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Adam Ujma, Anna Lis
Czestochowa University of Technology,
Faculty of Civil Engineering
ul. Akademicka 3, 42-201 Czestochowa, Poland

ENERGY AND ECOLOGICAL EFFICIENCY AS A RESULT THERMAL MODERNIZATION OF BUILDINGS

Наведено реальні результати термомодернізації на основі моніторингу їх ефективності, який проводили в навчальному закладі в одній з групи будівель у Сілезії від 2011 до 2015 р.. Теплова модернізація будівель полягала у теплоізоляції огороджень, крізь які були тепловтрати, улаштування центрального внутрішнього джерела тепла для систем опалення та гарячого водопостачання. Термомодернізацію проводили комплексно, відповідно до основних завдань, які було визначено при проведенні енергоаудиту. Відсутність теплоізоляції огороджень була причиною того, що будівля не відповідала вимогам теплозахисту і була неенергоефективною через значні втрати енергії. Метою теплової модернізації було підвищення ефективності використання енергії системами опалення та гарячого водопостачання. Проаналізовано споживання енергії для опалення будівель, споживання електроенергії та викиди продуктів згоряння палива в атмосферу. Цей аналіз проведено для оцінювання впливу енергоощадних заходів на стан зовнішнього середовища. Результати проведеної термомодернізації показали значне зниження використання енергії, а отже, зменшення витрати палива, рівня шкідливих викидів і експлуатаційних затрат будівлі.

Ключові слова: термомодернізація, енергетична та екологічна ефективність, викиди забруднюючих речовин в атмосферу, викиди парникових газів.

The article presents the real results of the thermal modernization activity based on the monitoring of their effects conducted in selected educational building from 2011 to 2015, which was a representative of the evaluated group of buildings in the Silesian province. Thermal modernization of the buildings consisting in insulation of partitions by which heat loss from the building were followed, installation the central internal heat source for heating and domestic hot water heating systems was performed in a complex manner and in accordance with the guidelines resulting from the energy audit. The lack of thermal insulation in partitions caused that the building failed to comply with thermal protection requirements and was not energy efficient therefore generating considerable energy losses. The thermal modernization activities were aimed at improving the efficiency of the energy use for heating and preparation of the domestic warm water. The analysis includes energy consumption for heating of the building, electricity consumption and pollutant emissions to atmosphere of fuel combustion product. This analysis was carried out to evaluate the influence of energy saving activities on the state of the external environment. The monitoring of the results from conducted thermal modernization showed significant energy reduction effect and therefore also fuel consumption, emission levels and exploitation costs of the building.

Key words: thermal modernization, energy and ecological efficiency, pollutant emissions to atmosphere, greenhouse gases.

Introduction. Buildings existing in Poland, both residential and public are characterized by a great potential in terms of energy and ecological efficiency. The greatest possibility in the implementation of energy and ecological efficiency activities creates a saving of media consumption: heat, natural gas, coal

fuel, electricity, water. Presently the energy efficiency is a widely addressed issue in strategic documents determining the development direction of the Union Member States. The impulse for action in this direction was depletion of natural energy resources, increase in fuel prices, increased dependence on energy imports and high environmental pollution by combustion products contributing to changes in the Earth's climate. Energy efficiency is a valuable means to address these challenges. One of the ways to increasing energy efficiency of existing buildings and reduction of emissions (especially greenhouse gas GHG) are the thermal modernization activity. It has been estimated that through the complex thermal modernization of an average building in accordance with the currently valid regulations up to 40 % of energy may be saved.

Indigenous production of primary energy carriers declined in Poland in 2014 and amounted to 2853.8 TJ. Consumption of primary energy was higher than production by more than 50 % and amounted to 4320.5 PJ in 2014 [1]. Building stock of European Union covers about 200 million buildings, out of which 6 million are located in Poland. Energy used in buildings accounts for a significant percentage of a country's total energy consumption. This percentage depends greatly on the degree of electrification, the level of urbanization, the amount of building area per capita, the prevailing climate, as well as national and local policies to promote efficiency. Realization and exploitation of buildings involves in European Union in the period 2009–2013 about 42 % of total energy consumption, bat in Poland, this value is higher at about 7 % [1, 2, 3]. Buildings consume more energy than transport and industry and use also about 25 % of global water.

Energy consumption in buildings is divided into heating, ventilation, cooling, hot water, lighting and electrical equipment. Structure energy consumption in the period 2009–2012 in residential and public utility buildings according to its destiny in European Union and in Poland is shown in Fig. 1 and 2.

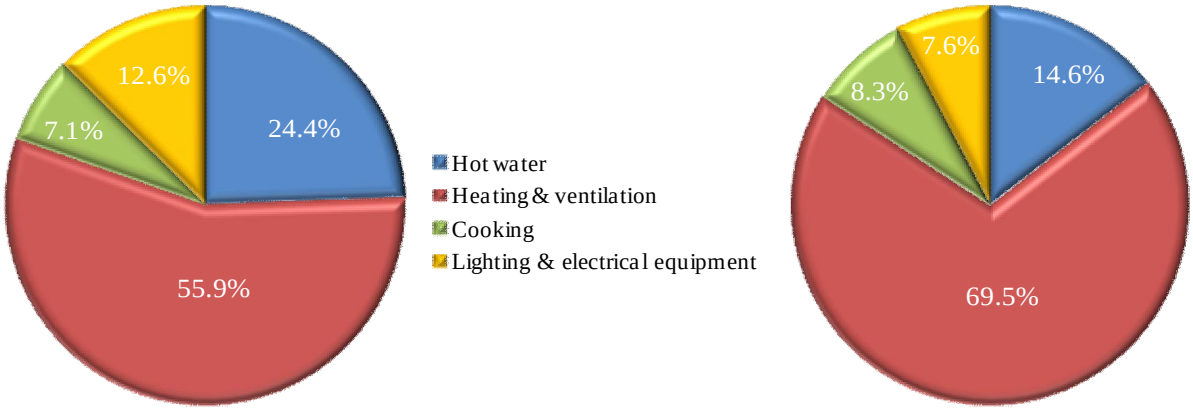


Fig. 1. Energy consumption in residential buildings in EU and PL in the period 2006–2012 [4–7]

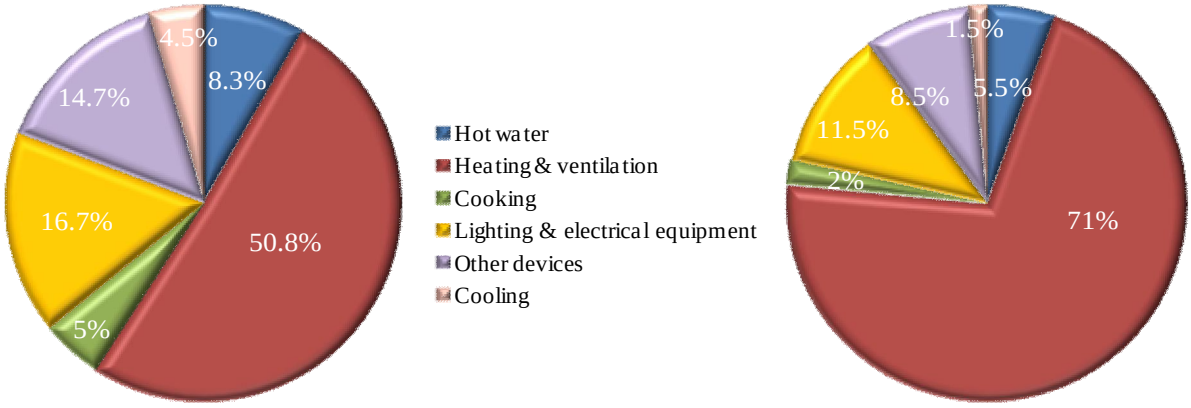


Fig. 2. Energy consumption in public utility buildings in EU and PL in the period 2006–2012 [4–7]

The thermal protection of buildings and rationalization of water consumption are directly related with energy savings but also with other aspects. A significant importance has the process of reducing the pollutants emissions to the atmosphere from fuel combustion process, especially greenhouse gases emissions or very dangerous particulate matter PM 2,5 i 10. Energy consumption is one of the major causes of greenhouse gas emissions. The sources of emission are non-renewable fuels used for generation of energy. Recently in Poland production of hard coal, lignite, crude oil, natural gas and others energy carriers decreased. The most important energy carrier produced is hard coal, which share amounted to 61.0 % in 2014. The second important energy carrier is lignite with share of 18.2 %. The share of natural gas amounted to 5.5 % and crude oil to 1.4 % [1]. The most important energy carrier consumed is hard coal which share amounted to 40.4 %. The share of crude oil amounted to 23.8 % and the share of natural gas to 14.1 %. Consumption of lignite amounted to 12.0 % of total consumption [1]. Fig. 3 shows structure of household energy consumption per one inhabitant in European Union and in Poland in 2014 year.

The structure of primary energy carriers consumption did not change significantly during last years. The share of hard coal declines and the share of crude oil and renewable energy sources increases. Starting from 2021 all newly constructed buildings will be required to have very low energy consumption, covered mainly by the renewable energy resources. Therefore, it is necessary to promote and implement environmental friendly technologies based on the renewable energy resources and to increase the application of these energy resources. In Poland share of renewable energy in gross final energy consumption in 2014 year was 11.4 % [8, 10]. Fig. 4 shows structure of primary energy production from renewable sources in European Union and in Poland in 2014 year.

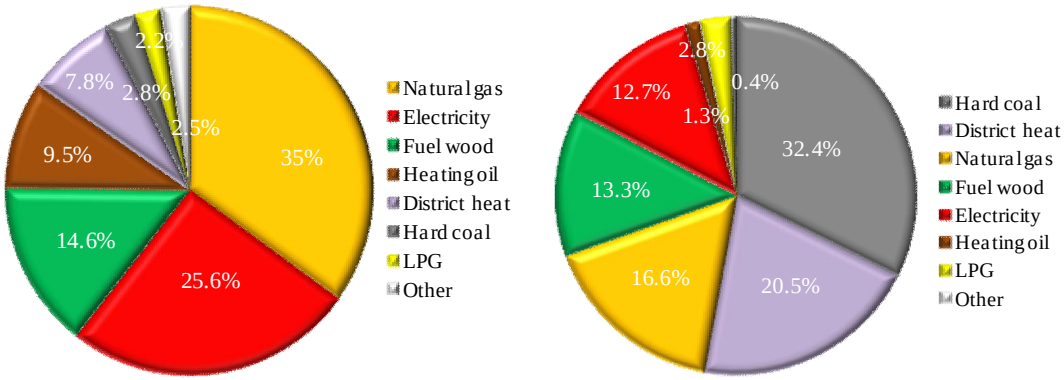


Fig. 3. Structure of household energy consumption per one inhabitant in EU and PL in 2014 year [8, 9]

The strategy for the development of renewable energy sources in Poland and European Union assumes increase the share of renewable energy sources in our final energy consumption to 20 %. In 2012, energy from renewable sources accounted for 14.1 % of gross final energy consumption in the EU, representing some 70 % of the target for 2020. The consumption of renewable energy increased annually by 3.5 % from 2010 to 2012 [10].

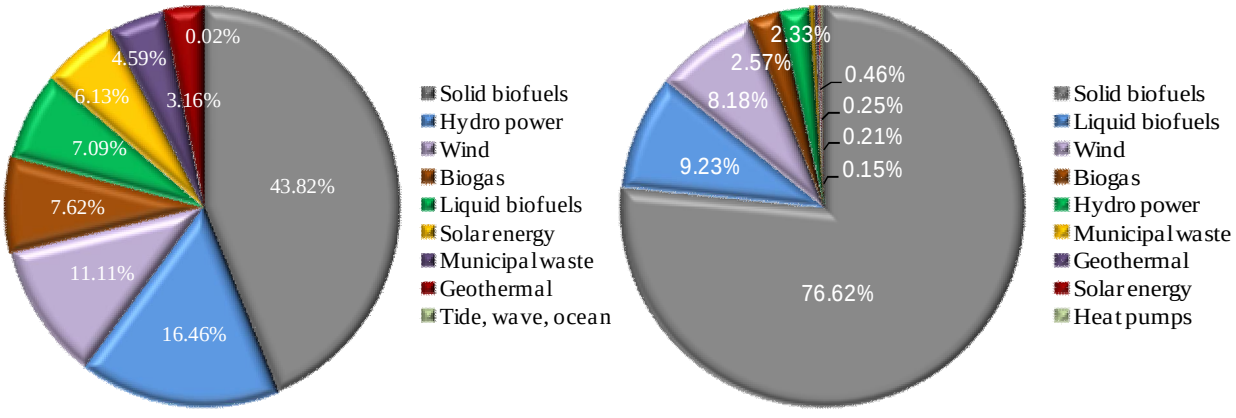
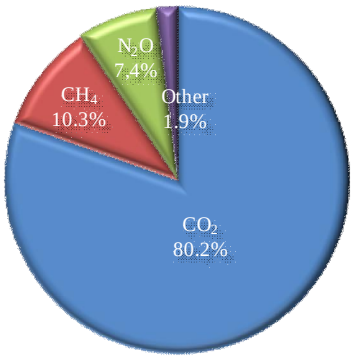


Fig. 4. Structure of primary energy production from renewable sources in EU and PL in 2014 year [8]

Major environmental pollution by combustion products of fossil fuels leads to negative changes in the global climate. The reason for this is the greenhouse effect caused by greenhouse gases. Buildings emit approximately 1/3 of GHG. The primary greenhouse gas is carbon dioxide (CO_2). Its emissions in 2014 accounted for about 80.2 % among all greenhouse gases (Fig. 5).

It is estimated that concentration CO_2 in the atmosphere has increased from 280 ppm in 1750 year to the level 400 ppm in 2014 and it raises on average 2–3 ppm each year [11]. It is estimated that considerable changes in the earth environment will take place if the global temperatures increase by more than 2 °C. A warming of 2 °C corresponds to a carbon dioxide concentration of about 450 ppm in the atmosphere [12, 13]. The concentration of methane (CH_4) in the same period has increased just over a 1 ppm, nitrous oxide (N_2O) by 0.056 ppm, perfluoromethane (CF_6) by 45 ppt and sulfurhaxafluoride (SF_6) by 4.4 ppt. [12, 13]. Indications of greenhouse gases in 2014 in various weather stations are presented in Figure 6.

Fig. 5. Shares of the main greenhouse gases in Poland in 2012 year [11]



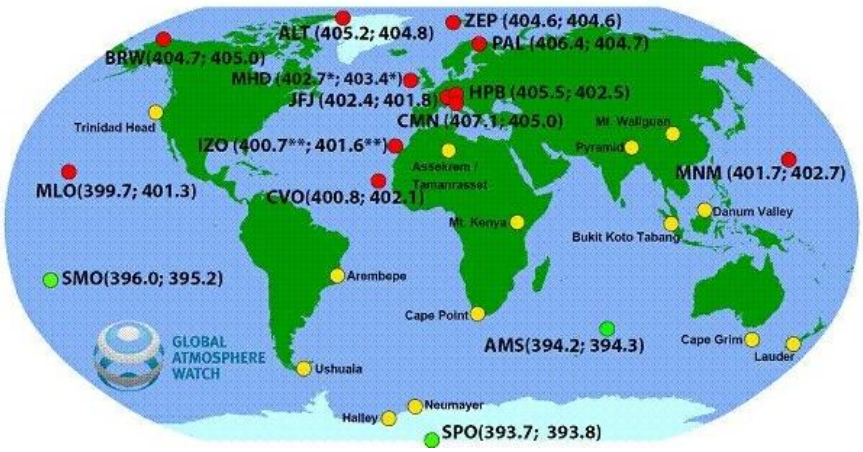


Fig. 6. Indications of greenhouse gases in 2014 in various weather stations [14]

Poland's membership of the EU entails a wide array of environmental-protection requirements. Some have been satisfied by Poland to a greater extent than required, e.g. as regards greenhouse gases emissions, the reduction of which in 2008–2012 in relation to the base year, i.e. 1988, should be 6 %. In 2012 Poland achieved a reduction of 31 % in the emission of greenhouse gases, expressed as a carbon dioxide equivalent, in relation to the base year, in particular, the emission of carbon dioxide dropped by 31 %, methane by 45 %, and nitrous oxide by 31 %. The reduction in greenhouse gases emission achieved by Poland has therefore considerably exceeded the level required under the Kyoto Protocol. In 2013 compared to the previous year further reduction in greenhouse gases emission was observed, with the biggest reduction achieved in case of carbon dioxide emission [11]. In 2012 the surplus of greenhouse gas emission reductions in relation to the target for 2008 to 2012 for Poland was 23 %. Unfortunately hydrofluorocarbons (HFCs) emissions has increased six-fold and sulfurhaxafluoride (SF_6) twice since 2000. However was recorded a nearly 12-fold reduction of perfluorocarbons PFCs.

Purpose of work: the analysis of the real effects of the thermal modernization activity in educational building based on their monitoring from 2011 to 2015. The analysis includes energy consumption for heating of the building, electricity consumption and pollutant emissions to atmosphere of fuel combustion products. This analysis was carried out to evaluate the influence of energy saving activities on the state of the external environment, especially greenhouse gases emissions.

Thermal modernization activity in research building. For analysis was chosen educational building. Building has undergone comprehensive thermal modernization in 2010, and the obtained results are representative for the monitored educational building group. Chosen school building (Fig. 6) is similar in the technical characteristics to other buildings of this type in Poland. The building was constructed in 1966, using traditional technology.

Fig. 7. Entrance elevation of monitored building

The lack of thermal insulation in partitions caused that the building failed to comply with thermal protection requirements and was not energy efficient therefore generating considerable energy losses. The thermal modernization activities included the thermal insulation of the external barriers and replacement of some equipment of the buildings. Activities were aimed at improving the efficiency of the energy use for heating and preparation of the domestic warm water. Thermal modernization works performed in research building aimed at improving the energy performance of the building, increasing its energy efficiency, reducing its negative impact on the environment and improve the interior microclimate. Parameters of the energy performance of the building before and after thermal modernization, determined on the basis of the energy audit analysis are presented in Table 1.

Table 1

Energy performance parameters of the building before and after thermal modernization

No.	Parameters	Before thermal modernization	After thermal modernization
1	U - external walls, W/(m^{2}K)	1.40	0.22
2	U - walls of the cellar in the ground, W/(m^{2}K)	1.39	1.39
3	U - flat roof, W/(m^{2}K)	0.68	0.16
4	U - ceiling above the cellar, W/(m^{2}K)	1.14	1.14
5	U - floor of the ground floor on the grounds, W/(m^{2}K)	0.73	0.73
6	U - floor in the basement on the grounds, W/(m^{2}K)	1.27	1.27
7	U - existing wooden windows/PCV windows, W/(m^{2}K)	3.00	1.40
8	U - external doors, W/(m^{2}K)	3.50	2.50
9	EU, kWh/(m^{2}year)	285.7	142.4
10	EK, kWh/(m^{2}year)	526.0	149.4
11	EP, kWh/(m^{2}year)	578.6	164.3

Thermal modernization of the building was performed in a complex manner and in accordance with the guidelines resulting from the energy audit. Its effect was monitored from 2011 to 2015.

Research results. The monitoring of the results from conducted modernization showed significant energy (Fig. 8) consumption reduction effect, as well as costs associated with this consumption. Before thermal modernization the average energy consumption was about 1000 GJ/year, and after the thermal modernization dropped to 420 GJ/year. The year 2010, when the thermal modernization was carried out, was transitional year which is not included in the analysis.

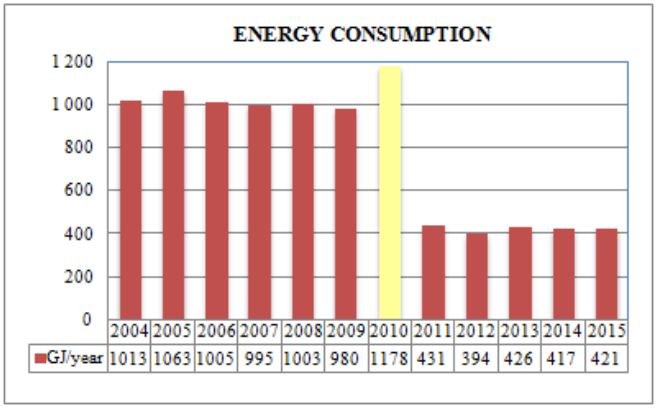


Fig. 8. Energy reduction effect

Except that other components of media consumption and associated costs was monitored. Before thermal modernization the average electricity consumption in the analyzed object was about 16 100 kWh/year, and after thermal modernization dropped to 12 500 kWh/year (Fig. 9).

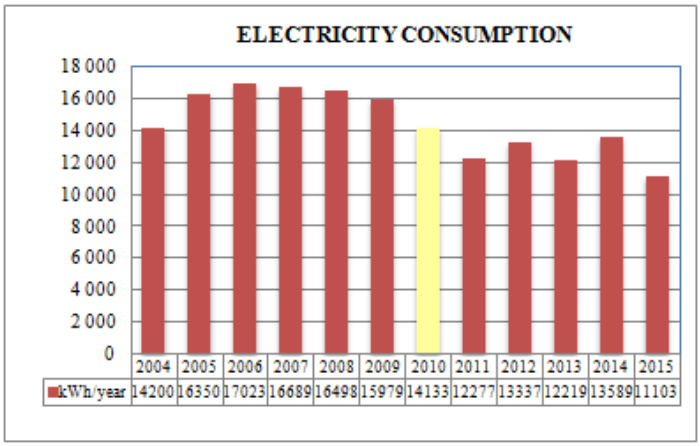


Fig. 9. Electricity reduction effect

A special attention was paid to the reduction of pollutant emissions to atmosphere of fuel combustion products, particularly of greenhouse gases emissions. On the basis of gas consumption was estimated direct ecological effect typical pollutants such as sulphur dioxide SO_2, nitrogen oxides NO_x, carbon monoxide CO, benzo(a)pyrene B(a)P and dust (Table 2).

Table 2

Direct pollutant emissions to atmosphere before and after thermal modernization

Type of pollutants	Number of pollutants, kg/year		Reduction of emissions	
	Before	After	kg/year	%
SO_2	600,5	0,4	600,1	99,7
NO_x	133,4	1,7	131,7	98,7
CO	4 170,0	3,9	4 166,7	99,9
B(a)P	0,8	0,1	0,7	99,9
Dust	208,5	0,8	207,7	99,6
Total	1 124,5	673,9	5 106,4	99,9

As a result of the activities that have contributed to improving the energy efficiency of research building was achieved about 99,9 % reduction in pollutant emissions to atmosphere. A substantial decrease in emissions was caused also to the conversion of coal heating to gas heating.

Table 3 shows the emissions of greenhouse gases CO_2, CH_4, and N_2O generated during the process of heating, domestic hot water preparation and electricity consumption in recalculation on CO_2 before and after thermal modernization. For the calculations was used Global Warming Potential indicator (GWP) equal 25 kg CO_2 per 1 kg of CH_4 and 298 kg CO_2 per 1 kg of N_2O.

Table 3

CO_2, CH_4 and N_2O emission calculated to equivalent of CO_2

Greenhouse gases	Before thermal modernization		After thermal modernization		Reduction	
	kg CO_2/ year	kg/(m^2year)	kg CO_2/ year	kg/(m^2year)	kg CO_2/ year	%
CO_2	98 157,8	1 148,1	33 711,3	293,6	64 446,5	81,1
CH_4	6 858,2	59,7	197,6	0,2	6 660,6	97,1
N_2O	456,04	0,7	93,63	0,08	362,4	79,5
Total	105 472,0	1 208,2	34 002,5	293,9	71 469,5	67,8

After thermal modernization a reduction of carbon dioxide emissions at the level of 68 % was achieved. The average annual reduction of CO_2 per one school student amounted to 674,3 kg and with the emission of CH_4 and N_2O has reached the value of 746,1 kg/student/years. It should be noted that at present according to the methodology for calculating the energy performance of buildings the mandatory requirements is given in the certificate the value of the calculated CO_2 emissions in kg/(m^2year) (Table 3). The sizes of emission reduction of analyzed pollutants are shown in Figure 10.

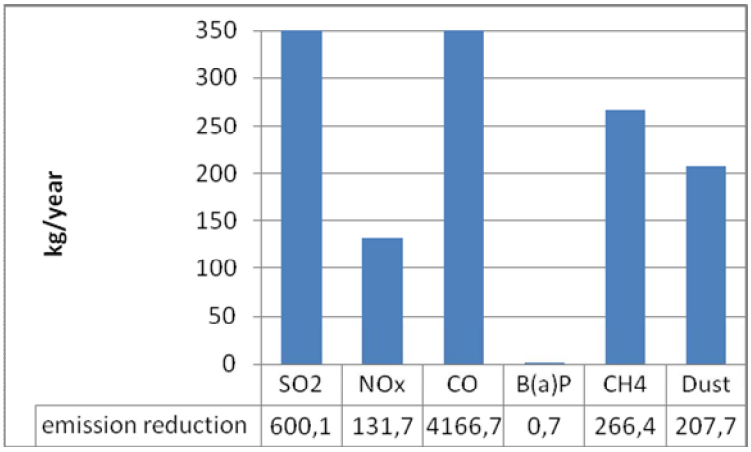


Fig. 10. Size of emissions reduction of analyzed pollutants

Equivalent pollutant emissions to atmosphere before and after thermal modernization in recalculation on sulphur dioxide are introduced in Table 4.

Table 4

Equivalent pollutant emissions to atmosphere before and after thermal modernization

Type of pollutants	Number of pollutants		Reduction of emissions	
	Before	After	kg SO_2/year	%
	kg SO_2/year			
SO_2	600,5	0,4	600,1	99,9
NO_x	66,7	0,9	65,8	98,7
B(a)P	16 680,0	0,0	16 680,0	100,0
Dust	104,3	1,0	103,3	99,0
Total	19 536,5	2,3	19 532,2	~100,0

The sulphur dioxide, a component of smog and closely related chemicals are known primarily as a cause of acid rain. Seeing that the air pollutants, emitted into the atmosphere are responsible for a number of adverse environmental effects, that is therefore necessary to take any action to reduce them.

Conclusion. In the last decade Poland has made huge progress in environmental protection, reducing the dependence of economic growth on a number of environmental pressure factors. However, further limitations on resource exploitation and on the amounts of energy and substances emitted into the environment, still pose a challenge to implementing the principles of sustainable economic development and to strengthening efficiency-oriented trends. One of the ways of increasing the energy efficiency of buildings and reduction of emissions are the activities related with thermal modernization of buildings. The thermal modernization activities in Poland have been conducted for more than twenty years, the implemented provisions constitute a basis for performing these activities in a complex manner and cost-effectively, considering the investment and utilization expenses.

The article presents the impact of pollutant emissions by improving the energy efficiency of the school building. Particular attention was paid to the reduction of the greenhouse effect as a result of building thermal modernization. The monitoring of the results from conducted thermal modernization pointed out a number of benefits resulting from this type of activity:

1. average energy reduction effect by approximately 54,9 % was observed,
2. thermal modernization had impact on reducing the greenhouse effect by reducing greenhouse gases,
3. reduction of carbon dioxide emissions at the level of 68 % was achieved,
4. sulphur dioxide, nitrogen oxides, carbon monoxide, benzo(a)pyrene and dust emissions have dropped at about 99,9 %,
5. there was occurred reduction of electricity consumption at about 7,6 %,
6. water consumption has not changed to a considerable extent,
7. emissions of harmful pollutants into the atmosphere was declined,
8. comprehensive thermal activities of a buildings brings the greatest effects and the shortest time of return on invested capital.

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