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4. MODERNIZATION OF EXISTING BUILDINGS

4.1. Improving energy efficiency of buildings

New buildings are constructed to demanding energy performance levels set by national legislation, therefore existing buildings require improvements in their envelops and systems to decrease energy consumption.

4.1.1. Characteristics of the renovation market

Under the existing Energy Performance of Buildings Directive, all new buildings in EU countries must be nearly zero-energy buildings by 31 December 2020 (public buildings by 31 December 2018). Majority of existing buildings were constructed prior to introducing any formal energy performance requirements, as a result of which the quality of the building stock is considerably below that which can be achieved today. Therefore, they need appropriate modernization, that is improvement of existing building technical features of a building which should lead first of all to reduction in energy demand. This operation not only limits heat losses and energy costs but also improves the exploitation conditions of rooms in the building. It can be an independent modernization venture or within the frames of rebuilding or complete refurbishment. As shown in table 4.1 (Firląg, 2016; BPIE et al., 2016) we can distinguish three stages of renovation.

In ZEBRA (Nearly Zero-Energy Building Strategy 2020) three renovation levels are also defined: “low”, “medium” and “deep”. Their definition is different across EU countries and corresponds to different levels of energy savings. For that reason, ZEBRA developed an indicator of “major renovation equivalent” where the total cost of the renovation relating to the envelope or its systems is higher than 25% of the value of the building, or more than 25% of the surface of the building envelope undergoes renovation. The building’s final energy demand for heating can be reduced by 50 to 80%.

Table 4.1. Stages of building renovation and estimated cost of the renovation work (Source: Firląg, 2016; BPIE et al., 2016)

Stages of building modernization	Activities to achieve the desired degree of renovation	The annual costs of the renovation (defined in 2013) regarding m^2 of heated usable area	
		In residential building	In non-residential
Light renovation	– modernization or replacement of heat source	40 €	40 €
Medium renovation	– modernization or replacement of heat source together with – replacement of window and door joinery or thermal insulation of a façade	75 €	80 €
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.	125 €	170 €

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 index of demand for usable energy for heating and ventilation may be about 70-80 kWh/m^2 per year. The greatest benefit could bring comprehensive thermal modernization, but its conducting requires high investment costs (table 4.1).

In recent years, the issue of deep modernization or modernization to the NZEB (nearly zero-energy building) or passive standard has been increasingly discussed (Węglarz, 2015; Firląg, 2016). Because of deep thermal modernization, the final energy consumption for heating, ventilation and hot water preparation can be reduced by approximately 70% and index of demand for usable energy for heating and ventilation may be about 20 kWh/m^2 per year.

The savings that can be achieved depend on type of the building, construction period, but also on the state of it previous retrofit. The EU building stock is quite heterogeneous. According to the buildings database (the EU Building Stock Observatory) published by The European Commission to track the energy performance of buildings across all Member States, 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 like Cyprus, Malta and Italy. A breakdown of non-residential buildings by categories is not homogeneous and depends on the economic structure of each sector. On average, three quarters of the service floor area is covered by offices (including both private and public; 30%), wholesale (27%) and education (16%). In Poland, the highest share in all non-residential buildings have office and education buildings (26% each) and commercial buildings (25%).

In Polish non-residential buildings most of the energy is consumed by heating, ventilation and 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). In Fig. 4.1 is shown the structure of energy use in households and non-residential buildings in Poland in 2012.

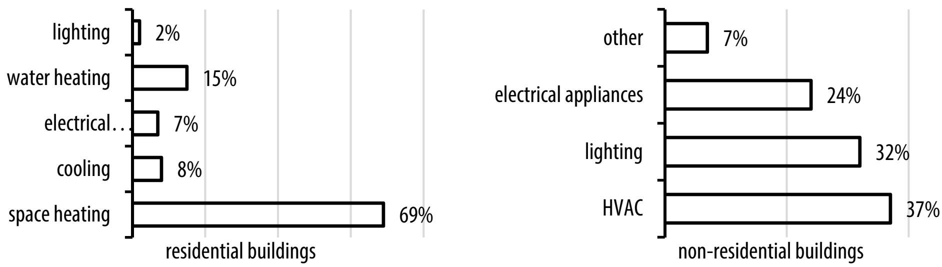

Fig. 4.1. Structure of energy use in buildings in Poland in 2012 (Source: BPIE et al., 2016)

Percentage of stock that has been modernized in Poland is shown in table 4.2.

Table 4.2. Thermal modernization statistics (Source: NAPE SA, 2012)

Construction period	Percent of stock that has been thermally modernized [%]
up to 1945	7
1946-1966	11
1967-1985	16
1986-1992	14
1993-2002	8
2002-2008	new buildings constructed under prevailing obligatory performance standards
after 2008	

According to the Central Statistical Office, approximately 50% of residential buildings in Poland have been insulated but below optimal levels. More than 70% of single-family houses have inadequate thermal insulation. Most of the buildings without thermal insulation were built before 1989. Additionally, heating technology is outdated. The most popular fuel is highly polluting coal, burned in old coal-fired boilers (Firląg, 2016). Only 1% of all houses in Poland can be considered energy efficient, primarily those that have been built in the last few years.

Thermal balance and the share of heat losses through individual building components depend upon technical condition, thermal quality as well as building geometry. Sample percentages are shown in table 4.3.

Table 4.3. Structure of heat losses through individual building components existing single-family building

building element	
walls	20-30%
roof	10-25%
windows	15-25%
basement / floor on the ground	3-6%
ventilation (natural)	30-40%

4.1.2. Current and modern solutions used for modernization

Traditional insulation materials (e.g. polystyrene or mineral wool – table 4.4) are commonly used for thermal insulation of building envelope, mainly due to their availability and price (lower than the price of modern materials).

One of the most popular methods of executing thermal modernization of external walls is ETICS (External Thermal Insulation Composite System). The thermal insulation material with a thin layer of plaster as a finishing component, is fastened to the outside wall. A layer of structural material (concrete or masonry) reduces the temperature fluctuations in the room and levels off differences in temperature on the inner surface of the wall (due to possible defects in the insulation layer).

Sometimes, especially in historic buildings, there is a need to insulate the walls from the inside. This method has some risks. One of them is the possibility of dampening the wall. Due to the low external temperature, the temperature inside the wall decreases considerably, causing condensation at the contact of the structural layer and thermal insulation. External walls do not have the possibility to accumulate heat which adversely affects the microclimate of the rooms. Another disadvantage is the occurring of thermal bridges which are difficult to eliminate while conducting thermal insulations from the inside. In this case, in addition to providing adequate thermal insulation of the wall, considering the humidity phenomenon is very important.

Table 4.4. Current and modern building solutions (Source: Staniaszek et al., 2014)

	Commonly used technologies	Modern solutions and technologies
Envelope insulation	Traditional insulation materials: – stone wool, glass wool, slag wool, – expanded polystyrene (EPS) and extruded polystyrene (XPS), polyurethane foam, – blown-in fibres wool or cellulose, – thermal spacer.	Modern materials: – nano-cellular polyurethane foam, – aerogel, – vacuum insulated panels – VIP.
Envelope prefabrication	– prefabrication sandwich panels.	– prefabricated façade and roof modules used to construct a new building envelope outside the existing building, – installation of prefabricated façades with solar thermal collectors.
Windows	Windows with low thermal conductivity: – double or triple glazed, – filled with noble gases like argon, krypton, xenon, – low-E coating applied to the glass to reduce radiant heat transfer, – shutters and window louvres, – automatically controlled louvres.	Windows with very low thermal conductivity: – increased insulation of the window frame, – vacuum windows, – dynamic glass (glass adapting to external conditions): thermal and electrochromic.
Roofing	– cold roof (covered with reflective material), – green roof (covered with vegetation).	– materials reflecting thermal radiation resistant to weather and UV radiation, – roof-integrated PV panels.

The current requirements of thermal protection of buildings in Poland are laid down in the Regulation of the Minister of Transport, Construction and Maritime Economy of 5 July 2013. For reconstructed buildings, external walls should meet the thermal insulation requirements included in the Regulation and window area should meet partial requirements. The maximum thermal transmittance coefficient for the walls, from January 2017, is 0.23 W/m^{2}K, for roofs 0.18 W/m^{2}K, and for the floor on the ground 0.30 W/m^{2}K. From January 2021 these requirements will be stricter.

The thickness of thermal insulation materials essential to obtain the expected thermal transmittance of external walls is shown in table 4.5. It was assumed that the thermal resistance of the bearing layers equaled 0.20 m^{2}K/W.

The thickness of insulation material should be determined not only by the minimum technical requirements, but it also needs to be based on the economic criterion. The issues concerning the choice of appropriate thickness of thermal insulation in building walls and optimal heat transfer coefficient have been described in many scientific papers (Attlmayr, 1974; Becher, 1974; Bogusławski, 1969, Bruckmayer and Lang 1972; Eichler, 1982; Górzyński, 1985; Kunze, 1976; Kisielewicz, 1976; Kozierski, 1968; Laskowski, 2005; Petzold, 1975; Pogorzelski, 1998; Robakiewicz, 1998; Sanecki, and Skoczek, 1966; Stachniewicz, 2002). Practical ineffectiveness of static methods that do not take into account changes in the value of money over time were also discussed by Kisielewicz and Rudczyk-Malijewska (Kisielewicz, 1976; Rudczyk-Malijewska, 1999). In other publications (Laskowski, 2005, Pogorzelski, 1998; Rudczyk-Malijewska, 1999; Stachniewicz, 2002) several modifications of the formula to calculate the NPV were made.

Table 4.5. Essential thickness of insulation for external walls (Source: KAPE S.A., 2012)

Type of insulation material	Design thermal conductivity λ [W/m·K]	thickness of insulation material [m]				
		with the expected wall heat transfer coefficient U				
		0.20W/m²K	0.15W/m²K	0.12W/m²K	0.10W/m²K	0.08W/m²K
Mineral Wool	0.034-0.045	16-21	21-28	27-36	33-43	41-55
Polystyrene (expanded) EPS	0.031-0.042	14-19	20-26	25-33	30-40	38-51
Polystyrene (extruded) XPS	0.034-0.040	16-19	21-25	27-32	33-39	41-49
Cellulose	0.037-0.043	17-20	23-27	29-34	36-41	45-52
Polyurethane Foam	0.025-0.035	12-16	16-22	20-28	24-34	30-42

For newly designed buildings this indicator is calculated as given by Equation 4.1:

$$NPV = -Kd + G_0\left(\frac{1}{R_0} - \frac{1}{R_0 + \frac{d}{\lambda}}\right)\sum_{t=1}^{n} \frac{(1+s)^t}{(1+r)^t}, \tag{4.1}$$

where:

K – cost of insulation material with assembling (€/m³),
d – thickness of the thermal insulation layer (m),
G_0 – quotient of annual heating cost referenced to 1 m² of wall area and thermal transmittance coefficient characterizing it ((€·K)/W),
R_0 – thermal resistance of the septum layers, i.e. structures, lining excluding heat insulation, together with heat transfer resistances on the surfaces of the partitions ((m²·K)/W),
λ – thermal conductivity of the thermal insulation material (W/(m·K)),
n – the assumed number of years of operation of the design thermal insulation (–),
s – growth rate of heating cost over inflation rate (%),
r – discount rate (%).

In the studies of other authors (e.g. Laskowski, 2005), slightly differing modifications of the formula 4.1 were made but did not alter its substantive meaning. This formula has a different form in case of thermal modernization of existing buildings. However, all modified formulas, after bringing them into the form of the NPV=f(d), allow, after using the extremum condition of the NPV function (Equation 4.2), to obtain the same equations to determine the optimal thickness of insulation material (Equation 4.4) and the optimum heat transfer coefficient (Equation 4.4).

$$\frac{\partial NPV}{\partial d} = 0\,, \tag{4.2}$$

$$d_{opt} = \lambda \sqrt{\frac{G_0 \sum_{t=1}^{n} \frac{(1+s)^t}{(1+r)^t}}{\lambda K}} - R_o \lambda, \tag{4.3}$$

$$U_{opt} = \sqrt{\frac{\lambda K}{G_0 \sum_{t=1}^{n} \frac{(1+s)^t}{(1+r)^t}}}. \tag{4.4}$$

The quotient of the annual heating cost, referenced to 1 m^2 of the wall area and heat transfer coefficient characterizing this wall, in the case of the double tariff (heating from the district heating network) can be calculated (Pogorzelski, 1998) as given by Equation 4.5:

$$G_0 = 12A(t_i - t_e) + BL_{Sd}, \tag{4.5}$$

where:

A – fixed monthly fee associated with the distribution and transmission of energy (€/MW),

B – variable fee charge for heat (€/GJ),

L_{Sd} – number of degree-days of heating period (1K·1day).

In table 4.6 we present the results of the calculation (done using formulas 4.3 and 4.4) of optimal thickness of polystyrene for insulating one and a half brick wall in an apartment building in Warsaw heated from the district heating network.

The optimum thickness of insulation in this case was 0.55 m, and the thermal transmittance of wall after the thermal retrofitting (0.07 W/m^{2}K) was much less than the value required by the current regulations for typical buildings.

Table 4.6. Values of parameters affecting the optimum thickness of wall insulation material and results of calculations of d_{opt} and U_{opt} (Jezierski & Sadowska. 2016)

Input data									Result of calculation	
λ	K	R	L_{Sd}	B	r	s	VAT	t	d_{opt}	U_{opt}
W/(m·K)	zł/m³	m²·K/W	K·days	zl/GJ	%	%	%	year	m	W/(m²K)
0.04	120	0.7	3686	0.50	6.5	3	23	30	0.553	0.069

The optimum value of the thermal transmittance coefficient can also be determined by the cost-optimal method according to Equation 4.6:

$$K_{CZ,j} = K_{M,j} + \sum_{i=1}^{30} (K_{E,j} \cdot R_d(i)) , \tag{4.6}$$

where:
$K_{CZ,j}$ – unit cumulative cost index for variant j (€/m²),
$K_{M,j}$ – costs of thermal insulation of the external partition for variant j (€/m²),
$K_{E,j}$ – operating costs due to heat loss through 1m² partition for variant j (€/m²),
$R_d(i)$ – discount factor for the year i, in which the infiltration, the change in energy prices and the discount rate were taken into account (–).

Table 4.7. Traditional and modern solutions and technologies used in installation systems (Source: Staniaszek et al., 2014)

	Commonly used technologies	Modern solutions and technologies
Ventilation and heating	– automatic (humidity sensitive) air diffusers and humidity sensitive ventilation grilles, – mechanical ventilation, – hybrid ventilation, – efficient recuperators – supply and exhaust ventilation with heat recovery.	– advanced control systems of ventilation efficiency.
Installation of hot water and central heating	– high efficiency boilers, – RES – biomass boilers, heat pumps (air, ground), – solar collectors (vacuum and flat), – photovoltaic panels; – heating mats (electrical) for floor and wall heating, – fan heaters, radiant heating, – automatic control and thermostatic valves, – aerators to DHW installations.	– hybrid systems – solar collectors cooperating with heat pump systems – micro cogeneration – cogeneration – Stirling engine.

This approach seems more appropriate nowadays because under Directive 2010/31/EU on the Energy Performance of Buildings, new energy requirements should be determined using the cost-optimal method.

Increasingly popular during modernization of buildings is the use of modern technologies for installation of heating, hot water or ventilation, as well as the use of renewable energy sources (table 4.5). In Poland, it is mainly biomass energy obtained in the combustion process or solar energy that are used for hot water heating or electricity (Firląg, 2016). Unfortunately, it is often the case that the installations of renewable energy sources are poorly designed (oversized) or used in inappropriate buildings (e.g. solar collectors in education buildings that are not used in the summer).

Significant improvements in energy efficiency require application of not only modern solutions and technologies but also numerous legal, organizational and financial instruments. According to the Status Report (BPIE 2016), public funding for renovation needs to be increased, in Poland notably for single family houses. The focus should shift towards carrying out comprehensive, deep renovations. Sub-optimal measures such as low insulation thicknesses should not be permitted under publicly funded schemes, and financial schemes need to be devised which offer an attractive and engaging way for building owners to invest in renovation.

4.2. Retrofitting of education buildings

Public buildings, including a huge and important group of education buildings, are most often renovated structures together with the residential housing.

4.2.1. Energy consumption in education sector

The energy consumption in buildings located in the EU countries is higher than for instance in industry. It is estimated as 37% of final energy in most places, however in some countries, for instance in the UK, even more – 39% of the global usage (Perez et al., 2008). One of the most significant groups in the public buildings sector are schools where energy is used for heating, cooling, hot water production, lighting and electrical appliances (Gaitani et al., 2010), but the overall energy distribution depends greatly on the climate. For example, in the UK heating accounts for over 60% of delivered energy (Gaitani et al., 2010), while in Poland for about 70%. Countries like Spain, Greece or Italy use most energy for cooling (Dimoudi A. & Kostarela P., 2009). In some countries – for instance in Mexico – energy usage is mostly connected with electrical devices, which consumes 35% of global energy, and only 7% is used for heating (Perez et al., 2008; Rosas-Flores et al., 2011). The overall distribution also depends on the building envelope type, number of users and local price policy, although the environmental factors are also important. Countries all over the world try to reduce CO_2 emission, which can be greatly aided through the comprehensive buildings retrofitting (including HVAC systems, hot water preparation, lighting and improving thermal insulation of the building structure). On 12 December 2015, 195 countries taking part in the 2015 United Nations Climate Change Conference, COP 21 agreed to sign the Paris Agreement on the reduction of emissions as part of the method for reducing greenhouse gases. The local energy policy was shown in several papers. The problem of energy consumption in the UK was discussed (Taylor et al., 2010, Ward et al., 2008). The consumption heating demand of schools in Greece was presented (Santamouris et al., 2007; Dascalaki and Sermpetzoglou, 2011; Theodosiou and Ordoumpozanis, 2008) which varied from 32 to 139.2 kWh/(m^2·year). The research conducted in Turkey, where the average energy consumption in residential buildings is about 200 kWh/m^2 per year, much more than the average value in Europe which is 100 kWh/m^2 per year, showed that 47% of energy could be saved (Cakmanaus, 2007). Corgnati et al. (2008) discussed the main thermal consumption indexes in the schools located in Italy. According to Desideri and Proietti (Desideri and Proietti, 2002), thermal energy savings, after introducing improvements, could reach 38%. Similar audits were conducted in other countries, for instance Spain (Asdrubali et al., 2008).

4.2.2. Characteristic energetic parameters of schools in Bialystok (Poland)

With the aim to describe situation in education buildings in Poland, the data was collected from all public schools (primary, medium and high) located in Bialystok, where the energy was supplied from the city power plant. Schools in Bialystok differed significantly in their volume, envelope parameters, but they were representative of the situation in most major cities in Poland. The analysis was carried out on a group of 43 buildings (single schools and units). The total volume for each building was various, so schools were divided into 3 groups:
I – volume below 15000 m^3 (16 buildings),
II – volume between 15000 and 30000 m^3 (17 buildings),
III – volume above 30000 m^3 (11 buildings).

The monthly energy consumption was recorded by heat meters located in each building and data was provided by the technical office of MPEC. The data was gathered over 5-year period. The majority of buildings in the sample had thermal insulation of external elements and double or even triple-glazed windows (table 4.8).

It should be emphasized that the average indoor temperature in most buildings was 20°C (only in 2 schools it was 19°C and in the remaining 12 schools 21-23°C), which was connected with the thermal comfort conditions. Ventilation heat loss in the examined buildings ranged between 21% and 69% of total loss. The value depended on the building envelope standard and the number of users.

Table 4.8. Parameters of schools located in Bialystok (source: own elaboration)

Group	School No.	Year of construction	U value [W/m²K]			Year of the building's modernization	Radiators / pipes	Heating system regulation	Average temperature [°C]
			windows	walls	roof				
Small schools	1	1956	1.7	0.24	0.2	2006	Changed in 1986/1986	Yes	20
	2	1959	1.7	0.23	0.2	2006 (part)	Old/old 1959	yes	21
	3	1919	1.7	0.20	0.2	2008	Old/old 1960	yes	20
	4	1972	1.7	0.30	0.3	2003 (part)	Old/old 1972	yes	20
	5	1952	3.0	1.20	1.0	2003	Old/old 1952	Yes/no	20
	6	1983	1.7	0.24	0.2	2005	Old/ changed in 2005	Yes	20
	7	1984	1.7	0.8-0.3	0.3	2003 (part)	Old/ changed in 2005	Yes/no	20
	8	1973	1.7	0.23	0.2	2007	Old/old 1973	Yes	20
	9	1930	1.7	0.23	0.2	2006	changed in 2006	Yes	20
	10	1948	2.0	1.0	0.2	2002 (part)	Old/ changed in 2002	Yes	20
	11	1960	1.7	0.8-0.3	0.2-8	2008 (part)	Old/changed in 2008	Yes	20
	12	1959	1.5	0.20	0.2	2010	changed in 2010	Yes	23
	13	1984	2.6/1.5	0.86	0.8	–	Old/changed in 2002	Yes	20
	14	1964	3.0	1.15	0.8	–	Old/old 1964	Yes/no	21
	15	1960	1.7	0.26	0.3	2002	Old/old 1960	Yes	22
	16	1977	2.0	0.26	0.3	2002	Old/old 1977	Yes	20

Group	School No.	Year of construction	U value [W/m^{2}K]			Year of the building's modernization	Radiators / pipes	Heating system regulation	Average temperature [°C]
			windows	walls	roof				
Miedium-sized schools	1	1976/81*	1.7	0.23	0.2	2007	Old/old 1981	Yes	20
	2	1983	2.6	0.85	0,8	–	Old/old 1983	Yes	20
	3	1974	1.7	0.23	0.2	2006	Old/old 1974	Yes	20
	4	1966	1.7	0.23	0.2	2007	Old/old 1966	Yes	21
	5	1979	1.7	0.24	0.2	2006	Old/old 1979	Yes	20
	6	1983	1.7	0.24	0.2	2007	Old/ changed in 2007	Yes	20
	7	1982	2.6/1,5	0.75	0.8	–	Old/old 1982	Yes	20
	8	1988	2.6	0.85	0.9	–	Old/old 1968	Yes	20
	9	1988	1.7	0.20	0.2	2008	Old/ changed in 2008	Yes	21
	10	1969	1.7	0.24	0.2	2005	Old/ changed in 2005	Yes	22
	11	1967	1.7	0.20	0.2	2008	Old/ changed in 2008	Yes	20
	12	1970	1.7	0.23	0.2	2005	Old/ changed in 2005	Yes	21
	13	1928	1.7	0.24	0.2	2005	Old/old 1968	Yes	20
	14	1971	1.7	0.24	0.2	2004	Old/old 1971	Yes	21
	15	1970	1.7	0.20	0.2	2009/11	Old/ changed in 2011	Yes	22
	16	1971	1.7	0.88	0.2	2005	Old/old 1971	Yes	20
large schools	1	1991	1.7	0.20	0.2	2008	Old/old 1991	Yes	22
	2	1999/2002*	1.7	0.30	0.3	–	New 2002	Yes	20
	3	2001/2003*	1.7	0.30	0.3	–	New 2003	Yes	20
	4	1963	1.7	0.25	0.3	2005	Old/old 1963	yes	22
	5	2010	1.5	0.20	0.2	–	New 2010	yes	19
	6	1973	1.7	0.20	0.2	2010	Old/new 2010	yes	20
	7	1983	2.6/1.7	0.80	0.8	–	Old/old 1983	yes	19
	8	1988	2.6/1.7	0.75	0.5	–	Old/old 1988	yes	20
	9	1982	1.7	0.22	0.2	2007	Old/new 2007	yes	20
	10	1983	1.7	0.22	0.2	2007	Old/new 2007	yes	20
	11	1987	1.7	0.20	0.2	2009	Old/new 2009	yes	20

* in case of different parts of buildings

In Fig. 4.2 we show the thermal energy consumption for heating per unit area E_A (kWh/m^2 per year) calculated as the ratio of the thermal energy consumption in one year to the total heated area of the building.

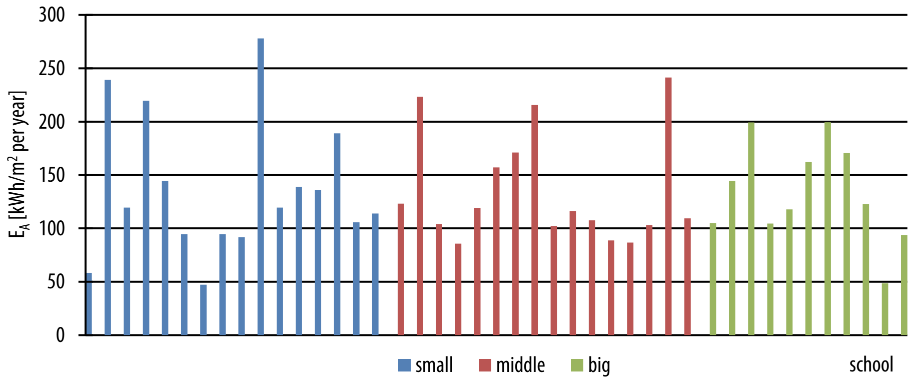

Fig. 4.2. Thermal energy consumption for heating per unit area E_A (Source: Krawczyk, 2016)

As shown by Balaras (Balaras et al., 2006), the average heating energy consumption in Poland is 261.1 kWh/(m^2·year). In Bialystok, the highest value of 241.5 kWh/m^{2}yr was observed for a middle-sized school. The value obtained for a group of schools in Bialystok is lower and amounts to an average of 135.0 kWh/(m^2·year) (in small schools 136.9 kWh/(m^2·year), middle-sized schools 134.7 kWh/(m^2·year) and in large schools 133.5 kWh/(m^2·year) although it is slightly higher than values showed by Cholewa and Siuta-Olcha (Cholewa & Siuta-Olcha, 2015) for residential buildings in Poland (86-113 kWh/(m^2·year))This shows the changes that have occurred in energy consumption and building parameters over the last few years. According to Casalas (Casalas, 2005), the average value for Spain was about 75.0 kWh/(m^2·year).

Schools built between 1980 and 2000 reached different values, depending on the range of modernisation done. The highest E_A values were observed at schools with high U for walls and roofs, with old windows, whereas lower values were recorded in buildings in which thorough modernization of the building envelope had been carried out. Concluding, the differences in energy consumption were connected with the year in which schools were built or renovated, the inside temperature, the school type and location (the number of students was lower in the area with lower population density) as well as the number of weekly working hours. Real effects of improvements done in the building envelope and HVAC systems in a school were investigated and described by Krawczyk (Krawczyk, 2014). The results of her analysis showed that the archived effect was the decrease in energy consumption on the level of 33%, while the planned energy consumption reduction was about 59-71%. The source of difference could be partly explicated by the increase of indoor temperature (before modernization some classrooms were underheated). It is worthy to note that theoretical expectations could differ from actual savings.

4.3. Retrofitting of residential buildings

The building stock by type of dwellings differs significantly across the EU. In the United Kingdom and Ireland, single-family dwellings are the dominant type (above 80%), while in Spain and Estonia, multi-family dwellings represent more than 70% of all dwellings. If we look at the EU average, there is an almost equal share of both types of dwellings, with the average of 49% for multi-family dwellings.

4.3.1. Energy performance of single-family buildings in climatic conditions of northeast Poland

In Poland single family buildings constitute almost a half (46.4%) of all residential buildings (according to the data from the Central Statistical Office of 2012). Their energy efficiency is often very low. Almost every fourth of all single-family buildings were erected before WWII and over half of them in the times of socialism. Many facilities were constructed single-handedly or by small companies based on the simplest construction and with the use of the cheapest materials. According to the studies conducted by the Institute of Environmental Economics (IEE) in 2014 almost 70% of Polish single-family houses are heated with the use of coal boilers and furnaces. Nearly 60% of all single-family houses use very inefficient solid fuel boilers which emit a significant amount of pollutants (Firląg, 2016). It has disastrous consequences for air quality in the country.

To investigate the energy performance of single-family houses located in north-eastern Poland, a group of 52 objects was selected (table 4.9). These buildings were constructed between 1940-1988. The owners decided to implement a comprehensive thermo-modernization with the use of the Thermo-Renovation Fund. Therefore, energy audits were prepared which included the calculation of the demand for heat in the state before the thermo-modernization. These results have been verified by long-term operational data. The heat demand was also calculated after the treatments recommended in the audits. In the analysed buildings there was natural ventilation. It was not proposed to replace it with a mechanical one because of the economic inefficiency of this solution during the modernization of existing buildings. In none of the buildings EK was lower than 65 kWh/(m^2yr).

Table 4.9. Parameters of single-family houses located in northeast region of Poland (Source: own elaboration)

Building nr	The year of construction	Heated area [m^2]	Cubature [m^3]	Energy consumption for heating per unit area [kWh/m^2 per year]	
				Before modernization	After modernization
1	1981	292.70	756.3	200.22	97.91
2	1971	244.40	642.8	192.80	84.95
3	1980	224.00	539.0	198.67	103.18
4	1980	236.70	560.2	203.54	93.07
5	1955	163.10	385.7	228.91	89.14
6	1983	273.20	723.1	222.34	66.91
7	1940	68.46	173.2	343.22	107.16
8	1958	128.30	321.3	422.22	79.56
9	1979	184.25	437.2	200.87	91.45
10	1986	176.60	425.2	192.85	128.41
11	1977	221.60	533.9	240.40	87.58
12	1964	127.10	343.8	396.79	107.92
13	1970	306.20	728.5	169.85	70.68
14	1986	382.57	927.1	205.87	80.04
15	1960	269.80	635.9	198.40	84.17
16	1978	45.22	113.1	559.38	128.61
17	1966	188.22	478.7	338.10	102.46
18	1960	255.50	610.3	243.73	85.02
19	1954	177.70	476.1	395.75	101.20
20	1954	190.00	508.5	298.05	87.79
21	1984	238.30	568.8	118.16	70.58
22	1970	108.40	296.0	383.48	112.46
23	1955	184.60	459.0	265.55	75.45
24	1971	119.58	298.9	330.75	85.79
25	1984	152.25	404.1	467.66	102.98
26	1989	228.00	651.0	456.99	110.35
27	1982	287.00	634.3	231.70	93.28
28	1985	175.80	453.2	126.48	90.53
29	1952	287.79	801.4	167.58	65.06

Building nr	The year of construction	Heated area [m^2]	Cubature [m^3]	Energy consumption for heating per unit area [kWh/m^2 per year]	
				Before modernization	After modernization
30	1988	201.44	502.0	209.18	89.41
31	1964	122.70	383.0	363.67	112.45
32	1967	99.98	250.0	242.71	104.72
33	1987	149.95	412.0	360.19	78.07
34	1980	238.17	570.7	215.55	90.83
35	1970	282.41	729.0	219.31	94.87
36	1961	139.18	334.7	219.24	78.88
37	1973	165.84	447.8	287.62	121.85
38	1960	165.07	431.6	186.67	69.47
39	1986	229.55	551.0	210.91	96.97
40	1985	230.40	557.0	146.29	112.31
41	1988	233.86	565.0	158.51	88.69
42	1970	126.90	364.4	324.31	94.48
43	1985	210.20	600.5	208.69	79.72
44	1978	188.00	461.8	238.09	80.68
45	1980	194.15	514.7	271.10	85.57
46	1980	231.09	607.9	233.33	90.10
47	1974	120.80	302.0	346.28	93.89
48	1986	117.10	318.0	221.85	104.72
49	1984	161.46	456.0	251.73	65.26
50	1974	189.00	450.0	222.94	86.19
51	1982	224.70	606.7	414.65	78.44
52	1985	180.60	415.0	254.43	83.65

In Fig 4.3, 52 buildings were compared with three energy-efficient buildings also built in the climate conditions of north-eastern Poland (Sadowska, 2011). They were built in the years 1999-2003, and in the following years they were monitored in order to confirm their low energy consumption. In these buildings more than the standard thickness of thermal insulation was used (in the three-layer walls and the roof 18-cm-thick layer of mineral wool was laid, in the roof additionally 0.02 m layer of polystyrene, in the floor on the ground 0.01 m layer of polystyrene). The supply and exhaust ventilations with heat recovery and a ground heat exchanger were installed. These solutions enabled to obtain indicators of energy demand lower than 55 kWh/(m^{2}yr).

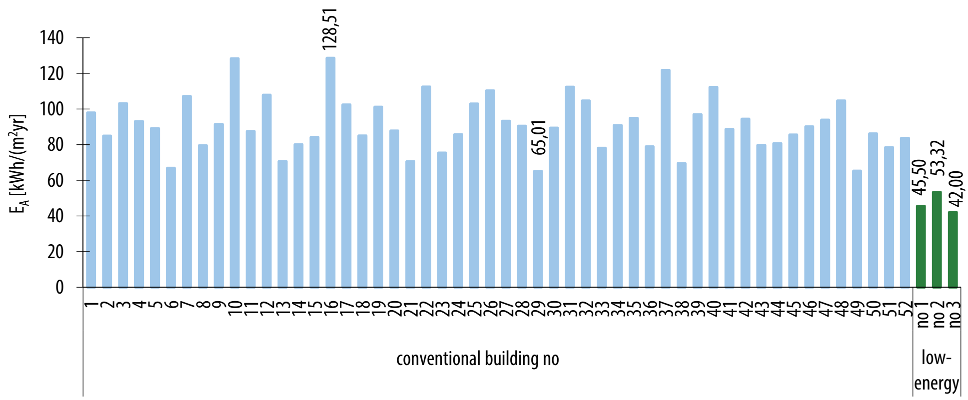

Fig. 4.3. Energy consumption for heating per unit area in 52 conventional single-family houses and 3 low-energy buildings (Source: own elaboration)

The average heating energy consumption obtained for a group of single-family houses with natural ventilation, located in northeast region of Poland is 91,63 kWh/(m^2yr). The use of a mechanical ventilation system with heat recovery in low-energy houses has allowed to obtain energy consumption equal to 42.00 ÷ 53.32 kWh/(m^2yr).

4.3.2. Predictable effects of thermal retrofitting of apartment buildings

Seven apartment buildings, constructed between 1959 and 1993 in the Podlaskie Voivodship, were analysed (Sadowska, 2014). Their basic data is shown in Table 3.8.

Table 4.10. Parameters of apartment buildings (Source: own elaboration)

Building nr	number of			Heated area [m²]	Cubature [m³]
	staircases	floors	flats		
1	2	4	16	868.80	3 990.0
2	3	4	24	1 304.40	5 948.0
3	6	5	60	3 712.00	15 666.0
4	3	12	89	3 938.57	17 194.0
5	1	5	25	1 088.50	5 294.0
6	3	5	45	1 791.06	8 536.0
7	1	2+attic	10	418.50	2 714.0

The external walls of the buildings have been modernized to meet the requirements of thermal protection according to the Regulation of the Minister of Transport, Construction and Maritime Economy of 5 July 2013. All the buildings had natural ventilation. Four locations were analysed: Suwalki (climatic zone V), Bialystok (climatic zone IV), Warsaw (climatic zone III) and Szczecin (climate zone I). Differences in the heat demand of the same buildings located in different parts of Poland are significant (table 4.9).

Table 4.11. Energy consumption in apartment buildings (Source: own elaboration)

Building nr	location of the building			
	Suwalki	Bialystok	Warsaw	Szczecin
	Energy consumption for heating per unit area [kWh/m^2 per year]			
1	101.6	93.0	81.4	70.2
2	98.7	90.2	78.9	68.0
3	88.3	82.5	72.6	63.0
4	93.6	85.4	77.8	64.5
5	111.6	104.0	89.6	84.0
6	108.5	100.0	88.2	76.9
7	117.1	108.7	96.7	85.5

Energy consumption for heating per unit area of buildings located in Suwalki is higher than the ones located in Szczecin, from 33% (in case of building No. 5) to 45% (buildings 1, 2 and 4). For buildings in Bialystok, these differences range from 24 to 33%, and in Warsaw from 7 to 21%. For buildings located in Bialystok, the difference is 24 to 33%, while in Warsaw it is 7 to 21%. The lowest unit energy consumption of 63.0 kWh/(m^2·year) was achieved in building no. 3 located in Szczecin. Buildings located in the north-eastern region of Poland have higher E_A values, ranging from 82.5 to 117.1 kWh/(m^2·year) and differ between the location in Bialystok and Suwalki by 7-10% (Polish climatic zones IV and V).

4.3.3. Case study: deep thermal renovation

In order to show the possibilities of reducing thermal energy consumption after deep thermal modernization, an apartment building located in north-eastern Poland was chosen. Improvements of the envelope, installations (with the use of renewable energy) and lighting were proposed to meet deep thermal renovation requirements (Polish regulations of thermal protection which will come into force on January 1, 2021). This building (table 4.12), constructed of prefabricated reinforced concrete slabs, needed renovation due to its high energy consumption. The walls were insulated with 0.05 m of expanded polystyrene and the ventilated flat roof had 0.08 m-thick insulation of mineral wool.

Table 4.12. General information about the analysed apartment building (Source: own elaboration)

Time of construction	1970s
Number of flats / occupants	40 / 110
Area	2 971.3 m^2
Usable area	2 248.0 m^2
Cubature	8 918 m^3
Number of floors / staircases	5 / 4

Another insulating layer of 0.15 m of expanded polystyrene was mounted on the walls. The roof was sealed, and an additional insulation layer of 0.26 m of mineral wool was applied, which increased the total insulation thickness to 0.34 m. The existing windows were replaced (table 4.13). The insulation of the floor in the basement was not considered. The connection to the district heating supply was maintained. A new central heating installation was made. Thermostatic valves were installed in the domestic hot water system.

In addition, lighting in the administrative part of the building was replaced with LED lighting. Six pieces of PV panels (10.10 m^2) were installed on the roof (with the power of 1.5 kWp and the annual electricity production of approximately 1572 kWh).

Table 4.13. *U*-values of the building construction elements (Source: own elaboration)

U-values [W/m^2·K]	Before retrofitting	After retrofitting
External wall	0.28; 0.73$^{*)}$	0.20
Basement walls	0.83; 1.14; 1.31; 2.32	0.18; 0.19; 0.19; 0.20 (t_i<16°C)
Vestibule walls	1.93	0.23 (t_i<16°C)
Roof	0.61	0.13
Roof of the vestibules	3.35	0.25 (t_i<16°C)
Windows (flats)	2.00	0.90
Windows (staircases. basement. vestibules)	2.60	1.40 (t_i<16°C)
External doors	5.10	1.30
$^{*)}$ external bearing walls were previously insulated with 8 cm polystyrene.		

The calculations show the possibilities of energy consumption reduction due to deep thermal modernization of an apartment building (table 4.12). The expected value of

EP=65 kWh/(m²·year) in accordance with Polish national regulations that will come into force in 2021 has not been achieved. There is a possibility to reduce EP value by providing a renewable source of energy for the hot water system (e.g. using panel solar collector – assuming 50% share *EP*=53.47 kWh/(m²·year).

Table 4.14. Results of calculation (Source: own elaboration)

	Before retrofitting	After retrofitting	Savings	
Final energy demand [kWh/m²·year]				
Space heating	102.70	23.92	78.78	76.71%
Domestic hot water	62.08	44.35	17.73	28.56%
Total	164.78	68.27	96.51	58.57%
Primary energy [kWh/m²·year]				
Space heating	119.13	27.75	91.38	76.71%
Domestic hot water	72.01	51.44	20.57	28.56%
Total	191.14	79.19	111.95	58.57%

The use of LED lighting in the administrative part of the building reduced the energy demand for lighting from 1.74 kW/m²year to 0.64 kWh/(m²·year) and the installation of PV panels cut down the energy usage to 0.53 kWh/(m²·year).

In conclusion, it should be noted that using proper window type and insulation thickness to meet the maximum *U*-values of walls does not guarantee that the building will achieve the expected value of *EP* factor. Primary energy factor *EP* depends mainly on the source of heat and it can be significantly reduced using renewable energy sources.

References

Asdrubali, F., Bonaut, M., Battisti, M. & Venegas M. (2008) Comparative study of energy regulations for buildings in Italy and Spain. *Energy and Buildings,* 40, 1805-1815

Attlmayr, E. (1974) Baukosten minimaler Warmeschutz. Heizung. *Luftung Haustechnik*. 10

Balaras, C.A., Droutusa, K., Dascalaki, E. & Kontoyiannidis, S. (2005) Heating energy consumption and resulting environmental impact of European apartment buildings. *Energy and Buildings,* 37, 429-442

Becher, P. (1974) Okonomisk varmeisolering 74. *Byggeindustrien*. 4

Bogusławski, L. D. (1969) *Techniko-ekonomiczeske rasczety pri projektirowanii narużnych ograzdżajuszczich zdanii*. Moskwa. Izd. Vyszaszaja Szkoła

BPIE, Staniaszek, D. & Firląg, Sz. (2016) *Financing building energy performance improvement in Poland*. Status report

Bruckmayer, F. & Lang, J. (1972) Wirtschaftlicher Warmeschutz – Teil 3. Forschungsgesellschaft fur Wohnen. *Bauen und Planen*. H.42. Wein

Casals, X.G. (2006) Analysis of energy regulation and certification in Europe: Their role. limitations and differences. *Energy and Buildings,* 38, 381-392

Cakmanus, I. (2007) Renovation of existing office buildings in regard to energy economy: An example from Ankara. Turkey. *Building and Environment,* 42, 1348-1357

Cholewa, T. & Siuta-Olcha, A. (2015) Long term experimental evaluation of the influence of heat cost allocators on energy consumption in a multifamily building. *Energy and Buildings,* 104, 122-130

Corgnati, S., Corrado, V. & Filippi, M. (2008) A method of heating consumption assessment in existing buildings: A field survey concerning 120 Italian schools. *Energy and Buildings*, 40, 801-809

Desideri, U. & Proietti, S. (2002) Analysis of energy consumption in the high schools of a province in central Italy. *Energy and Buildings,* 34, 1003-1016

Dascalaki, E. & Sermpetzoglou, V. (2011) Energy performance and indoor environmental quality in Hellenic schools. *Energy and Buildings,* 43, 718-727

Dimoudi, A. & Kostarela, P. (2009) Energy monitoring and conservation potential in school buildings in the C climatic zone of Greece. *Renewable Energy,* 34, 289-296

Directive 2010/31/EU of the European Parliament and the Council of 19 May 2010 on the energy performance of buildings

Eichler, F. & Arndt, H. (1982) *Bauphysikalische Entwurfslehre. Bautechnischer Warme- und Feuchtigkeitsschutz.*VEB Verlag fur Bauwesen. Berlin

Firląg, Sz. (2016) The renovation market in Poland. *Rynek Instalacyjny*. 7-8, 24-26

Gaitani, N., Lehmann, C., Santamouris, M., Mihalakakou, G. & Patargias, P. (2010) Using principal components and clusters analysis in the heating evolution of school building sector. *Applied Energy,* 87, 2079-2086

Górzyński, J. (1985) *Audyting energetyczny obiektów przemysłowych*. Fundacja Poszanowania Energii. Warszawa

Jezierski, W. & Sadowska, B. (2016) Optimum thermal insulation thickness of external walls in current economic conditions. *Inżynieria i Budownictwo,* 72/8, 421-425

KAPE S.A. (2012) *Energy – efficient houses – Best practice handbook* (in Polish)

Kisilewicz, J. (1976) *Metodyka projektowania budynków mieszkalnych o ekonomicznie uzasadnionej charakterystyce cieplnej*. Doctoral thesis. Wydział Budownictwa Lądowego Politechniki Krakowskiej. Kraków

Kozierski, J. (1968) *Wpływ kształtowania zewnętrznych przegród budynków mieszkalnych na koszty inwestycyjne i eksploatacyjne ich ogrzewania*. MZPPAiB. Warszawa

Krawczyk, D. A. (2014) Theoretical and real effect of the school's thermal modernization – A case study. *Energy and Buildings,* 81, 30-37

Krawczyk, D. A. (2016) The potential reduction of the energy consumption and greenhouse gasses emission from schools in Poland (poster presentation). *Energy Systems Conference: 21st Century Challenges, QEII Centre,* Westminster, London, UK)

Laskowski, L. (2005) *Ochrona cieplna i charakterystyka energetyczna budynku*. Oficyna Wydawnicza Politechniki Warszawskiej. Warszawa

NAPE SA (2012) *Polish building typology TABULA*. Scientific report. Waesaw

Perez-Lombard, I., Ortiz, J. & Pout, Ch. (2008) A review on buildings energy consumption information. *Energy and Buildings,* 40, 394-398

Petzold, K. (1975) *Tabellen zur Ermittlung der wirtschaftlichen Warmedammung bei Aussenwanden*

Pogorzelski, J. A. (1998) Opłacalna grubość izolacji cieplnej przegród zewnętrznych. *Materiały Budowlane*, 1

Robakiewicz, M. (1998) Optymalizacja grubości warstw izolacji termicznej przegród budowlanych. *IV Ogólnopolska Konferencja Naukowo-Techniczna: Problemy projektowania. realizacji i eksploatacji budynków o niskim zapotrzebowaniu na energię – ENERGODOM'98*. Kraków – Mogilany. 365-378

Rosas-Flores, J. A., Rosas-Flores, D. & Galvez A. M. (2011) Saturation. energy consumption. CO_2 emission and energy efficiency from urban and rural household appliances in Mexico. *Energy and Buildings,* 43, 10-18

Rudczyk-Malijewska, E. (1999) *Optymalizacja izolacji cieplnej przegród budowlanych w aspekcie efektywności ekonomicznej* Doctoral thesis. Bialystok Technical University

Sanecki, J. & Skoczek, W. (1966) *Ekonomika ogrzewania budynków.* Arkady. Warszawa

Sadowska, B. (2010) *Operational model of design of energy-saving residential buildings*. Doctoral thesis. Bialystok Technical University

Sadowska, B. (2014) Efektywność wznoszenia budynków w standardach NF40 i NF15. *XXVIII Międzynarodowa Konferencja Naukowo-Techniczna EKOMILITARIS*. Warszawa. 83-84

Santamouris, M., Mihalakakou, G., Patargias, P., Gaitani, N., Sfakianaki, K., Papaglastra, M., Pavlou, C., Primikiri, E., Geros, V., Assimakoupoulos, M., Mitoula, R. & Zerefos, S. (2007) Using intelligent techniques to classify the energy performance of school buildings. *Applied Energy,* 39, 45-51

Stachniewicz, R. (2002) *Efektywność termomodernizacji budynków w zabudowie miejskiej*. Doctoral thesis. Bialystok Technical University

Staniaszek, D. Zaborowski, M., Węglrz, A., Panek, A. & Dziamara-Rzucidło, K. (2014) *Stategy of buildings refrafiting.* Roadmap 2050. Cracow (in Polish)

Taylor, S., Peacock, A., Banfill, P. & Shao, L. (2010) Reduction of greenhouse gas emissions from UK hotels in 2030. *Building and Environment,* 45, 1389-1400

Theodosiou, T. & Ordoumpozanis, K. (2008) Energy. comfort and indoor air quality in nursery and elementary school buildings in the cold climate zone of Greece. *Energy and Buildings,* 40, 2207-2214

Ward, I., Ogbonna, A. & Altan, H. (2008) Sector review of UK higher education energy consumption. *Energy Policy,* 36, 2939-2949

Węglarz, A. (2015) The deep building thermomodernization in Poland. *Rynek instalacyjny,* 9, 19-22