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THE BENEFITS OF IMPROVING THE TECHNICAL CONDITION OF A BUILDING IN THE CONTEXT OF ENERGY EFFICIENCY

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ABSTRACT: This article deals with the impact of thermal upgrading measures on the energy efficiency of a building. The thesis is that improvement of the technical condition through: increasing the thermal insulation of walls, modernisation of ventilation system, regular inspections and repairs of central heating boilers, modernisation of hot water preparation systems, the introduction of alternative energy sources or using modern technologies in construction, affects the increase of energy efficiency of this building.

KEYWORDS: energy efficiency of the building, technical condition of the building, thermomodernization measures of buildings

No. 2(77) 2021 • pages: 56-80 https://doi.org/10.34659/2021/2/12 JEL: Q42, R39

Introduction

In light of the current legislation on environmental protection and energy conservation, the energy efficiency of buildings is a major challenge not only for private property owners, but also the managers of public buildings. The main reasons for the building's excessive consumption of thermal energy are inadequate insulation of the external envelope and low efficiency of the central heating system. Therefore, to improve the energy efficiency of the object, many improvements called thermomodernization are carried out.

This article aims to assess the impact of the technical condition of a selected public building on its energy efficiency. A school building was chosen for the analysis. Based on the energy audit, the technical condition of the object before thermomodernization was analysed, with particular emphasis on thermal energy consumption. Then seven variants of thermomodernization were indicated, and the scope of works for the optimal variant was specified. Detailed analysis and technical condition assessment of the building after thermomodernization allowed to compare the energy demand of the building for heating and domestic hot water preparation. It also allowed indicating the elements which significantly affect the reduction of this demand. The improvement of the energy efficiency of a building brings benefits on several levels. The most expected are the financial savings achieved by reducing the building's thermal energy demand, which concludes that the achieved energy effect translates into an economic effect. In addition, a building that uses less fuel has a positive impact on the environment. Therefore, an extended approach to energy and the related issue of energy efficiency is included in the Sustainable Energy Policy. This concept links energy use to all aspects of sustainability: social, economic and environmental. The purpose of sustainable energy policy is to improve the standard of living of society while maintaining a balance between energy security, meeting the needs of society, the competitiveness of services and environmental protection (Lis, 2009).

Related research

The energy efficiency of a building in the context of environmental protection

Topics related to the energy efficiency of buildings, resulting from the improvement of their technical condition, is taken up by many authors in various studies. In Poland, for many years, the analysis and assessment of the technical condition of buildings from the point of view of their importance in the efficient energy management are dealt with, among others, by Górzyński, Nadolna, Lis, Sadowska, Stachniewicz, Kaliszuk-Wietecka, Węglarz, Krajewska, Drozd and many others.

Limited resources of fossil fuels and the resulting increase in their prices affects the increased emphasis on environmental protection and the emergence of more and more new legal regulations on thermal protection of buildings (Górzyński, 2012). Inevitably linked to this is the energy efficiency concept, which is explained as „the ratio of the achieved amount of the utility effect of a given object (...) to the amount of energy consumption by this object" (Law of May 20 2016 on Energy Efficiency). In other words, it is the relationship of the amount of energy used to heat a building before and after its modernisation or thermomodernization.

In order to determine the energy demand of a facility, it is necessary to analyse the energy performance of a building. According to the Energy Performance of Buildings Act of August 29 2014, this term is explained as the energy data and indices of a building that determine „the total energy demand required for their usage in accordance for their intended purpose". According to the model certificate of the energy performance of a building, which is an annexe to the Regulation of the Minister of Investment and Development of February 27 2015. (item 376), currently, there are three indices necessary to perform such characteristics: *Eu* – an indicator of annual demand for usable energy [kWh/(m^2-yr)], *Ek* – an indicator of annual demand for final energy [kWh/(m^2-yr)] and *Ep* – an indicator of annual demand for non-renewable primary energy [(kWh/m^2-yr)]. In addition, ECO_2, describing carbon dioxide emissions [t CO_2/(m^2-yr)], and % RES, or the share of renewable energy sources in the annual final energy demand.

In order to improve the energy efficiency of the building, thermomodernization of the building is carried out, which means certain actions aimed at reducing the expenses incurred for heating the building and preparing hot water. The thermomodernization brings a number of other benefits such as less fuel used to heat the building, reduction of pollutant emissions to the environment as well as improvement of the external appearance of the building. In order for the thermomodernization measures to have the intended effect of improving energy efficiency, it is necessary to carry out a full energy audit before starting the thermomodernization works (Nadolna, 2014).

The energy audit as „a study specifying the scope, technical and economic parameters of a thermomodernization project, indicating the optimum solution, in particular from the point of view of project implementation costs and energy savings". This document contains, among others: technical and construction inventory of the building together with the characteristics of installations and heating systems. If the energy audit shows that as a result of thermomodernization measures there the following will occur:

- reducing annual energy demand by 10% for buildings in which only the heating system is modernised or by 25% for other buildings, or
- reduction of annual energy losses by at least 25%, or
- reduce annual heat acquisition expenditures by at least 20% or
- switching to a renewable energy source.

The investor can apply for a „thermomodernization bonus", i.e. a bonus for repaying a part of the loan taken for thermomodernization (Act of November 21 2008 on supporting thermomodernization and renovation).

The concept of energy efficiency can be broadly understood as a set of different types of actions, behaviours and conditions that come down to minimising energy losses and the costs incurred for its generation (Lis, 2009). A large part here plays environmental protection and more and more new legal regulations, not only Polish but also European.

Factors affecting building energy efficiency

Factors determining energy efficiency can be divided into external, which is meant climatic conditions or urban conditions, and internal, which can include: the way the building is used or the types of installations in which the building is equipped (Sadowska, 2016).

The factors most often cited by experts are:

- the period during which a given building object is designed and then erected and used. The type of building materials, energy carriers or equipment and installation elements undoubtedly affect the energy consumption of the building (Górzyński, 2012);
- architectural solutions resulting from local spatial development plans should be taken into account at the design stage. The applied solutions should serve to minimise the negative impacts of wind and maximise the use of solar radiation (Kaliszuk-Wietecka, Węglarz, 2019);
- a solid, which in its most favourable shape should be simple and compact, e.g. a cube. It is connected with the building shape coefficient A/V, which is the ratio of the external partition surface to the heated volume of the building. An extended body of the building, containing recesses, bays or arcades, increases heat transfer which is associated with excessive energy consumption (Firląg, Warsaw 2019);
- thermal insulation of external and internal partitions, walls adjacent to expansion joints, walls of unheated underground storeys, roofs, flat roofs and ceilings under or over unheated rooms, floors on the ground, which in turn increases the tightness of the building and reduces the share of

infiltration losses. The proper technical condition of window and door woodwork is also important;
- the ventilation system used (Kaliszuk-Wietecka, Węglarz, 2019);
- type of central heating system (Kaliszuk-Wietecka, Węglarz, 2019);
- the hot water preparation system implemented in it;
- the lighting system used and furnishing it with household appliances and electronics (Firląg, 2014).

Types of thermal upgrading measures

Thermomodernisation consists of making changes to reduce heat loss and provide more economical and energy-efficient heating for the interior and domestic water. The main reason for the high consumption of heating energy is excessive heat loss from the building. As already mentioned, it penetrates outside the building through inadequately insulated external walls and windows, roof and floor on the ground. For that reason, thermomodernization is usually performed:
- insulation of external walls of the building;
- replacement of window and door woodwork;
- roof or flat roof insulation;
- insulating the ceiling above an unheated basement or insulating the floor on the ground.

Thermomodernization of the building also concerns its internal installations and consists, among others, in:
- modernisation or replacement of the heating system;
- start using RES (renewable energy sources) for heating purposes, e.g. by installing solar collectors or heat pumps;
- the use of mechanical ventilation with heat recovery (recuperation);
- insulation of exposed central heating and hot water pipes;
- improvement of the domestic hot water preparation system.

Research methodology

Methods of assessing the technical condition of buildings

There are several methods of assessing the technical condition of buildings. One of the most common is the visual method, which is carried out on the basis of visual inspection of the building, also taking into account the age of durability and operation of the building. It is characterised by quickness of execution and widespread acceptance of the results. Visual assessment of a building's technical condition can be augmented by either exploratory or laboratory testing for samples taken from the building (Drozd, 2017).

The visual assessment can be performed using the following formula (1) for the weighted-average method of building deterioration (Drozd, 2017):

$$Sz = \sum_i^n \frac{U_{ei} \cdot Sze_i}{100}, \quad (1)$$

where:
Sz – is the weighted average degree of technical wear and tear of an object expressed as a percentage;
U_{ei} – percentage share of the value of the i-th element in the cost of the entire building (...);
Sze_i – the degree of wear of the i-th element (...) expressed as a percentage;
n – number of integrated elements;
i – another element.

The value for U_{ei} is determined according to source materials, or as in the case of the value for Sze_i, it is determined by an appraiser. Thus, adequate knowledge and experience are required in this case (Drozd, 2017). In addition to the visual method, time-based methods are often used, which are used depending on the degree of care for a given object. A distinction is made (Drozd, 2017):

- linear method, the so-called proportionality method, which is adopted in the case of buildings in poor use, for which repairs were not carried out or were performed rarely:

$$Sz = \frac{t}{T} \cdot 100\%, \quad (2)$$

where:
Sz – is the degree of technical wear and tear;
t – determines the age of the building in years;
T – shows the expected life of the facility expressed in years.

- non-linear method, used for buildings for which renovations were performed regularly:

$$Sz = \frac{t(t+T)}{2 \cdot T^2} \cdot 100\%. \quad (3)$$

- the parabolic method, for buildings according to which the owner or manager expresses special care by performing repairs more often than usual:

$$Sz = \frac{t^2}{T^2} \cdot 100\%. \quad (4)$$

Other methods are also known for determining the technical wear and tear of a building, mostly used in the West. They are characterised by greater complexity of formulas, but they do not introduce new parameters except the already mentioned: age of the building t and durability of the building These are methods: „Graff, Gerarde, Hague, Tschellestnigg" (Drozd, 2017).

Case study

Study Subject. Characteristics of a public building

The subject of the analysis is a public building dating back to the 1920s that served as an elementary school and was intended for educational purposes. The analysed building is located in the area under preservationist protection – in „B" zone, which means strict preservationist protection of the historical urban layout. Modernisation of the building was allowed in order to adjust it to current standards or in case of a desire to increase its aesthetic value. However, any activity required a conservator's agreement. The investor carrying out the comprehensive thermomodernization obtained the necessary permission from the Voivodship Conservator of Monuments, with the emphasis on the obligation to make smooth plaster on the external walls.

Comprehensive thermomodernization of the analysed building was aimed at lowering the operating costs of heating the building and preparing hot water and meeting the requirements of thermal protection of the building.

Analysis of the technical condition of the building before thermomodernization

The analysed building is a rectangular-plan object with a building shape factor of 0.50 [1/m]. It was built in traditional brick technology, two-story, with a partial basement and an attic.

The building consists of two parts: the main building with two balconies, cornices and lisens on the top floor and the second part of the building – slightly lower, serving as an administration building. The building has a gable roof, on a wooden rafter framing with rafter and purlin structure, covered with flat metal sheets. Window frames – tripartite or bipartite PVC windows – in good technical condition and not in need of replacement. The building is adapted to the needs of the disabled – there are two ramps, two parking spaces and an elevator.

Basic data regarding the area, cubic capacity and building dimensions are presented in table 1.

Table 1. Basic technical parameters of the analysed building

No.	Parameter	Value	Unit
1.	length	41.46	m
2.	width	12.09	m
3.	height	11.40	m
4.	build-up area	about 550.00	m^2
5.	usable area	937,10	m^2
6.	communication area	265.17	m^2
7.	cubage	about 4000.00	m^3
8.	cubic capacity of the heated part	3095.00	m^3

Source: Sarosiek et al., 2015.

The external walls of the building are made of 54 cm thick solid brick and plaster on both sides. The ceiling under the unheated attic is a dense rib ceiling. These partitions are characterised by insufficient thermal insulation. The values of heat transfer coefficient U [W/(m^2·K)] for external partitions are as follows:

- external basement walls: $U = 1.151$ for above ground basement walls and $U = 0.661$ for walls in the ground;
- external walls of above-ground: $U = 1.151$;
- ceiling under unheated attic: $U = 0.973$;
- exterior entrance doors: $U = 2.00$ (for above-ground section doors) and $U = 5.10$ (for basement doors).

These values were too high in relation to the requirements included in technical conditions that buildings and their location should meet. In order to reduce them and thus limit heat losses, it was necessary to insulate the building envelope and the floor under the unheated attic with a thermal insulation material e.g. foamed polystyrene. It was also advisable to replace the old door frames with modern doors of low heat transfer coefficient U.

The central heating system of the building consisted of an eco-pea coal boiler room from 2010 with central regulation, traditional and previously unmodernised two-pipe system with bottom distribution and sectional cast iron radiators without thermostatic valves. The technical condition of radiator valves did not allow for their regulation due to the possibility of leakage.

Table 2. Efficiency coefficients of central heating installation before thermomodernization of the building

Components of the efficiency index	Value	Additional information
ηg	0.70	determined on the basis of an on-site visit of an energy audit
ηd	0.80	ducts without insulation in the unheated part
ηe	0.77	central adjustment, no local adjustment
ηs	1.00	no buffer tank

Source: Sarosiek et al., 2015.

Characterisation of the central heating system can be done by the efficiency coefficients (table 2) shown in the above table. The total efficiency of the heating system o was calculated using the following formula (5):

$$\eta_o = \eta_g \cdot \eta_d \cdot \eta_e \cdot \eta_s, \tag{5}$$

where:
η_g – is the efficiency of heat generation;
η_d – heat transfer efficiency;
η_e – efficiency of regulation and use of the heating system;
η_s – represents the efficiency of accumulation.

Based on the energy audit of the education building in question, the total efficiency of the heating system is:

$$\eta_o = 0.70 \cdot 0.80 \cdot 0.77 \cdot 1.00 = 0.4312.$$

In addition, this document presents the energy characteristics of the building, the calculations of which were performed using the computer program Audytor OZC 4.8 Pro, for meteorological data from the station Bialystok. Peak heating power (demand for thermal power) is 95.58 kW. Seasonal demand for heat in standard heating season is 1,209.32 GJ/year, and taking into account the efficiency of the central heating system, this value increases to 2,804.55 GJ/year. In order to improve the efficiency of the heating system, it was necessary to perform a completely new central heating installation together with the replacement of radiators with thermostatic valves on each one.

Analysing the technical condition of the building before modernisation, one should also pay attention to the method of preparation of usable hot water at the designed temperature of 60°C. During the heating season, the hot water was prepared in the existing boiler room for eco-pea coal.

During the summer season, hot water was supplied by electricity through the use of electric water heaters. The hot water supply pipes are galvanised steel pipes, and the entire installation is routed alongside the cold water and sewage pipes. According to the design data, the average annual hot water consumption was 274 m^3.

Air exchange is mainly through gravity ventilation. In addition, there is also micro-ventilation of windows. Due to the old door carpentry, there could be periodically an excessive influx of cold air during the winter season, thus affecting the heat consumption needed to heat the ventilation air.

According to the energy audit of the building in question, the ventilation airflow, calculated in accordance with the requirements of in PN-83/B-03430/Az3:2000 „Wentylacja w budynkach mieszkalnych zamieszkania zbiorowego i użyteczności publicznej" („Ventilation in residential buildings of collective residence and public utility buildings"), was 2,358 m^3/h.

Summarising the technical condition of the various components of the educational building, it was necessary to introduce several thermomodernization improvements in order to reduce the consumption of thermal energy, reduce the costs associated with its production and adapt the building to current guidelines for thermal protection. For implementing these works, the investor received funding from the European Regional Development Fund under the Regional Operational Program of the Province for 2014-2020, action 5.3 Energy efficiency in the housing sector and public utility buildings.

Determination of optimal variant of thermomodernization undertaking

The energy audit of the building in question presents seven different variants of thermomodernization undertakings. The differences between them consist, among others of: the scope of proposed works, planned costs of execution of these works, annual savings of energy costs, as well as percentage savings of energy demand, taking into account the total efficiency.

- The first variant assumed: replacement of the entrance door to the overground part of the building, insulation of the external walls of the basement, replacement of the entrance door to the basement part of the building, insulation of the external walls of the overground part of the building, replacement of the hot water system, insulation of the ceiling under the unheated attic and replacement of the central heating system. The planned total cost was 366,662.00 PLN. Annual savings of energy costs could reach almost 64 thousand PLN. Percentage saving of energy demand was predicted within 70.50%;
- The scope of works of the second variant was very similar to the first one, but the replacement of the entrance door to the overground part of the building was omitted. The planned cost of works was calculated for the

amount of 345,522.00 PLN. The annual saving in energy costs would reach just over 63 thousand PLN, so in comparison to the first variant, it is almost a thousand PLN lower. Percentage saving of energy demand amounted to 69.49%;

- The third variant was reduced by insulation works on external basement walls. Total costs decreased to 325,469.00 PLN, and annual energy cost savings to just over 62 thousand PLN. Percentage saving of energy demand decreased to 68.30%;
- The works planned in the fourth variant included insulation of external walls of the building above ground and the ceiling under the unheated attic, as well as replacement of central heating and hot water installations. Planned costs were calculated at 322,529.00 PLN, and an annual saving of energy costs decreased relatively little, compared to the third variant, to the amount of 61,859.00 PLN. The percentage saving in energy demand, in comparison with the third variant, decreased by 0.18%;
- The fifth variant was limited only to the thermal insulation of the ceiling under the unheated attic and replacement of the hot water and central heating systems. The costs of such works oscillated around 229,673.00 PLN. As a consequence, compared to previous variants, the annual saving of energy costs decreased to 52,370.00 PLN and the percentage saving of energy demand to 57.28%;
- The scope of work in the sixth variant, in comparison to the fifth, has been reduced by the replacement of the hot water installation. The cost of their implementation was set at just over 209 thousand PLN and energy cost savings of over 51,000 PLN per annum. Savings in energy demand was calculated at 57.01%;
- The seventh variant – was limited only to the replacement of the central heating installation for the amount of 138,823.00 PLN. Energy cost savings were calculated at 22,745 PLN per year. Also, the saving of energy demand, in comparison to the sixth variant, could decrease more than twice – 25.99%.

The optimal variant, which meets all the requirements in the light of the Act of November 21, 2008, on supporting thermomodernization and renovations, is variant no. 1.

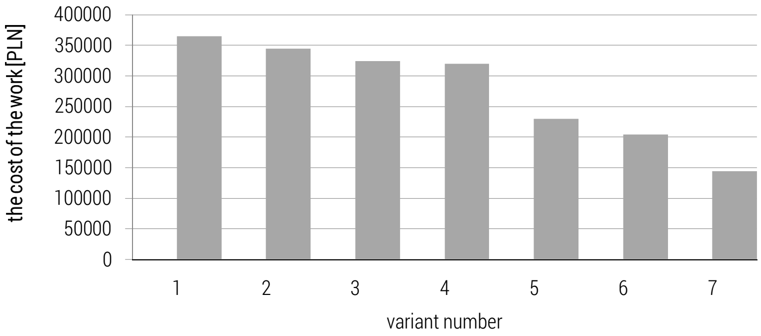

Figure 1. Planned total costs of thermomodernization works for seven variants

Source: author's work based on energy audit (Sarosiek et al., 2015).

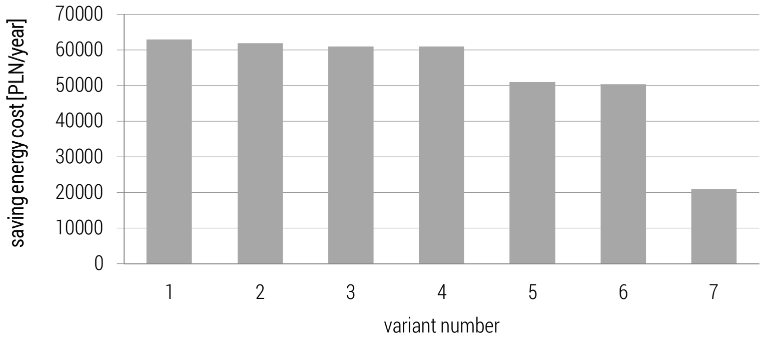

Figure 2. Annual energy cost savings for seven variants

Source: author's work based on energy audit (Sarosiek et al., 2015).

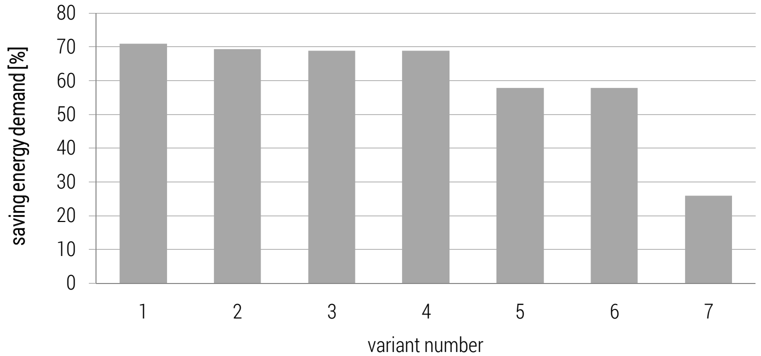

Figure 3. Percentage Energy Demand Savings with Total Efficiency

Source: author's work based on energy audit (Sarosiek et al., 2015).

Within the scope of works, it was necessary to insulate external walls of the building basements in such a way that thermal resistance of the insulation layer amounted to $R = 4.25$ (m^2·K)/W. For example, a part of the basement above ground level should be insulated with polystyrene with a thickness of 17 cm and thermal conductivity coefficient $\lambda = 0.04$ W/(m·K). The part located below the ground level had to be insulated with extruded styrofoam. The surface of basement walls which had to be insulated, amounted to 91.70 m^2. The cost of this work was estimated at 218.68 PLN per 1 m^2, which gives a total amount of 20,053 PLN. The external walls of the above-ground part of the building had to be insulated similarly to the above-ground part of the basement – with a 17 cm thick layer of insulation (styrofoam) with $\lambda = 0.04$ W/(m·K). The cost of insulating 636.00 m^2 was estimated at 92,856 PLN. The next thermomodernization work was the insulation of the ceiling over the last storey of the building with a 23 cm thick layer of mineral wool with $\lambda = 0.04$ W/(m·K), at the cost of 70,528 PLN. The works also included replacement of old entrance doors to the basements, at the cost of 2,940 PLN, and entrance doors to the overground part, at the cost of 21,140 PLN, with heat transfer coefficient $U = 1.30$ W/(m^2·K) each.

In order to improve the preparation of usable hot water, the installation of a solar installation has been proposed to support the existing heat sources – eco-pea coal boiler in the winter season and electric heaters outside the heating season. The total planned cost of this investment was estimated at over 20 thousand PLN. One of the most costly works was to perform a completely new central heating installation, including radiators and thermostatic valves on each. The calculated cost of the last proposed thermomodernization improvement is almost 129 thousand PLN. Heat demand, according to the optimal variant, would be 134,028 kWh/year.

In conclusion, it can be said that the scope of work included in the optimal variant of this project will reduce the energy consumption needed to heat the building and to prepare domestic hot water. This is part of the government's efforts to improve energy efficiency in the public sector. In addition, the purpose of this work is also to increase the aesthetic value of the building. The condition is to keep the same form and colour of the facade, which will preserve the historic value of the building.

Analysis of the technical condition of the school building after thermomodernization

The scope of thermomodernization works was not limited only to improvements proposed in the optimal variant. There were also performed many additional works improving both technical and visual condition of the building. In order to assess the technical condition of the school building after thermomodernization, technical documentation of the project and visual method based on inspection were used.

One of the key works which was carried out as part of complex thermomodernization was the insulation of external walls of the building. For this purpose, a number of necessary works were carried out. Initially, downpipes, exterior window sills, balcony railings, lighting, etc. were removed. Then, external walls were prepared for thermal insulation by washing with water, repairing plasters, filling cavities in walls and priming with deep penetrating primer. Then, according to the recommendations contained in the optimal variant of the energy audit, the walls were insulated with 17 cm thick polystyrene foam, using the light-wet method, which involves attaching the thermal insulation material to the wall, then covering it with a reinforcing layer, such as glass fabric, and finishing with a thin-coat plaster (Bajno, Grzybowska, 2017). This method is characterised by good sealing of the wall surface, durability and allows maintaining the traditional appearance of the building façade. The facade coating was made of silicate plaster. Also, the architectural details were insulated while maintaining their original proportions: cordon cornice, crowning cornices, lisens and decorative elements over the windows. The façade was painted with light sand colour, and architectural details were highlighted with white paint. According to the energy audit of the analysed building, after insulating the above-ground walls, the heat transfer coefficient will decrease from U = 1.151 W/(m^2·K) to U = 0.195 W/(m^2·K). Two balconies have also been insulated with 5 cm thick foamed polystyrene together with the execution of water insulation. On their surface, stoneware tiles were laid. The renovation of external walls also included the replacement of entrance doors to the ground floor with doors with the heat transfer coefficient of U = 1.30 W/(m^2·K). In addition, the balustrades were cleaned.

The balcony and staircase railings have been cleaned and painted, and new external window sills made of galvanised steel have been installed. Spikes were installed at the level of the cornice to protect the elevation against birds without posing any danger to them.

The basement and foundation walls were also insulated. Before starting the works, existing green areas were protected against possible damage. After dismantling the sidewalk surface and the band around the building, the building was dug out to the level of footings. Initially, a layer of waterproofing was made with dispersion mass. Next, the base and walls of the building were insulated to a depth of 160 cm using 17 cm thick Styrodur.

Below the ground level, a bucket foil was also placed, which additionally insulates the underground parts of the building. The plinths were finished with mosaic plaster in dark brown colour. In addition, the cellar window wells were renovated, the cellar door was replaced with a door with improved insulation parameters, for which the heat transfer coefficient is U = 1.3 W/(m^2·K), and the cellar stairs were renovated by laying stoneware tiles.

As part of thermomodernization works, the roof covering was renovated together with Solar installation and installation of solar collectors. After disassembly of antennas, lightning protection system, guttering and former metal roofing, rafters were extended in order to make the eaves sticking out in front of the wall. Then completely new roofing was made of brick-red tile together with wind insulation. At the same time, a new lightning protection system was installed, chimneys were renovated, and flashings were made. The highest ceiling was also insulated by installing a vapour barrier, mineral wool mats with a total thickness of 23 cm and a pressure layer made of light concrete with a thickness of 4 cm. The roof hatch over the staircase was also replaced.

The scope of thermomodernization works also included the execution of the solar installation supporting the preparation of usable hot water. For this purpose, solar collectors were mounted on the roof of the connecting passage between the analysed building and the second school building not included in the analysis and thermomodernization. Three Vitosol 200-F flat-plate collectors with a total surface area of 7.26 m^2 were selected. The connecting element between the solar thermal system and the existing DHW system is a 400-litre vertical bivalent water heater.

It serves as the primary hot water storage tank. When the amount of sunlight is not sufficient for the solar system to heat water to the required temperature, hot water is prepared through the top coil connected to the existing DHW cylinder.

When the amount of solar radiation is not sufficient for the solar system to heat water to the proper temperature, hot water is prepared through the upper coil connected to the existing central heating boiler. Radiators have also been replaced throughout the building.

The radiators were chosen according to the geometry and thermal power requirements of the room. Each radiator is equipped with a thermostatic valve.

Measures to improve the efficiency parameters of the heating system included: execution of a new central heating system with its insulation, made of steel pipes and installation of new radiators, which were selected according to the geometry and thermal power requirements of the room. Each radiator was equipped with a thermostatic valve with a head. For example, in a room (vestibule) with an area of 2.83 m^2 and a volume of 7.924 m^3, a radiator 0.6 m high, 0.4 m long and 0.06 m deep was installed. Its actual heating power is 292 W.

The main purpose of improving the technical condition of the building in question was to increase its energy efficiency. Significant influence on energy consumption in the analysed object had external partitions. The uninsulated walls, the leaky entrance door and the rusted roof, due to their insufficient insulation, caused heat losses by penetration. Also, the ceiling under the unheated attic had insufficient thermal insulation. The traditional central heating system, due to its low efficiency, was also qualified for modernisation. In addition to thermomodernization improvements, renewable energy sources were also used. Solar collectors were installed in order to heat up domestic hot water, thus reducing the consumption of electricity needed for its production. Another aim of thermomodernization of the discussed object was to adjust it to the requirements of thermal protection of the building, which will be obligatory in Poland since January 1, 2021. A positive aspect of this undertaking was the cost of investment execution, which was fully financed from European funds. This made it possible to carry out individual works at the same time.

Energy saving in heating and hot water preparation will reduce the costs of public institutions functioning. In addition, the improvement of technical conditions positively influenced the aesthetics of the building while preserving its historic values.

Results of the project

The influence of a building's technical condition on its energy efficiency

The main method to determine and indicate the impact of the technical condition of the selected building on its energy efficiency is the presented case study. One of the most important issues to be compared is the heat demand for heating the building and preparing domestic hot water.

The analysis shows that the works carried out in the optimal variant of thermomodernization allow saving more than 70% of energy demand. This energy saving value is influenced by several factors. The first of them is the limitation of energy losses by penetration through external partitions, which is the result of:

- insulation of external walls of overground and basements;
- thermal insulation of ceiling under the unheated attic;
- replacement of roofing with a new one;
- replacement of old door carpentry to the basement and;
- overground part of the building.

The lower values of the heat transfer coefficient *U* for the external partitions (table 3) indicate that they have become a better heat insulator. Insulating materials have been selected in such a way that the value of their *U*-value meets the requirements for thermal protection of buildings effective from January 1, 2021 – according to current guidelines contained in the Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location.

From the economic point of view, the optimal thickness of insulating material for the external walls of the above-ground building was 10 cm. However, due to the maximum value of the *U* coefficient indicated in the above mentioned Ordinance, which was 0.20 W/(m²·K) at room temperature $t_i \geq 16^oC$, It was decided that the insulation material would be 17 cm thick.

Table 3. Values of *U*-value for external walls of the building in question before and after thermomodernization

Outer partition		Factor value U (W/(m² · K))	
External basement walls*		Before thermomodernization	After thermomodernization
Above-ground external walls		0.83	0.183
Ceiling under an unheated attic		1.151	0.195
External basement walls*		0.973	0.148
Front door	to the basements	5.10	1.30
	to the overground part	2.00	1.30

* weighted average of basement wall area for coefficients: ***U*** = 1.151 W/(m² · K) for basement above-ground walls and ***U*** = 0.661 W/(m² · K) for walls in the ground

Source: author's work based on energy audit, Sarosiek et al., 2015, 2017.

The second element affecting energy savings in the building in question was replacing the central heating system with a new one, along with new radiators. This work improved the efficiency of the heating system. In particular, they changed:

- heat transfer efficiency (η_d), whose coefficient increased from 0.80 to 0.90, and
- the efficiency of regulation and use of the heating system (η_e), whose coefficient increased from 0.77 to 0.88.

Thermomodernization works reduced heat losses by penetration and ventilation (table 4) in the limit of 44.25%. Therefore, the annual heat demand for heating the building has also decreased (figure 4), keeping the thermal comfort of the building users at the same level. Before thermomodernization, the calculated energy consumption for heating the building (final energy for heating purposes) was 2,804.55 GJ/year. After the improvement, according to the data contained in the ex post audit, this value decreased more than three times to 825.12 GJ/year. The heat saving, in this case, was 70.58%.

Table 4. Heat losses for the building before and after thermomodernization

		Before thermomodernisation	After thermomodernisation
heat loss (W)	by penetration	63,157	22,420
	by ventilation	32,426	30,872

Source: author's work based on energy audit, Sarosiek et al., 2015, 2017.

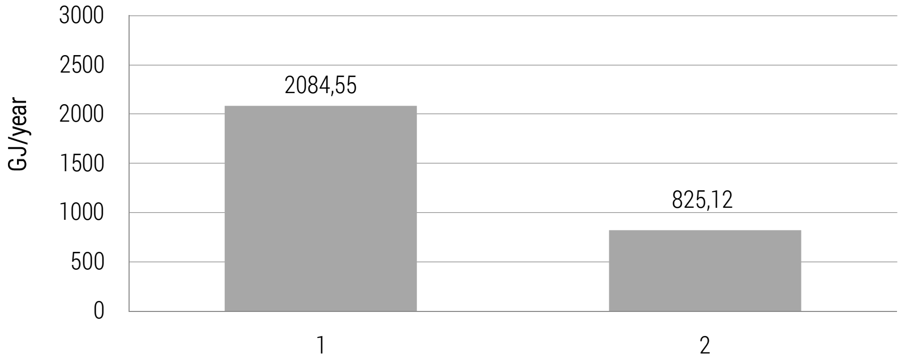

Figure 4. Change in the calculated energy consumption for heating the building
Source: Author's work.

Another element affecting the reduction of heat demand in this building are the solar collectors. They were installed in order to support the existing domestic hot water sources: an eco-pea coal boiler in the heating season and electric heaters outside the heating season.

Heat demand (final energy) for hot water purposes (figure 5), before thermomodernization, was respectively: 65.54 GJ/year coming from the boiler house and 13.58 GJ/year from electricity. The data included in the ex-post audit of the analysed building indicate that the solar installation will allow saving up to 40% of the heat used for DHW purposes. Because of this, the individual values were reduced to: 29.49 GJ/year (boiler house) and 6.11 GJ/year (electricity). Thus, the total energy saving for domestic hot water heating was 43.52 GJ/year.

Reduction of energy consumption for total building heating and hot water preparation was 2,022.95 GJ/year, which gives 561,930.56 kWh/year.

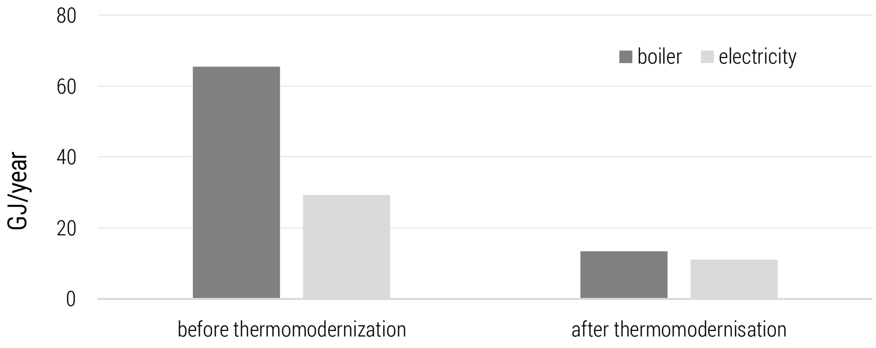

Figure 5. Change of heat demand for hot utility water before and after thermomodernization of the building

Source: author's work.

In order to present in a clear way the changes caused by thermomodernization works, it is necessary to compare the primary energy consumption before and after the improvements (table 5). In order to determine it, the values of the final energy for heating and hot water preparation and the values of the coefficient of the non-renewable primary energy input for the generation and delivery of the energy carrier or energy for the technical systems have been taken from the Regulation on the methodology of determining the energy performance of a building or parts of a building and energy performance certificates.

Table 5. Primary energy of the building in question before and after thermomodernization

Energy consumption target	Ek value (GJ/year)	Non-renewable primary energy input factor	Ep consumption (GJ/year)	Total Ep consumption (kWh/year)	Ep indicator (kWh/ ($m^2 \cdot$ year))
before thermomodernisation					
heating	2 804.55	0.20	560.91	170,766.67	182.23
water heater	65.54	0.20	13.11		
	13.58	3.00	40.74		
after thermomodernisation					
heating	825.12	0.20	165.02	52,569.44	56.10
water heater	29.49	0.20	5.90		
	6.11	3.00	18.33		

Source: author's work.

Based on the data presented in the table below (table 5), the *Ep* factor [kWh/(m^2·year)] was calculated, showing the consumption of non-renewable primary energy. Determining *Ep* coefficient is the quotient of total demand for primary energy expressed in kWh/year before or after thermomodernization and the heated surface of the building, which for this building is 937.1 m^2. The indicator *Ep* before thermomodernization was 182.23 kWh/(m^2·year), and after finishing works *Ep* = 56.10 kWh/(m^2·year). So, the process of thermomodernization of the building allowed to reduce the value of *Ep* index more than three times.

As a result of the analysis, it was found that the works carried out within the optimal variant of thermomodernization allowed for a significant reduction of building's energy demand for heating and preparation of usable hot water without worsening the thermal comfort of its users.

The reduction of heat losses and the investment in renewable energy sources have enabled energy savings of 70%. This value and threefold reduction of *Ep* indicator confirm that the technical qualification made within the optimal variant of thermomodernization undertaking had a definite influence on the improvement of energy efficiency of this building.

Change in costs incurred for heating the building and for hot water preparation

Besides the improvement of energy efficiency of the building, the expected effect of thermomodernization works was the reduction of operating costs for heating and hot water preparation. According to the data included in the ex-post audit of the analysed building, thermomodernization improvements resulted in energy cost savings of 63,949.00 PLN per year. This value consists of both reductions of charges for heating and hot water preparation.

It was calculated that 1 GJ/year for heating and domestic hot water (prepared in the boiler house) costs 31.06 PLN. This fee also includes boiler room service charge, i.e. the cost of the stoker's salary. The price of 1 GJ/year of preparing domestic hot water in electric heaters was 180.56 PLN. These values are the same both before and after thermomodernization.

A detailed breakdown of heating and hot water expenditures is shown in the graph above (figure 6). The analysis shows that the total costs incurred for heating and usable hot water before thermomodernization amounted to 91,911 PLN per year. The amount of annual fee after thermomodernization works results from the application of: calculated thermal power, calculated internal temperatures in the building and standard heating season and equals 27,962 PLN. Comparing both values, the charges for heating and hot water decreased almost by 70%.

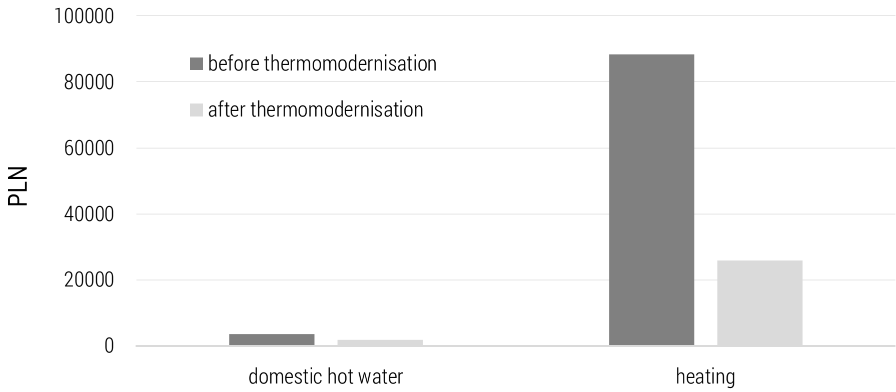

Figure 6. Change of costs borne for heating and domestic hot water in the analysed building

Source: author's work.

Energy and financial savings resulting from the thermomodernization of the discussed building shows the positive influence of the improvement of the technical condition of the object on its energy efficiency.

Costs of thermomodernization works and payback time

An inseparable element of each project, which is usually the starting point of the investor's work, is an analysis of the financial profitability of such an investment and examining the time needed to return the outlays incurred for its execution. In this case, the investor obtained co-financing from the European Regional Development Fund for the realisation of a wide range of thermomodernization works. The value of thermomodernization improvements of the optimal variant was valued at 366,662 PLN, and energy cost savings resulting from their implementation amount to 63,949 PLN.

To assess the profitability of the investment one of the simple methods was used, namely the Simple Pay Back Time (SPBT) method. This method determines the time in years needed to return the financial input incurred in the implementation of the investment. The SPBT value is determined by the following formula (6) (Stachniewicz, 2012):

$$SPBT = \frac{N_U}{\Delta O_{r\,c.o.}}, \tag{6}$$

where:

N_U – total cost of performing the given thermomodernization improvement [PLN]

$\Delta_{r\,c.o.}$ – energy cost savings resulting from its implementation expressed in PLN per year.

For the works carried out as part of thermomodernization, the time of return on investment was calculated (table 6) according to formula (6). The execution of a new central heating system required the highest financial costs, but at the same time has the shortest payback time of 5.66 years. The highest SPBT value was calculated for the improvement consisting of replacing the entrance door to the above-ground part, which amounted to 62.46 years.

Table 6. List of SPBT for individual thermal upgrading works according to increasing value

No.	Type of improvement	SPBT (years)	Cost of works (PLN)
1.	New central heating installation.	5.66	128,823
2.	Insulation of the ceiling under an unheated attic	11.89	70,528
3.	Solar installation	12.70	20,322
4.	Thermal insulation of above-ground external walls	13.30	92,856
5.	Replacement of entrance doors to basements	20.03	2,940
6.	Thermal insulation of external basement walls	32.25	20,053
7.	Replacement of entrance doors to the overground part	62.46	21,140

Source: author's work.

The payback time SPBT, calculated for the entire thermomodernization project according to formula (6) is:

$$SPBT = \frac{366{,}662}{63{,}949} = 5.73 \quad \text{years.}$$

Considering relatively short time of return of expenses incurred during thermomodernization works and using subsidies from the EU funds, it can be concluded that the investment in question was effective also from the economic point of view.

Conclusions

On the basis of the analysis of the building components efficiency and the energy consumption before and after thermomodernization, it was concluded that the improvement of the technical condition of the selected object and the investment in renewable energy sources contributed to a significant reduction in its energy demand. Thus, the thermomodernization improvements resulted in the improved energy efficiency of the building.

The energy efficiency improvement of the selected building also allowed to reduce the expenses for heating and hot water preparation. Energy cost savings oscillate around 63,949 PLN per year. Total payback time was calculated at 5.73 years. Taking into account the fact that the thermomodernization works were financed by the European Union, the high annual energy cost savings and the relatively short payback time, it was assessed that the investment was effective also from the economic point of view. The energy savings resulting from thermomodernization allow stating that the energy efficiency of the building depends on its technical condition.

Acknowledgements

The research was carried out as part of study no. WZ/WB-IIL/6/2019 at the Bialystok University of Technology and financed from a subvention provided by the Minister of Science and Higher Education.

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