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ECONOMIC ANALYSIS OF DEEP THERMOMODERNIZATION OF THE BUILDING

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Purpose: The aim of this paper is to examine the multifaceted field of deep thermomodernization of the 11-storey hotel building located in Bialystok, with an emphasis on unraveling the complex interaction between energy efficiency and economic considerations.
Design/methodology/approach: Today, there are several methods used to gauge the most effective ways of cutting energy demand, including Simply Pay Back Time (SPBT), Pay Back Time (PBT), Net Present Value (NPV), Net Present Value Ratio (NPVR), Internal Rate of Return (IRR), and Dynamic Pay Back Time (DPBT). In Poland, studies mostly based on SPBT due to its precision and accuracy, which offers clearer and more reliable outcomes compared to other methods. However, combining multiple methods can enhance result clarity and reliability even further. During examination, we initially used SPBT to assess the impacts of energy-saving measures, resulting in clear and dependable insights into efficiency improvements.
Findings: Total energy gain after deep thermomodernization is 42%. It shows that after the implementation of deep thermomodernization, annual heating expenditures were reduced by almost half (by 41%). The simple payback time (SPBT) for individual thermal modernization projects ranged from 4,32 years for external walls to 15,41 years for external doors and 13.74 years for ventilated flat roof and 10,34 for windows.
Practical implications: Our research efforts have made our building more durable and valuable. Additionally, we have economized our building by minimizing energy consumption and reducing annual heating costs as much as possible.
Social implications: Deep thermomodernization can reduce energy costs, increase environmental awareness, and improve quality of life by increasing society's energy efficiency. This can reinforce a sense of social responsibility and shape environmental policies. Change can be achieved in the industry by encouraging it through public policy.
Originality/value: Research has shown that as technology advances, it should also be reflected in the construction sector. Instead of demolishing old buildings and rebuilding, which is costly and environmentally unfriendly, deep thermomodernization offers a more economical and eco-friendly solution for renovation. Calculations and comparisons have pointed to its effectiveness.
Keywords: Energy savings, investment costs, economic analysis.
Category of the paper: Research paper.

1. Introduction

In today's global pursuit of sustainable development and climate action, deep thermomodernization is emerging as a compelling strategy in the built environment. This comprehensive approach to renovating or retrofitting buildings aims not only to reduce carbon emissions, but also to increase energy efficiency and resilience to climate impacts, with the main aim being to minimize energy loss and reduce heating costs. However, the decision to deep thermomodernization involves complex economic considerations, ranging from initial investment costs to long-term financial returns and financing mechanisms for such projects.

This article discusses the economic analysis and importance of deep thermomodernization, aiming to explain the complexities, challenges and transformative impact potential in structures. Examining the costs, benefits, and systemic consequences of deep thermomodernization initiatives, this analysis aims to provide information that can inform policy formulation, guide investment strategies, and inspire innovative solutions to address both environmental and economic imperatives.

Deep thermomodernization involves fundamental changes to a building's structure and systems. This approach is applicable to all buildings, regardless of age, to deliver lasting energy savings, reduce environmental impact and increase actual property value. The European Union has set ambitious targets for building renovations to meet energy efficiency standards, with initiatives such as the "Clean Energy for all European Union countries" package. In Poland, the Long-Term Building Improvement Strategy outlines deep thermomodernization plans targeting near-zero energy building standards and increased use of renewable energy sources. Engineers and planners must carefully balance energy efficiency with economic viability, considering factors such as construction materials, design complexity, and long-term sustainability.

2. Methods used in the building thermomodernization proces

The methods used in the building thermomodernization process include a variety of techniques aimed at increasing energy efficiency and reducing environmental impact. Here are some common methods used in this process.

Insulation upgrades: Insulation upgrades is known as the application of materials that reduce or prevent heat transfer between the interior and exterior of buildings and increase thermal performance.

- External wall ınsulation.
- Internal wall ınsulation.
- Roof ınsulation.
- Floor ınsulation.
- Cavity wall ınsulation.

Window and door upgrades: Changing or improving windows and doors is an important detail to minimize heat transfer, air leakage and increase overall energy efficiency.

- Double or triple glazing.
- Low-e coatings.
- Insulated doors.
- Weather stripping.

HVAC system upgrades: It refers to upgrading or optimizing heating, ventilation and air conditioning (HVAC) systems to improve energy efficiency, indoor air quality and overall system performance in buildings.

- High-efficiency furnaces.
- Heat pumps.
- Programmable thermostats.
- Zoned heating and cooling.

Renewable energy ıntegration: The incorporation of renewable energy sources, such as solar panels or wind turbines, to generate electricity for a building, reducing dependence on non-renewable sources.

- Solar photovoltaic (PV) panels.
- Solar thermal systems.
- Wind turbines.
- Geothermal heating systems.

Smart building technologies: It refers to the application of advanced technologies such as smart thermostats and automatic lighting systems to manage and optimize building operations for increased energy efficiency in buildings

- Building energy management systems (bems).
- Smart thermostats.
- Automated lighting controls.
- Occupancy sensors.

Green roof ınstallation: Green roof is known as the addition of vegetation to the roof surface of a building, providing insulation, absorbing rainwater and providing environmental benefits.

- Extensive green roofs (mainly vegetation).
- Intensive green roofs (include a variety of plants).
- Roof gardens.

Facade renovation: It is the process of improving or changing the external appearance of a building to improve insulation in structures, eliminate thermal bridging problems and improve overall energy performance.

– External cladding.
– Thermal bridge reduction.
– High-performance facade materials.

Thermal mass ıntegration: Incorporating materials with high thermal mass to absorb, store, and release heat, contributing to temperature regulation and energy efficiency

– Use of high thermal mass materials.
– Thermal mass placement for temperature regulation.

Each of the above methods addresses different aspects of deep thermomodernization of buildings, and the selection of specific methods should take into account the characteristics of the building, the local climate and the desired level of energy efficiency.

3. Materials used in thermomodernization

Thermomodernization of buildings involves the use of various materials to enhance the energy efficiency, insulation, and overall performance. More than 40 types of major thermal insulation materials are available worldwide. Based on the types of raw materials used, these thermal insulation materials can be divided into two broad groups: organic (carbon-based) and inorganic (lacking carbon-hydrogen bonds, mineral) insulations.

Organic materials, non-organic materials, and HI-TECH materials insulations can be further subdivided into natural and synthetic insulations based on the sourcing of raw materials and their processing. Here are some common materials used in thermomodernization.

Expanded Polystyrene (EPS) Insulation: A thermal insulation made from expanded polystyrene beads, manufactured by heat-expanding the beads using high-pressure steam. It's commonly used in construction due to its lightweight and insulating properties.

Extruded Polystyrene (XPS) Insulation: Another type of thermal insulation made from polystyrene, manufactured by mixing beads with additives and a blowing agent in an extruder. The resulting foam is shaped, cooled, and cut to size.

Polyethylene (PE) Insulation: Also known as PE foam, used primarily for insulating pipes and soft packaging. It's made from polymerized ethylene and various catalysts, extruded into foam form.

Spray Foam Insulation: A type of insulation applied as a spray, expanding to fill gaps and cavities. It can be closed-cell or open-cell foam and is known for its effectiveness but has faced health and environmental concerns.

Structural Insulated Panels (SIPs): Composite panels with thermal insulation, increasingly used in construction for faster building. They consist of two sheets of wood or steel with insulation bonded between them.

Magic Wallpaper and Thermal Paint: Thin coatings claimed to mitigate condensation, made from various aggregates, resins, and additives like expanded polystyrene, carbon black, or graphite.

Hemp-Lime Insulation (Hempcrete): A biocomposite insulation and wall material made from hemp fibers and lime. It's considered carbon-negative due to the sequestration of more carbon by hemp plants than emitted during production.

Mineral Wool Insulation: Made from rock or glass wool, known for its thermal and acoustic insulation properties. It's widely used in construction.

Polyisocyanurate (PIR) and Polyurethane (PUR) Insulation: Closed-cell plastic foam insulation produced from polyol and isocyanate. Used in areas with limited space due to its high insulating efficiency.

Sheep Wool Insulation: A niche product made from sheep wool, known for being hygroscopic (adsorbing moisture) yet hydrophobic (repelling liquid water).

Phenolic Insulation Boards: Known for their high thermal efficiency and fire safety, made from phenol, urea, and melamine-formaldehyde polymers.

Cotton Waste Insulation: Made from recycled textile fibers like cotton, wool, and denim waste. It's eco-friendly and available under various product names.

Aircrete (Aerated Concrete and Autoclaved Aerated Concrete): Lightweight concrete blocks with better thermal performance than traditional blocks, made from pulverized fuel ash with added cement, lime, and a foaming agent.

Insulating Clay Bricks: Similar to regular clay bricks but with honeycomb air holes for insulation. Used to enhance thermal performance in building envelopes.

Glass Wool Insulation: Made from glass fibers arranged with a binder, offering both thermal and acoustic insulation properties. Widely used in construction.

Thermal Break Windows and Doors: Feature insulating materials between interior and exterior surfaces to minimize heat transfer, reducing energy loss.

Wood Fibre Insulation: Provides insulation and a natural aesthetic, chosen for sustainability and design versatility. It's known for its high moisture buffer and moderate thermal conductivity

Waterproof Membranes: Essential for preventing water infiltration into building structures, ensuring the integrity of roofs.

The materials which are using during thermomodernization could save the energy and extends the life of the building. Beside this it makes the building more economical for the future and increases value of the building.

4. Case study of the economic profitability of the thermal modernization process

Rotary House ul., also known as Assistant Hotel. Zwierzyniecka in Białystok is an important architectural building affiliated with the Białystok University of Technology. The design and development of this building has been meticulously documented over the years, providing a historical summary of its architectural evolution and various changes. Information about the building was obtained from the energy audit of the building (Sadowska, Sarosiek, 2018).

4.1. Description of the building selected for analysis and of the existing state

The first architectural design of the Rotary House was prepared by the General Construction Design Office in Warsaw in 1978. This basic document outlines the structural aspects and plan of the building, capturing the essence of its original design. Meticulous details from this period provide a glimpse into the architectural trends and ideas prevalent in the late 1970s.

One of the critical aspects of the building, as documented in existing design materials, is the central heating installation. The 1978 design includes plans and specifications for the heating system, which is an integral part of the comfort and functionality of the building. The centrality of this system is a testament to the foresight in providing a conducive environment within the Assistant Hotel.

Fast forward to 2006, Rotary House is undergoing a modernization project for its warming center. This initiative reflects the determination to keep pace with technological advances and meet the evolving needs of the facility. Documents from this period shed light on the engineering considerations and innovations used in improving heating infrastructure.

In 2013, the focus shifted to sustainable energy solutions with the construction design of a solar hot water installation. This forward-looking approach is in line with contemporary environmental awareness and emphasizes the integration of renewable energy sources into building systems. In addition, the partial demolition and construction of the new lightning protection facility underlines the commitment to safety and compliance with modern standards.

The involvement of the plumbing design studio further highlights the collaboration of specialized professionals in the development of the building's infrastructure. Their contributions in June 2013 were instrumental in resolving water supply issues and ensuring the safety of building occupants through an improved lightning protection system.

The commitment to energy efficiency is even more evident in the intention to implement the measures proposed in the energy audit (Sadowska, Sarosiek, 2018) carried out in accordance with the Law of 21 November 2008 on the promotion of thermal modernization and renovation (Act of 21 November 2008…). This proactive measure is in line with contemporary practices in ensuring sustainable and cost-effective building management.

The declared maximum self-contribution of 0% and the loan option covering 100% of the total planned costs demonstrate a strategic financial approach to the modernization project. This financial structure creates comprehensive improvement opportunities without placing an undue burden on the investor's immediate financial resources.

The building, also designated as a Mass Housing building, was built in 1979 and was officially opened for use in 1980. Prefabricated materials were used in the construction of the building, which was a common practice in such structures at that time.

The Mass Housing building, consisting of a total of 120 flats, provides housing opportunities for a significant number of residents. The estimated occupancy rate of the building is around 217 people (Sadowska, Sarosiek, 2018). The decision to embark on deep thermomodernization processes demonstrates a commitment to improving the energy efficiency and overall environmental performance of the building in line with contemporary standards and regulations for sustainable and resource-efficient construction.

Ultimately, the Rotary House is a testament to architectural evolution and adaptability. From its founding in 1978 to its most recent modernization efforts, the documentation and collaborative efforts of professionals reflect the dedication to maintaining a state-of-the-art facility. Integration of sustainable energy solutions, adherence to building standards, and financial planning strategies position Rotary House as a model for responsible and forward-thinking building management in academia.

4.2. Selection of methods to reduce energy demand

Today, there are various methods available for determining the most effective ways to reduce energy demand. Among these methods are Simply Pay Back Time (SPBT), Pay Back Time (PBT), Net Present Value (NPV), Net Present Value Ratio (NPVR), Internal Rate of Return (IRR), and Dynamic Pay Back Time (DPBT).

While there are numerous methods to choose from, studies conducted in Poland predominantly utilize Simply Pay Back Time (SPBT). This method is favored because it offers more precise and accurate results. However, employing multiple methods can lead to even more precise outcomes than those obtained through singular calculations, enhancing the clarity and reliability of the results.

In our examination of a building, we began calculating the effects of changes using Simply Pay Back Time (SPBT). This allowed us to obtain clear and reliable results, providing valuable insights into the efficiency of energy reduction measures.

Thermal conductivity or U-value measures how much heat passes through building materials. Lower U-values indicate better insulation, which translates to energy savings, improved comfort, and compliance with regulations. Investing in high-quality insulation with low U-values ensures sustainable and cost-effective buildings. The values seen in the table show the pre-thermomodernization values of our current building. As understood from the values, it can be seen that our building is old and energy savings are significant.

Table 1.
Thermal transmittance of partitions before thermomodernization

Building Element	For the Existing Building 'U' = (W/(m^2.K)
Warm ceiling downwards	0,783
Ventilated flat roof	0,422
External walls of staircases (rounded part)	0,403
External wall first floor	1,122
External wall(ground floor)	1,267
Window (For ground floor)	2,6
Window (For all another floors)	2,6
Doors	3

Source: Own study.

The deep thermomodernization process aims to provide solutions to these problems. This process aims to reduce energy consumption by increasing the energy efficiency of the building and therefore reduce operating costs. Therefore, examining the data obtained after deep Thermomodernization is of great importance. This data will help us evaluate the effectiveness of improvements made and guide future decisions.

Table 2 contains information on the results of thermal modernization. It has been determined that the energy consumption of the existing building and the cost spent on heat are quite high annually when taken into account before deep thermomodernization. Total annual energy consumption was calculated as 1,870,884.18 kWh. This shows that the current structural condition of the building is not energy efficient and causes unnecessary energy losses.

Table 2.
Results of the economic analysis for existing stage

Energy Needs	Unit	Before Thermomodernization
Energy needs for heating	kWh/year	1 196 266,43
	GJ/year	4306,56
Heat for domestic hot water	kWh/year	674 617,75
	GJ/year	2 428,62
Total energy needs	kWh/year	1 870 884,18
	GJ/year	6 735,18
Annual cost of heat supplied	PLN/year	466 658

Source: Own study.

In the same period, the annual cost of the building for heating was determined as 466,658 PLN. The high cost highlights the inefficiency and energy waste of current heating systems. This increases the operating costs of the building and creates an unsustainable situation in the long term.

According to the calculations made before Deep Thermomodernization on our current building, it was determined that our building was classified as B2 in terms of energy efficiency. This implies that our current building regulations falls within the B2 energy efficiency class according to building regulations.

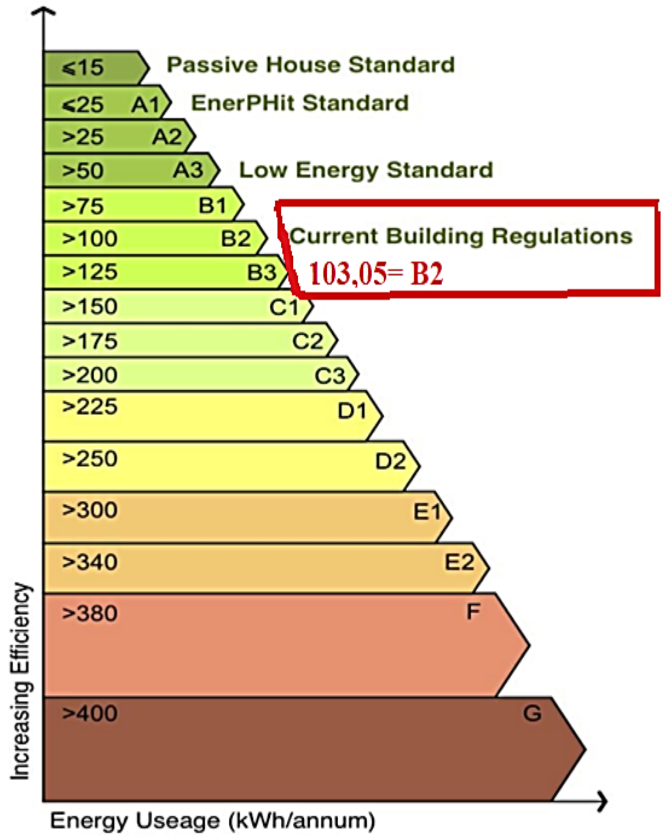

Figure 1. Classification of building before deep thermomodernization.

Source: Own study, https://termomodernizacja.pl/klasy-energetyczne-sprawdz-w-ktorej-bedzie-twoj-dom/

Energy classification is typically used as a measure to assess buildings' energy consumption and efficiency. The B2 class usually indicates buildings with moderate energy efficiency. Thus, it means that our building's energy consumption is at the current level and could be made more efficient. Such classification helps identify the need for improvements aimed at energy savings and reducing environmental impact.

4.3. Determination of energy saving in individual thermal modernization variants and economic analysis

Let's examine the economic changes that occur after deep thermomodernization is carried out in our current building. The comprehensive scope of thermomodernization activities for the optimum scenario encompasses a series of measures aimed at enhancing a building's thermal performance and energy efficiency. These measures are designed to strengthen the building envelope and optimize energy consumption.

Initially, an energy study and assessment are conducted. This involves analyzing the current energy usage and identifying potential energy losses within the building. Subsequently, improvements are implemented on the building's exterior. This includes selecting high-performance insulation materials and installing external insulation systems to increase thermal resistance.

Table 3.
Thermal transmittance of partitions After Deep thermomodernization

Building Element	For the Existing Building 'U'= (W/(m^2.K)	After renovation 'U'= (W/(m^2.K)
Warm ceiling downwards	0,783	0,783
Ventilated flat roof	0,422	0,15
External walls of staircases (rounded part)	0,403	0,2
External wall first floor	1,122	0,2
External wall(ground floor)	1,267	0,2
Window (For ground floor)	2,6	0,9
Window (For all another floors)	2,6	0,9
Doors	3	1,3

Source: Own study.

Regarding the roof, the modernization process requires updating or installing insulation for flat or pitched roofs, focusing on ensuring adequate ventilation. Additionally, windows and doors are replaced or upgraded to energy-efficient models. This may involve installing glazed windows with low-emissivity coatings and improving door sealing mechanisms to minimize heat loss and improve overall thermal efficiency.

As a result of our investigations, we determined that the current heat permeability coefficient of the building is significantly lower than the standards it must meet after renovation. In reality, all the values we reviewed are well below the required standards.

This situation shows in the table above how important the renovation work is for our building. After the renovation, we focused on minimizing heat loss. In this process, the standards in Bialystok, Poland were taken into account.

Table 4.
Results of the economic analysis after thermomodernization

Energy needs	Unit	Before thermomodernization	After thermomodernization
Energy needs for heating	kWh/year	1 196 266,43	706 476,60
	GJ/year	4306,56	2543,3
Heat for domestic hot water	kWh/year	674 617,75	674 617,75
	GJ/year	2 428,62	2 428,62
Total energy needs	kWh/year	1 870 884,18	1 381 094,35
	GJ/year	6 735,18	4 971,92
Annual cost of heat supplied	PLN/year	466 658	275,597.30

Source: Own study.

Table 4 shows the annual energy demand for heating before and after thermal modernization. With the application of all considered treatments, energy demand was reduced by 42%. This shows how important deep thermal insulation is and that energy losses should be minimized in every building. Since no improvements have been made to this system, no changes have been made to the domestic hot water heating processes.

Following the implementation of deep thermomodernization, a significant reduction in the total annual heating cost was seen. The annual heating cost, which was originally 466,658 PLN, has now dropped to 275,593.30 PLN. This success shows that annual heating expenditures were reduced by almost half (41%) after the implementation of deep thermomodernization.

The data collected highlights the effectiveness of deep thermomodernization in preventing heat loss and improving energy efficiency. Research findings show that this technology not only significantly reduces operating costs but also carries the potential for long-term energy savings in the future.

In this context, it can be concluded that deep thermomodernization is a significant long-term investment. It not only optimizes costs, but also contributes to environmental sustainability by minimizing heat loss and increasing energy efficiency. We believe that our efforts to minimize heat loss and increase energy efficiency are an important step towards optimizing operating costs and reducing environmental impact

Conclusions

1. Deep thermomodernization of the casing of the 11-story Rotary House of the Asystenta Hotel at the Białystok University of Technology campus, including thermal insulation of walls, roof and replacement of windows and doors, allows for energy savings of 42%.
2. The greatest percentage of energy savings was achieved by insulating the external walls 23%, followed by replacing windows 16,5%, ventilated flat roof improvement about 2%, and replacing doors 0,5%. The total exchange after deep thermomodernization is 42%.
3. After taking into account the amount of heat for preparing domestic hot water (constituting a significant share in the total heat demand), the percentage savings as a result of thermal modernization would amount to 26.2%.
4. The simple payback time (SPBT) for individual thermal modernization projects ranged from 4,32 years for external walls to 15,41 years for external doors and 13.74 years for ventilated flat roof and 10,34 for windows.
5. After the application of deep thermomodernization, the total annual cost for heating has seen a significant reduction. The yearly heating cost, which was initially 466,658 PLN, has now decreased to 275,593.30 PLN. This achievement indicates that annual expenditure on heating has nearly halved (by 41%) following the implementation of deep thermomodernization.

References

1. Act of 21 November 2008 on support for thermomodernisation and renovation. *Journal of Laws 2008, no. 223, 1459.* Poland, as amended.
2. Akram, N., Farooq, P., Haq, M.U., Nabeel, M., Asghar, F. (2024). Evaluating the Financial Feasibility of Renewable Energy Integration in Construction Sector. *The Asian Bulletin Of Green Management And Circular Economy*, *4*(1). Lahore, pp. 1-15.
3. Krawczyk, A.D. (2022). *Sustaınable Buıldıngs Development Of Low Energy And Eco-Frıendly Constructıons.* Bialystok, pp. 207-225.
4. Bartoszek, M., Guzik, J., Ronowski, K., Wysocki, K. (2019). *Termomodernizacja. Przedsięwzięcia, efekty, finansowanie.* Krosno: Wydawnictwo i Handel Książkami „KaBe", pp. 33-54.
5. Barwińska-Małajowicz, A., Pyrek, R., Szczotka, K., Szymiczek, J., Piecuch, T. (2023). Improving the Energy Efficiency of Public Utility Buildings in Poland through Thermomodernization and Renewable Energy Sources—A Case Study. *Energies*, *16*(10), 4021. Rzeszow, pp. 9-18.
6. Chwieduk, D. (2003). Towards sustainable-energy buildings. *Applied energy*, *76*(1-3), Warsaw, 211-217.
7. Ding, G.K. (2014). Life cycle assessment (LCA) of sustainable building materials: an overview. *Eco-efficient construction and building materials.* Sydney, Australia, pp. 38-62.
8. EN 12831:2006; *Energy performance of buildings - Method for calculation of the design heat load.*
9. Hafner, M., Raimondi, P.P. (2020). Priorities and challenges of the EU energy transition: From the European Green Package to the new Green Deal. *Russian Journal of Economics, 6(4),* 374-389.
10. Hens, H. (2023). *Building Physics - Heat, Air and Moisture.* Berlin, pp. 100-150.
11. ISO 13790:2008 (2008). *European Standard: Energy Performance of Buildings-Calculation of Energy Use for Space Heating and Cooling*. Brussels, Belgium: CEN.
12. ISO 6946:2017 (2017). *Building Components and Building Elements—Thermal Resistance and Thermal Transmittance—Calculation Method*. Geneva, Switzerland: ISO.
13. Krawczyk, D.A., Ruiz de Adana, M., Moreno-Pérez, M.F., Bullejos Marín, D., Teleszewski, T., Teilans, A. (2022). *Sustainable buildings. Designing and management of cost-effective and eco-friendly system*. Bialystok, pp. 88-107.
14. Latif, E., Bevan, R., Woolley, T. (2019). *Thermal ınsulatıon materials for building applications*. London.
15. Marushchak, U., Pozniak, O. (2022). Analysis of wall materials according to thermal parameters. *Theory and Building Practice*, *4*(1). Lviv, pp. 63-70.

16. Oikonomou, V., Becchis, F., Steg, L., Russolillo, D. (2009). *Energy saving and energy efficiency concepts for policy making. Energy policy.* London, pp. 4787-4796.
17. Piotrowska-Woroniak, J., Cieśliński, K., Woroniak, G., Bielskus, J. (2022). The Impact of Thermo-Modernization and Forecast Regulation on the Reduction of Thermal Energy Consumption and Reduction of Pollutant Emissions into the Atmosphere on the Example of Prefabricated Buildings. *Energies, 15(8), 2758*. Bialystok, pp. 02-40.
18. Piotrowska-Woroniak, J., Szul, T., Cieśliński, K., Krilek, J. (2022). The Impact of Weather-Forecast-Based Regulation on Energy Savings for Heating in Multi-Family Buildings. *Energies*, *15*(19), 7279. Krakow/Bialystok, pp. 10-13.
19. Piwowar, A., Dzikuć, M. (2024). The Economic and Social Dimension of Energy Transformation in the Face of the Energy Crisis: The Case of Poland. *Energies*, *17*(2), 403. Wrocław, pp. 03-10.
20. Robakiewicz, M. (2023). *Swiadectwa energetyczne budynkow*. Warszawa, pp. 147-173.
21. Sadowska, B. (2018). *Effects of deep thermal modernization and use of renewable energy in public buildings in north-eastern Poland*. Proceedings of the 20th International Scientific Conference Engineering for Rural Development, Jelgava, Latvia, pp. 26-28.
22. Sadowska, B., Piotrowska-Woroniak, J., Woroniak, G., Sarosiek, W. (2022*). Energy and Economic Efficiency of the Thermomodernization of an Educational Building and Reduction of Pollutant Emissions*—A Case Study. *Energies*, *15*(8), 2886. Bialystok, pp. 5-10.
23. Sadowska, B., Sarosiek, W. (2018). *Energy audit of the Rotary House* (Audyt energetyczny budynku Hotelu Asystenta w Białymstoku przy ul. Zwierzynieckiej 4). *NAPE SA, Białystok*.
24. Santamouris, M., Vasilakopoulou, K. (2021). Present and future energy consumption of buildings: Challenges and opportunities towards decarbonisation. *e-Prime-Advances in Electrical Engineering, Electronics and Energy, 1*, 100002.
25. Watkins, D.E. (2011). *Heating Services in Buildings.* Hoboken, New Jersey, United States, pp. 55-105.