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The efficiency of energy-saving activities in the process of thermal modernization of multi-family buildings

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Abstract: The introduction of innovative technologies and solutions and the adaptation of existing building resources to the standards of energy-efficient construction combines economic effects with care for the health and comfort of users as well as limiting the negative impact of buildings on the environment and climate. The thermal modernization of buildings is one way of saving energy. It is estimated that households are the largest heat consumers. In the article, the analysis of the effects of heat consumption reduction was performed for multi-family buildings. The basic effects of thermal modernization relate to economic issues associated with the reduction of fuel, water and electricity consumption, and thus incurred fees. The effects also refer to reducing the amount of air pollution, improving indoor microclimate conditions and user safety, as well as eliminating energy poverty and stimulating public awareness of energy-saving activities.

Keywords: multi-family buildings, thermal modernization, energy saving, environmental pollution, interior microclimate

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Introduction

Maintaining the current level of production and living standards, while caring for the environment and health of societies, is possible due to the rational management of energy and proper shaping of the energy performance of buildings. The provisions of EU directives have obliged member states to take actions related to increased energy efficiency, reduced greenhouse gas emissions and increased share of renewable energy sources in final energy consumptions (*A Roadmap; Energy; EUROPE 2020; Directive 2012/27/EU*).

One of the elements of rationalizing the energy consumption in buildings and reducing emissions are projects related to the thermal modernization of existing objects. The essence of implementing a thermal modernization program is to achieve benefits, not only energy-wise or for the environment, but also economically, functionally, socially, integrationally, and more. According to expert estimates from the Building Performance Institute Europe, the annual energy savings through thermal modernization may by 2030 achieved 26% of consumption from 2013, whereas the total net social benefits by 2045 could reach about 170 billion euros (*Energy Efficiency*; *Global*; Guła, 2014). Energy efficiency, low-carbon economy, and renewable energy would result in an emission reduction of 48-58% by 2030 and of 80-95% by 2050 (*A Roadmap*; Bukowski, 2013; Gielena et al., 2019; Guła, 2014).

It is estimated that the largest heat consumers in Poland are households, their share in the heat consumption market is about 50% (*Energy consumption*). According to the National Census of Population and Housing prepared in 2011, there were 5 542 600 single and multi-family residential buildings in Poland, of which approximately 4 million were built before 1990 (*Apartments*; *Inhabited*; *National*). The energy-efficiency potential for these buildings is very high due to the low thermal insulation standards in force in buildings of this age. The structure of energy consumption in residential buildings built in specific years is shown in Figure 1.

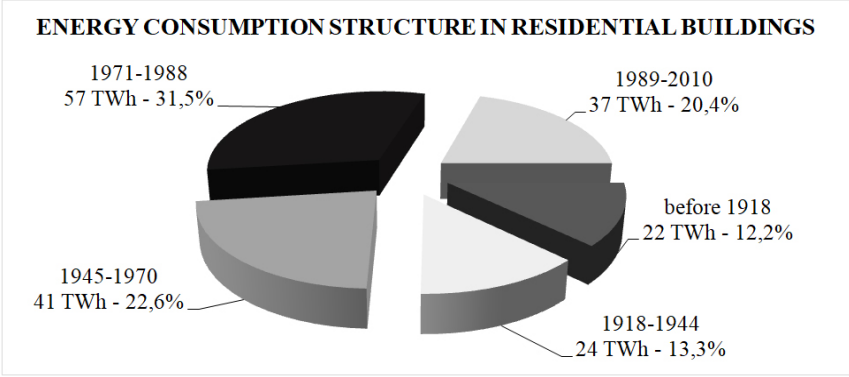

Fig. 1. The structure of energy consumption in residential buildings in Poland by construction period (*Apartments; Inhabited; National*)

About 70% of heat consumption in residential buildings is carried out from individual sources mainly from coal (to 10.8 mln Mg annually) which is estimated to be responsible for 55% PM 2.5 and 23% NO_x emissions in recent years (*Energy statistics*; *The Environmental*; Stala-Szlugaj, 2018; *The state*).

Given the significant heat consumption in residential buildings and their negative impact on the environment, a program of thermal modernization among this group of buildings would bring various measurable benefits (Alsabry et al., 2017; Derbiszewski & Jędrzejak, 2017; Dubrakova, 2019; Guła, 2014; Krawczyk et al., 2019; Lis, 2019).

1. Object of the research

The object of the research was the effects of reducing energy consumption in a group of 8 multi-family buildings. The analyzed buildings are multi-family residential buildings built in the 1950s or 60s. The buildings were made using traditional techniques, with brick walls and precast beam and hollow tile ceilings. The buildings were three or four storeys, complete with basement and an unused attic. Although the structural elements were intact, the general technical condition of the buildings was poor. First of all, the façades were damaged, there were numerous defects in the external plaster and flashings. The lack of thermal insulation, both in the walls and ceilings, caused significant heat loss. Also, the old wooden windows and doors were characterized by low insulation and loose fit. Partially replaced PVC windows did not meet the requirements for thermal insulation. The values of heat transfer coefficients for the building envelopes before and after thermal modernization are presented in Table 1.

Table 1. Heat transfer coefficient of analyzed buildings (*own research*)

Building envelope	Heat transfer coefficient [W/(m^2 K)]			
	Before thermal modernization		After thermal modernization	
	Harmonic mean	Standard deviation	Harmonic mean	Standard deviation
Walls	1.27	0.17	0.22	0.03
Ceiling under the attic	1.44	0.32	0.16	0.02
Ceilings above basements	1.26	0.23	0.29	0.04
Roof	0.88	–	0.28	–
Windows	2.40	0.40	1.60	0.30
Doors	3.37	0.56	2.03	0.66

Two buildings were already connected to the central heating network, three to the local area network and gas water heaters. The others had individual heating and hot water preparation. Heating of buildings and preparation of hot water was mainly based on solid fuels especially coal. The installations were outdated and inefficient. There was a lack of patency of some chimneys and ventilation ducts.

Based on an audit analysis, extensive thermal modernization of the studied buildings was undertaken. As part of the thermal modernization, the insulation of the building envelope and replacement of windows and external doors were made. Insulation of the building envelope was made using mainly polystyrene and mineral wool, windows were replaced with modern PVC models and doors with modern PVC or wood varieties. Also, modernization of the heating and hot water preparation system was carried out. In buildings with individual heating, the creation of a boiler room, central heating system, and preparation of hot water was proposed.

In addition, cold water and sewage installations were renovated in several buildings, as well as, defective ventilation cleared.

2. Energy and economic efficiency of thermal modernization

The economic benefits resulting from the reduction of fuel, water and electricity consumption are, above all, the reduction of charges incurred for the use of buildings, but also the increase in economic development in sectors related to thermal modernization, including the number of new jobs or the reduction of expenses for the improvement of public health and the state and protection of the environment (Al Horr, 2016; *Economic*; Guła, 2014).

As a result of thermal modernization, the final energy demand for heating, ventilation and hot water decreased in the range of 35-65%. Before modernization, the final energy demand was on average 186.4 kWh/m^2 year at standard deviation 54.6 kWh/m^2 year and after modernization decreased to 89.6 kWh/m^2 year on average at standard deviation 21.3 kWh/m^2 year. The reduction of energy demand would cause an average of about 45% decrease in fees. After thermal modernization, the consumption of water decreased, about 10%, and electricity about 26%, due to the lack of necessity to reheat the rooms and the use of energy-saving lighting. The average area of the flat was 80 m^2 and annual energy consumption in a household was 84 GJ, costing about 1300 € (*Energy consumption*). Obviously the steady increase in fuel and energy costs results in a steady increase in the operating costs of buildings. However, abandoning the thermal modernization program in a measurable way would increase these costs even more (Fig. 2).

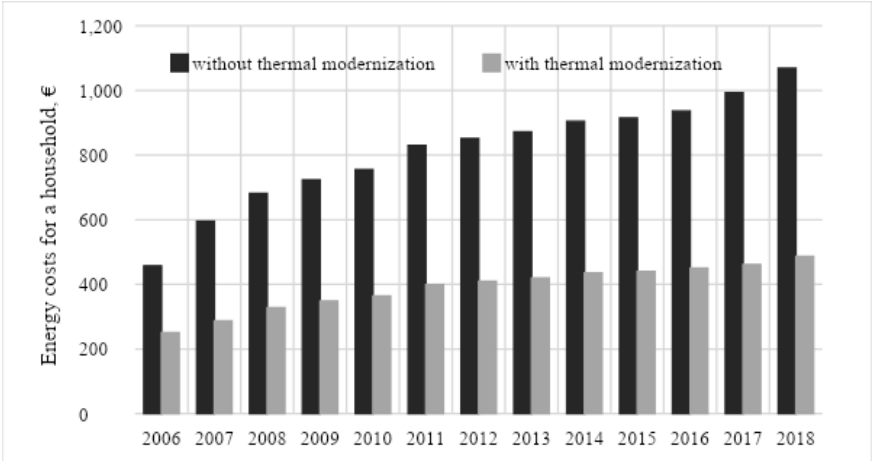

Fig. 2. Average annual central heating and domestic hot water costs for a household compared to costs without thermal modernization (*own research*)

However, abandoning the thermal modernization program in any measurable way would increase these costs. The replacement of coal by gas may not cause

measurable economic benefits but it would significantly reduce low-carbon emissions and costs associated with coal boiler exploitation.

3. Environmental efficiency of thermal modernization

Environmental benefits are associated with the reduction of emissions of harmful substances into the atmosphere from the combustion of fuels, primarily solid fuels, used to generate energy. The use of solid fuels, mainly poor quality coal and wood (used by 45.4% of households) (*Energy consumption*) leads to negative changes in the Earth's climate and the deterioration of the quality of life and human health, as well as an increase in mortality. Harmful substances that especially increase the risk of cardiovascular and respiratory diseases or death are above all particulate matters PM10 and PM2.5, polycyclic aromatic hydrocarbons, e.g. benzo(a)pyrene, dioxins, sulphur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide, as well as heavy metals (*Economic*; *Evolution*; Gurjar, 2010). Poor air quality is particularly troublesome during the heating season. Pollutants introduced into the air as a result of emissions accumulate around the area of production and are, under unfavourable weather conditions, the cause of the formation of smog.

The reduction of energy demand, and thus the amount of fuel necessary to produce it (hard coal was accepted for district heating) translated into the reduction of emissions of harmful substances into the atmosphere. This is particularly beneficial in the case of private boiler rooms. The percentage reduction in emissions of selected harmful substances into the atmosphere after quitting coal thanks to thermal modernization is shown in Figure 3.

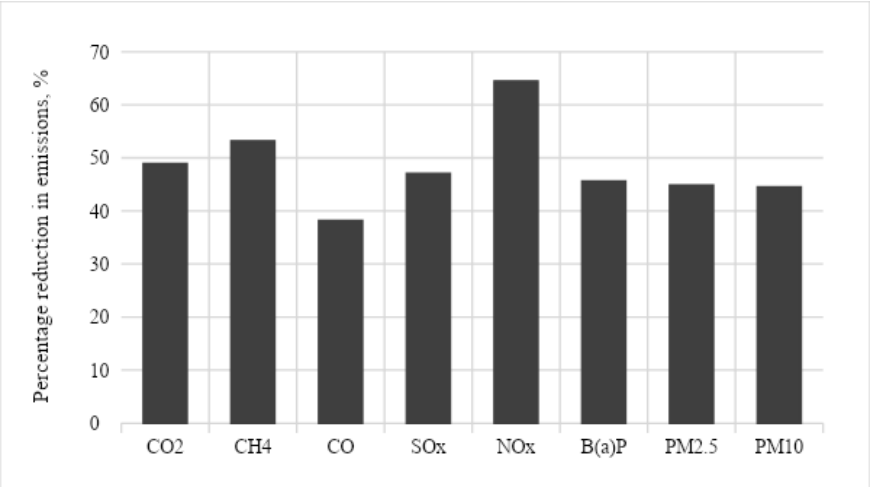

Fig. 3. Percentage reduction in emissions of select harmful substances (*own research*)

The use of gas as an energy carrier would cause almost a 98-100% reduction of pollution to the atmosphere.

4. Usable efficiency of thermal modernization

The utility benefits are associated most of all with the improvement of the quality of the indoor environment, thermal comfort, and living comfort. Errors in the implementation of the energy efficiency program, increasing the tightness of buildings and inadequate ventilation often results in the worsening of the microclimate quality and intensifies the symptoms associated with poor health. (Godish, 2016; Sowa 2018).

The results of the research conducted among residents in the analyzed buildings regarding the condition of interior microclimate and thermal comfort of residents indicate a significant improvement in the room's environmental conditions and the feelings associated with being there. An increase in indoor air temperature and a decrease in air humidity were observed. High humidity is unfavourable in saving energy. Occasionally, mould found on the inside of partitions and retaining windows has disappeared.

The thermal comfort of the inhabitants was also radically improved. Before carrying out thermal modernization works, as much as 70% of residents indicated the inadequate condition of the indoor environment (Fig. 4).

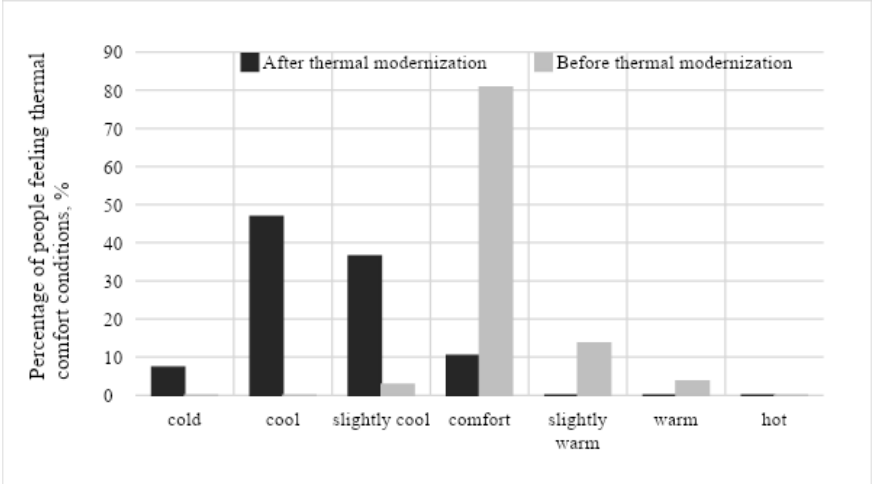

Fig. 4. The conditions of thermal comfort of the inhabitants (*own research*)

During the research, sick-building syndrome symptoms were noted in long-term residents of the rooms. The study was based on questionnaires. The occurrence of symptoms in the studied population of people before and after thermal modernization is presented in Table 2.

Some of the sick building syndrome symptoms, most notably, flu-like symptoms or nose irritation and rhinitis partly receded after thermal modernization. Increased fatigue, sleepiness, and difficulty in concentration possibly related to overheating of the rooms, excessive tightness of windows or the increase of carbon dioxide levels in the rooms.

Table 2. Sick building syndrome symptoms before and after modernization (*own research*)

Sick building syndrome symptoms	Percent symptom occurrence	
	Before thermal modernization	After thermal modernization
Eye irritation	20.5	7.2
Throat irritation, cough	44.9	16.8
Nose irritation, rhinitis	40.1	24.7
Headache	33.8	29.1
Itching and dry skin	14.6	11.8
Flu-like symptoms	27.4	9.8
Malaise	38.6	17.3
Difficulty in concentration	27.8	38.4
Fatigue and sleepiness	23.1	37.3

As a result of the thermal modernization works, there was an improvement in safety related to the elimination of individual heating sources and the risk of poisoning from inefficient smoke and ventilation ducts. In individually heated buildings, the creation of a central heating system and hot water preparation has contributed to the improvement of the quality of flats, especially important for the elderly. The elimination of individual heating sources has contributed to increasing the cleanliness of the rooms and reducing the costs of renovating them. In general, residents rated the quality of housing before thermal modernization as unsatisfactory (51.3%) and poor (12.3%). After the thermal modernization works, the majority of residents assessed the quality of housing as very good.

An important aspect of the thermo-modernization works carried out in the analyzed buildings is the improvement of the apartment standard, which contributed to the increase in their value as well as the attractiveness associated with the possible sale. Renovation of the façade brought an aesthetic effect, which was further strengthened by the arrangement of the environment.

5. Social efficiency of thermal modernization

Social benefits are primarily associated with the reduction of energy poverty, stimulating public awareness of energy-saving activities and social exclusion. Conducting activities related to extensive thermal modernization of the building structure, especially within degraded areas, can be a positive element conducive to urban regeneration.

Conducting extensive thermal modernization of the building reduced the costs associated with its operation, which undoubtedly improves the financial situation of poorer residents. An increase in fuel prices could lead to energy poverty, which occurs when the costs of ensuring an adequate indoor temperature in winter and summer exceed 10-20% of the household budget (Thomson et al., 2017).

Preparation, implementation and use of the results of a thermal modernization project may also result in a number of beneficial elements in the area of functioning of the local community. The social awareness and activity of the inhabitants are stimulated, they are more willing to take care of the common property. The implementation of energy-efficient solutions favours the energy-saving and ecological attitude of residents and is a model for the owners of neighbouring residential buildings. Exemplarily implemented thermal modernization projects can become an impulse to stimulate this type of activity among building owners and administrators, especially in smaller, often more integrated local communities.

Summary

The share of energy consumption for heating in the overall energy consumption balance has been steadily decreasing in recent years, thanks to the introduction of increasingly stringent requirements in terms of thermal insulation and energy-saving, as well as installation of more efficient heating devices and intensification of activities in the field of thermal modernization of buildings. Such activities fit perfectly into the idea of sustainable development. Satisfying the basic needs of society as well as preserving, protecting and restoring the proper condition of the Earth's natural environment. Conducting extensive thermal modernization not only allows for the rationalization of energy consumption or reduction of building operation costs but at the same time minimizes the harmful impact of the building on the environment, resulting from the use of natural resources and the emission of harmful substances generated in the process of fuel combustion. It also improves the condition of the interior environment, increases its comfort and brings numerous benefits in the social sphere.

The article presented the results of thermal modernization activities carried out in a group of multi-family residential buildings. The problem of noncompliance with applicable requirements in the field of thermal protection of buildings is extremely important as it currently concerns a significant part of existing housing resources. In addition to the economic benefits resulting from the obtained energy effect, thermal modernization activities have contributed to the improvement of the outside air quality, interior microenvironment and thermal comfort of people, as well as to the increase in the standard of use of buildings and the quality of life of their residents. Improving the comfort and safety of use is important especially for people of elderly age, who often make up the majority of residents in buildings with particularly unfavourable energy parameters. Creating one boiler room in a building prevents the combustion of all kinds of plastics or rubber waste, so commonly practiced by individual furnace users, which is a source of highly toxic, polycyclic aromatic hydrocarbons, dibenzofurans or dioxins. This contributes to the increase of ecological awareness of the local community in the scope of reducing environmental pollution by-products of combustion during the heating of buildings. Thermal modernization was particularly beneficial for people with lower incomes. Conducting thermal modernization radically reduces operating costs,

and thus improve the financial situation of poor social groups, eliminates the phenomenon of energy poverty, and also increasing the value of the owned property. An underestimated effect of thermal modernization is also the possibility of a beneficial effect on the consolidation and stimulation of the activity of local communities. Thermal modernization can also be an impulse to undertake revitalization activities.

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Efektywność działań energooszczędnych w procesie termomodernizacji budynków wielorodzinnych

Streszczenie: Wprowadzenie innowacyjnych technologii i rozwiązań oraz dostosowanie istniejących zasobów budowlanych do standardów budownictwa energooszczędnego łączy efekty ekonomiczne z dbałością o zdrowie i komfort użytkowników, a także ogranicza negatywny wpływ budynków na środowisko i klimat. Jednym z elementów oszczędzania energii jest termomodernizacja budynków. Szacuje się, że gospodarstwa domowe są największymi odbiorcami ciepła. W artykule przeprowadzono analizę efektów ograniczenia zużycia ciepła dla budynków wielorodzinnych. Podstawowe efekty przeprowadzonej termomodernizacji dotyczą zagadnień ekonomicznych związanych z redukcją zużycia paliwa, wody i energii elektrycznej, a tym samym zmniejszeniem ponoszonych opłat. Efekty wiążą się również ze zmniejszeniem zanieczyszczenia powietrza, poprawą warunków mikroklimatu w pomieszczeniach i bezpieczeństwa użytkowników, a także eliminacją ubóstwa energetycznego i stymulowaniem świadomości społecznej odnośnie do działań zmniejszających zużycie energii.

Słowa kluczowe: budynki wielorodzinne, termomodernizacja, oszczędność energii, zanieczyszczenie środowiska, mikroklimat wnętrz