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RENOVATION OF BUILDINGS AS AN ESSENTIAL ELEMENT OF ACTION IN "GREEN DEAL" – A CASE STUDY

RENOWACJA BUDYNKÓW JAKO ISTOTNY ELEMENT „ZIELONEGO ŁADU" – STUDIUM PRZYPADKU

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Abstract

The article highlighted that renovation buildings are an essential action in the European Green Deal. The objective of this study was to assess the energy performance of renovation concepts selected building components on multi-family house. Typical Polish 1950s building was used as a baseline reference, and it was shown that very similar renovation concepts can be successfully applied in other buildings that provides good bases to develop standardized solutions. Energy performance of common renovation concepts was assessed both by in situ tests (with an unaided eye and including the use of a thermal imaging camera) and with national calculation methodologies. The renovation concepts included selected building components: improved envelope insulation with exterior windows and doors and heating system. The effects of the performed renovation were supplemented by the calculation of reduction of greenhouse gas emissions into the atmosphere, as a result of reducing the demand for heat supply to rooms.

Keywords: building renovation, energy efficiency targets, in situ test methods, causes of greenhouse gas emissions

Streszczenie

W artykule podkreślono, że renowacja budynków jest istotnym działaniem w ramach Europejskiego Zielonego Ładu. Celem omawianego badania była ocena charakterystyki energetycznej zaproponowanej metody renowacji wybranych elementów budynku wielorodzinnego. Jako punkt odniesienia wykorzystano typowy polski budynek z lat 50. i wykazano, że bardzo podobne metody renowacji można z powodzeniem zastosować w innych budynkach, co stanowi dobrą podstawę do opracowania standardowych rozwiązań. Charakterystyka energetyczna zaproponowanej metody renowacji została oceniona zarówno za pomocą badań wykonanych bezpośrednio na terenie obiektu (okiem nieuzbrojonym i przy użyciu kamery termowizyjnej), jak też z wykorzystaniem krajowych metod obliczeniowych. Proponowane metody renowacji obejmowały wybrane elementy budynku: poprawę izolacyjności przegród zewnętrznych z oknami i drzwiami zewnętrznymi oraz system ogrzewania. Efekty wyżej wymienionej metody renowacji uzupełniono o obliczenia redukcji emisji gazów cieplarnianych do atmosfery w wyniku zmniejszenia zapotrzebowania na ciepło dostarczane do pomieszczeń.

Słowa kluczowe: renowacja budynków, cele w zakresie efektywności energetycznej, metody badania bezpośrednio na obiekcie, przyczyny emisji gazów cieplarnianych

1. INTRODUCTION

The European "Green deal" is an international concept aimed at achieving environmental neutrality. Pro-environmental measures and, above all, reducing greenhouse gas emissions are gradually being implemented into all areas of work and life.

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Environmental measures in European Union countries are aimed at preventing climate change by, among other things, significantly reducing the consumption of fossil fuels. Renewable energy sources and waste processing are being promoted. For these measures to bring the expected success they should be implemented in all EU member states, including Poland. It is necessary to introduce them in all economic sectors, including the construction industry, where greenhouse gas emissions into the atmosphere are significant. The entire construction process, beginning with the extraction and transportation of raw materials, their processing to produce finished products, and then further transportation to customers and incorporation into buildings, contributes to the production of pollutants harmful to the atmosphere. However, it is not only the process of producing new building materials and their subsequent incorporation into facilities that is an indirect cause of carbon dioxide overproduction. Existing buildings are also a source of greenhouse gas emissions due to their inadequate thermal insulation and often, unfortunately, numerous places of heat loss. Currently, caring only about the high energy standards of newly designed buildings is insufficient to meet the intended environmental effects. Measures are also needed to drastically reduce the energy intensity and improve the technical condition of the existing building stock [1]. The existing building stock is estimated to need major renovations in the near future. At the same time, the EU energy-efficiency strategy entails upgrading the energy performance of renovated buildings to meet the nearly-zero energy standard. To upgrade existing buildings, two main groups of measures can be adopted: thermally-improved building envelope and energy-efficient technical devices [2]. Selection of building materials can significantly reduce the production primary energy and associated CO_2 emissions by up to 62% and 77%, respectively. The results suggest that a careful material choice can significantly contribute to reduce primary energy use and CO_2 emissions associated with energy renovation of buildings, especially when renewable-based materials are used [2-4]. Examples of percentages of heat loss through the building envelope are shown in Figure 1 [5].

Progressive climate change is forcing pro-environmental measures to reduce carbon dioxide into the earth's atmosphere, which can be achieved indirectly by reducing the demand for thermal energy. The effect of such actions on the Polish territory are amendments to the "Regulation on technical conditions to be met by buildings and their location" [6]. The latest amendments, introduced as of January 2021, tightened the requirements for the maximum permissible value of the heat transfer coefficient through the building envelope (U) of rooms heated with maintained temperatures of at least 16°C, respectively, no more than: for external walls – 0.20 W/(m²·K), for ceilings over unheated underground spaces – 0.25 W/(m²·K), for ceilings – 0.15 W/(m²·K), for windows – 0.90 W/(m²·K), for doors in external partitions – 1.30 W/(m²·K). Detailed rules and methods for calculating the above properties are included in the standards: PN-EN ISO 6946: 2017-10 "Building components and building elements – Thermal resistance and heat transfer coefficient – Methods of calculation" [7] and PN-

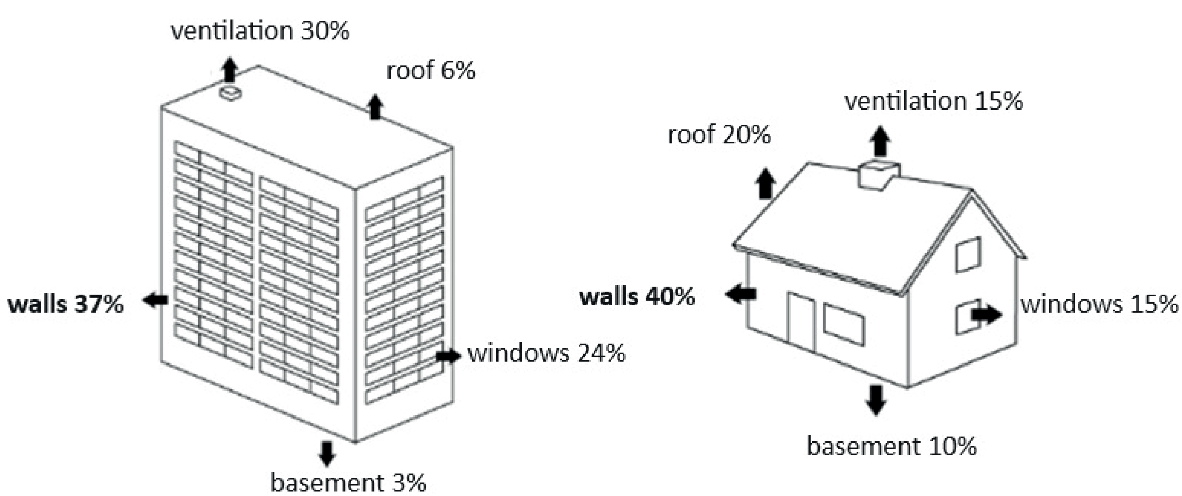

Fig. 1. Examples of percentages of heat loss through building partitions [5]

EN ISO 13370:2017-09 "Thermal performance of buildings – Heat transfer through the ground – Methods of calculation" [8].

Work on thermal modernization of building partitions is undertaken not only in older buildings, built according to previously applicable thermal and humidity requirements [6]. Renovations are also carried out in newer buildings when their users decide to reduce heating costs. Insufficient thickness of the thermal insulation layer on the surface of the building envelope is often accompanied by problems of leakage of the heating system or its low efficiency, which is an additional motive for its reconstruction. In this case, the solution recommended by the "green deal" is to replace the heat source with a heat pump using green energy. Modern ecological heat sources are becoming more and more common, and access to energy from renewable sources is steadily increasing.

The idea of creating a tight energy-efficient building requires, among other things, the use of a thermal insulation layer of such thickness that it guarantees the least possible heat loss, thus ensuring thermal comfort in the rooms in use.

Typical thermal insulation materials used in thermal insulation work include mineral wool boards conforming to PN-EN 13162 [9] and expanded polystyrene (EPS) boards conforming to PN-EN 13163 [10]. To obtain a satisfactory solution it is also necessary to choose the right insulation system. From its selection and proper execution depends not only the durability of the facade, but also the quality and comfort of life of the building's occupants and the energy efficiency of the investment. It is well known that proper insulation of a building's exterior walls can reduce its heating costs by up to 50%. Among the most popular insulation systems used in Poland is the ETICS system [11-13].

However, it should not be forgotten that a thermally protected building is not only insulated vertical and horizontal partitions, but also properly selected and installed window frames, a ventilation system to ensure circulation and an efficient heating system [14].

2. OBJECT UNDER STUDY AND TEST METHODS

2.1. The object under study

The object in question is a multi-family residential building located in Warsaw, consisting of seven above-ground floors and one underground floor. The total volume of the heated part is 17 thousand m^3. Longitudinal walls of the building with windows and external doors located in an east-west direction. The building was constructed in the 1950s in the column and rib technology, on reinforced concrete footings. The walls of the building are made of aerated concrete blocks with 15 cm thick polystyrene insulation. From the outside, thin-coat plaster laid on a grid. PVC window frames in with visible signs of use (age of windows about 15 years). Double-glazed windows with a design heat transfer coefficient of U = 1.9 W/(m^2·K), exterior doors with a design heat transfer coefficient of U = 2.50 W/(m^2·K). The roof covering was made in the form of a solid flat roof, with a base layer of trough panels on the surface of which a thermal insulation layer of mineral wool was laid, with a total thickness of 18 cm, covered with a roofing made of two layers of asphalt felt with an unidentified matrix.

The building is heated with heat supplied from the municipal network, with a thermal node located in rooms on floor –1. Water system and waste water discharge to a plumbing system connected to the municipal network. Gravity ventilation, with ventilation ducts only to the bathrooms and kitchen.

The object in question was tested in order to determine the causes of heat losses reported by its users, with particular emphasis on the evaluation of heat penetration through the walls of the building and the evaluation of the efficiency of the heating system.

2.2. Research methods

Only selected aspects of building renovation have been addressed.

All calculations have been made according to the calculation procedures formulated in the current European and international standards introduced into the set of national standards, so only research methods were established without prescribing standard provisions.

The following assessment/research methods were used to identify the problem:

- site visit - during which hot spots requiring further detailed assessment were identified. At this stage, only visual assessment with the naked eye was used. Particular attention was paid to the technical condition of window frames and thermal insulation of vertical and horizontal partitions. Information on the thickness of the layers of Styrofoam and mineral wool was obtained from the as-built documentation of previous renovation work. The visual inspection also included the central heating system (technical condition of insulation);
- testing with a thermal imaging camera of the central heating risers in accordance with the testing

methodology described in PN-EN 13187:2001 [15]. Examination of the object was done with a thermal imaging camera FLIR E8 Pro Kamera for the presence of thermal bridges outside the object. The results showed presence of hot spots. The basic technical data of the camera used are as follows: detector resolution 320 × 240 pixels, field of View (FOV) 33° × 25, Thermal Sensitivity <50 mK, Temperature Range –20°C to 550°C.

Outdoor measurements were made in the fall of 2022 from 7:00 to 9:00 pm i.e. prior to renovation, to identify problems in the building, with the following ambient conditions:

- outdoor temperature: about 1°C,
- average wind speed: 2 m/s,
- wind direction: west,

in contrast, indoor measurements were taken in the spring of 2023 from 10 a.m. to 2 p.m., i.e. after the renovation work has been carried out, in order to establish the effects of the repair work carried out, with the following ambient conditions:

- outdoor temperature: about 18°C,
- average wind speed: 4-5 m/s,
- wind direction: east;

➢ performance simulation calculations of the efficiency of the thermal node resulting from the specifics of the device and the heat transfer coefficients through the partitions using the computer program Auditor OZC and as the inverse value of thermal resistance for the layers in question.

The obtained results of the calculations additionally allowed estimating the effects of proposed renovation work in terms of the amount of reduction in greenhouse gas emissions resulting from the reduction of heat loss through the building envelope, found during the inspection of the facility.

3. RESULTS AND DISCUSSION

During the inspection of the building, no visible cavities or leaks were observed within the thermal insulation layers of the vertical and horizontal partitions. Thermal imaging camera examinations also revealed no leaks in the vertical partitions, in areas without additional window and door openings. Locally, leaks were found within the window frames, visible to the unaided eye, with a perceptible intrusion of cooler air around the window frames.

Table 1 summarizes the average values of the heat transfer coefficient of the building envelope of the subject building, for the existing technical state before the renovation work. These values are the average of 6 measurements taken for each partition in sensitive areas, i.e. those showing clear symptoms of insufficient thermal insulation, after evaluation with a thermal imaging camera and organoleptic method. The coefficient of variation was used to statistically evaluate the results. The coefficient of variation, is a measure of dispersion and is therefore used to measure the degree of variation in the value of a variable. A high value of the coefficient means high variability of the trait and indicates the heterogeneity of the population under study, a low value indicates low variability of the trait and homogeneity of the population under study. In the present case, the results obtained indicate homogeneity, as the values of the coefficients of variation are relatively low. The calculations were performed in accordance with the standard PN-EN ISO 6946: 2017-10 [7], taking as output values the readings from the thermal imaging camera determined during the object tests.

Table 1. Average values of heat transfer coefficients of selected building partitions (state before thermal modernization)

	Partition	Heat transfer coefficient of the partition [W/(m^{2}K)]/ coefficient of variation [%]
1.	Exterior wall (south side)	0.24/2.05%
2.	Ceiling	0.22/2.35%
3.	Ceiling over basement	1.03/1.58%
4.	Exterior windows (south side)	2.34/1.05%
5.	Exterior doors leading to the building	2.00/1.98%

As a supplement to the evaluation of interior microclimate parameters of the building, the efficiency of the heating system was determined. which is derived from the specifications of the device and was defined in accordance with current legislation. Calculations were based on the Regulation on the methodology of calculating the energy performance of a building [16]. The values of seasonal heat demand for the existing state were compared with the required values, ensuring the comfort of the interior spaces. The results obtained show the results of the tests carried out before the renovation, and simulated values calculated using the OZC auditor software [16] for the assumed state after renovation. Values are summarized in Tables 2 and 3.

Table 2. Component efficiencies of the heating system before thermomodernization

	Type of efficiency	Value [-]
1	Generation efficiency	0.94
2	Transmission efficiency	0.80
3	Utilization control efficiency	0.77
4	Accumulation efficiency	1.00

Table 3. Seasonal heat and power demand

Variant	Seasonal heat demand	Thermal power requirement (circulation pump drive)
	GJ	kW
Condition before modernization	2 510.97	425.78
Condition after modernization	960.06	234.64
Difference	1550.91	191.14

A visual assessment of the technical condition of the heat substation and the central heating system further confirmed, visible to the naked eye, mechanical damage to parts of the system and corrosion of fittings. In addition, locally on the central heating risers there are gaps in the thermal covers of the pipes, and the existing thermal insulation is damp. It can be presumed that that dampness originated in areas of pipe leaks, caused by damage to joints and lack of ad hoc maintenance work. An example of an image from a thermal imaging camera of the central heating riser of the building in question before the start of thermal upgrading work is shown in Figure 2. The distribution of isotherms around the CO pipe allows us to determine the dysfunctional areas in relation to the thermal insulation shielding the CO pipe from heat loss.

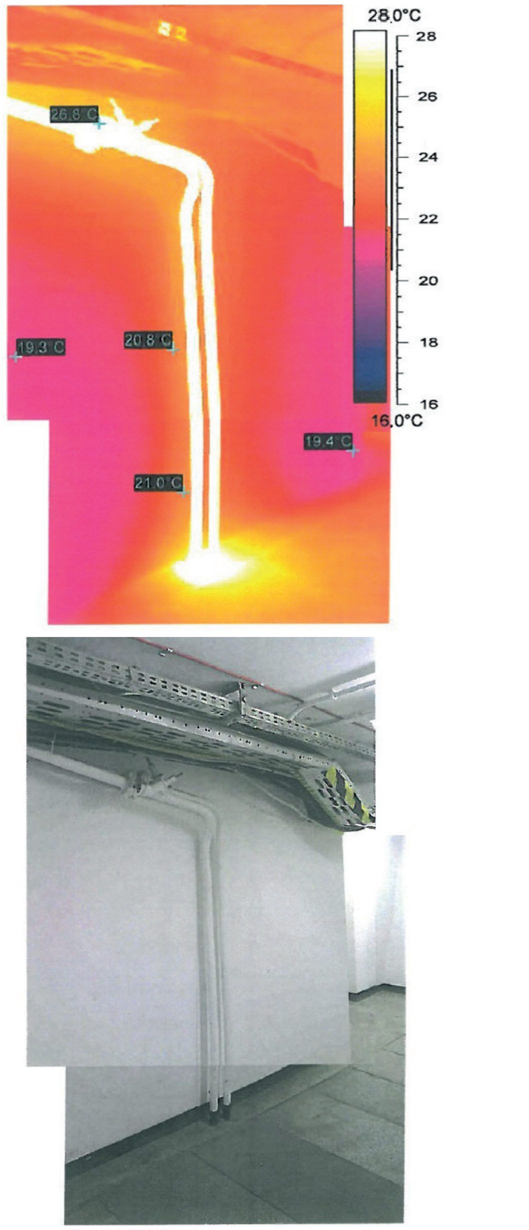

Fig. 2. Distribution of isotherms around the CO riser in the thermal imaging camera image (Flir System AB)

Figure 3 shows a section of the window along with the window frame on the surface of which traces of biological corrosion are visible, caused by a reduction in temperature on the internal surface of the partition at the thermal bridge (the junction between the external wall and the window). The risk of mould growth at the thermal bridge location is checked by comparing the design value of the temperature factor at the thermal bridge location f_{Rsi} (based on the minimum temperature at the thermal bridge location $t_{min.}$, indoor air temperature t_i, outdoor air temperature t_e) with the limiting (critical) value $f_{Rsi(kryt.)}$). It is assumed that when $f_{Rsi} \geq f_{Rsi(kryt.)}$ there is no risk of surface condensation (i.e. no risk of mould growth). The critical temperature factor $f_{Rsi.(kryt.)}$ was determined according to regulation [6]:

– in a simplified way for t_i = 20°C, φ = 50%, $f_{Rsi.(kryt.)}$ = 0.72,
– in an accurate manner (taking into account the parameters of outdoor and indoor air).

Calculation procedures in this respect are presented, among others, in the work [17]. The critical value of the temperature factor $f_{Rsi.(kryt.)}$ for the third humidity class in the room at t_i = 20°C is for the Warsaw location $f_{Rsi.(kryt.)}$ = 0.789. Based on the inspection and measurements carried out, it can be concluded that in the analyzed building (at the junction of the external wall with the window) there was a significant decrease in temperature on the internal surface of the partition, which led to the risk of surface condensation – Figure 3.

It is necessary to carry out the above calculations and analyses at the stage of designing the thermal insulation of the envelope as part of thermomodernisation, taking into account the parameters of the external and internal air.

Fig. 3. Biological corrosion visible on the surface of the window reveal

The visual inspection of the building allowed a preliminary determination of the scale of the problem, and supplementing it with additional research and calculations, allowed the development of a concept for a repair solution. Based on a visual assessment of the building envelope, hot spots were selected that could be the main cause of heat loss. Visible symptoms of biological corrosion on the window frames (Fig. 3) allow us to assume that heat loss is occurring in these areas. In addition, local leaks within the plaster and thermal insulation layer are visible around the window frames, further adding to the identified problem. In contrast, no visible symptoms of this phenomenon were found on the wall surfaces and under the ceiling. Admittedly, the results of the calculations indicate that the permissible values of heat transfer coefficients are exceeded on all the tested partitions, but in the case of the external walls and for the ceiling, the calculated values are within the limits of the measurement error, confirming the conclusions established based on previous observations made during the inspection of the building. Thus, the calculated values of the heat transfer coefficient for these partitions are, respectively, for:

– sample exterior wall (south side) 0.24 W/(m^2·K), with required ≤ 0.2 W/(m^2·K);
– roof – 0.22 W/(m^2·K), with the required ≤ 0.15 W/(m^2·K).

The partitions analysed do not meet the basic thermal criterion in terms of U-value. The main heat losses occur within the ceiling above the basement, for which the calculated heat transfer coefficient is 1.03 W/(m^2·K), with the required ≤ 0.25 W/(m^2·K), and in the area of window openings and exterior doors. Heat loss around the window reveals on the west wall, as determined by the heat transfer coefficient, is of 2.34 W/(m^2·K), with a permissible value of up to 0.90 W/(m^2·K), and for exterior doors of 2.00 W/(m^2·K) with a permissible value of up to 1.30 W/(m^2·K). The aforementioned comparisons are shown graphically on Figure 4.

Identification of weak points in the building under consideration with a thermal imaging camera are shown in the Figure 5.

The research and analysis performed allowed the development of a renovation concept. The renovation work began with replacing the windows and sealing the window reveals, after first removing the effects of biological corrosion. The renovation work thus began with mycological tests, submitting samples taken from the window frames to a specialized

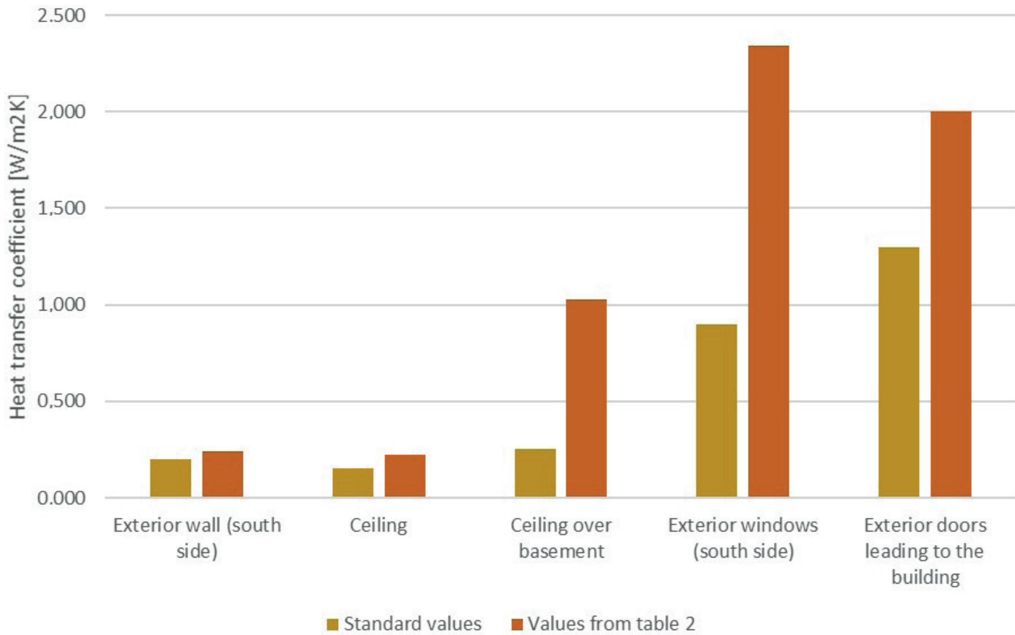

Fig. 4. Comparative comparison of the values of heat transmission through partitions from table 2 with standard values [6]

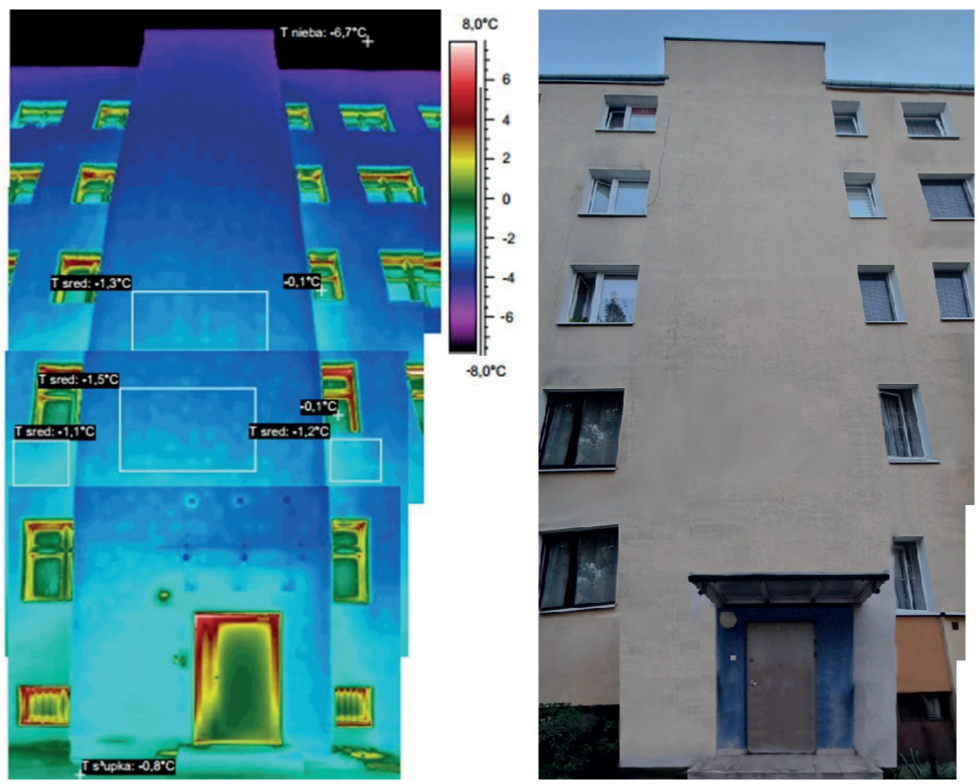

Fig. 5. Identification of weak points in the building under consideration with a thermal imaging camera (Flir System AB)

research laboratory in order to determine the type of fungus present and, based on this, to select the right fungicide. The found strain of *Aspergillus Niger* fungus turned out to be a typical type of mold fungus, often found on the surface of facade materials, including in the region of thermal bridges. Since this fungus produces toxic substances like aflatoxins, ochratoxins, which can be dangerous to health, it was important to completely deactivate it. Infected surfaces were thoroughly washed and then covered with a fungicide, additionally removing plaster in areas where the infection had progressed deep into this layer. Due to the toxicity of the preparation, the rooms were ventilated for up to 28 days. The next step was to replace the windows in the building, with triple-pane windows with ventilators embedded in the window frames, while remembering to ensure effective ventilation of the rooms. The entrance doors to the building were also replaced, using doors with a heat transfer coefficient of no more than 1.0 W/(m^2·K). It was recommended that window jambs are sealed in the area where the frames are embedded, against the formation of thermal bridges, causing condensation on the inner surfaces of the windows (frames and sashes), the surfaces of the jambs or in the window/wall joints. The correct execution of the external wall-window joint should be carried out after an analysis of the physical parameters of the building joints in terms of additional heat loss (linear heat transfer coefficient) and limiting the occurrence of surface condensation (biological corrosion). Calculations and analyses in this respect are presented in works [17-19].

Correctly installed windows should be:
– on the interior side of the rooms – vapor-proof,
– on the inside – thermally insulating,
– from the outside – vapor-permeable.

The first stage of the renovation work also included repairing the heat node to reduce heat loss on the central heating system. When trying to reduce energy consumption in a central heating system or in a domestic water heating system, it is necessary to consider the annual operating efficiency of the heating and the domestic hot water heating system. A boiler operates under dynamic conditions, so it essential to know the methodology and the model of annual operating efficiency calculation for thermo technical systems. For example the outlet temperature of the flue gases with conventional gas boilers is considerably higher than the ambient temperature and consequently the heat loss occurs; it is then vented off into the environment as a result of heat transfer. The heat loss may be reduced if a condensing heat exchanger is installed, which will, on the other hand, increase the boiler efficiency by more than 10% [20].

It was also assumed that the malfunction of the thermal node located in the basement floor could be one of the causes of inadequate heat flow within the –1/0 interstory ceiling. For this reason, the first stage of the renovation work refrained from insulating this ceiling, recommending that it is observed after the completion of the repair of the node and possibly carried out in the second stage of the work, if the need is still identified.

Confirmation of the effectiveness of the repair work performed is provided by the analysis of seasonal heat demand and heating power before and after the repair work. The values of these changes, presented in Table 4, were determined using the computer program OZC Auditor for this purpose.

After replacing windows and doors and overhauling the heat substation, seasonal heat demand was reduced by 60%. This contributes to energy savings of 1.500 GJ. In terms of power expressed in kilowatts, the gain after the renovation work is at 190 kW, compared to the original state.

The performed renovation work contributed both to improving the technical condition of the facility and the conditions of use of the premises and had a positive impact on the environment. As a result of the performed work, the demand for heat in the building decreased, i.e. the amount of fossil fuels consumed for this purpose was reduced, thus indirectly contributing to the reduction of carbon dioxide emissions, as shown in Table 4.

The data presented in Table 4, expressed in GJ/year or kW/year for the situation before and after the renovation, represent the demand for auxiliary energy and district heating (heating and hot water).

A comparative summary of energy demand before and after the renovation is presented below (Fig. 6).

Table 4. Comparison of energy demand before and after the renovation and the effect of reducing CO_2 emissions after the renovation work

Type of energy	Comparison of energy demand, [GJ/year] or [kWh/year]			Comparison of CO_2 emissions, [Mg]		
	before renovation	after renovation	final result of reduction	before renovation	after renovation	final result f reduction
District heat – heating and hot water	7 843.14	2 165.71	5 677.43	754.98	208.47	546.51
Auxiliary energy	273 668.90	247 791.90	25 877.00	193.76	175.44	18.32
Total emission reductions of CO_2 [Mg]				948.74	383.91	564.83

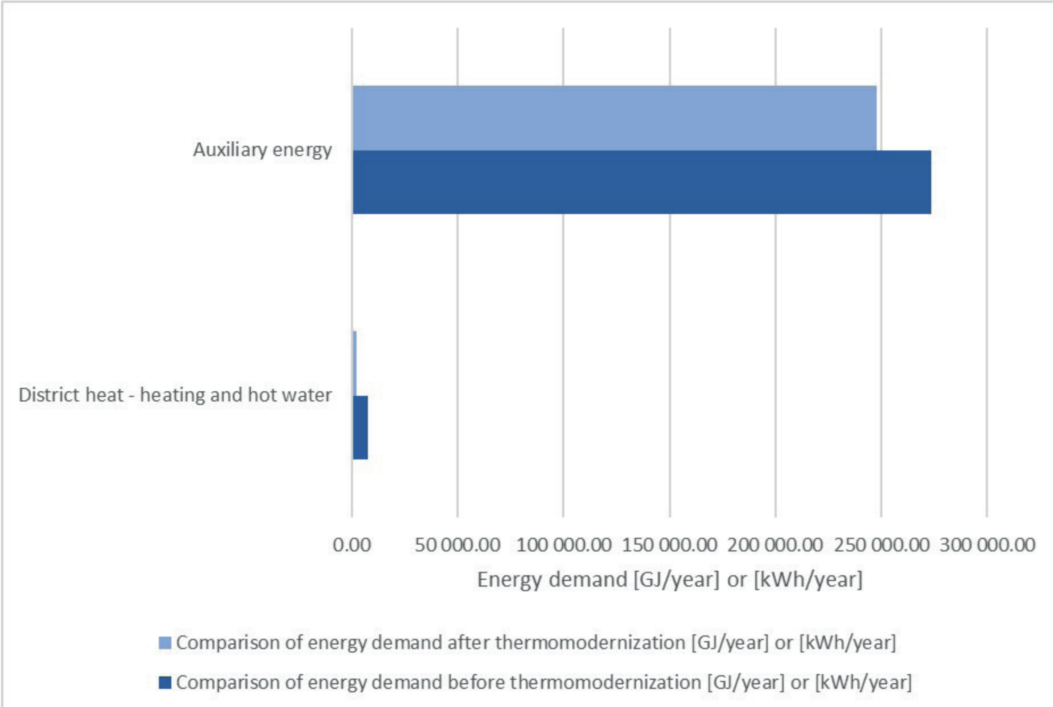

Fig. 6. Comparison of energy demand before and after renovation

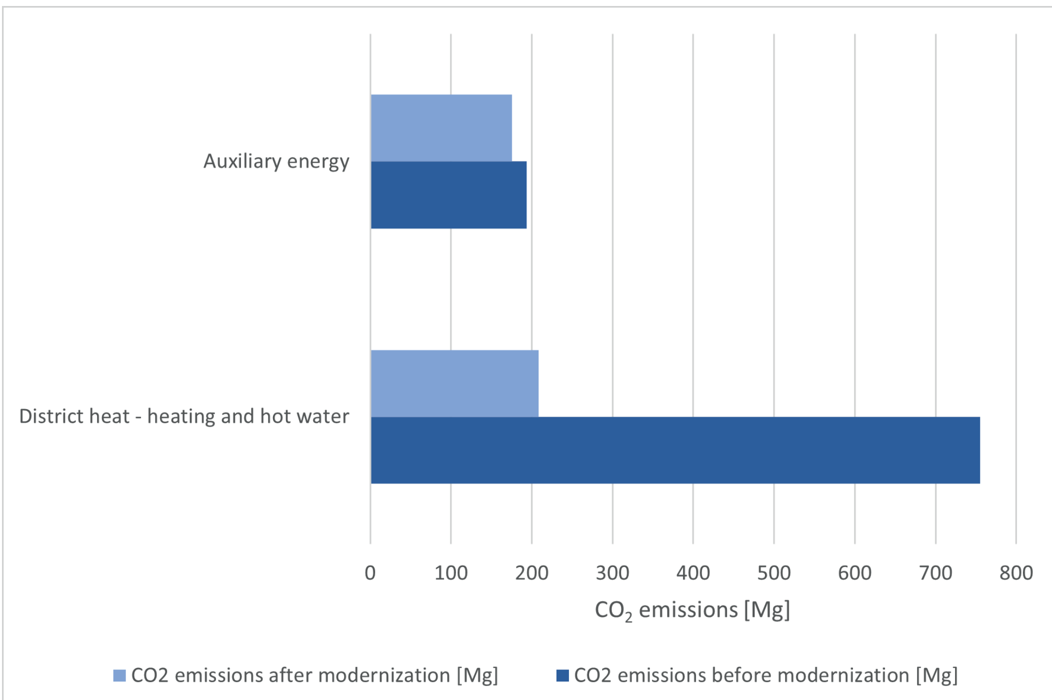

Fig. 7. Comparison of carbon dioxide emissions before and after thermal renovation

The renovation work contributed to a reduction in carbon dioxide emissions. The total amount of pollutants decreased almost threefold to 383.91 Mg. The resulting volume is 564.83 Mg less compared to the original state (Fig. 7).

According to calculations, it should be noted that there is a significant drop in CO_2 emissions in terms of both electricity and district heating (central heating and hot water) following the modernisation work.

The economic benefit of retrofit actions for old buildings depends on possibly increasing building value and rents and also on the achieved energy savings. To estimate the savings, usually the calculated energy demand before and after the renovation is compared. Several studies show [21], that calculated energy demand and consumed energy often show great differences, especially for old buildings before the 1970s. One important input parameter for the energy demand calculation is the u-value of the façade which is commonly chosen by the energy expert on site, out of a catalogue, where typical values for certain wall constructions are presented. The reduction of carbon dioxide emissions from dwellings was highlighted as a positive environmental impact of energy renovations, particularly due to the improvement of thermal insulation properties [21].

The economic benefit of retrofit actions for old buildings was found to depend on achieved energy savings, indicating the potential for reducing CO_2 emissions through energy-efficient renovations. It is clear that energy demand typically decreases after renovation, and there is a potential for reducing CO_2 emissions through energy-efficient renovation measures [21, 22]. However, it is important to note that the specific quantification of CO_2 emissions reduction may require additional data.

4. CONCLUSIONS

The article analysed selected, in the opinion of the authors, important problems, often occurring in construction, related to the improper functioning of the building envelope in the heat and humidity range. These analyses were performed on the example of a randomly selected multifamily residential building. This paper presents only selected aspects of building thermomodernisation resulting from changing thermal requirements according to the regulation [6].

As part of the research and analysis carried out, the main building partitions were evaluated for their susceptibility to heat transmission and the impact of these losses on increasing greenhouse gas emissions into the atmosphere. These analyses allow to formulate the following conclusions regarding areas that need to be assessed when assessing the energy efficiency of renovated buildings and methods of their tests:

- the following sequence of research and analysis is useful: a survey of the building to determine hot spots, measurements of temperature distribution in individual pre-selected sections, e.g. using thermal imaging cameras, determination of the type, condition and quality of materials used in building partitions, computer calculations of basic thermal properties including adoption of correct values for the thermal conductivity coefficients of materials in the building envelope;
- assessing the energy efficiency of a building should the basic building envelope, i.e. walls, ceilings, including roof coverings, but also sensitive places that contribute to the formation of thermal bridges in buildings such as: windows and exterior doors, and the efficiency of the central heating system, with particular attention to the technical condition of thermal insulation lagging of pipes;
- assessing the installation of window frames for elimination of thermal bridges, which are one of the causes of biological corrosion, negatively affecting the health of room users;
- assessing effective insulation of all components of the central heating system which has a significant impact on its efficiency and the reduction of heat loss in the building. Regular inspections and ad hoc repairs ensure that the equipment maintains its high efficiency over the period of its assumed life cycle.

Carried out analysis done for building under renovation confirms the relationship between the efficiency of the heating system, the tightness of the window frames and the amount of energy demand. Elimination of places generating heat losses in buildings contributes to a reduction in the demand for thermal energy, which consequently has a positive impact on the environment, due to a reduction in the amount of fossil fuels required to generate this heat. Only the correct and efficient operation of all building elements makes it possible to achieve satisfactory results by reducing heat losses by up to 60%, thereby contributing to lower maintenance costs of the facility, and by reducing the need for fossil fuel consumption, indirectly also, to environmental protection.

An indirect goal of above mentioned measures was to reduce carbon dioxide emissions into the atmosphere. The intention has been achieved for tested building, which can be seen in the total amount of carbon dioxide reduced. The amount of carbon dioxide has decreased almost threefold to 383.91 Mg, which translates into smaller environmental pollution.

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