326.21 GJ) of thermal energy in the building, which directly translates into lower operating costs for the building. The improvement in energy efficiency ratios ranges from 37.49% (final energy) to almost 59.59% (annual demand for non-renewable primary energy), and the reduction in CO_2 emissions by reducing the demand for energy used in the building is nearly 49.58% (unit amount of CO_2 emissions).

The use of energy from renewable sources contributes to the reduction in energy consumption from fossil sources and the reduction in pollutant emissions. The use of RES should be preceded by at least a simplified economic analysis that consists of determining the costs and profits resulting from the project. As the prices of systems for obtaining energy from renewable sources are systematically decreasing, the profitability of such solutions is increasing. However, the amount of savings obtained depends on many factors and is often lower than assumed. Well-conducted thermomodernization and the use of RES have effects in the form of reduced operating costs and reduced negative impacts on the environment, especially with respect to actions to reduce smog. We then achieve measurable effects in the form of improving comfort and quality of life and increasing the market value of the building.

7. Summary

Thermomodernization is the best and fastest way to achieve savings and reduce energy consumption, and thus reduce the operating costs of a building. Thermal modernization is related to the implementation of tight thermal insulation. However, in order to actually reduce energy consumption and achieve the optimal energy efficiency of a building, one should also remember improvements to the efficiency of the ventilation system, which is the second important element of the energy balance of buildings, next to losses due to penetration through external partitions. The key and important element is the energy audit. Incorrect installation of thermal insulation may not bring the expected energy and cost savings. Thermomodernization, if carried out correctly, is very energy-efficient and economical.

The benefits of thermomodernization are not only the improvement of energy efficiency and savings in operating costs, but also the fight against smog, the reduction in carbon dioxide emissions and clean air. There must be comprehensive action with respect to the three aspects mentioned above—energy, economic and ecological—and a focus on optimizing the solutions used, with an analysis of the possibility of their technical implementation in a specific facility.

The results and the procedure for the energy modernization of buildings are quite prospective due to the fact that a very thorough modernization of all energy-inefficient external partitions has already been carried out.

The design thermal load of the building has been reduced to the maximum and thermal bridges have been eliminated; the building is very tight and does not waste excessive energy. The prospect of further development of work to improve efficiency should focus on replacing the existing condensing gas boiler with devices using renewable energy sources, e.g., compressor heat pumps connected to a hybrid installation with photovoltaic panels to power it.

Improving energy efficiency and rational use of existing energy resources in the face of growing energy demand are areas to which Poland attaches great importance. The current spectrum of possible actions aimed at increasing energy efficiency, and thus reducing operating costs, is huge. For this reason, solutions that improve energy efficiency are attracting more and more interest from entrepreneurs, local government units as well as individual consumers. The fight against climate change starts now because in modern society, buildings are the main consumers of energy. Carrying out the above pro-efficiency activities is the beginning of the road to achieving the expected savings. Conducting an audit allows you to identify opportunities to increase efficiency and obtain data to understand which energy-saving measures will be the most effective. The level of savings achieved is significantly influenced by the supervision and monitoring of the implemented solutions that increase energy efficiency; e.g., service inspections of devices, which make it possible to maintain them in the proper technical condition, allowing for operation with the highest efficiency. Actions aimed at ensuring the most effective use of a given element of infrastructure in terms of energy savings ensure their effective functioning and use are also important. Rational use of energy and taking measures to reduce its consumption allow the economy to operate more efficiently and economically and become more environmentally friendly. Many countries also recognize that energy efficiency brings benefits to national security, as it can contribute to reducing the level of energy imports from abroad and slow down the rate of depletion of domestic energy resources.

Author Contributions: Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision, project administration and funding acquisition, A.B.-M., K.S., J.S. and R.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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