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Decarbonization potential of the historic building in Warsaw

Potencjał dekarbonizacji zabytkowej kamienicy w Warszawie

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Abstract. The need to reduce the share of construction in the overall demand for non-renewable primary energy and to minimize carbon dioxide emissions during the operation stage of buildings requires the development of a plan for renovation and decarbonization of buildings. However, this process requires special planning for historic buildings. The article analyzes the existing state and develops two variants of renovation of one of Warsaw's pre-war historic apartment buildings at 23 Kopernika St. It examines how changes to the building can affect its energy efficiency and emissions of CO_2 and other pollutants, as well as improve indoor comfort. The main goal was to reduce the demand for non-renewable primary energy and minimize CO_2 emissions. The proposed solutions also took into account buildings architecture and surroundings.

Keywords: revonation; decarbonization; energy performance; historic building.

Streszczenie. Konieczność zmniejszenia udziału budownictwa w ogólnym zapotrzebowaniu na nieodnawialną energię pierwotną i minimalizacji emisji dwutlenku węgla na etapie eksploatacji budynków wymusza opracowanie planu termomodernizacji i dekarbonizacji budynków. Proces ten wymaga jednak szczególnego planowania w przypadku obiektów zabytkowych. W artykule przeprowadzono analizę stanu istniejącego i opracowano dwa warianty termomodernizacji jednej z przedwojennych, zabytkowych kamienic warszawskich przy ulicy Kopernika 23. Sprawdzono, jak zmiany w budynku mogą wpłynąć na jego efektywność energetyczną oraz emisję CO_2 i innych szkodliwych substancji, a także poprawę komfortu użytkowania budynków. Głównym założeniem było zmniejszenie zapotrzebowania na nieodnawialną energię pierwotną oraz zminimalizowanie emisji CO_2. W przedstawionych propozycjach wzięto również pod uwagę architekturę budynku i jego otoczenie.

Słowa kluczowe: termomodernizacja; dekarbonizacja; charakterystyka energetyczna; obiekt zabytkowy.

Construction sector plays a crucial role in combating climate change and environmental pollution, making it one of the most significant sectors in the economy. Buildings account for over 42% of energy consumption and more than 33% of carbon dioxide emissions in the European Union [1]. According to estimates from the KAPE, the final energy consumption in national building resources can be reduced by up to 75% without much additional costs [2]. Nevertheless, it is crucial to acknowledge that, as a member state of the European Union, Poland must adhere to the decarbonization requirements specified in EU regulations [1, 3]. These requirements will soon be implemented into our legal framework, as evidenced by the „Studium uwarunkowań i kierunków zagospodarowania przestrzennego m.st. Warszawy" [4]. Decarbonization is closely linked to reduction of energy demand of buildings from fossil sources. This can be achieved by improving the energy efficiency of buildings. Yet this process requires detailed planning. A comprehensive renovation is recommended for buildings with poor thermal insulation, inefficient technical systems and non-renewable heat sources. This approach brings economic benefits, improves user comfort and reduces the harmful environmental impact. Comprehensive renovation of buildings involves reduction of heat loss through external partitions and improving the energy efficiency of technical systems. For historical buildings, their historical value often necessitates unconventional actions during the renovation process [5]. Moreover, for large cities, it is crucial for planned renovation processes to be scalable and replicable. These challenges were the starting point for the analysis of the possibilities of renovation of historic buildings, using as an example one of the pre-war tenements in Warsaw at 23 Kopernika Stre-

Photo 1. Section of the front elevation of the building at 23 Kopernika Street together with a section of the neighbouring building
Fot. 1. Fragment elewacji frontowej budynku przy ul. Kopernika 23 wraz z fragmentem budynku sąsiedniego

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et (Fig. 1). Two variants were considered, significantly improving the building's energy performance and minimizing its CO_2 emissions. These variants also enhance user comfort and adapt usage standards to contemporary requirements.

Building Technical Condition Assessment

For the purposes of the conducted analysis, both a thermal assessment of the building and a basic visual assessment were carried out to determine its technical condition.

Research Methods and Results of Termographic Inspections. The thermographic diagnostics of objects in the context of decarbonization was previously addressed in the article from issue 3/2023 [6]. Thermographic inspections were conducted according to the standard „Thermal properties of buildings – Qualitative detection of thermal defects in building envelopes – Infrared method" [7]. For this purpose FLIR E76 thermal camera was used. The building inspection took place between 18:50 and 20:10. Throughout the measurements, the external air temperature ranged from 1.5°C (18:50) to 1.3°C (20:10). The measurement was conducted on March 2, 2022. The temperature inside the apartments was maintained at 21°C +/- 2°C. The temperature difference between the internal and external sides of the partition was approximately 20°C. These conditions are optimal for conducting research and allow for reliable results. Flir Tools software was used for the analysis of thermal images. On the thermograms, where various materials appeared, the emissivityof the dominant surface of plastered walls was assumed to be ε ~0.93.

Based on the research, it was found that the external envelope of the building is low quality. It is non-uniform and has very poor thermal insulation. The structure is not insulated and has a lot of thermal bridges (at balcony slabs, at window edges). Changes in heat flux density are noticeable due to the non-uniformity of the partition and architectural details. An example thermogram of both elevations is shown in Fig. 2.

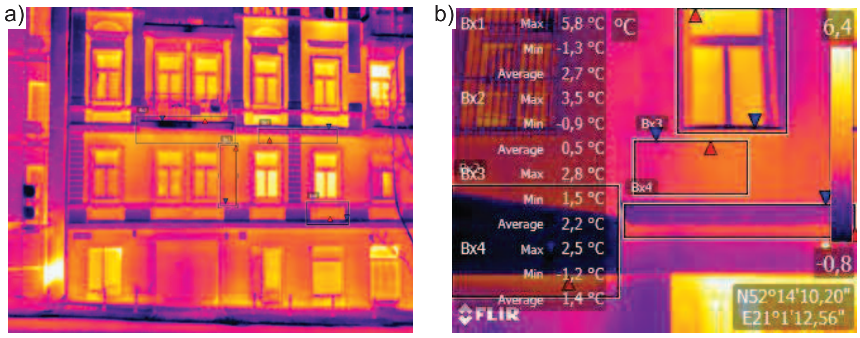

Photo 2. Thermal images of: a) the front elevation of the building; b) the back elevation of the building
Fot. 2. Zdjęcia termowizyjne: a) frontowej elewacji budynku; b) tylnej elewacji budynku

Description and evaluation of the Technical Condition. The building at 23 Kopernika Street is a four-story residential and commercial building with a storefronts and a basement. It was constructed in 1894 – 1895 and underwent a major renovation in the late 1930s. It is listed in the GEZ and its frontal facade is under the supervision of a conservator.

It was observed that the eastern section of the building's side is undamaged, and its condition can be described as good. The tenement fails to incorporate blue-green infrastructure solutions and is not designed to meet the requirements of individuals with disabilities. It lacks elevators, and the entrance is located on the street side with significant terrain slope.The condition of the building's installations was assessed as substandard. The building has gravity ventilation.

All walls, except the frontal one, are in poor technical condition. External walls are made of solid brick plastered on both sides. They lack thermal insulation. Their heat transfer coefficient exceeds current Technical Conditions requirements (Table 1). Thermal imaging studies confirmed the presence of numerous thermal bridges. Windows and doors contribute to significant heat loss due to their technical parameters and leakages. The ground floor also lacks thermal insulation. Heat transfer coefficient calculations were conducted in accordance with standards [8, 9], and a comparison of parameters with currently required values from technical conditions [10] is presented in Table 1. Due to the limited length of the article, detailed information regarding the thickness of layers for individual partitions has been omitted.

Renovation variants

It's crucial to understand the unique characteristics of historical buildings when planning the renovation. Proposed improvements must be discussed individually with the building conservator. All parties involved

Table 1. Heat transfer coefficient of partitions with values currently required and after modernization
Tabela 1. Współczynnik przenikania ciepła przegród przed i po modernizacji wraz z wartościami obecnie wymaganymi

Partition	Heat tansfer coefficient U [W/(m²•K)]	Required heat transfer coefficient according to WT 2021 U [W/(m²•K)]	Heat transfer coefficient after modernization U [W/(m²•K)]
Front exterior wall	0,69	0,20	0,33
Side exterior wall	0,69	0,20	0,16
Roof	0,46	0,15	0,14
External windows	2,60	0,90	0,90
External doors	2,60	1,40	1,4
Slab on the ground	0,44	0,30	0,18

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in the construction process must consider the actions taken in terms of their impact on the building's thermal parameters, and consequently, the economic and environmental aspects, architectural and historical values, as well as user comfort. Limitations on the thermal renovation process may rise from the necessity to preserve the historic facade, use specific materials (e.g., for windows), or maintain the interior.

In the case of the discussed tenement, necessary actions related to improving the parameters of external partitions and modernizing the heating and hot water system were proposed. Additionally, alternative solutions were suggested, including the superstructure of the building, the use of renewable energy sources, or the expansion of biologically active surfaces. All these proposed measures need to align with the requirements and constraints imposed by the conservator of historic buildings. The aim is to balance the enhancement of energy efficiency with the preservation of architectural and historical values, ensuring a sustainable and environmentally friendly approach to the renovation process.

Modernization of External Partitions. The initial step should be to reduce heat loss through partitions. For the courtyard-facing side (an elevation of no particular historical or architectural value), external insulation is proposed with thermal resistance of 3.9 m^2 K/W, single-layered with a plaster finish. The frontal wall is best insulated from the inside to preserve the historic facade, using insulation with a thermal resistance of 1.3 m^2 K/W, finished with gypsum board. The passage through the building should be insulated in the same way as the side walls facing the courtyard. The ground floor and roof also need insulation. 35 cm thick insulation material with a thermal conductivity coefficient of 0.031 W/mK, is proposed for the roof, while 10 cm thick insulation with a thermal conductivity coefficient of 0.031 W/mK, is suggested for the floor. The thermal renovation concept includes constructing a new floor in the building and adding one lightweight floor. A new roof structure would accommodate the proposed insulation thickness. Window replacement is proposed with modern windows of identical dimensions, shapes, and divisions, meeting current requirements. Similar replacement is suggested for doors to improve the building's airtightness without altering its appearance.

A proposition is made to add an additional floor, based on the 2000 conservation documentation and considering the height difference with neighboring buildings. This action would likely obtain funds for financing the renovation (rental income) and for aligning the height of the building with its neighboring structures. The height of the roof would be adjusted to match that of the building at 25 Kopernika Street. The additional construction would be made of lightweight wood (meeting fire protection requirements) to avoid excessive load on the existing structure. The new roof would have a mansard structure, providing an additional 200 m^2 of living or office space. Renting or selling such a large usable area in a highly profitable location would cover a significant portion of the renovation costs. The calculated U-values for the proposed new elements are compared with current requirements in Table 1.

For historic buildings, especially those undergoing non-standard insulation, the risk of surface condensation promoting the growth of mold (especially at structural connections, where ideal insulation may be impossible due to conservation guidelines) and accumulating interlayer condensation over the years should be examined. In the case of the discussed building, these issues were evaluated for the internally insulated external wall. The calculations did not indicate the occurrence of increasing condensation within the wall, mitigating the risk of the mentioned phenomena over time.

Modernization of Central Heating, Domestic Hot Water and Ventilation System.

Considered solutions:

1) application of automation to control the installations, disconnecting the building from the district heating network, and using air heat pumps for heating and hot water preparation. Adding photovoltaic panels in the form of solar tiles on the roof to cover auxiliary energy needs. Detailed analyses in this regard, such as the amount of energy produced, were not included in the article due to its limited length. It is necessary to consider the replacement of radiators adapted to lower parameters when replacing the heat source with heat pumps. This makes implementation of this solution more complex;

2) application of automation to control the installations while keeping the building connected to the district heating network.

In both solutions, all pipes in the boiler room should be insulated. Currently, the pipes are only partially insulated. The modernization involves using a better radiator control system with PI thermostatic valves, including an automatic differential pressure regulator ensuring both temperature regulation and automatic system balancing.

To modernize the heating system, automatic temperature regulation valves were proposed to improve the control system at the heating substation. For domestic hot water, the use of thermostatic mixing batteries to reduce hot water consumption and thermal balancing valves regulating the temperature in each vertical section of the installation, regardless of distance, is recommended. Also, for reducing the energy demand for heating and domestic hot water systems, individual heat meters were proposed, making residents more aware of their energy consumption. To improve efficiency, a domestic hot water tank in the building's heating substation was suggested.

In both solutions, the replacement of gravity ventilation with balanced ventilation with heat recovery is planned.

Architecture and Environment. Two options for roof coverage (Fig. 3) and building superstructure were analyzed for which the building conservator should give an approval (a similar superstructure has already been implemented on a neighboring object, also under supervision).

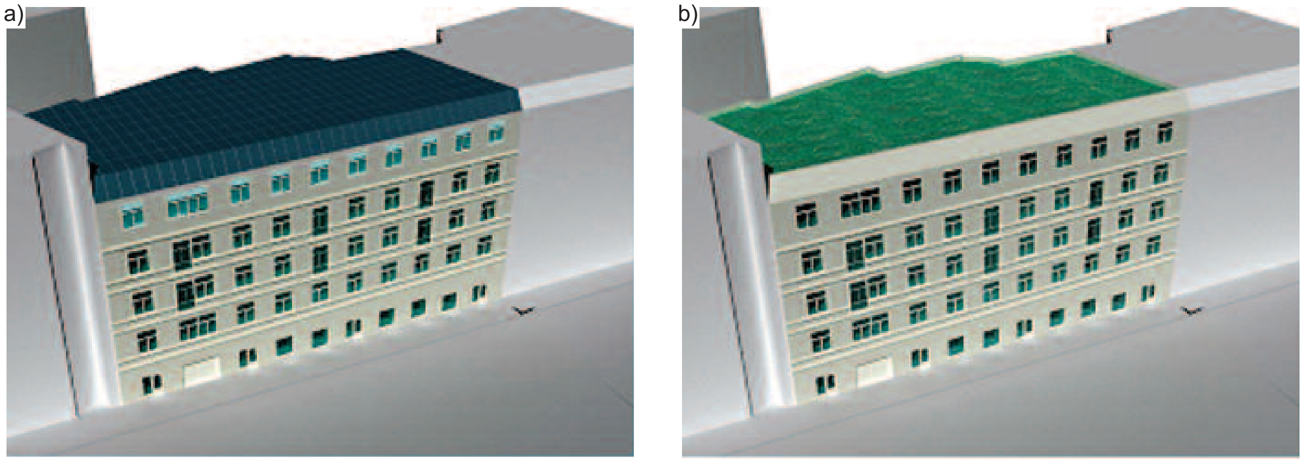

Fig. 1. Visualization of two proposals for building extension: a) roof covered with photovoltaic panels; b) extensive green roof
Rys. 1. Wizualizacja dwóch propozycji nadbudowy budynku: a) dach pokryty panelami fotowoltaicznymi; b) dach zielony ekstensywny

In the first option, the roof would be covered with photovoltaic panels. Advantages of this solution include:

- no significant impact on the historic appearance of the tenement;
- lightweight and cost-effective installation compared to the "roof & panels";
- the possibility of using energy generated by panels to meet auxiliary energy needs;
- the option to use excess electricity during the summer for powering a heat pump, catering to domestic hot water needs, or supplying the proposed elevators in the modernization.

In the second option, a green roof with sedum plants was proposed. Advantages of this green roof solution include:

- preventing overheating of the attic;
- improving aesthetics and reducing dust pollution;
- preventing disruptive flooding incidents;
- water retention and delaying the runoff of rainwater from the roof.

It is possible to install an external elevator next to the southern staircase. It is difficult to fit the second elevator near the semi-circular staircase without compromising access to light and the apartment area. Therefore, the elevator will only go to the top floor. This improves accessibility for people with disabilities to apartments near staircase 1. The proposed solutions are visible in Fig. 2.

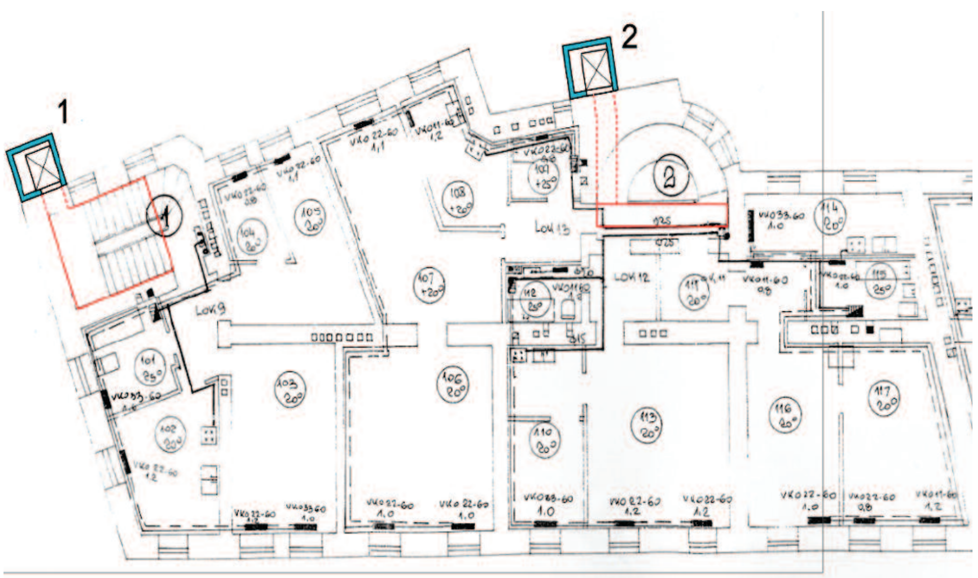

Fig. 2. Building plan with location of added lifts
Rys. 2. Rzut budynku z lokalizacją dostawionych wind

There is an option to build the one floor height courtyard adjacent to the western wall to increase the value of the property, biologically active surface area, create better integration opportunities, and install the aforementioned elevators more effectively. This action also allows access to the building from Ordynacka Street, creating an alternative entrance suitable for people with limited mobility due to the smaller slope on this street.

Effects of Renovation

Energy Efficiency. For the study, calculations were performed of the primary non-renewable energy demand and its indicators for two previously described renovation variants according to the regulation [11] in the Audytor OZC program. The superstructure by one floor allowed an increase in solar gains and radiation gains. Although the surface area of heat loss through building elements increased, additional thermal insulation reduced transmission losses by about half. Simultaneously, heat losses from ventilation were significantly reduced. Both options yield very similar results in improving energy efficiency. The comparison of obtained energy demand indicators is presented in Table 2. It should be noted that the both renovation variants did not meet the requirements for the primary non-renewable energy demand (EP) indicator.

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Table 2. Comparison of energy demand
Tabela 2. Porównanie zapotrzebowania na energię

Characteristics	Current state [kWh/m²year]	1nd option [kWh/m²year]	2nd option [kWh/m²year]
Usable energy consumption per unit	154,2	46,4	45,8
Final energy demand including auxiliary devices	214,9	33,3	74,6
Unit energy demand for non-renewable primary energy including auxiliary devices	197,2	79,1	81,9
Unit boundary demand for non-renewable primary energy for a building according to WT 2021		65,0	

In the first renovation option, heat pumps would be powered by electricity from the power grid. The primary energy factor (w_i) for the grid is high and was 2.5, resulting in high EP values.

In the second option, the building would still be connected to the district heating, but the average wi factor would be only about 0.9. The building cannot generate enough green energy to meet its needs. External support is needed for complete decarbonization, which could be possible with changes in the national energy mix or the decarbonization of the district heating network. However, these changes were not part of this study, even though information from the district heating supplier indicated planned actions in this regard. Unfortunately, in the case of Warsaw, the district heating provider does not own generation sources, making actions in this area challenging.

Emission Reduction. The building is supplied with district heating. In Poland it is mostly produced from fossil fuels, primarily hard coal which leads to significant emissions. Electricity in the building is sourced from the power grid, This increases the emissions of both CO_2 and other pollutants. The total pollution emissions are presented in Table 3. Both renovation variants would reduce this pollution. In the first option, CO_2 emissions would be reduced by 40%, and in the second, by 44%.

Table 3. Comparison of total emissions before and after retrofit
Tabela 3. Porównanie całkowitej emisji przed i po modernizacji

State building	SO_2 [kg/year]	NO_2 [kg/year]	CO [kg/year]	CO_2 [t/year]	Particles [kg/year]
Current state	207,4	166,6	21,7	122,6	4,78
1st option for thermal modernization	194,5	92,0	2,3	73,1	3,07
2nd option for thermal modernization	132,7	90,7	9,4	68,1	2,71

Conclusions

Based on the calculations and analyses, the following conclusions can be drawn:

1) renovationof the analyzed building can results in a 40% reduction in CO_2 emissions for variant I and a 44% reduction for variant II. The additional floor allows easier implementation of planned improvements, such as installing PV panels or a green roof and introducing balanced ventilation with heat recovery. In the case of new building elements it easier to meet the current thermal insulation requirements;

2) considering the costs of conducting renovation works and the often suitable strength parameters of historic buildings, it is worth considering the possibility of their superstructure. Estimated total costs for renoavtion with a superstructure (in 2023) range from 2.6 to 2.9 million PLN, depending on the chosen option. The green roof option more affordable solution. Renovation costs could be covered mostly by selling an additional 200 m² of usable space on the added floor;

3) comprehensive renovation of historic buildings will be possible only with the decarbonization of the energy carriers supplied to them – district heating and electricity. The potential for on-site renewable energy production is usually limited. These conclusions arise not only from the presented analysis but also from the „Engineers of the New Generation" project carried out in cooperation between the Warsaw University of Technology, the Embassy of the Kingdom of Denmark, the City of Warsaw and Danfoss. The project aimed to develop decarbonization plans for selected buildings in Warsaw by 2050.

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