EFFECTS OF DEEP THERMAL MODERNIZATION AND USE OF RENEWABLE ENERGY IN PUBLIC BUILDINGS IN NORTH-EASTERN POLAND

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Abstract. Rational use of energy in buildings, their maintenance and proper exploitation are important issues, because they determine the standards of life and health of the population. In existing buildings, it is necessary to carry out ongoing repairs or modernization to maintain proper technical condition as well as to reduce energy consumption and CO_2 emissions. This is part of the global activities aimed at increasing energy efficiency and care for the natural environment. Retrofitting may involve the building envelope, ventilation system, heating system, hot water preparation, lighting and the use of renewable energy. The best results are achieved because of comprehensive deep thermal modernization. The paper analyses the possibilities of energy consumption reduction because of deep thermal modernization and the use of renewable energy in few public buildings in rural areas in north-eastern Poland. This is a case study based on energy audits. Energy consumption decreased by 46-65 % and CO2 emissions by over 80 %. The share of renewable energy from solar collectors and photovoltaic panels was not high (from 3 % to 15 %). The cost of saving the energy unit during deep thermo-modernization in the test sample was higher than its current price.

Keywords: deep thermal modernization, renewable energy, public buildings, reduction of energy consumption, CO_2 emission.

Introduction

Savings that can be obtained as a result of thermal modernization depend mainly on the construction period and the changes made in the provisions concerning the heat transfer coefficient of exterior walls and ceilings of buildings (Table 1).

Table 1

Changes of the heat transfer coefficient *U* for the rooms in the buildings, heated more than 16 °C and the demand of final energy [1; 2]

Year of coming into force (Polish Norm)	Required thermal transmittance coefficient *U* for selected partitions, $W \cdot m^{-2} \cdot K^{-1}$			Final energy, $kWh \cdot m^{-2} \cdot yr^{-1}$
	windows-doors	walls	roof	
since 1958 (PN-57/B02405)	–	1.16-1.42	0.87	> 240
since 1968 (PN-64/B03404)	–	1.16	0.87	200-260
since 1976 (PN-74/B03404)	–	1.16	0.70	
since 1983 (PN-82/B02020)	2.00-2.60	0.75	0.45	160-200
since 1992 (PN-91/B02020)	2.00-2.60	0.55-0.70	0.30	120-160
since 16th of December 2002 (Technical requirements – the ordinance)	2.00-2.60	0.30-0.65	0.25	90-120
since 1st of January 2014 (Technical requirements – the ordinance)	1.30-1.50	0.25	0.20	–
since 1st of January 2017 (Technical requirements – the ordinance)	1.10-1.30	0.23	0.18	–
since 1st of January 2021 (Technical requirements – the ordinance)	0.90-1.10	0.20	0.15	–

As a result of thermal modernization carried out under current energy performance standards, the final energy consumption for heating, ventilation and hot water preparation can be reduced by approximately 25-50 % and the index of demand for usable energy for heating and ventilation may be about 70-80 $kWh \cdot m^{-2} \cdot yr^{-1}$.

In recent years, the issue of deep modernization or modernization to the NZEB (nearly zero-energy building) or passive standard has been increasingly discussed [3-5]. Because of deep thermal modernization, the final energy consumption for heating, ventilation and hot water preparation can be reduced by approximately 70 % and the index of demand for usable energy for heating and ventilation may be about 20 kWh·m^{-2}·yr^{-1}.

The energy savings possible to achieve depend also on the condition of its previous modernization. Three stages of building thermal-modernization can be distinguished [3; 5].

- light (low) renovation (modernization or replacement of heat source);
- medium renovation (modernization or replacement of heat source together with replacement of window and door joinery or thermal insulation of a facade);
- complex renovation (total or partial replacement of energy sources, the use of renewables or the use of high-efficiency cogeneration, replacement of the central heating and DHW with insulation – in accordance with current technical and construction regulations, replacement of window and door joinery, insulation of the whole external envelope – façades, flat roof and the ceiling/ floor, repair of balconies).

The costs of the renovation (defined in 2013 [5; 6]) regarding m^2 of heated usable area of non-residential buildings were:

- 40 EUR for light (low) renovation,
- 80 EUR for medium renovation,
- 170 EUR for complex renovation.

The type of building is also important because the structure of energy consumption is completely different. In Polish non-residential buildings most of the energy is consumed by heating and ventilation or if need be by air conditioning (HVAC) (37 %), followed by lighting (32 %) and electrical appliances (24 %). In residential buildings energy is used mainly to meet space heating requirements (69 % of total energy consumption) and water heating (15 %). According to the buildings database (the EU Building Stock Observatory) published by The European Commission, the EU building stock is quite heterogeneous and most of the floor area belongs to residential buildings. The share varies considerably, from around 60 % in Slovakia, Netherlands and Austria to more than 85 % in the southern countries of Cyprus, Malta and Italy. In Poland, the highest share in all non-residential buildings have office and education buildings (26 % each) and commercial buildings (25 %).

Nowadays, environmental factors are not without significance. Countries all over the world try to reduce CO_2 emission. In 2015, during the COP21, the Paris Agreement on emission reduction was signed as part of the greenhouse gas reduction method.

Materials and methods

The analysis was carried out on a group of 5 public buildings located in rural areas in north-eastern Poland. Majority of them (Table 2) were constructed prior to introducing in Poland any formal energy performance requirements, as a result of which thermal quality of partitions is considerably below that, which can be achieved today. In buildings constructed in the 1970s and in 1976-1983 thermal insulation of part of the façade and in two buildings partial roof insulation was made. The majority of windows joinery in the sample has been replaced. Ventilation heat loss in the examined buildings ranged between 23 % (in the building constructed in 1959) and 48 % (in the building constructed in 1976) of total loss. The value depended on the building envelope standard. The average indoor temperature in the two buildings was 20 ºC, while in the others it was lower than 20°C (after considering rooms for other purposes than, e.g., classrooms or offices). The average temperature in basements was 9.8-13.3 ºC.

Table 2

Characteristics of the analysed buildings before retrofitting

Year of construction	Heated area, m^2	Temperature, ºC	*U* value, W·m^{-2}·K^{-1}			Heat source	
			windows	walls	roof	Heating	Hot water
1959	783.2	19.4	1.70	1.08	0.83	oil boiler	electric heater
1970s	911.6	20	1.70	0.37/0.96 1.15/1.18	2.55	oil boiler	eco-pea coal boiler

Table 2 (continued)

Year of construction	Heated area, m^2	Temperature, °C	*U* value, $W \cdot m^{-2} \cdot K^{-1}$			Heat source	
			windows	walls	roof	Heating	Hot water
1978	987.3	20 / 9.8	1.70	0,86	0,52	oil boiler	electric heater + oil boiler + solar collectors
1986	974.6	18.9/13.3	1.30/3.00	0.75/1.71	0.38	oil boiler	electric heater
1976-1983	6 437.3	17.6	1.70/3.12	0.28/0.65/ 0.82/1.00	0.13/ 0.46	coal boiler	electric heater

These buildings needed renovation due to the high energy consumption. Energy audits [7] were carried out for them. Improvements of the envelope to meet the Polish regulations of thermal protection, which will come into force on January 1, 2021 (table 1), were proposed. The thermal insulation layer was mounted on the walls of all buildings. The roofs were sealed, and an additional insulation layer was applied. All windows in building constructed in the 70's and old windows in buildings from 1986 and 1976 were replaced. The new central heating installations were made. Lighting was replaced with LED lighting (without a building constructed in 1959). Additional activities:

- in the building constructed in 1959: replacement of energy source (pellet stove), the use of solar collectors,
- in the building constructed in the 70's: the use of mechanical ventilation with heat recovery and the use of solar collectors,
- in the building constructed in 1978: replacement of energy source (oil-fired condensing boiler), the use of photovoltaic panels,
- in the building constructed in 1986: replacement of energy source (pellet stove), the use of photovoltaic panels,
- in the building constructed in 1976-1983: the use of photovoltaic panels.

Results and discussion

The calculations indicate significant possibilities of reducing energy consumption as a result of work on improving the efficiency of energy use for heating in the sample (Figure 1). Increasing the insulation of external partitions and improving the ventilation system have reduced the usable energy index for heating by 33-69 %. The savings achieved in individual buildings (69 %; 68 %; 48 %; 45 % and 33 %) corresponded with the year of their construction (except for the building being built in 1976-1983, in which 10 % of the walls and 34 % of the roofs had low U-value before modernization). After taking into account the replacement of the central heating installations and heat sources, the final energy savings for heating amounted to 48-72 %.

In the analysed group, the share of heat demand for preparation of hot water in the structure of energy consumption was lower in school buildings and in the office (3-6 % before modernization and 7-20 % after modernization) and higher in the kindergarten and the social welfare building (14-15 % before modernization and 29-39 % after modernization). The share of energy demand for lighting ranged from 8 % to 16 % before modernization and from 7 % to 19 % after modernization (Figure 2).

The final energy consumption reduction was 46-65 %. The share of savings resulting from the modernization of lighting was low (5-11 %), even if in some cases the installation of photovoltaic panels was supported. The majority of savings were connected with the reduction of energy demand for heating and ventilation. The greatest reduction (61 %) was achieved in a building constructed in the 1970s, in which mechanical ventilation with heat recovery was applied, the smallest (44 %) in a building from 1976-1983, where no heat source was mentioned. The domestic hot water preparation system has not been modernized. In rural areas, it was adhered mainly with the use of electric heaters or a boiler, in one case with the use of solar collectors. Application during the modernization of solar collectors in the building constructed in 1959 did not reduce the demand for final energy for preparation of hot water, but even increased it.

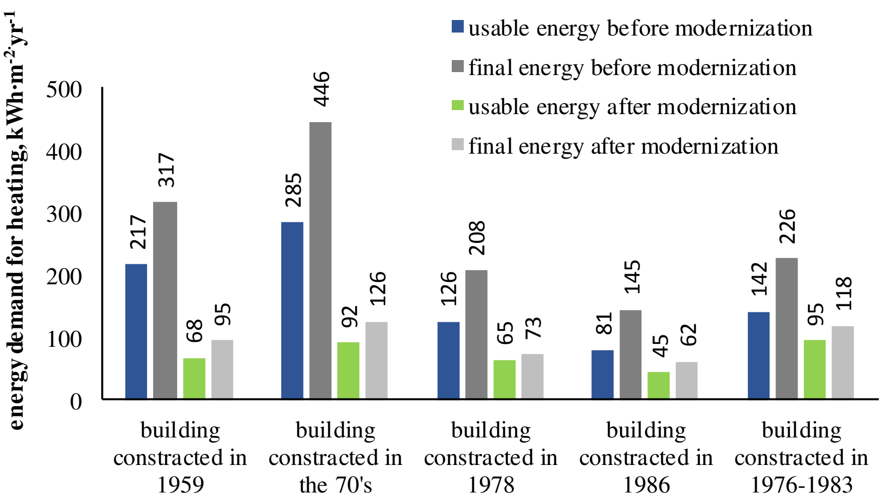

Fig. 1. **Energy demand for heating per unit area**

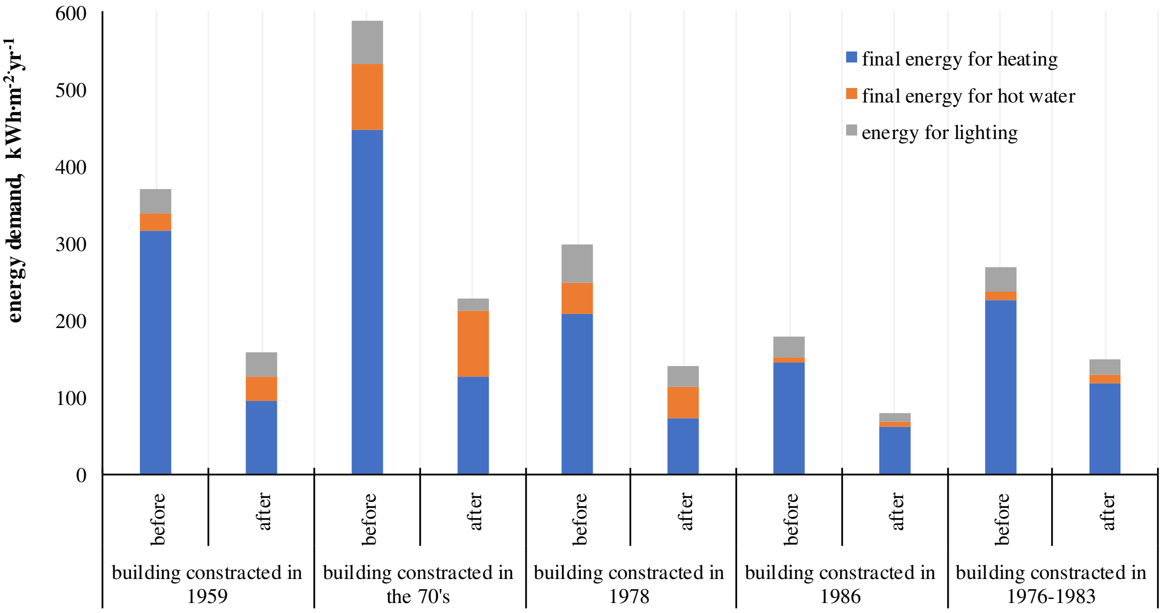

Fig. 2. **Structure of energy consumption in analysed buildings before and after deep thermal modernization**

The share of energy from solar collectors in the school building (built in 1959) and in the kindergarten (from 1978) amounted to 3 % after modernization and 15 % in the help centre building. The use of photovoltaic panels can provide 2 % of energy in the kindergarten, 3 % in a large school building and 15 % in an office building.

In accordance with the Polish national regulations, buildings after thermal modernization do not have to meet the expected for new buildings value of non-renewable primary energy indicator (EP). This indicator does not give information about the thermal quality of the building, because it depends mainly on the type of heat source.

However, in the process of applying for co-financing, an annual reduction of the primary energy demand was needed. In the analysed sample it ranged from 193 MWh to 994 MWh and depended not only on the size of the building, but also on the type of the heat source. A significant decrease in the non-renewable primary energy results in the use of renewable heat sources (pellet stoves).

Figure 3 shows the reduction of CO_2 emission resulting from modernization activities in absolute terms, as well as per unit of heated area. The largest total reduction was obtained in the largest building; however, the ecological efficiency of thermal modernization can be discussed on the basis of the emission related to the heated area.

Attention is drawn to the large annual reduction of CO_2 in the analysed buildings, amounting to more than 549 t.

The reduction of CO_2 emissions in individual buildings was:

- in the building constructed in 1959: 83 %,
- in the building constructed in the 70's: 65 %,
- in the building constructed in 1978: 54 %,
- in the building constructed in 1986: 86 %,
- in the building constructed in 1976-1983: 45 %.

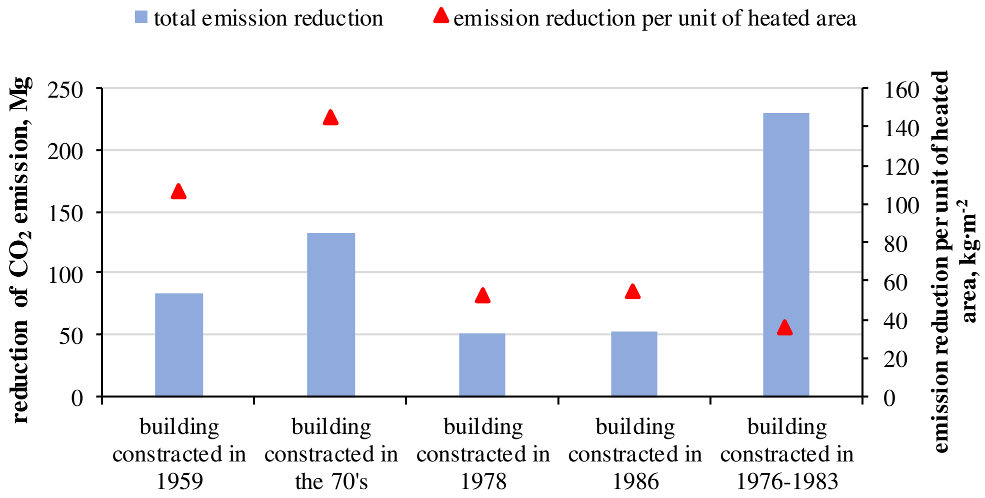

Fig. 3. **Total reduction of CO_2 emission and reduction per unit of heated area**

Investment costs per unit of heated area were varied (from 84 to 333 EUR·m^{-2} – Figure 4) and depended on the scope of thermal modernization. According to the criterion defined in [5, 6], almost all analysed cases of modernization can be qualifying as complex deep thermal modernization. Only in the case of a building constructed in the years 1976-1983, where no heat source replacement was, the unit cost only slightly exceeded the level determined for medium modernization.

The cost of energy savings shown in Figure 4 has been determined based on the average 15-year lifetime of all improvements. It ranged from 6 to 29 EUR·GJ^{-1} and in almost all cases exceeded the current unit cost of heat energy. In such cases, all types of funds supporting the improvement of the energy quality of buildings are very useful.

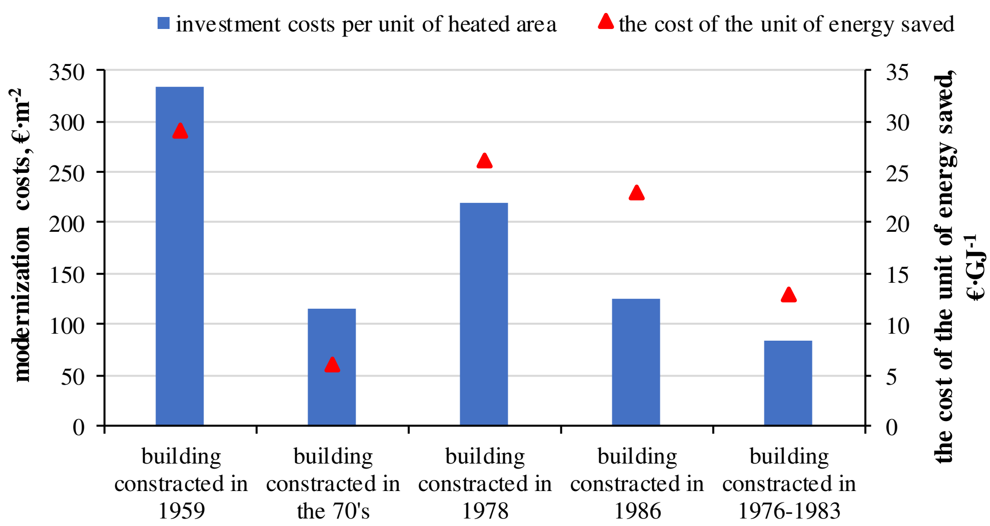

Fig. 4. **Investment costs per unit of heated area and cost of unit of energy saved**

Conclusions

1. Savings that can be obtained as a result of thermal modernization depend on many factors. Deep thermo-modernization of public buildings allowed for significant final energy savings, in the analysed sample by 46-65 %. It was also possible to significantly reduce CO_2 emissions (by 45-86 %).
2. The share of energy possible for obtaining from solar collectors in the analysed public buildings was not high – from 3 % in the kindergarten and small school building to 15 % in the social welfare building. The use of photovoltaic panels can provide 2 % of energy in the kindergarten, 3 % in a large school building and 15 % in an office building.
3. Replacement of the heat source with a biomass boiler (possible in rural areas) during a comprehensive modernization resulted in a significant reduction of CO_2 emission (by over 80 %).
4. The cost of saving the energy unit during deep thermo-modernization in the test sample was higher than its current price, which is why investments are economically unprofitable. However, due to the large energy and environmental effects, it is worth implementing them.

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