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D.T3.2.3 ENERGY SIMULATIONS AND TECHNICAL IMPROVEMENT OPTIONS– CLASSROOMS, SPORT HALLS, CANTEENS

Poland

Version 1
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Ministry of Science and Higher Education
Republic of Poland

I. Building #1 SP 61 (ul. Białobrzeska 27, 02-340 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building was built in 1956 and stays in unchanged form till today. The envelope is well preserved however it has not been modernized since the original state, except windows and roof modernization in 1998. Furthermore in 2015 windows in the sport hall have been changed. External partitions are not thermally insulated, thus heat resistance is very low. Windows are in very bad condition thus modernization should be considered, possibly together with a thermal insulation of external walls. In 1998 the heating system and electric system have been modernized. The building is heated with a heat exchanger powered by the district heating. The heating installation is in a good condition. Heat is distributed with plate water convectors equipped with thermostats. The building does not have any mechanical ventilation or other HVAC system except the kitchen which has been equipped with exhaust fans. The lighting in almost the whole building is provided with 2x58 W fluorescent fittings, except small rooms such as toilets, storage rooms etc. The lighting is controlled manually by users. The building does not have any BMS system.

The general overview of the building allowed for giving a poor opinion about energy efficiency of the building. The measured final energy indicator for heating in the past year equals 235.36 kWh/m^{2}a, which is very high.

1.2. Summary table: existing state of the builiding

Category	Value
Building type[1]	Educational building
Constriction year / major reconstruction year	1956 / 1998
Building fabric[2]	Full brick and stone slab of sandstone, aerated brick and reinforced concrete slab (roof)
Building useful area [m^2]	2450
Useful area of the audited zone [m^2]	Classrooms: 993.95 m^2 Sport hall: 237.9 m^2 Canteen: 192.91 m^2 (with facilities)
Shape factor - building [1/m]	0.28
Building volume [m^3]	8744

[1] Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

[2] E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

Volume of the audited zone [m^3]	Classrooms: 3181 m^3 Sport hall:1665 m^3 Canteen:617 m^3(with facilities)
Shape factor - audited zone [1/m]	Classrooms: 0.31 Sport hall: 0.14 Canteen:0.31 (with facilities)
Number of floors	3
Number of building users	650
Heating system	District heating, heat convectors with thermostats
Domestic hot water (DHW) system	District heating, the same source as the central heating
Cooling system	There is no cooling system in the building
Lightning system	2x58W fluorescent bulbs switched on manually when needed, the sport hall is equipped with halogen lighting
Primary energy consumption - total [kWh/m^2a]	318.9
Primary energy consumption - heating [kWh/m^2a]	224.7
Primary energy consumption - DHW [kWh/m^2a]	16.6
Primary energy consumption - cooling [kWh/m^2a]	n/a
Primary energy consumption - lightning [kWh/m^2a]	77.6
Final energy consumption - total [kWh/m^2a]	287.7
Final energy consumption - heating [kWh/m^2a]	245.4
Final energy consumption - DHW [kWh/m^2a]	16.4
Final energy consumption - cooling [kWh/m^2a]	n/a
Final energy consumption - lightning [kWh/m^2a]	25.9
CO_2 emissions - total [kg/m^2a]	105.56
CO_2 emissions - heating [kg/m^2a]	80.57
CO_2 emissions - DHW [kg/m^2a]	6.43
CO_2 emissions - cooling [kg/m^2a]	n/a
CO_2 emissions - lightning [kg/m^2a]	18.57

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to the total energy savings after applying measures together in Variant 1 and Variant 2.

The recommended Variant 1 is a typical thermal modernisation scheme applied in Poland, that is usually introduced when the owner of the building is applying for financial subsidies for thermal modernisation. Application of all measures allows to meet current technical requirements for buildings, namely maximum U-values for external walls, roof, and windows.

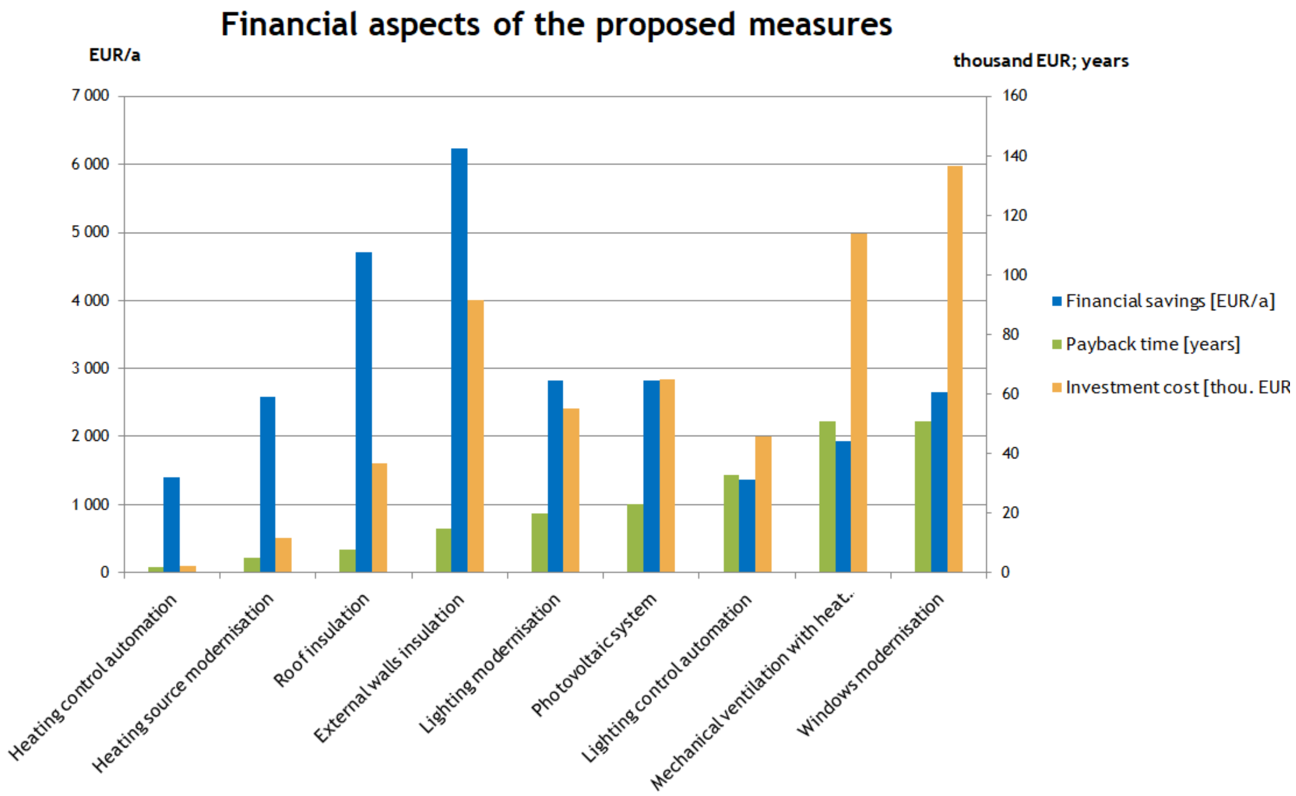
The maximum efficiency Variant 2 is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values lower than 0 kWh/m^{2}a. This value however is only achieved because of energy consumption calculation in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

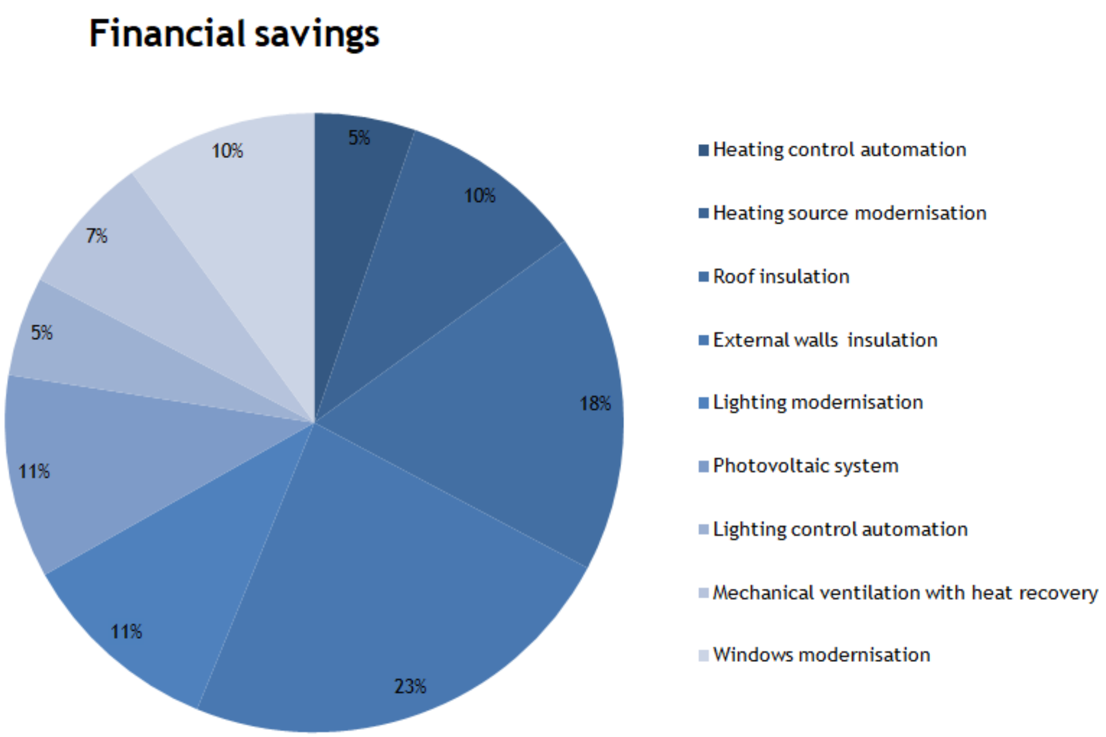
The table presented in section 1.4 contains all analysed measures. Measures 1-6 are considered as a basic modernisation (Variant 1). In order to achieve the nZEB standard, measures 7-9 are added.

For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

1.4. Summary table: suggested measures, energy savings, financial savings

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR]	Payback time [years]
1.	External walls insulation	205,830	185,247	68.39	6,223	91,924	15
2.	Windows modernisation	88,204	79,383	29.31	2,667	136,360	51
3.	Roof insulation	156,159	140,543	51.89	4,721	36,767	8
4.	Heating source modernisation	85,466	93,400	28.40	2,583	11,628	5
5.	Lighting modernisation	38,020	114,060	27.30	2,829	55,261	20
6.	Heating control automation	54,242	48,818	18.02	1,407	2,326	2
7.	Mechanical ventilation with heat recovery	73,796	46,175	24.52	1,942	113,953	51
8.	Lighting control automation	18,526	55,580	13.3	1,379	46,051	33
9.	Photovoltaic system	-	114,000	-	2,828	65,116	23





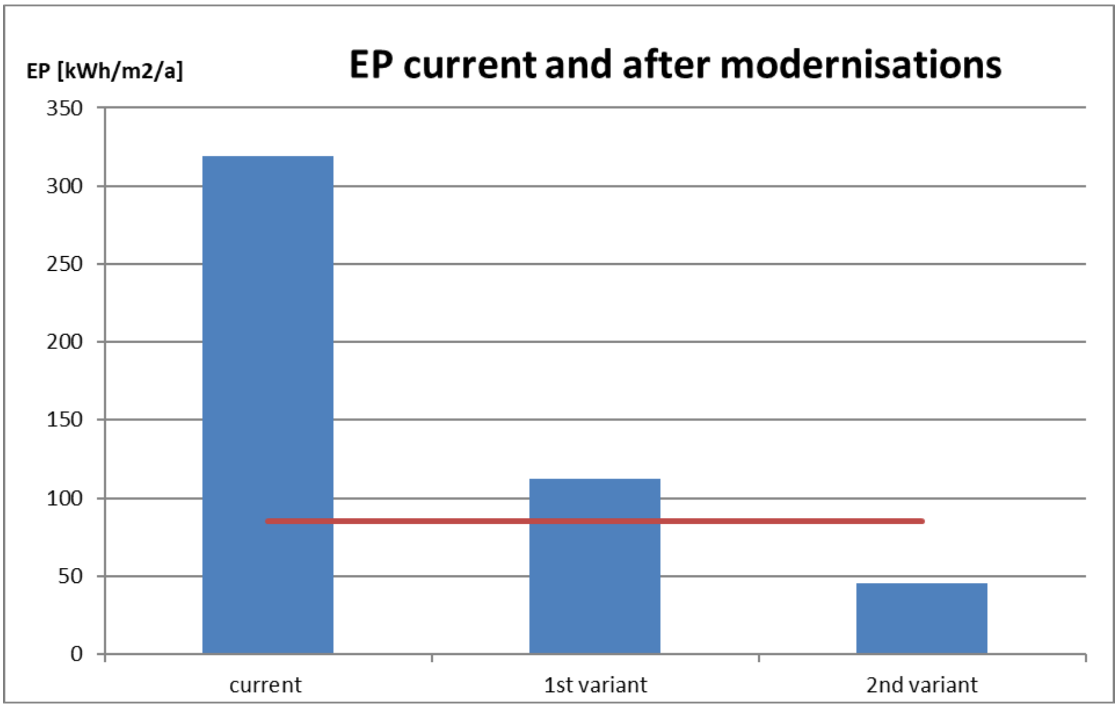
The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. Considering this, the best measure is the is modernisation of the heating source, which is one of the basic options proposed as a part of a thermal modernisation plan. The windows exchange payback time is the highest, but it is still on average level. High investment cost of installing the mechanical ventilation system in combination with technical difficulties makes it an additional option considered only as a part of the maximum efficiency variant.

In the table below, the shares of primary energy savings due to analysed measures in each space have been presented.

Table 1 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen with facilities	Rest of the building
1.	External walls insulation	36.67%	16.43%	10.83%	36.08%
2.	Windows modernisation	42.84%	-	8.16%	48.99%
3.	Roof insulation	45.23%	25.47%	5.86%	23.45%
4.	Heating source modernisation	37.68%	19.39%	9.22%	33.72%
5.	Lighting modernisation	43.92%	2.25%	8.52%	45.30%
6.	Heating control automation	38.19%	17.10%	8.87%	35.84%
7.	Mechanical ventilation with heat recovery	38.57%	9.30%	12.87%	39.26%
8.	Lighting control automation	43.92%	2.25%	8.52%	45.30%

Total primary energy consumption before and after implementations of measures according to 1st and 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

The school is already equipped with thermostats so there is no need of improving them.

The modernisation includes changes in time of a district heating heat exchanger usage. Currently it is assumed that the heating source produces heat 24 hours a day, 7 days a week, leading to inefficiency of the heating system. Even though some telemetry system is installed, it is not known whether it has any control solutions or it is only used for remote diagnosis and consumption control. When no lessons are held nor the sport hall is occupied, there is no need to heat the space. Currently only an external temperature automatic control is installed in the system. Installation of traditional heating control allowing for night and weekend temperature reduction could allow for significant energy savings with low investment cost. Also, in case there is already a controller installed, it is recommended to perform heating system rinsing and regulation. The calculated total efficiency of the system would increase from the current 0.85, to 1.05[3], according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 2 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	641,407	555,941	85,466
Primary energy [kWh/a]	591,095	497,695	93,400
CO_2 emission [Mg/a]	213.13	184.73	28.40

Table 3 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,584	11,628	5

The estimated payback time is around 5 years. The investment cost is around 12 000 EUR. The payback time is low due to the fact that walls and roof are in poor condition so there is a huge loss in heat through these partitions. As the result even the smallest change in the heating source will give great impact.

The heating system modernisation would result in a reduction of primary energy consumption in classrooms, sport halls, and canteen with facilities.

2.1.1.1. Classrooms

[3] Efficiency >1.0 is caused by applying temperature reduction in nights and weekends.

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 35,193 kWh/a, which gives 37.72% reduction in the building.

2.1.1.2. Sport halls

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 18,110 kWh/a, which gives 19.42% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 8,611 kWh/a, which gives 9.22% reduction in the building.

2.1.2. Heating control automation

The weather forecast control system (for example Egain or Promar) is used to control the heating system, based on the local weather forecasts. It reduces time when building becomes overheated, during periods when there are high external temperature amplitudes during the day. This solution increases the efficiency of the system`s regulation allowing for energy savings. The calculated total efficiency of the system would increase from the current 0.85, to 0.93, according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building. Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 4 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	641,407	587,165	54,242
Primary energy [kWh/a]	591,095	542,277	48,818
CO_2 emission [Mg/a]	213.13	195.10	18.03

Table 5 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,407	2,326	2

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however for this solution is around 1-3 years.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 18,644 kWh/a, which gives 38.22% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 8,348 kWh/a, which gives 17.12% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,330 kWh/a, which gives 8.92% reduction in the building.

2.2. Water and sewage system

No changes to the sewage system are considered.

2.3. HVAC

The whole building is now ventilated naturally, except the kitchen which is equipped with the mechanical exhaust ventilation.

An installation of mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows for reduction of final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 6 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	641,407	567,611	73,796
Primary energy [kWh/a]	591,095	544,920	46,175
CO_2 emission [Mg/a]	213.13	181.07	32.06

Table 7 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,231	113,953	51

In practical terms installing the mechanical ventilation system in the existing building might be problematic and is not considered in a typical thermal modernisation scheme. This measure is proposed as a part of maximum efficiency Variant 2, which aims at fulfilling requirement for newly designed buildings.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.3.1.1. Classrooms

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 17,810 kWh/a, which gives 38.62% reduction in the building.

2.3.1.2. Sport halls

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 4,294 kWh/a, which gives 9.32% reduction in the building.

2.3.1.3. Canteen

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 5,943 kWh/a, which gives 12.92% reduction in the building.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in this kind of buildings is not a commonly used installation, only in selected circumstances.

2.5. Electric system

According to the invoices provided by the school staff, total annual consumption of electricity is 64,938 kWh. The vast majority of electrical energy is consumed by lighting, but also there are some devices using electricity, like computers or projectors. On the other hand, it is hard to estimate the actual consumption of each device, though electrical energy consumption reduction calculations are the estimations, as it is not well known how exactly electrical energy is being consumed in the building.

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones and installing automatic control which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is possibility of decreasing of the electrical power which will reduce electricity costs. This however will not decrease the energy consumption. The lightning exchange measure is described in section 2.8.

2.6. Building envelope

2.6.1. External walls insulation

Thermal modernisation of the building includes insulation of the external walls, foundation walls and the roof, as well as windows modernisation. It is usually most profitable when all of the thermal modernisation measures are performed together, as a large share of costs is associated with preparation of construction field, ex. construction of scaffoldings etc.

External walls insulation decreases the heat transfer coefficient, which influences heat loss through the walls. The building envelope has not been modernised since the original state and the heat transfer coefficient is estimated at 1.16 $W/m^2 \bullet K$, which is high. Thermal modernisation of the building assumes insulation of the external walls with 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 $W/m \bullet K$.

The heat resistance of the insulation material is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

Where d – thickness [m], λ - thermal conductivity [W/m•K]

The overall heat transfer coefficient U after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the external walls' parameters are presented in the table below.

Table 8 Heat parameters of the external walls

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
1.16	0.04	0.14	3.50	0.23

The heat transfer coefficient of the external walls after the proposed modernisation equals 0.23 W/m²•K.

Values of the energy savings, CO_2 reduction as well as the savings are presented in the tables below.

Table 9 Energy savings and CO_2 reduction after external walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	641,407	435,577	205,830
Primary energy [kWh/a]	591,095	405,848	185,247
CO_2 emission [Mg/a]	213.13	144.73	68.40

Table 10 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
6,223	91,924	15

The investment cost of the external walls' insulation is relatively high, the financial savings though are also satisfactory, which results in payback time of 15 years. Thus, this measure is treated as one of the basic options considered in a typical thermal modernisation scheme.

External walls insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.1. Classrooms

External walls insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 67,930 kWh/a, which gives 36.72% reduction in the building.

2.6.1.2. Sport halls

External walls insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 30,436 kWh/a, which gives 16.42% reduction in the building.

2.6.1.3. Canteen

External walls insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 20,062 kWh/a, which gives 10.82% reduction in the building.

2.6.2 Windows modernisation

Windows modernisation includes an exchange of the windows with new ones of U=1.1 W/m^2•K. In the existing state the windows besides the sport hall are leaky and their heat transfer coefficient equals 2.6W/m^2•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 11 Energy savings and CO_2 reduction after windows modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	641,407	553,203	88,204
Primary energy [kWh/a]	591,095	511,712	79,383
CO_2 emission [Mg/a]	213.13	183.82	29.31

Table 12 Financial savings and investment cost of windows modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,667	136,360	51

The long payback time of the windows modernisation results from the fact that windows are already quite new in spot hall.

Windows modernisation would result in a reduction of primary energy consumption in classrooms and canteen with facilities.

Primary energy in the amount of 34,008 kWh/a would be saved in classrooms, while 0 kWh/a would be saved in the Sport hall and 6,478 kWh/a would be saved in the canteen and its facilities.

2.6.3 Roof insulation

Roof insulation allows the improvement of heat parameters, which decreases heat loss. In the proposed modernisation variant, the insulation with 18 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K is considered.

The overall heat resistance is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the roof materials and parameters are presented in the table below.

Table 13 Heat parameters of the roof

Current heat transfer coefficient [W/m^2•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m^2•K/W]	Heat transfer coefficient [W/m^2•K]

1.81	0.04	0.18	5.14	0.18

The heat transfer coefficient of the roof after the proposed modernisation equals 0.18 W/m^2•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 14 Energy savings and CO_2 reduction after roof insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	641,407	485,248	156,159
Primary energy [kWh/a]	591,095	450,532	140,543
CO_2 emission [Mg/a]	213.13	161.24	51.89

Table 15 Financial savings and investment cost of roof insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4,721	36,767	8

Annual financial savings from the roof insulation are about 4,700 EUR. The payback time is 8 years. The measure will also improve the thermal comfort in the building and is considered as one of the basic options proposed as a part of typical thermal modernisation. The roof was pointed out as the weakest point in this facility that it why its renovation is so beneficial.

Roof insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.4. Classrooms

Roof insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 63,568 kWh/a, which gives 45.22% reduction in the building.

2.6.1.5. Sport halls

Roof insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 35,796 kWh/a, which gives 25.52% reduction in the building.

2.6.1.6. Canteen

Roof insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 8,236 kWh/a, which gives 5.92% reduction in the building.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, a photovoltaic installation of a capacity up to 40 kWp is defined as a small installation and can be connected to the power grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 63% of the roof – 660 m^2. In Warsaw the productivity of PV is about 950 kWh/kWp/a so this installation would provide 38,000 kWh a year.

2.8. Lighting system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 16 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	63,366	25,346	38,020
Primary energy [kWh/a]	190,099	176,039	114,060
CO_2 emission [Mg/a]	45.50	18.2	27.30

Table 17 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,829	55,261	20

Financial savings from the lighting modernisation are about 2 800 EUR and payback time is 20 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 50,095 kWh/a, which gives 43.92% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 2,566 kWh/a, which gives 2.32% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 9,718 kWh/a, which gives 8,.2% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing automatic control which is based on the amount of light from the outside (DALI system) and presence of people in a room/corridor (motion sensors). In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 18 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	63,366	44,840	18,526
Primary energy [kWh/a]	190,099	134,519	55,580
CO_2 emission [Mg/a]	45.50	32.20	13.3

Table 19 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,379	46,051	33

Investment cost of the modernisation is about 46,000 EUR. Payback time of the measure is rather reasonable with the level of 33 years. As this option decreases electricity consumption, primary energy savings are relatively high, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 24,411 kWh/a, which gives 43.92% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 1,251 kWh/a, which gives 2.32% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,735 kWh/a, which gives 8.52% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the first variant is limited by foundation program specifications and the second variant is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the second variant the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control. Users should be trained how to use the system, so that it would work effectively and properly.

In the first variant it is the heating which is, as the only system, controlled automatically. This means that users can turn off the lighting only manually. The last person leaving specific room ought to always remember to turn off the lights. Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 5 parameters: size of the school, amount of energy it consumes/ loses by specific element, number of heaters and annual usage cost, and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service.

Table 20 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	External walls insulation	1 m^2	42	-
2.	Windows modernisation	1 m^2	233	-
3.	Roof insulation	1 m^2	35	-
4.	Heating source modernisation	1 heater	134	11,628
5.	Lighting modernisation	1 W	1.74	-
6.	Heating control automation	Annual usage	233	2,326
7.	Mechanical ventilation with heat recovery	1 m^2	47	-
8.	Lighting control automation	1 W	0.58	-
9.	Photovoltaic system	1 kWp	1,628	-

2.12.2. Accuracy

During the process of measures evaluation a few simplifications have been implemented. Firstly, the analytical model was adjusted so that it consumes possibly similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the actual savings can be a bit lower, while energy consumption would be lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, in reality they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), heat – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Insulation of external walls and roof - experience from the Polish market shows that huge share of total costs is labour and materials, however scaffolding and equipment may represent up to 30% of total costs. Accuracy level is around 80%.

Windows modernisation – In this case the main cost are new windows. Accuracy level can be estimated at 90%.

Heating source modernisation and control automation – Prices found on a website of a company providing such solutions. Accuracy level is around 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs per about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy is around 90%.

Mechanical ventilation – based on author's experience and expert opinions, however estimation is not easy due to the variety of situations when vent ducts cannot be installed. Accuracy level is around 80%.

Photovoltaic system – this price is standard on the Polish market, so the accuracy is around 95%.

2.12.3. Methods and standards used

Most of methods were based on author's experience, knowledge and internet offers from companies.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 21 Standards used during energy audit

	Applied version	**English version**
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements
2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings – Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła.	EN ISO 6946 Building components and building elements - Thermal

	Metoda obliczeń.”	resistance and thermal transmittance - Calculation methods
6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków - Wymiana ciepła przez grunt - Metody obliczania.”	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach - Liniowy współczynnik przenikania ciepła - Metody uproszczone i wartości orientacyjne.”	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia.”	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane - Właściwości cieplno-wilgotnościowe - Tabelarycznewartościobliczenioweiproceduryokreślaniadeklarowanychiobliczeniowychwartościcieplnych"	ISO 10456:2007 Building materials and products -- Hydrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania”	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system”	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 “Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance”	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 22 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia termo modernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit
3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawieszczegółowegozakresuisposobusporządzaniaaudytuefektywnościenergetycznej, wzorukartyaudytuefektywnościenergetycznejorazmetodyobliczaniaoszczędnościenergii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency audit card and methods for calculating energy savings

5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawiemetodologiiwyznaczaniacharakterystykienergetycznejbudynkulubczęścibudynkuorazświadectwcharakterystykienergetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) – raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) – raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme - 1st variant

3.1. Aim of the renovation plan

The aim of the first renovation plan is to modernize the building so that it meets Polish building standards and consumes less energy. As the result the costs of maintenance of the school will be lower. Such modernisation plan was chosen due to the possibility of getting funds from the BGK thermal-modernisation and renovation program, which is a national programme supporting thermal modernisation of buildings in Poland.

The first variant includes the following measures:

- External walls insulation
- Windows modernisation
- Roof insulation
- Heating source modernisation
- Lighting modernisation

The extent of each measure assumes meeting the minimum requirements, even if the costs are high or the payback time is long. There are no other boundaries to renovate this building in a way proposed above.

3.2. Criteria for ranking energy efficiency improvement measures

The main criterion was to meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 $W/m^2 \cdot K$
- heat transfer coefficient of windows: U = 1.1 $W/m^2 \cdot K$
- heat transfer coefficient of roofs: U = 0.18 $W/m^2 \cdot K$

Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not.

Last criterion is the improvement of thermal comfort in the building. This however cannot be measured, but it is important to remember that sometimes it is more important to improve comfort than to save money.

3.3. Potential interactions with other proposed recommendation

The only affected parameter is the heating source. Each modernisation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. The impact of interactions between measures have been considered in the Variants (see row “Total” in chapter 3.2 and 4.2) Tables in chapters 3.5 and 4.5 include impact of interactions. Lighting has no effect on any of other renovations.

3.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23$W/m^2 \cdot K$

Roof insulation – the best option is to use 18 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.18 W/m²•K

Replacement of windows – In this case there is no other option but to replace all old windows with new ones with heat transfer coefficient of 1.1 W/m²•K value.

Heating source improvements – Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs to LED ones.

When it comes to lighting and heating source both money and final energy savings were considered. LEDs are one of the eco-friendliest lighting choices whilst also their high efficiency leads to economical savings. When it comes to the heating source, installing heating source automation decreases the usage of heating when it is not necessary (weekends and nights), so it improves the system`s efficiency.

The measures considered in the 1st variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 23 Measures included in the 1st variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating source modernisation	85,466	93,400	28.40	2,583	11,628	5
2.	Roof insulation	156,159	140,543	51.89	4,721	36,767	8
3.	External walls insulation	205,830	185,247	68.39	6,223	91,924	15
4.	Lighting modernisation	38,020	114,060	27.30	2,829	55,261	20
5.	Windows modernisation	88,204	79,383	29.31	2,667	136,360	51
	Total	474,445	506,842	172.01	16,023	331,941	21

The most beneficial option, with 5 years payback time, is the heating source modernisation due to its low investment cost. It is important to note that after insulation of walls and roof its impact will be lower because losses of heat will be reduced significantly. The windows modernisation has the longest payback time, however, as indicated in previous paragraphs, it has another significant advantage, such as solving the problem with cold winters causing discomfort for people nearby windows.

3.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	318.9	112.0
Primary energy consumption - heating [kWh/m²a]	224.7	64.4
Primary energy consumption - DHW [kWh/m²a]	16.6	16.6
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	77.6	31.0

Final energy consumption - total [kWh/m²a]	287.7	94.0
Final energy consumption - heating [kWh/m²a]	245.4	67.2
Final energy consumption - DHW [kWh/m²a]	16.4	16.4
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	25.9	10.3
CO_2 emissions - total [kg/m²a]	105.56	35.23
CO_2 emissions - heating [kg/m²a]	80.57	21.37
CO_2 emissions - DHW [kg/m²a]	6.43	6.43
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	18.57	7.43

The 1st renovation variant allows reducing final energy consumption by around 474 MWh/a and primary energy consumption by around 506 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 330,000 EUR and the estimated payback time is at the level of 21 years. The EP factor of the building after implementing the proposed measures would achieve 112 kWh/m²/a, which makes the building much more efficient. This however does not fulfil the required maximum 85 kWh/m²/a to reach the nZEB standard.

4. Renovation scheme - 2nd variant

4.1. Aim of the renovation plan

The aim of the second renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The second variant includes all measures of the 1st variant with the following additional renovations:

- Heating control automation (weather forecast control)
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

4.2. Criteria for ranking energy efficiency improvement measures

The aim of the second variant is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows for large final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

4.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation, heating control automation, etc.) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. Also, changes in usage time of the heating system influences other measures decreasing the heat consumption – turning the heating off during nights and weekends decreases energy savings from walls and roof insulation as well as windows modernisation or mechanical ventilation with heat recovery, as the time they work and generate savings is also shorter.

Lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row “Total” in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions.

4.4. Suggested measures (optimal implementation plan)

Based on previous paragraphs the implementation plan includes the following measures:

Insulation of external walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23W/m^2•K.

Roof insulation – the best option is to use 18 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K.

Replacement of windows – In this case there is no other option but to replace all old windows with new ones with heat transfer coefficient with 1.1 W/m^2•K value.

Heating source improvements – Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs for LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the weather forecast control system (e.g. Egain/Promar etc.), which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the 2nd variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 24 Measures included in the 2nd variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating control automation	54,242	48,818	18.02	1,407	2,326	2
2.	Heating source modernisation	85,466	93,400	28.40	2,583	11,628	5
3.	Roof insulation	156,159	140,543	51.89	4,721	36,767	8
4.	External walls insulation	205,830	185,247	68.39	6,223	91,924	15
5.	Lighting modernisation	38,020	114,060	27.30	2,829	55,261	20
6.	Photovoltaic system	-	114,000	-	2828	65,116	23
7.	Lighting control automation	44,840	55,580	13.3	1,379	46,051	33
8.	Mechanical ventilation with heat recovery	73,796	46,175	29.31	1,942	113,953	51
9.	Windows modernisation	88,204	79,383	24.52	2,667	136,360	51
	Total	534,770	556,455	195,21	20,770	559,388	27

The shortest payback time (typically 1-3 years) is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view. The windows modernisation has the longest payback time, however, as indicated in previous paragraphs, it has another significant advantage, such as solving the problem with cold winters causing discomfort for people nearby windows.

4.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	318.9	45.2
Primary energy consumption - heating [kWh/m²a]	224.7	53.2
Primary energy consumption - DHW [kWh/m²a]	16.6	16.6
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	77.6	22.0
Final energy consumption - total [kWh/m²a]	287.7	69.4

Final energy consumption - heating [kWh/m²a]	245.4	45.6
Final energy consumption - DHW [kWh/m²a]	16.4	16.4
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	25.9	7.3
CO_2 emissions - total [kg/m²a]	105.56	25.88
CO_2 emissions - heating [kg/m²a]	80.57	14.19
CO_2 emissions - DHW [kg/m²a]	6.43	6.43
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	18.57	5.26

The 2nd renovation variant allows reducing final energy consumption by around 535 MWh/a and primary energy consumption by around 556 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 560,000 EUR and the estimated payback time is at the level of 27 years. The EP factor of the building after implementing the proposed measures would achieve about 45.2 kWh/m²/a, which makes the building much more efficient. The total cost of the maximum efficiency variant is significantly higher than the 1st variant, also in reference to the energy savings. Thus, the 1st variant is more realistic and is proposed as the basic one.

5. Attachments

No attachments.

II. Building #2 SP 340 building B (ul. Eugeniusza Lokajskiego 3, 02-793 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building was built between 1993 and 1997. It was constructed and designed in 3 stages. The building envelope is well preserved. Since the beginning, thermal insulation has been never upgraded. Only windows were changed around 2014. In one of the sport halls (fencing hall), a mechanical ventilation and air conditioning have been installed. The building is connected to the district heating network. Both central heating and domestic hot water system is supplied by a heat exchanger. The building has been insulated with a thick layer of polystyrene (6-8 cm) on the external walls, 16 cm of mineral wool on the roof, and 6 cm of hard polystyrene on the ground floor. The building is ventilated naturally except the large sport hall and the fencing hall. The large sport hall is equipped with mechanical exhaust fans located on the ceiling; however, they have not been used for a long time. The fencing hall has been recently equipped with a new air handling unit with heat recovery. The lighting system is composed of traditional fluorescent bulbs controlled manually by users. The building does not have any BMS system.

The general overview of the building allowed for giving good opinion about energy efficiency of the building. The measured final energy indicator for heating during past year was 122.95 kWh/m^{2}a, which is typical for this type of building.

1.2. Summary table: existing state of the builiding

Category	Value
Building type[4]	Educational building
Constriction year / major reconstruction year	1993-1997
Building fabric[5]	Ceramic full brick, ceramic hole brick; hollow blocks made of cellular concrete (ceiling)
Building useful area [m^2]	5,915.30
Useful area of the audited zone [m^2]	Classrooms: 1,692.6 m^2 Sport hall: 712 m^2 Canteen: 224.1 m^2 (with facilities)
Shape factor - building [1/m]	0.23

[4]Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

[5]E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

Building volume [m³]	25,718
Volume of the audited zone [m³]	Classrooms: 5,924 m³ Sport hall: 7,262 m³ Canteen: 784 m³ (with facilities)
Shape factor - audited zone [1/m]	Classrooms: 0.29 Sport hall: 0.1 Canteen: 0.29
Number of floors	4
Number of building users	1,100
Heating system	District heating, heat convectors, ¾ of them without thermostats
Domestic hot water (DHW) system	District heating, the same source as the central heating
Cooling system	The only cooling system in the building is fencing sport hall. It is used only when needed.
Lightning system	2x58W fluorescent bulbs switched on manually when needed, the sport hall is equipped with 3x58W fluorescent bulbs
Primary energy consumption - total [kWh/m²a]	162.5
Primary energy consumption - heating [kWh/m²a]	74.0
Primary energy consumption - DHW [kWh/m²a]	29.1
Primary energy consumption - cooling [kWh/m²a]	n/a
Primary energy consumption - lightning [kWh/m²a]	59.3
Final energy consumption - total [kWh/m²a]	127.4
Final energy consumption - heating [kWh/m²a]	76.2
Final energy consumption - DHW [kWh/m²a]	31.5
Final energy consumption - cooling [kWh/m²a]	n/a
Final energy consumption - lightning [kWh/m²a]	19.8
CO_2 emissions - total [kg/m²a]	47.59
CO_2 emissions - heating [kg/m²a]	20.01
CO_2 emissions - DHW [kg/m²a]	13.96
CO_2 emissions - cooling [kg/m²a]	n/a
CO_2 emissions - lightning [kg/m²a]	13.53

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to total energy savings after applying measures together in Variant 1 and Variant 2.

The recommended Variant 1 is a typical thermal modernisation scheme applied in Poland, that is usually introduced when the owner of the building is applying for financial subsidies for thermal modernisation. Application of all measures allows to meet current technical requirements for buildings, namely maximum U-values for external walls, roof, and windows.

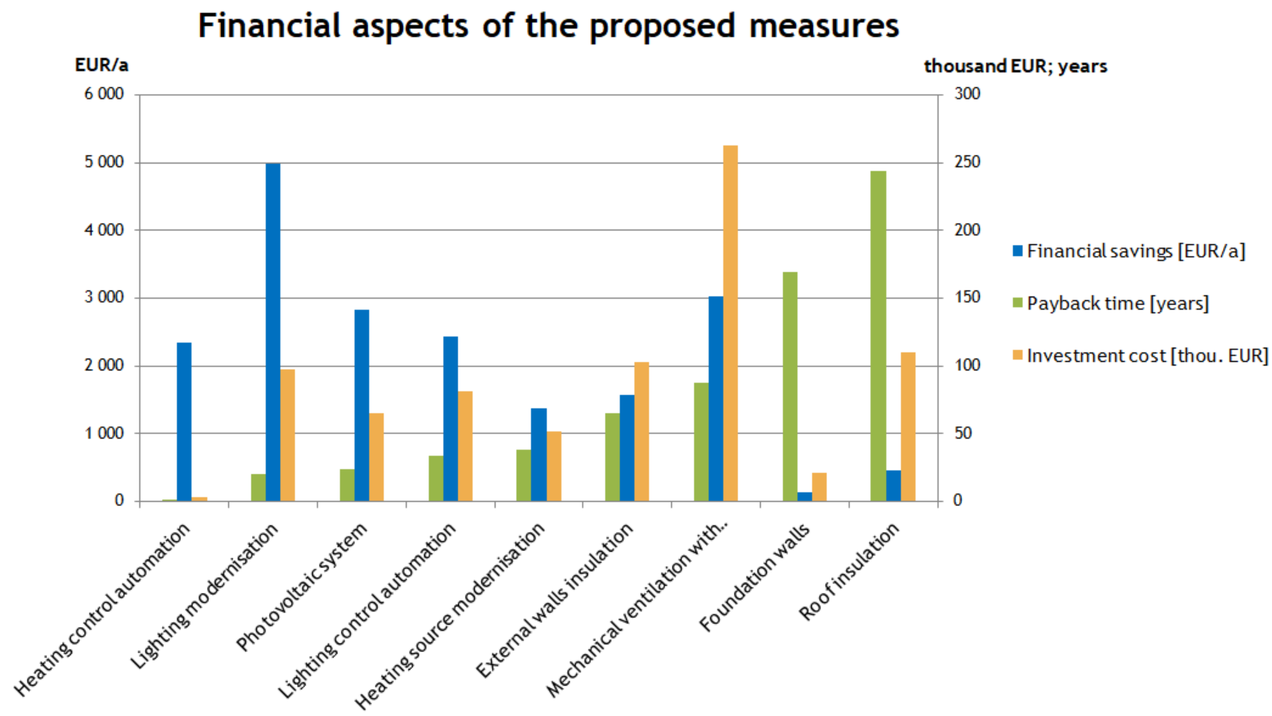
The maximum efficiency Variant 2 is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in the Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values lower than 0 kWh/m^{2}a. This value however is only achieved because of energy consumption calculation in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

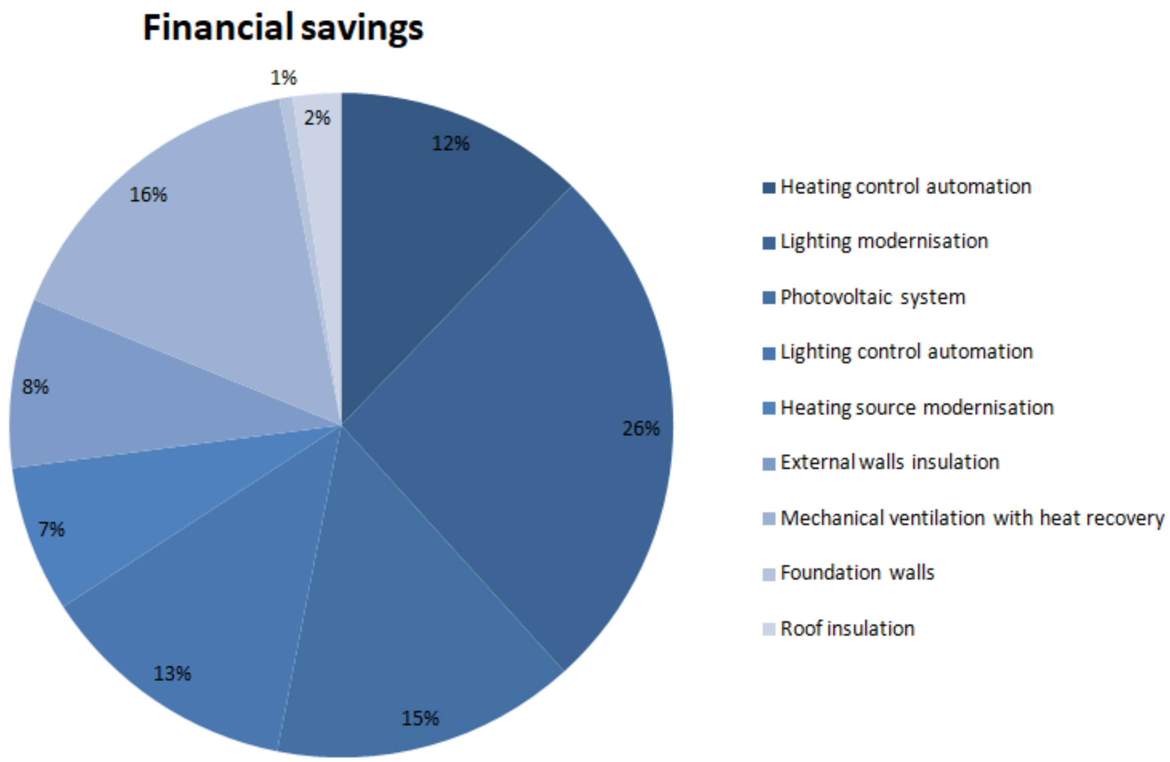
The table presented in section 1.4 contains all analysed measures. Measures 1-6 are considered as a basic modernisation (Variant 1). In order to achieve the nZEB standard, measures 7-9 are added.

For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

1.4. Summary table: suggested measures, energy savings, financial savings

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	51,974	46,777	17.27	1,571	102,254	65
2.	Foundation walls	4,051	3,646	1.35	122	20,722	169
3.	Roof insulation	14,880	13,392	4.94	450	109,539	243
4.	Heating source modernisation	45,026	40,523	14.96	1,361	51,395	38
5.	Lighting modernisation	66,869	200,606	48.01	4,976	97,193	20
6.	Heating control automation	84,764	76,287	28.17	2,330	2,326	1
7.	Mechanical ventilation with heat recovery	99,961	38,468	33.22	3,022	262,060	87
8.	Lighting control automation	32,585	97,754	23.40	2,425	80,994	33
9.	Photovoltaic system	-	114,000	-	2,828	65,116	23





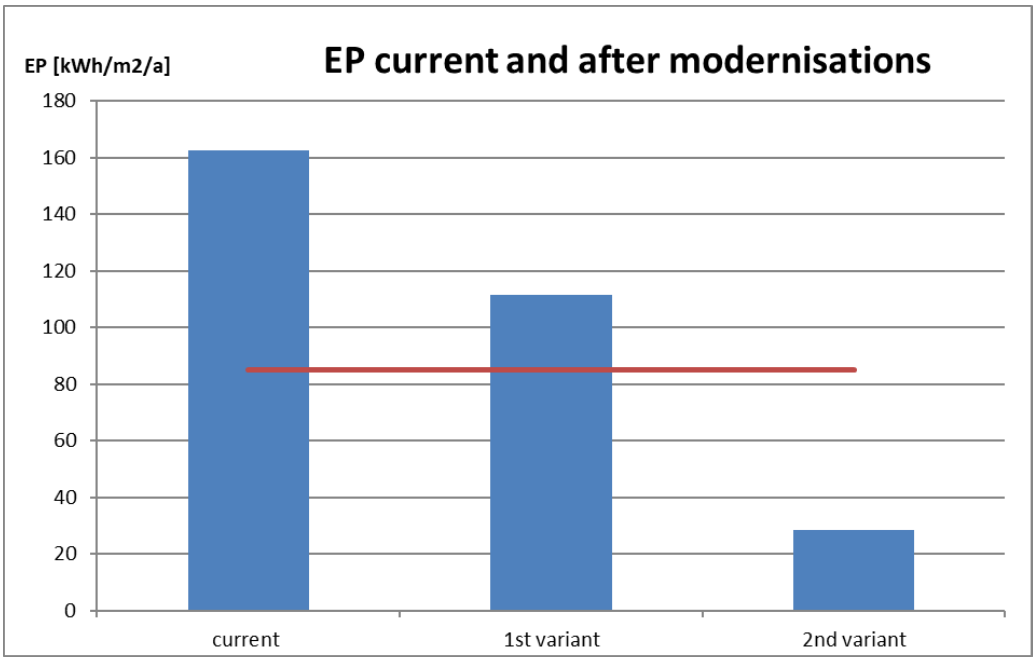
The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. Considering this, the best measure is the modernisation is the lighting improvement, which is one of the basic options proposed as a part of a thermal modernisation plan. The extremely long payback time of the roof modernisation results from the fact that it is already well preserved (U = 0.23 W/(m^2*K)) and is near to meet required heat transfer coefficient of value U = 0.18 W/(m^2*K)). High investment cost of installing the mechanical ventilation system in combination with technical difficulties makes it an additional option considered only as a part of the maximum efficiency variant.

In the table below, the shares of primary energy savings due to analysed measures in each space have been presented.

Table 25 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen with facilities	Rest of the building
1.	External walls insulation	37.42%	8.21%	2.47%	51.90%
2.	Foundation walls	6.30%	18.63%	-	75.07%
3.	Roof insulation	32.04%	19.32%	-	48.64%
4.	Heating source modernisation	19.49%	11.85%	3.68%	64.98%
5.	Lighting modernisation	32.80%	4.60%	4.35%	58.25%
6.	Heating control automation	28.12%	15.04%	3.55%	53.29%
7.	Mechanical ventilation with heat recovery	9.82%	15.41%	12.91%	61.86%
8.	Lighting control automation	32.80%	4.60%	4.34%	58.25%

Total primary energy consumption before and after implementations of measures according to 1st and 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

The main problem with the heating system is the lack of thermostats on most of the plate heaters. This causes frequent overheating of the building, which results in heat waste due to ventilation by windows opening and decreases thermal comfort of the building`s users as well. The only part of the building, where heaters are equipped with thermostats, is the sport hall.

The proposed renovation of the heating system includes an exchange of the old convectors with new plate heaters with thermostats.

The modernisation includes changes in time usage of a district heating heat exchanger. It is considered that the heat source produces heat 24 hours a day, 7 days a week, leading to inefficiency of the heating system. When no lessons are held nor the sport hall is unoccupied, the space heating is unnecessary. Currently only an external temperature automatic control is installed in the system. Installation of traditional heating control allowing for night and weekend temperature reduction could allow for significant energy savings with low investment cost. Also, in case there is already a controller installed, it is recommended to perform heating system rinsing and regulation. The calculated total efficiency of the system would increase from the current 0.85, to 1.05[6], according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 26 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	606,360	561,334	45,026
Primary energy [kWh/a]	581,151	540,628	40,523
CO_2 emission [Mg/a]	201.48	186.52	14.96

Table 27 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,361	51,395	38

Estimated payback time is around 38 years. The investment cost is around 51,000 EUR, however, this will improve comfort and will result in reduced number of interventions of the technical staff than in defective current installation. After the modernisation the problems with overheating and aerated heaters on the top floor corridors will be solved.

[6] Efficiency >1.0 is caused by applying temperature reduction in nights and weekends.

The heating source modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.1.1. Classrooms

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 7,898 kWh/a, which gives 19.52% reduction in the building.

2.1.1.2. Sport halls

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 4,802 kWh/a, which gives 11.92% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,491 kWh/a, which gives 3.72% reduction in the building.

2.1.2. Heating control automation

The weather forecast control system (for example Egain or Promar) is used to control the heating system, based on the local weather forecasts. It reduces the time when building becomes overheated, during some periods when there are high external temperature amplitudes during the day. This solution increases the efficiency of the system`s regulation allowing for energy savings. The calculated total efficiency of the system would increase from the current 0.85, to 0.93, according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building. Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 28 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	606,360	521,596	84,764
Primary energy [kWh/a]	581,151	504,864	76,287
CO_2 emission [Mg/a]	201.48	173.32	28.16

Table 29 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,330	2,326	1

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however is around 1-3 years.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 21,452 kWh/a, which gives 28.12% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 11,474 kWh/a, which gives 15.02% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,708 kWh/a, which gives 3.62% reduction in the building.

2.2. Water and sewage system

No changes to the sewage system are considered.

2.3. HVAC

The whole building is now ventilated naturally, except the kitchen, which is equipped with the mechanical exhaust ventilation, and one of the sport halls (fencing sport hall).

Installing the mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows a reduction in final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 30 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	606,360	506,399	99,961
Primary energy [kWh/a]	581,151	542,683	38,468
CO_2 emission [Mg/a]	201.48	168.27	33.21

Table 31 Financial savings and investment cost of mechanical ventilation with heat recovery

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,022	262,060	87

In practical terms installing the mechanical ventilation system in the existing building might be problematic and is not considered in a typical thermal modernisation scheme. This measure is proposed as a part of maximum efficiency Variant 2, which aims at fulfilling requirement for newly designed buildings.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.3.1.1. Classrooms

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 3,778 kWh/a, which gives 9.82% reduction in the building.

2.3.1.2. Sport halls

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 5,928 kWh/a, which gives 15.42% reduction in the building.

2.3.1.3. Canteen

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,966 kWh/a, which gives 12.92% reduction in the building.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in this kind of buildings is not a commonly used installation, only in selected circumstances.

2.5. Electric system

In the existing state of the building, it has been estimated that the lighting consumes around 111,448 kWh of energy. The vast majority of electrical energy is consumed by lighting, but also there are some devices using electricity, like computers or projectors, also mechanical ventilation in fencing sport hall. On the other hand, it is hard to estimate the actual consumption of each device, though electrical energy consumption reduction calculations are the estimations, as it is not well known how exactly electrical energy is being consumed in the building.

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones and installing automatic control which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is possibility of decreasing of the electrical power which will reduce electricity costs. This however will not decrease the energy consumption.

2.6. Building envelope

2.6.1. External walls insulation

Thermal modernisation of the building includes insulation of the external walls, foundation walls and the roof, as well as windows modernisation. It is usually most profitable when all of the thermal modernisation measures are performed together, as a large share of costs is associated with preparation of construction field, ex. construction of scaffoldings etc.

External walls insulation decreases the heat transfer coefficient, which influences heat loss through the walls. The building envelope has not been modernised since the original state and the heat transfer coefficient is estimated at average 0.38 W/m²•K, which is quite low. Thermal modernisation of the building assumes insulation of the external walls with 8 cm for first stage and 6 cm for second and third stage of the school of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. This is enough to reach heat transfer coefficient required by Polish law. Consideration of a thicker layer of insulation is recommended in case it will not cause too large shadings around the windows.

The heat resistance of the insulation material is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

Where d – thickness [m], λ - thermal conductivity [W/m•K]

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the external walls' parameters are presented in the table below.

Table 32 Heat parameters of the external walls

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.42	0.04	0.08	2.00	0.23
0.35	0.04	0.06	1.48	0.23

The heat transfer coefficient of the external walls after the proposed modernisation equals 0.23 W/m²•K.

Values of the energy savings, CO_2 reduction as well as the savings are presented in the tables below.

Table 33 Energy savings and CO_2 reduction after external walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	606,360	554,386	51,974
Primary energy [kWh/a]	581,151	534,374	46,777
CO_2 emission [Mg/a]	201.48	184.21	17.27

Table 34 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,571	102,254	65

The investment cost of the external walls' insulation is relatively high, the financial savings though are acceptable, which results in payback time of 65 years. Thus, this measure is treated as one of the basic options considered in a typical thermal modernisation scheme.

External walls insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.1. Classrooms

External walls insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 17,504 kWh/a, which gives 37.42% reduction in the building.

2.6.1.2. Sport halls

External walls insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 3,840 kWh/a, which gives 8.22% reduction in the building.

2.6.1.3. Canteen

External walls insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,155 kWh/a, which gives 2.52% reduction in the building.

2.6.2. Foundation walls insulation

Foundation walls insulation, the same way as external walls insulation, improves the heat parameters and decreases heat loss to the ground. The modernisation assumes insulation of the foundation walls with 4 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. The heat transfer coefficient of the foundation walls depends on the depth under the ground level. This influence is included in the equivalent heat transfer coefficient. Information on the external walls' parameters are presented in the table below.

Table 35 Heat parameters of the foundation walls

Current heat transfer coefficient [W/m^2•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m^2•K/W]	Heat transfer coefficient [W/m^2•K]
0.3	0.04	0.04	1	0.23

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 36 Energy savings and CO_2 reduction after foundation walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	606,360	602,309	4,051
Primary energy [kWh/a]	581,151	577,505	3,646
CO_2 emission [Mg/a]	201.48	200.14	1.34

Table 37 Financial savings and investment cost of foundation walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
122	20,722	169

Foundation walls are a small part of all the building walls, which causes low percentage of financial savings from this measure. The payback time at the level of 169 years is extremely high, however, when all the measures are considered together, implementing foundation walls insulation does not have much impact on the payback time of the whole modernisation in both variants. This results of the investment cost, which percentage in the total cost of the modernisation is not high.

Insulation of foundation walls would result in a reduction of primary energy consumption in classrooms, one sport hall and some other zones, like corridors, storage rooms etc.

Primary energy in the amount of 230 kWh/a would be saved in classrooms, while 679 kWh/a would be saved in the Sport hall and 0 kWh/a would be saved in the canteen and its facilities.

2.6.3 Roof insulation

Roof insulation allows the improvement of heat parameters, which decreases heat loss. In the proposed modernisation variant, the insulation with 4 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K is considered.

The overall heat resistance after addition of new insulation is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

The overall heat transfer coefficient is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the roof materials and parameters are presented in the table below.

Table 38 Heat parameters of the roof

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.23	0.04	0.04	1	0.18

The heat transfer coefficient of the roof after the proposed modernisation equals 0.18 W/m²•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 39 Energy savings and CO_2 reduction after roof insulation

	Existing	After	Savings/reduction

		implementation	
Final energy [kWh/a]	606,360	485,248	156,159
Primary energy [kWh/a]	581,151	450,532	140,543
CO_2 emission [Mg/a]	201.48	161.24	40.24

Table 40 Financial savings and investment cost of roof insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
450	109,539	243

Annual financial savings from the roof insulation are about 450 EUR. The payback time is 243 years. The measure should slightly improve the thermal comfort in the building and is considered as one of the basic options proposed as a part of typical thermal modernisation. However, roof was already in a great condition but if external walls are to be insulated it is recommended to upgrade the roof as well.

Roof insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

Primary energy in the amount of 4,291 kWh/a would be saved in classrooms, while 2,587 kWh/a would be saved in the Sport hall and 0 kWh/a would be saved in the canteen and its facilities.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, Photovoltaic installation of power up to 40 kWp is defined as a small installation and can be connected to the grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 25% of the roof – 660 m^2. In Warsaw the productivity of PV is about 950 kWh/kWp so this installation would provide 38,000 kWh a year.

2.8. Lighting system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 41 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	111,448	44,579	66,869
Primary energy [kWh/a]	334,344	133,738	200,606
CO_2 emission [Mg/a]	80.02	32.01	48.01

Table 42 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4,976	97,193	20

Financial savings from lighting modernisation are about 5 000 EUR and payback time is 20 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 65,799 kWh/a, which gives 32.82% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 9,228 kWh/a, which gives 4.62% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 8,726 kWh/a, which gives 4.42% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing automatic control which is based on the amount of light from the outside and presence of people in a room. In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 43 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	111,448	78,863	32,585
Primary energy [kWh/a]	334,344	236,590	97,754
CO_2 emission [Mg/a]	80.02	56.62	23.40

Table 44 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,425	80,994	33

Investment cost of the modernisation is about 80,000 EUR. Payback time of the measure is rather reasonable with the level of 33 years. As this option decreases electricity consumption, primary energy savings are relatively high, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 32,063 kWh/a, which gives 32.82% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 4,497 kWh/a, which gives 4.62% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,243 kWh/a, which gives 4.32% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the first variant is limited by foundation program specifications and the second variant is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the second variant the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control. Users should be trained how to use the system, so that it would work effectively and properly.

In the first variant it is the heating which is, as the only system, controlled automatically. This means that users can turn off the lighting only manually. The last person leaving specific room ought to always remember to turn off the lights. Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 5 parameters: size of the school, amount of energy it consumes/ loses by specific element, number of heaters and annual usage cost and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service.

Table 45 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	External walls insulation	1 m^2	42	-
2.	Foundation walls	1 m^2	105	-
3.	Roof insulation	1 m^2	35	-
4.	Heating source modernisation	1 heater	134	11628
5.	Lighting modernisation	1 W	1.74	-
6.	Heating control automation	Annual usage	233	2326
7.	Mechanical ventilation with heat recovery	1 m^2	47	-
8.	Lighting control automation	1 W	0.58	-
9.	Photovoltaic system	1 kWp	1628	-

2.12.2. Accuracy

During the process of measures evaluation a few simplifications have been done. Firstly, the analytical model was adjusted so that it consumes similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the actual savings can be a bit lower, while energy consumption would be lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, in reality they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), heat – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Insulation of external walls and roof - experience from the Polish market shows that huge share of total costs is labour and materials, however scaffolding and equipment may represent up to 30% of total costs. Accuracy level is around 80%.

Windows modernisation – In this case the main cost are new windows. Accuracy level can be estimated at 90%.

Heating source modernisation and control automation – Prices found on a website of a company providing such solutions. Accuracy level is around 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs per about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy is around 90%.

Mechanical ventilation – based on author's experience and expert opinions, however estimation is not easy due to the variety of situations when vent ducts cannot be installed. Accuracy level is around 80%.

Photovoltaic system – this price is standard on the Polish market, so the accuracy is around 95%.

2.12.3. Methods and standards used

Most of methods were based on author's experience, knowledge and internet offers from companies providing specific solutions.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the *Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building* separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 46 Standards used during energy audit

	Applied version	English version
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements

2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings - Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczeń."	EN ISO 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods
6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków – Wymiana ciepła przez grunt - Metody obliczania."	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach – Liniowy współczynnik przenikania ciepła – Metody uproszczone i wartości orientacyjne."	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia."	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane – Właściwości cieplno-wilgotnościowe – Tabelaryczne wartości obliczeniowe i procedury określania deklarowanych i obliczeniowych wartości cieplnych"	ISO 10456:2007 Building materials and products -- Hydrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania"	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system"	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 "Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance"	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 47 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia termo modernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit

3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metody obliczania oszczędności energii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency audit card and methods for calculating energy savings
5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) – raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) – raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme - 1st variant

3.1. Aim of the renovation plan

The aim of the first renovation plan is to modernise the building so that it meets Polish building standards and consumes less energy. As the result the costs of maintenance of the school will be lower. Such modernisation plan was chosen due to the possibility of getting funds from the BGK thermal-modernisation and renovation program, which is a national programme supporting thermal modernisation of buildings in Poland.

The first variant includes the following measures:

- External walls insulation
- Foundation walls insulation
- Roof insulation
- Heating source modernisation
- Lighting modernisation

The extent of each measure assumes meeting the minimum requirements, even if the costs are high or the payback time is long. There are no other boundaries to renovate this building in a way proposed above.

3.2. Criteria for ranking energy efficiency improvement measures

The main criterion was to meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 $W/m^2 \bullet K$
- heat transfer coefficient of roofs: U = 0.18 $W/m^2 \bullet K$

Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not.

Last criterion is the improvement of thermal comfort in the building. This however cannot be measured, but it is important to remember that sometimes it is more important to improve comfort than to save money.

3.3. Potential interactions with other proposed recommendation

The only affected parameter is the heating source. Each modernisation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. The impact of interactions between measures have been considered in the Variants (see row “Total” in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions. Lighting has no effect on any of other renovations.

3.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls – the most efficient way is to use 6 cm or 8 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23W/ $m^2 \bullet K$

Roof insulation – the best option is to use 4 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K

Heating source improvements – Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs to LED ones.

When it comes to lighting and heating source both money and final energy savings were considered. LEDs are one of the eco-friendliest lighting choices whilst also their high efficiency leads to economical savings. When it comes to the heating source, installing heating source automation decreases the usage of heating when it is not necessary (weekends and nights), so it improves the system`s efficiency.

The measures considered in the 1st variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 48 Measures included in the 1st variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Lighting modernisation	66,869	200,606	48.01	4,976	97,193	20
2.	Heating source modernisation	45,026	40,523	14.96	1,361	51,395	38
3.	External walls insulation	51,974	46,777	17.27	1,571	102,254	65
4.	Foundation walls	4,051	3,646	1.35	122	20,722	169
5.	Roof insulation	14,880	13,392	4.94	450	109,539	243
	Total	163,926	287,958	80.26	7,911	381,105	48

The most beneficial option, with 20 years payback time, is lighting modernisation due to the fact that other elements are in good condition. The roof modernisation has the longest payback time, as it is already in great condition.

3.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m^{2}a]	162.5	111.4
Primary energy consumption - heating [kWh/m^{2}a]	74.0	58.5
Primary energy consumption - DHW [kWh/m^{2}a]	29.1	29.1
Primary energy consumption - cooling [kWh/m^{2}a]	n/a	n/a
Primary energy consumption - lighting [kWh/m^{2}a]	59.3	23.7
Final energy consumption - total [kWh/m^{2}a]	127.4	98.3
Final energy consumption - heating [kWh/m^{2}a]	76.2	58.9
Final energy consumption - DHW [kWh/m^{2}a]	31.5	31.5

Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	19.8	7.9
CO_2 emissions - total [kg/m²a]	47.59	34.02
CO_2 emissions - heating [kg/m²a]	20.01	14.65
CO_2 emissions - DHW [kg/m²a]	13.96	13.96
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	13.53	5.41

The 1st renovation variant allows reducing final energy consumption by around 164 MWh/a and primary energy consumption by around 288 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 381000 EUR and the estimated payback time is at the level of 48 years. The EP factor of the building after implementing the proposed measures would achieve about 111.4 kWh/m²/a, which makes the building much more efficient.

4. Renovation scheme - 2nd variant

4.1. Aim of the renovation plan

The aim of the second renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The second variant includes all measures of the 1st variant with the following additional renovations:

- Heating control automation
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

4.2. Criteria for ranking energy efficiency improvement measures

The aim of the second variant is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows for large final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

4.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (roof and walls insulation, heating control automation, etc.) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. Also, changes in usage time of the heating system influences other measures decreasing the heat consumption – turning the heating off during nights and weekends decreases energy savings from walls and roof insulation or mechanical ventilation with heat recovery, as the time they work and generate savings is also shorter.

Lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions.

4.4. Suggested measures (optimal implementation plan)

Based on previous paragraphs the implementation plan includes the following measures:

Insulation of external walls – the most efficient way is to use 6 or 8 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23W/m^2•K.

Roof insulation – the best option is to use 4 cm of polystyrene with thermal conductivity parameter of λ=0,04. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K.

Heating source improvements - Replacing old convectors with new plate heaters or thermostats assembly with convectors. Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used

Lighting – Exchange of fluorescent bulbs for LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the weather forecast control system (e.g. Egain/Promar etc.), which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the 2nd variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 49 Measures included in the 2nd variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating control automation	84,764	76,287	28.17	2,330	2326	1

2.	Lighting modernisation	66,869	200,606	48.01	4,976	97,193	20
3.	Photovoltaic system	-	114,000	-	2,828	65,116	23
4.	Lighting control automation	32,585	97,754	23.40	2,425	80,994	33
5.	Heating source modernisation	45,026	40,523	14.96	1,361	51,395	38
6.	External walls insulation	51,974	46,777	17.27	1,571	102,254	65
7.	Mechanical ventilation with heat recovery	99,961	38,468	33.22	3,022	262,060	87
8.	Foundation walls	4,051	3,646	1.35	122	20,722	169
9.	Roof insulation	14,880	13,392	4.94	450	109,539	243
	Total	311,603	396,742	134.36	15,546	791,602	51

The shortest payback time (typically 1-3 years) is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view. The roof modernisation has the longest payback time because it is already in great condition.

4.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	162.5	28.5
Primary energy consumption - heating [kWh/m²a]	74.0	46.1
Primary energy consumption - DHW [kWh/m²a]	29.1	29.1
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	59.3	16.8
Final energy consumption - total [kWh/m²a]	127.4	72.1
Final energy consumption - heating [kWh/m²a]	76.2	35
Final energy consumption - DHW [kWh/m²a]	31.5	31.5
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	19.8	5.6
CO_2 emissions - total [kg/m²a]	47.59	24.87
CO_2 emissions - heating [kg/m²a]	20.01	7.10
CO_2 emissions - DHW [kg/m²a]	13.96	13.96
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	13.53	3.83

The 2nd renovation variant allows reducing final energy consumption by around 312 MWh/a and primary energy consumption by around 397 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 792,000 EUR and the estimated payback time is at the level of 51 years. The EP factor of the building after implementing the proposed measures would achieve about 28.5 kWh/m^2/a, which makes the building much more efficient. The total costs of the maximum efficiency variant are significantly higher than the 1st variant, also in reference to the energy savings. Thus, the 1st variant is more realistic and is proposed as the basic one.

5. Attachments

No attachments.

III. Building #3 SP 378 (ul. Bartnicza 8, 00-814 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building was built between 1974 and 1976. The building envelope is well preserved. It has been slightly renewed since the original state, but it has not been thermally insulated. Windows were exchanged in 2006 with PCV framed double-glazed ones. In 2006 there was a modernization of the sport hall, and new mechanical ventilation with heat recovery and a water heating coil was installed. The mechanical ventilation is also installed in a canteen and in the kitchen. Its installation is dated for 1975 when the building was built. The rest of the building is ventilated naturally. The building is heated by heat exchanger connected to the district heating. The pipes with heating factor are insulated, but insulation is not tight. The heat is distributed by old pipe heaters on the corridors and old iron ribbed heaters in other rooms. Most of the convectors does not have thermostats. There are also some leakages in installation, so the water must be refilled periodically. The sports hall is also heated with ventilation air from air handling unit. The whole building is equipped with traditional T8 fluorescent bulbs manually controlled by users. The building does not have any BMS system.

The general overview of the building allowed for giving a neutral opinion about energy efficiency of the building. The measured final energy indicator for heating in the past year equals 131.54 kWh/m^{2}a, which is typical for this type of building.

1.2. Summary table: existing state of the builiding

Category	Value
Building type[7]	Educational building
Constriction year / major reconstruction year	1974-1976 / 2006
Building fabric[8]	Reinforced concrete slabs; reinforced concrete beam and ceramic block (roof)
Building useful area [m^2]	7,057
Useful area of the audited zone [m^2]	Classrooms: 1,683.8 m^2 Sport hall: 827 m^2 Canteen: 265.9 m^2 (with facilities)

[7]Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

[8]E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

Shape factor - building [1/m]	0.27
Building volume [m^3]	26,137
Volume of the audited zone [m^3]	Classrooms: 5,893 m^2 Sport hall: 6,203 m^2 Canteen: 1,490 m^2 (with facilities)
Shape factor - audited zone [1/m]	Classrooms: 0.29 Sport hall: 0.14 Canteen: 0.29 (with facilities)
Number of floors	4
Number of building users	800
Heating system	District heating, heat convectors without thermostats
Domestic hot water (DHW) system	District heating, the same source as the central heating
Cooling system	There is no cooling system in the building
Lightning system	2x40W fluorescent bulbs switched on manually when needed
Primary energy consumption - total [kWh/m^{2}a]	162.1
Primary energy consumption - heating [kWh/m^{2}a]	103.2
Primary energy consumption - DHW [kWh/m^{2}a]	16.5
Primary energy consumption - cooling [kWh/m^{2}a]	n/a
Primary energy consumption - lightning [kWh/m^{2}a]	42.4
Final energy consumption - total [kWh/m^{2}a]	140.7
Final energy consumption - heating [kWh/m^{2}a]	109.1
Final energy consumption - DHW [kWh/m^{2}a]	17.5
Final energy consumption - cooling [kWh/m^{2}a]	n/a
Final energy consumption - lightning [kWh/m^{2}a]	14.1
CO_2 emissions - total [kg/m^{2}a]	44.10
CO_2 emissions - heating [kg/m^{2}a]	29.85
CO_2 emissions - DHW [kg/m^{2}a]	5.68
CO_2 emissions - cooling [kg/m^{2}a]	n/a
CO_2 emissions - lightning [kg/m^{2}a]	8.57

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to total energy savings after applying measures together in Variant 1 and Variant 2.

The recommended Variant 1 is a typical thermal modernisation scheme applied in Poland, that is usually introduced when the owner of the building is applying for financial subsidies for thermal modernisation. Application of all measures allows to meet current technical requirements for buildings, namely maximum U-values for external walls, roof, and windows.

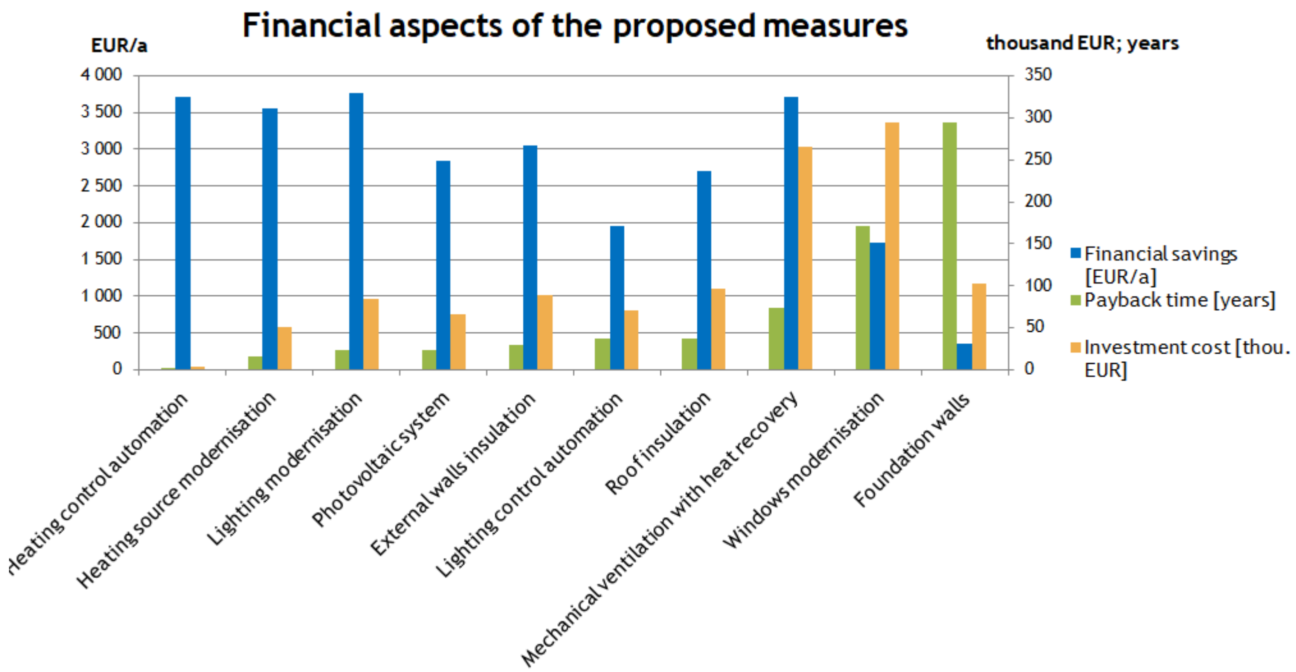
The maximum efficiency Variant 2 is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values lower than 0 kWh/m^{2}a. This value however is only achieved because of energy consumption calculation in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

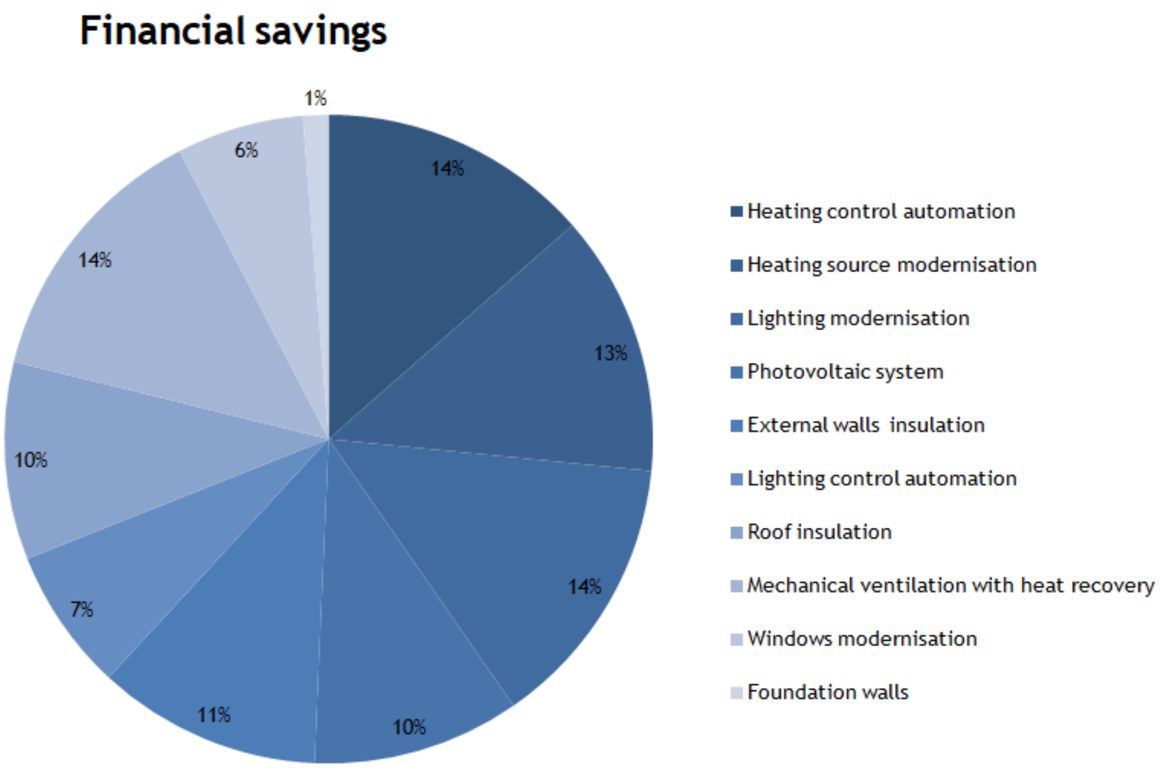
The table presented in section 1.4 contains all analysed measures. Measures 1-6 are considered as a basic modernisation (Variant 1). In order to achieve the nZEB standard, measures 7-10 are added.

For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

1.4. Summary table: suggested measures, energy savings, financial savings

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	100,845	90,760	31.90	3,049	87,652	29
2.	Foundation walls	11,529	10,375	3.65	349,	102,438	294
3.	Windows modernisation	57,186	51,467	18.09	1,729	293,933	170
4.	Roof insulation	88,943	80,048	28.13	2,689	96,056	36
5.	Heating source modernisation	117,549	105,793	37.13	3,554	50,419	15
6.	Lighting modernisation	50,565	151,693	36.31	3,763	82,994	22
7.	Heating control automation	130,057	117,050	41.13	3,699	2,326	1
8.	Mechanical ventilation with heat recovery	122,377	64,915	22.81	3,700	264,698	72
9.	Lighting control automation	26,143	78,429	18.77	1,946	69,995	36
10.	Photovoltaic system	-	114,000	-	2828	65,116	23





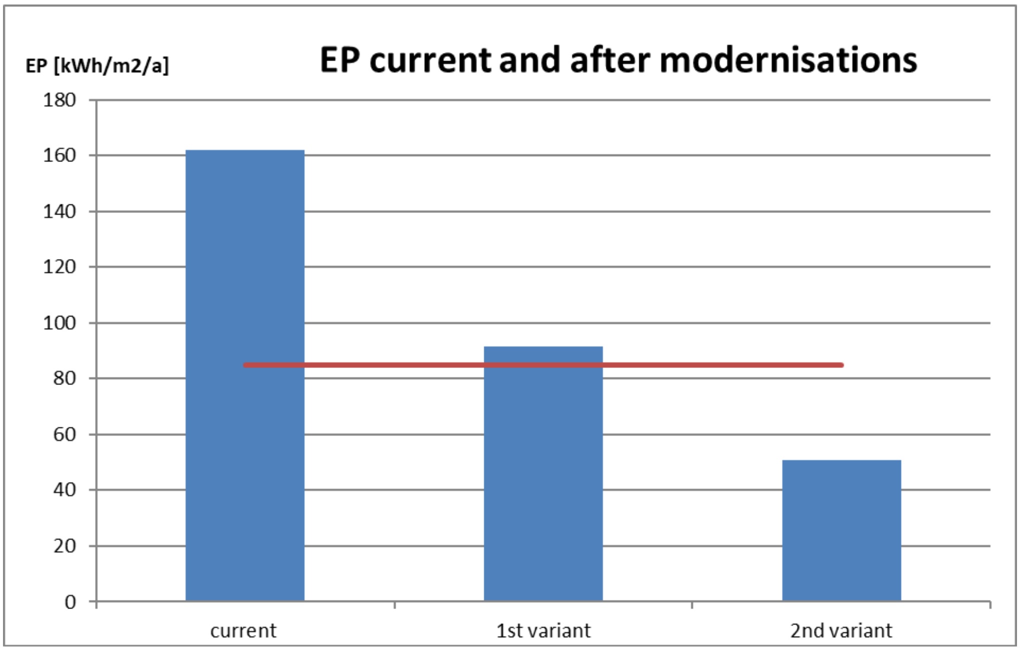
The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. Considering this, the best measure is the heating source modernisation, which is one of the basic options proposed as a part of a thermal modernisation plan. The extremely long payback time of the windows modernisation results from the fact that windows are already quite new. High investment cost of installing the mechanical ventilation system in combination with technical difficulties makes it an additional option considered only as a part of the maximum efficiency variant.

In the table below, the shares of primary energy savings due to analysed measures in each space have been presented.

Table 50 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen with facilities	Rest of the building
1.	External walls insulation	35.44%	32.01%	4.64%	27.91%
2.	Foundation walls	18.82%	-	-	81.18%
3.	Windows modernisation	42.50%	20.43%	5.16%	31.90%
4.	Roof insulation	35.66%	20.91%	-	43.43%
5.	Heating source modernisation	30.18%	23.75%	1.82%	44.25%
6.	Lighting modernisation	30.77%	6.18%	7.78%	55.27%
7.	Heating control automation	31.19%	21.39%	3.49%	43.94%
8.	Mechanical ventilation with heat recovery	15.23%	22.14%	12.96%	49.67%
9.	Lighting control automation	30.77%	6.18%	7.78%	55.27%

Total primary energy consumption before and after implementations of measures according to 1st and 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

The main problem with the heating system is the lack of thermostats on the plate heaters. This causes frequent overheating of the building, which results in heat waste due to ventilation by windows opening and decreases thermal comfort of the building`s users as well.

The proposed renovation of the heating system includes an exchange of the old convectors and iron ribbed heaters with new plate heaters with thermostats.

The modernisation includes changes in time usage of a district heating heat exchanger. Currently it is assumed that heating source produces heat 24 hours a day, 7 days a week, leading to inefficiency of the heating system. Even though some telemetry system is installed, it is not known whether it has any control solutions, or it is only used for remote diagnosis and consumption control. When no lessons are held nor the sport hall is unoccupied, the space heating is unnecessary. Currently only an external temperature automatic controls installed in the system. Installation of traditional heating control allowing for night and weekend temperature reduction could allow for significant energy savings with low investment cost. Also, in case there is already a controller installed, it is recommended to perform heating system rinsing and regulation. The calculated total efficiency of the system would increase from the current 0.85, to 1.05[9], according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 51 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	754,513	636,964	117,549
Primary energy [kWh/a]	713,405	607,612	105,793
CO_2 emission [Mg/a]	250.71	213.53	26.23

Table 52 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,554	50,419	15

Estimated payback time is around 15 years. The investment cost is around 50,000 EUR. Adding thermostats to radiators improves the system significantly and the cost is rather low for such an upgrade.

The heating source modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

[9] Efficiency >1.0 is caused by applying temperature reduction in nights and weekends.

2.1.1.1. Classrooms

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 31,928 kWh/a, which gives 30.22% reduction in the building.

2.1.1.2. Sport halls

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 25,126 kWh/a, which gives 23.82% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,925 kWh/a, which gives 1.82% reduction in the building.

2.1.2. Heating control automation

The weather forecast control (for example Egain or Promar) system is used to control the heating system provided by the local weather forecasts, reducing the time when building becomes overheated during some periods when there are high external temperature amplitudes during the day. This solution increases the efficiency of the system`s regulation allowing for energy savings. The calculated total efficiency of the system would increase from the current 0.85, to 0.93, according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building. Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 53 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	754,513	624,456	130,057
Primary energy [kWh/a]	713,405	596,355	117,050
CO_2 emission [Mg/a]	250.71	209.57	41.13

Table 54 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,699	2,326	1

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however is around 1-3 years.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 36,508 kWh/a, which gives 31.22% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 25,037 kWh/a, which gives 21.42% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,085 kWh/a, which gives 3.52% reduction in the building.

2.2. Water and sewage system

No changes to the sewage system are considered.

2.3. HVAC

The whole building is now ventilated naturally, except the kitchen and the sport hall which are equipped with the mechanical exhaust ventilation.

Installing the mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows a reduction in final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 55 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	754,513	632,136	122,377
Primary energy [kWh/a]	713,405	645,490	67,915
CO_2 emission [Mg/a]	250.71	226.84	23.87

Table 56 Financial savings and investment cost of mechanical ventilation with heat recovery

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,700	264,698	72

In practical terms installing the mechanical ventilation system in the existing building might be problematic and is not considered in a typical thermal modernisation scheme. This measure is proposed as a part of maximum efficiency Variant 2, which aims at fulfilling requirement for newly designed buildings.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.3.1.1. Classrooms

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 9,887 kWh/a, which gives 15.22% reduction in the building.

2.3.1.2. Sport halls

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 14,372 kWh/a, which gives 22.12% reduction in the building.

2.3.1.3. Canteen

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 8,413 kWh/a, which gives 13.02% reduction in the building.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in this kind of buildings is not a commonly used installation, only in selected circumstances.

2.5. Electric system

In the existing state of the building, it has been estimated that the lighting consumes around 84,274 kWh of energy. According to the invoices provided by the school staff, total annual consumption of electricity is 128,567 kWh. This difference is caused by the fact that aside from the lighting there are many devices using electricity, like computers or projectors and especially mechanical ventilation in the sport hall.

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones and installing automatic control which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is possibility of decreasing of the electrical power which will reduce electricity costs. This however will not decrease the energy consumption.

2.6. Building envelope

2.6.1. External walls insulation

Thermal modernisation of the building includes insulation of the external walls, foundation walls and the roof, as well as windows modernisation. It is usually most profitable when all of the thermal modernisation measures are performed together, as a large share of costs is associated with preparation of construction field, ex. construction of scaffoldings etc.

External walls insulation decreases the heat transfer coefficient, which influences heat loss through the walls. The building envelope has not been modernised since the original state and the heat transfer coefficient is estimated at 0.65 $W/m^2 \bullet K$, which is average. Thermal modernisation of the building assumes insulation of the external walls with 10 cm of polystyrene with thermal conductivity parameter of $\lambda=0.04$ $W/m \bullet K$.

The heat resistance of the insulation material is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

Where d – thickness [m], λ - thermal conductivity [W/m•K]

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the external walls' parameters are presented in the table below.

Table 57 Heat parameters of the external walls

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.65	0.04	0.10	2.86	0.23

The heat transfer coefficient of the external walls after the proposed modernisation equals 0.23 W/m²•K.

Values of the energy savings, CO_2 reduction as well as the savings are presented in the tables below.

Table 58 Energy savings and CO_2 reduction after external walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	754,513	653,668	100,845
Primary energy [kWh/a]	713,405	622,645	90,760
CO_2 emission [Mg/a]	250.71	226.84	41.74

Table 59 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,049	87,652	29

The investment cost of the external walls' insulation is relatively high, the financial savings though are also satisfactory, which results in payback time of 29 years. Thus, this measure is treated as one of the basic options considered in a typical thermal modernisation scheme.

External walls insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.1. Classrooms

External walls insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 32,165 kWh/a, which gives 35.42% reduction in the building.

2.6.1.2. Sport halls

External walls insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 29,052 kWh/a, which gives 32.02% reduction in the building.

2.6.1.3. Canteen

External walls insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,211 kWh/a, which gives 4.62% reduction in the building.

2.6.2. Foundation walls insulation

Foundation walls insulation, the same way as external walls insulation, improves the heat parameters and decreases heat loss to the ground. The modernisation assumes insulation of the foundation walls with 6 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. The heat transfer coefficient of the foundation walls depends on the depth under the ground level. This influence is included in the equivalent heat transfer coefficient. Information on the external walls' parameters are presented in the table below.

Table 60 Heat parameters of the foundation walls

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.33	0.04	0.06	1.36	0.23

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 61 Energy savings and CO_2 reduction after foundation walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	754,513	742,984	11,529
Primary energy [kWh/a]	713,405	703,030	10,375
CO_2 emission [Mg/a]	250.71	247.06	3.65

Table 62 Financial savings and investment cost of foundation walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]

349	102,438	294

Foundation walls are a small part of all the building walls, which causes low percentage of financial savings from this measure. The payback time at the level of 294 years is extremely high, however when all the measures are considered together, implementing foundation walls insulation does not have much impact on the payback time of the whole modernisation in both variants. This results of the investment cost, which percentage in the total cost of the modernisation is not high.

Foundation walls would result in a reduction of primary energy consumption in classrooms and other zones like corridors etc.

Primary energy in the amount of 1,953 kWh/a would be saved in classrooms, and 8,422 kWh/a would be saved in other zones.

2.6.3 Windows modernisation

Windows modernisation includes an exchange of the windows with new ones of U=1.1 W/m^2•K. In the existing state the windows are in good condition and their heat transfer coefficient equals 1.5 W/m^2•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 63 Energy savings and CO_2 reduction after windows modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	754,513	697,327	57,186
Primary energy [kWh/a]	713,405	661,938	51,467
CO_2 emission [Mg/a]	250.71	232.62	18.09

Table 64 Financial savings and investment cost of windows modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,729	293,933	170

The long payback time of the windows modernisation results from the fact that windows are already quite new.

Windows modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.2.1. Classrooms

Windows modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 21,873 kWh/a, which gives 42.52% reduction in the building.

2.6.2.2. Sport halls

Windows modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 10,515 kWh/a, which gives 20.42% reduction in the building.

2.6.2.3. Canteen

Windows modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,656 kWh/a, which gives 5.22% reduction in the building.

2.6.4 Roof insulation

Roof insulation allows the improvement of heat parameters, which decreases heat loss. In the proposed modernisation variant, the insulation with 12 cm for the main roof or 10 cm for the rest of the roof of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K is considered.

The overall heat resistance is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

The overall heat transfer coefficient is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the roof materials and parameters are presented in the table below.

Table 65 Heat parameters of the roof

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.35	0.04	0.10	2.86	0.18
0.50	0.04	0.12	3.43	0.18

The heat transfer coefficient of the roof after the proposed modernisation equals 0.18 W/m²•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 66 Energy savings and CO_2 reduction after roof insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	754,513	665,570	88,943
Primary energy [kWh/a]	713,405	633,357	80,048
CO_2 emission [Mg/a]	250.71	222.58	28.13

Table 67 Financial savings and investment cost of roof insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,689	96,056	36

Annual financial savings from the roof insulation are about 2,700 EUR. The payback time is 36 years. The measure will also improve the thermal comfort in the building and is considered as one of the basic options proposed as a part of typical thermal modernisation.

Roof insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

Primary energy in the amount of 28,545 kWh/a would be saved in classrooms, while 16,738 kWh/a would be saved in the Sport hall and 0 kWh/a would be saved in the canteen and its facilities.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, Photovoltaic installation of power up to 40 kWp is defined as a small installation and can be connected to the grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 22% of the roof – 660 m^2. In Warsaw the productivity of PV is about 950 kWh/kWp so this installation would provide 38,000 kWh a year.

2.8. Lighting system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 68 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	84,274	33,709	50,565
Primary energy [kWh/a]	252,821	101,128	151,693
CO_2 emission [Mg/a]	60.51	24.20	36.31

Table 69 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,763	82,994	22

Financial savings from lighting modernisation are about 3,700 EUR and payback time is 22 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 46,676 kWh/a, which gives 30.82% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 9,375 kWh/a, which gives 6.22% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 11,802 kWh/a, which gives 7.82% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing automatic control which is based on the amount of light from the outside and presence of people in a room. In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 70 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	84,274	58,131	26,143
Primary energy [kWh/a]	252,821	174,392	78,429
CO_2 emission [Mg/a]	60.51	41.74	18.77

Table 71 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,946	69,995	36

Investment cost of the modernisation is about 70,000 EUR. Payback time of the measure is rather reasonable with the level of 36 years. As this option decreases electricity consumption, primary energy savings are relatively high, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 24,133 kWh/a, which gives 30.82% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 4,847 kWh/a, which gives 6.22% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 6,102 kWh/a, which gives 7.82% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the first variant is limited by foundation program specifications and the second variant is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the second variant the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control. Users should be trained how to use the system, so that it would work effectively and properly.

In the first variant it is the heating which is, as the only system, controlled automatically. This means that users can turn off the lighting only manually. The last person leaving specific room ought to always remember to turn off the lights. Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 5 parameters: size of the school, amount of energy it consumes/ loses by specific element, number of heaters and annual usage cost and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service.

Table 72 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	External walls insulation	1 m^2	42	-
2.	Foundation walls insulation	1 m^2	105	-
3.	Windows modernisation	1 m^2	233	-
4.	Roof insulation	1 m^2	35	-
5.	Heating source modernisation	1 heater	134	11628
6.	Lighting modernisation	1 W	1.74	-
7.	Heating control automation	Annual usage	233	2326
8.	Mechanical ventilation with heat recovery	1 m^2	47	-
9.	Lighting control automation	1 W	0.58	-
10.	Photovoltaic system	1 kWp	1628	-

2.12.2. Accuracy

During the process of measures evaluation a few simplifications have been done. Firstly, the analytical model was adjusted so that it consumes similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the actual savings can be a bit lower, while energy consumption would be lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, in reality they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), heat – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Insulation of external walls and roof - experience from the Polish market shows that huge share of total costs is labour and materials, however scaffolding and equipment may represent up to 30% of total costs. Accuracy level is around 80%.

Windows modernisation – In this case the main cost are new windows. Accuracy level can be estimated at 90%.

Heating source modernisation and control automation – Prices found on a website of a company providing such solutions. Accuracy level is around 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs per about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy is around 90%.

Mechanical ventilation – based on author's experience and expert opinions, however estimation is not easy due to the variety of situations when vent ducts cannot be installed. Accuracy level is around 80%.

Photovoltaic system – this price is standard on the Polish market, so the accuracy is around 95%.

2.12.3. Methods and standards used

Most of methods were based on author's experience, knowledge and internet offers from companies providing specific solutions.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the *Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building* separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 73 Standards used during energy audit

	Applied version	English version
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements
2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings – Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczeń."	EN ISO 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods

6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków – Wymiana ciepła przez grunt – Metody obliczania.”	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach – Liniowy współczynnik przenikania ciepła – Metody uproszczone i wartości orientacyjne.”	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia.”	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane - Właściwości cieplno-wilgotnościowe – Tabelaryczne wartości obliczeniowe i procedury określania deklarowanych i obliczeniowych wartości cieplnych"	ISO 10456:2007 Building materials and products -- Hydrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania”	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system”	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 “Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance”	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 74 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia termo modernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit
3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metody obliczania oszczędności energii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency audit card and methods for calculating energy savings

5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) – raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) – raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme - 1st variant

3.1. Aim of the renovation plan

The aim of the first renovation plan is to modernize the building so that it meets Polish building standards and consumes less energy. As the result the costs of maintenance of the school will be lower. Such modernisation plan was chosen due to the possibility of getting funds from the BGK thermal-modernisation and renovation program, which is a national programme supporting thermal modernisation of buildings in Poland.

The first variant includes the following measures:

- External walls insulation
- Foundation walls insulation
- Windows modernisation
- Roof insulation
- Heating source modernisation
- Lighting modernisation

The extent of each measure assumes meeting the minimum requirements, even if the costs are high or the payback time is long. There are no other boundaries to renovate this building in a way proposed above.

3.2. Criteria for ranking energy efficiency improvement measures

The main criterion was to meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 $W/m^2 \cdot K$
- heat transfer coefficient of windows: U = 1.1 $W/m^2 \cdot K$
- heat transfer coefficient of roofs: U = 0.18 $W/m^2 \cdot K$

Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not.

Last criterion is the improvement of thermal comfort in the building. This however cannot be measured, but it is important to remember that sometimes it is more important to improve comfort than to save money.

3.3. Potential interactions with other proposed recommendation

The only affected parameter is the heating source. Each modernisation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. The impact of interactions between measures have been considered in the Variants (see row “Total” in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions. Lighting has no effect on any of other renovations.

3.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls – the most efficient way is to use 10 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23W/ $m^2 \cdot K$

Roof insulation – the best option is to use 10 cm or 12 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.18 W/m²•K

Replacement of windows – In this case there is no other option but to replace all old windows with new ones with heat transfer coefficient with 1.1 W/m²•K value

Heating source improvements – Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs to LED ones.

When it comes to lighting and heating source both money and final energy savings were considered. LEDs are one of the eco-friendliest lighting choices whilst also their high efficiency leads to economical savings. When it comes to the heating source, installing heating source automation decreases the usage of heating when it is not necessary (weekends and nights), so it improves the system`s efficiency.

The measures considered in the 1st variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 75 Measures included in the 1st variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating source modernisation	117,549	105,793	37.13	3,554	50,419	15
2.	Lighting modernisation	50,565	151,693	36.31	3,763	82,994	22
3.	External walls insulation	100,845	90,760	31.90	3,049	87,652	29
4.	Roof insulation	88,943	80,048	28.13	2,689	96,056	36
5.	Windows modernisation	57,186	51,467	18.09	1,729	293,933	170
6.	Foundation walls	11,529	10,375	3.65	349,	102,438	294
	Total	349,805	421,009	135.74	12,810	714,491	56

The most beneficial option, with 15 years payback time, is heating source modernisation due to its really low investment cost. Of course, after insulation of walls and the roof, its impact will be much lower because losses of heat will be reduced significantly. Besides the foundation walls insulation, the windows modernisation has the longest payback time because they are already in quite good condition.

3.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	162.1	91.5
Primary energy consumption - heating [kWh/m²a]	103.2	58.0
Primary energy consumption - DHW [kWh/m²a]	16.5	16.5
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a

Primary energy consumption - lighting [kWh/m²a]	42.4	17.0
Final energy consumption - total [kWh/m²a]	140.7	82.0
Final energy consumption - heating [kWh/m²a]	109.1	58.9
Final energy consumption - DHW [kWh/m²a]	17.5	17.5
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	14.1	5.7
CO_2 emissions - total [kg/m²a]	44.10	15,76
CO_2 emissions - heating [kg/m²a]	29.85	12.32
CO_2 emissions - DHW [kg/m²a]	5.68	5.68
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	8.57	3.43

The 1st renovation variant allows reducing final energy consumption by around 350 MWh/a and primary energy consumption by around 421 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 715,000 EUR and the estimated payback time is at the level of 56 years. The EP factor of the building after implementing the proposed measures would achieve about 91.5 kWh/m²/a, which makes the building much more efficient.

4. Renovation scheme - 2nd variant

4.1. Aim of the renovation plan

The aim of the second renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The second variant includes all measures of the 1st variant with the following additional renovations:

- Heating control automation
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

4.2. Criteria for ranking energy efficiency improvement measures

The aim of the second variant is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows for large final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

4.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation, heating control automation, etc.) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. Also, changes in usage time of the heating system influences other measures decreasing the heat consumption – turning the heating off during nights and weekends decreases energy savings from walls and roof insulation as well as windows modernisation or mechanical ventilation with heat recovery, as the time they work and generate savings is also shorter.

Lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions.

4.4. Suggested measures (optimal implementation plan)

Based on previous paragraphs the implementation plan includes the following measures:

Insulation of external walls – the most efficient way is to use 10 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23 $W/m^2 \bullet K$.

Roof insulation – the best option is to use 10 cm or 12 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.18 $W/m^2 \bullet K$

Replacement of windows – In this case there is no other option but to replace all old windows with new ones with heat transfer coefficient with 1.1 $W/m^2 \bullet K$ value.

Heating source improvements - Replacing old iron ribbed convectors with new plate heaters with thermostats. Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs for LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the weather forecast control system (e.g. Egain/Promar etc.), which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used to 0 m3/h.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the 2nd variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 76 Measures included in the 2nd variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating control automation	130,057	117,050	41.13	3,699	2,326	1
2.	Heating source modernisation	117,549	105,793	37.13	3,554	50,419	15
3.	Lighting modernisation	50,565	151,693	36.31	3,763	82,994	22
4.	Photovoltaic system	-	114,000	-	2828	65,116	23
5.	External walls insulation	100,845	90,760	31.90	3,049	87,652	29
6.	Lighting control automation	26,143	78,429	18.77	1,946	69,995	36
7.	Roof insulation	88,943	80,048	28.13	2,689	96,056	36
8.	Mechanical ventilation with heat recovery	122,377	64,915	22.81	3,700	264,698	72
9.	Windows modernisation	57,186	51,467	18.09	1,729	293,933	170
10.	Foundation walls	11,529	10,375	3.65	349	102,438	294
	Total	516,064	550,378	195.02	20,894	1,116,625	53

The shortest payback time (typically 1-3 years) is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view. Besides the foundation walls insulation, the windows modernisation has the longest payback time due to theirs good condition.

4.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	162.1	50.6
Primary energy consumption - heating [kWh/m²a]	103.2	41.6
Primary energy consumption - DHW [kWh/m²a]	16.5	16.5
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	42.4	11.7
Final energy consumption - total [kWh/m²a]	140.7	54.1

Final energy consumption - heating [kWh/m^{2}a]	109.1	32.7
Final energy consumption - DHW [kWh/m^{2}a]	17.5	17.5
Final energy consumption - cooling [kWh/m^{2}a]	n/a	n/a
Final energy consumption - lighting [kWh/m^{2}a]	14.1	3.9
CO_2 emissions - total [kg/m^{2}a]	44.10	16.47
CO_2 emissions - heating [kg/m^{2}a]	29.85	8.42
CO_2 emissions - DHW [kg/m^{2}a]	5.68	5.68
CO_2 emissions - cooling [kg/m^{2}a]	n/a	n/a
CO_2 emissions - lighting [kg/m^{2}a]	8.57	2.37

The 2nd renovation variant allows reducing final energy consumption by around 516 MWh/a and primary energy consumption by around 550 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 1,117,000 EUR and the estimated payback time is at the level of 53 years. The EP factor of the building after implementing the proposed measures would achieve about 50.6 kWh/m^2/a, which makes the building much more efficient. The total cost of the maximum efficiency variant is significantly higher than the 1st variant, also in reference to the energy savings. Thus, the 1st variant is more realistic and is proposed as the basic one.

5. Attachments

No attachments.

IV. Building #4 SP 341 (ul. Oławska 3, 01-494 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building was built between 1993 and 1998. It was designed in 4 stages. The building envelope is well preserved. Since the beginning, it has been well thermally insulated, with mineral wool on the roofs of 10-20 cm, and polystyrene on the external walls of 9-10 cm. The ground floor is insulated with 4 cm of hard polystyrene. There were no modernizations performed in the building yet. The building is ventilated naturally except the sport hall and the canteen kitchen which are equipped with mechanical ventilation. There are 13 cooling units installed in the building. The building is connected to the district heating network. Both the central heating and domestic hot water are supplied by the heat exchanger. The lighting system in the building is composed of traditional fluorescent bulbs controlled manually by users. The building does not have any BMS system.

The general overview of the building allowed for giving a good opinion about energy efficiency of the building. The measured final energy indicator for heating in the past year equals 127.40 kWh/m^{2}a, which is typical for this type of building.

1.2. Summary table: existing state of the builiding

Category	Value
Building type[10]	Educational building
Constriction year / major reconstruction year	1993-1998 / 2006
Building fabric[11]	Full brick and hole brick
Building useful area [m^2]	7,791
Useful area of the audited zone [m^2]	Classrooms: 1 808.6 m^2 Sport hall: 752.8 m^2 Canteen: 212.6 m^2 (with facilities)
Shape factor - building [1/m]	0.23
Building volume [m^3]	33 284
Volume of the audited zone [m^3]	Classrooms: 5,788 m^3 Sport hall: 5,721 m^3 Canteen: 680 m^3 (with facilities)

[10] Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

[11] E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

Shape factor - audited zone [1/m]	Classrooms: 0.31 Sport hall: 0.13 m^2 Canteen: 0.31 (with facilities)
Number of floors	3
Number of building users	1,350
Heating system	District heating, heat convectors with thermostats
Domestic hot water (DHW) system	District heating, the same source as the central heating
Cooling system	There are 17 cooling units in the building. Each of them is a small cooling unit with cooling capacity around 4-5 kW. Most of them are installed in administration rooms.
Lightning system	2x36W fluorescent bulbs switched on manually when needed, 15x400 for large sport hall
Primary energy consumption - total [kWh/m^2a]	140.7
Primary energy consumption - heating [kWh/m^2a]	79.2
Primary energy consumption - DHW [kWh/m^2a]	22.2
Primary energy consumption - cooling [kWh/m^2a]	n/a
Primary energy consumption - lightning [kWh/m^2a]	39.3
Final energy consumption - total [kWh/m^2a]	119.7
Final energy consumption - heating [kWh/m^2a]	82.6
Final energy consumption - DHW [kWh/m^2a]	24.0
Final energy consumption - cooling [kWh/m^2a]	n/a
Final energy consumption - lightning [kWh/m^2a]	13.1
CO_2 emissions - total [kg/m^2a]	44.83
CO_2 emissions - heating [kg/m^2a]	25.51
CO_2 emissions - DHW [kg/m^2a]	9.92
CO_2 emissions - cooling [kg/m^2a]	n/a
CO_2 emissions - lightning [kg/m^2a]	9.39

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to total energy savings after applying measures together in Variant 1 and Variant 2.

The recommended Variant 1 is a typical thermal modernisation scheme applied in Poland, that is usually introduced when the owner of the building is applying for financial subsidies for thermal modernisation. Application of all measures allows to meet current technical requirements for buildings, namely maximum U-values for external walls, roof, and windows.

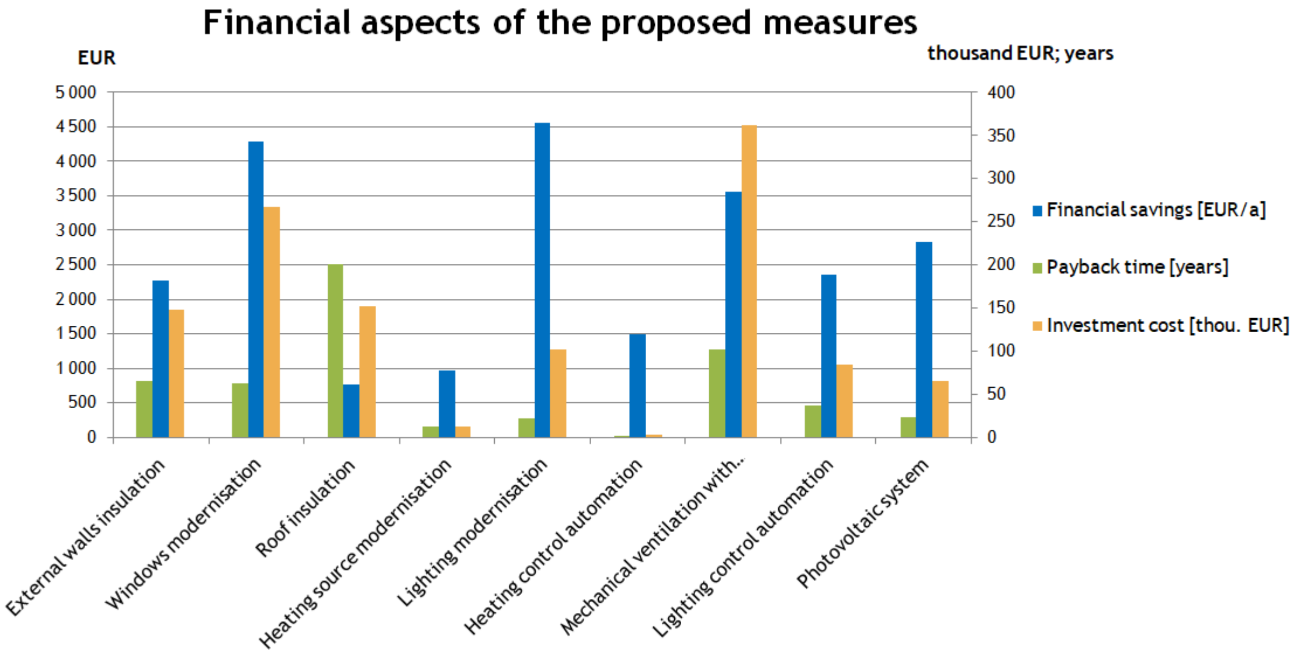
The maximum efficiency Variant 2 is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values lower than 0 kWh/m^2a. This value however is only achieved because of energy consumption calculation in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

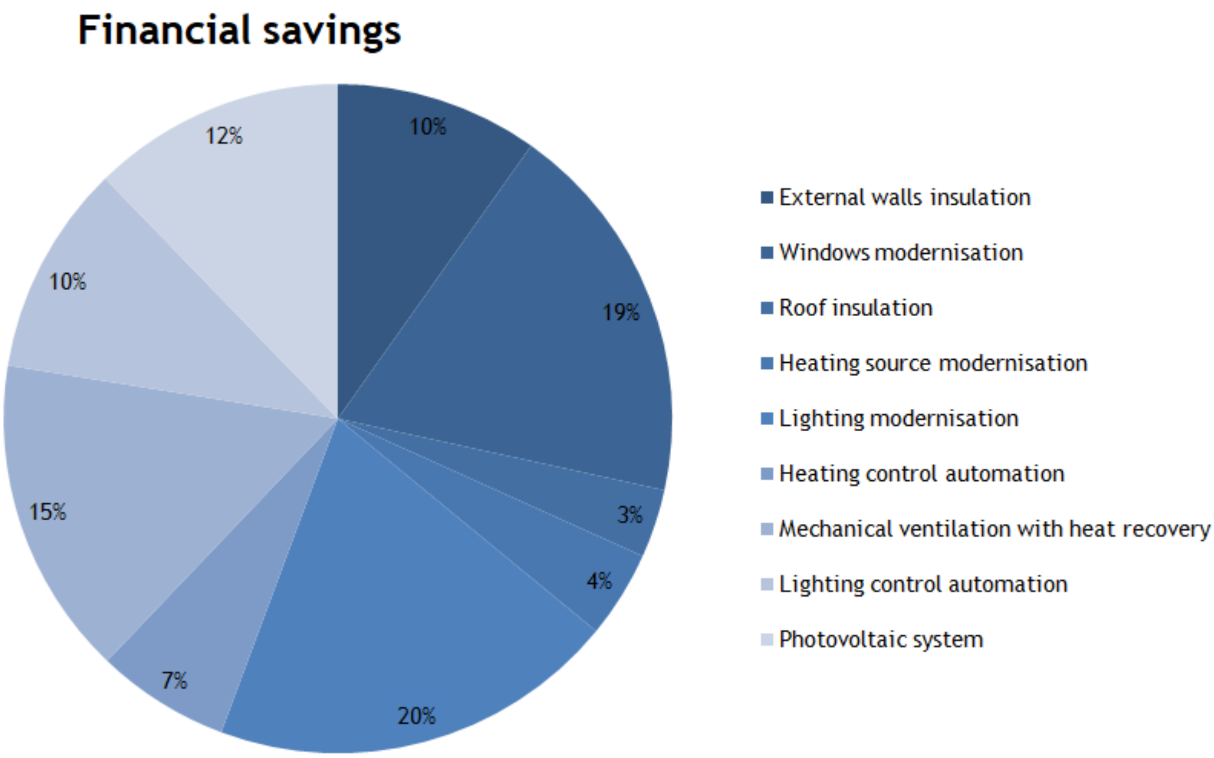
The table presented in section 1.4 contains all analysed measures. Measures 1-6 are considered as a basic modernisation (Variant 1). In order to achieve the nZEB standard, measures 7-9 are added.

For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

1.4. Summary table: suggested measures, energy savings, financial savings

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	74,909	34,295	11.98	2,265	148,163	65
2.	Windows modernisation	142,046	127,842	44.66	4,294	267,430	62
3.	Roof insulation	25,232	22,709	7.93	763	152,302	200
4.	Heating source modernisation	32,142	28,928	10.11	972	11,628	12
5.	Lighting modernisation	61,163	183,488	43.91	4,552	101,599	22
6.	Heating control automation	56,900	51,210	17.89	1,488	2,326	2
7.	Mechanical ventilation with heat recovery	117,682	37,901	13.24	3,558	362,372	102
8.	Lighting control automation	31,623	94,868	22.71	2,353	84,666	36
9.	Photovoltaic system	-	114,000	-	2,828	65,116	23





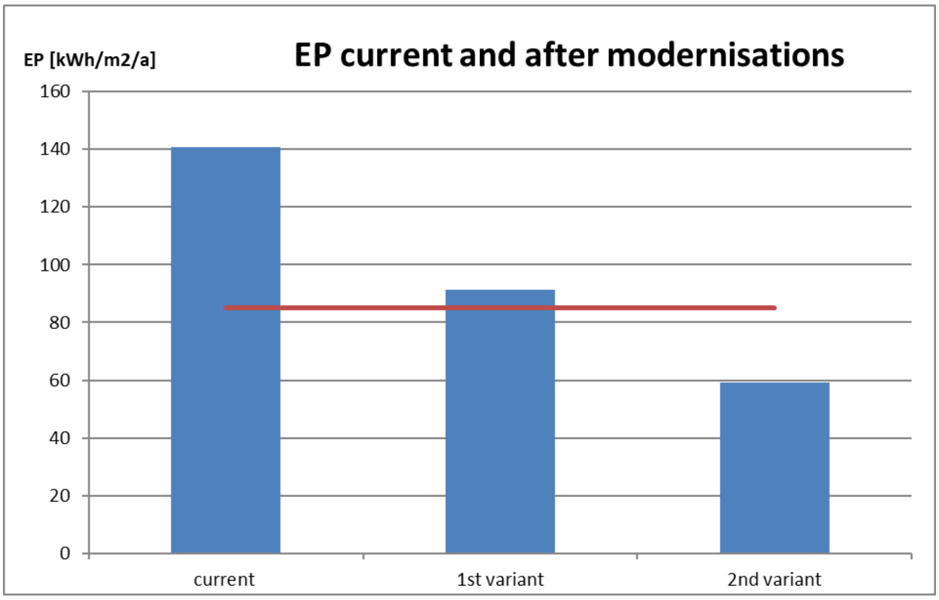
The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. Considering this, the best measure is the is modernisation of the heating source, which is one of the basic options proposed as a part of a thermal modernisation plan. The extremely long payback time of roof insulation results from the fact that it is already in good condition. High investment cost of installing the mechanical ventilation system in combination with technical difficulties makes it an additional option considered only as a part of the maximum efficiency variant.

In the table below, the shares of primary energy savings due to analysed measures in each space have been presented.

Table 77 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen with facilities	Rest of the building
1.	External walls insulation	45.74%	12.73%	1.92%	39.61%
2.	Windows modernisation	53.04%	9.85%	4.30%	32.80%
3.	Roof insulation	36.74%	12.07%	1.67%	49.51%
4.	Heating source modernisation	50.66%	10.64%	1.68%	37.11%
5.	Lighting modernisation	24.84%	4.65%	1.61%	68.90%
6.	Heating control automation	35.48%	11.66%	2.71%	50.14%
7.	Mechanical ventilation with heat recovery	0.35%	19.53%	8.90%	71.22%
8.	Lighting control automation	24.84%	4.65%	1.61%	68.90%

Total primary energy consumption before and after implementations of measures according to 1st and 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

The modernisation includes changes in time usage of a district heating heat exchanger. Currently it produces heat 24 hours a day, 7 days a week, leading to inefficiency of the heating system. When no lessons are held nor the sport hall is unoccupied, heating is unnecessary. There is no external temperature automatic control installed in the system. Installation of traditional heating control allowing for night and weekend temperature reduction could allow for significant energy savings with low investment cost. Also, in case there is already a controller installed, it is recommended to perform heating system rinsing and regulation. The calculated total efficiency of the system would increase from the current 0.85, to 1.05[12], according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 78 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	830,771	798,629	32,142
Primary energy [kWh/a]	790,157	761,229	28,928
CO_2 emission [Mg/a]	276.05	265.94	10.11

Table 79 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
972	11,628	12

Estimated payback time is around 12 years. The investment cost is around 12 000 EUR. Payback time is so low because there is no need to change anything with radiators and cost of a system is also low.

The heating source modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.1.1. Classrooms

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 14,655 kWh/a, which gives 50.72% reduction in the building.

2.1.1.2. Sport halls

[12] Efficiency >1.0 is caused by applying temperature reduction in nights and weekends.

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 3,078 kWh/a, which gives 10.62% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 486 kWh/a, which gives 1.72% reduction in the building.

2.1.2. Heating control automation

The weather forecast control (for example Egain or Promar) system is used to control the heating system provided by the local weather forecasts, reducing the time when building becomes overheated during some periods when there are high external temperature amplitudes during the day. This solution increases the efficiency of the system`s regulation allowing for energy savings. The calculated total efficiency of the system would increase from the current 0.85, to 0.93, according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building. Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 80 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	830,771	773,871	56,900
Primary energy [kWh/a]	790,157	738,947	51,210
CO_2 emission [Mg/a]	276.05	258.16	17.89

Table 81 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,488	2,326	2

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however is around 1-3 years.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 18,169 kWh/a, which gives 35.52% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 5,971 kWh/a, which gives 11.72% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,388 kWh/a, which gives 2.72% reduction in the building.

2.2. Water and sewage system

No changes to the sewage system are considered.

2.3. HVAC

The whole building is now ventilated naturally, except the kitchen and the sport hall which are equipped with the mechanical exhaust ventilation.

Installing the mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows a reduction in final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 82 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	830,771	713,089	117,682
Primary energy [kWh/a]	790,157	752,256	37,901
CO_2 emission [Mg/a]	276.05	262.81	13.24

Table 83 Financial savings and investment cost of mechanical ventilation with heat recovery

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,558	362,372	102

In practical terms installing the mechanical ventilation system in the existing building might be problematic and is not considered in a typical thermal modernisation scheme. This measure is proposed as a part of maximum efficiency Variant 2, which aims at fulfilling requirement for newly designed buildings.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

Primary energy in the amount of 133 kWh/a would be saved in classrooms, while 7,402 kWh/a would be saved in the Sport hall and 3,373 kWh/a would be saved in the canteen and its facilities.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in this kind of buildings is not a commonly used installation, only in selected circumstances. According to information gained from the school staff, the most powerful installation (located in the canteen) is used only during parents' meetings or other events which takes place very rarely.

2.5. Electric system

In the existing state of the building, it has been estimated that the lighting consumes around 101,938 kWh of energy. According to the invoices provided by the school staff, total annual consumption of electricity past year was 188,070 kWh. This difference is caused by the fact that aside from the lighting there are many devices using electricity, like computers and projectors. Also, mechanical ventilation in the Sport hall is responsible for electricity consumption.

The modernisation of the lighting system includes exchanging of fluorescent bulbs for LED ones and installing automatic control which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is possibility of decreasing of the electrical power which will reduce electricity costs. This however will not decrease the energy consumption.

2.6. Building envelope

2.6.1. External walls insulation

Thermal modernisation of the building includes insulation of the external walls, foundation walls and the roof, as well as windows modernisation. It is usually most profitable when all of the thermal modernisation measures are performed together, as a large share of costs is associated with preparation of construction field, ex. construction of scaffoldings etc.

External walls insulation decreases the heat transfer coefficient, which influences heat loss through the walls. The building envelope has not been modernised since the original state and the heat transfer coefficient is estimated at 0.3 for some walls and 0.32 $W/m^2 \bullet K$ for other walls which is low. Thermal modernisation of the building assumes insulation of the external walls with 4 and 5 cm of polystyrene (depending on the stage of the building) with thermal conductivity parameter of λ=0.04 W/m•K.

The heat resistance of the insulation material is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

Where d – thickness [m], λ - thermal conductivity [W/m•K]

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the external walls' parameters are presented in the table below.

Table 84 Heat parameters of the external walls

Current heat transfer	Polystyrene	Insulation	Insulation	Heat transfer

coefficient [W/m²•K]	thermal conductivity λ [W/m•K]	thickness [m]	resistance [m²•K/W]	coefficient [W/m²•K]
0.30	0.04	0.04	1.00	0.23
0.32	0.04	0.05	1.25	0.23

The heat transfer coefficient of the external walls after the proposed modernisation equals 0.23 W/m²•K.

Values of the energy savings, CO_2 reduction as well as the savings are presented in the tables below.

Table 85 Energy savings and CO_2 reduction after external walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	830,771	755,862	74,909
Primary energy [kWh/a]	790,157	755,862	34,295
CO_2 emission [Mg/a]	276.05	264.07	11.98

Table 86 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,265	148,163	65

The investment cost of the external walls' insulation is relatively high, the financial savings though are rather poor, which results in payback time of 65 years. Despite the case of this specific school, this measure is still treated as one of the basic options considered in a typical thermal modernisation scheme.

External walls insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.1. Classrooms

External walls insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 15,687 kWh/a, which gives 45.72% reduction in the building.

2.6.1.2. Sport halls

External walls insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 4,366 kWh/a, which gives 12.72% reduction in the building.

2.6.1.3. Canteen

External walls insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 658 kWh/a, which gives 1.92% reduction in the building.

2.6.2 Windows modernisation

Windows modernisation includes an exchange of the windows with new ones of U=1.1 W/m²•K. In the existing state the windows are leaky, and their heat transfer coefficient equals 2.6 W/m²•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 87 Energy savings and CO_2 reduction after windows modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	830,771	688,725	142,046
Primary energy [kWh/a]	790,157	662,315	127,842
CO_2 emission [Mg/a]	276.05	231.39	44.66

Table 88 Financial savings and investment cost of windows modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4,294	267,430	62

The long payback time of the windows modernisation results from the fact that windows are already quite new.

Windows modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.4. Classrooms

Windows modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 67,807 kWh/a, which gives 53.02% reduction in the building.

2.6.1.5. Sport halls

Windows modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 12,592 kWh/a, which gives 9.92% reduction in the building.

2.6.1.6. Canteen

Windows modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 5,497 kWh/a, which gives 4.32% reduction in the building.

2.6.5 Roof insulation

Roof insulation allows the improvement of heat parameters, which decreases heat loss. In this school there are 4 different types of roofs so there will be 4 different thicknesses: the insulation with 12 cm for the part built in stage I, 6 cm for stage II, 2 cm for stage III and 4 cm for stage IV. Each insulation will be made of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K.

The overall heat resistance is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the roof materials and parameters are presented in the table below.

Table 89 Heat parameters of the roof

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.35	0.04	0.10	2.86	0.18
0.24	0.04	0.06	3.43	0.18
0.2	0.04	0.02	0.5	0.18
0.22	0.04	0.04	1.00	0.18

The heat transfer coefficient of the roof after the proposed modernisation equals 0.18 W/m²•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 90 Energy savings and CO_2 reduction after roof insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	830,771	805,539	25,232
Primary energy [kWh/a]	790,157	767,448	22,709
CO_2 emission [Mg/a]	276.05	268.12	7.93

Table 91 Financial savings and investment cost of roof insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
763	152,302	200

Annual financial savings from the roof insulation are about 800 EUR. The payback time is 200 years. The numbers are so poor because the roof is already in good condition.

Roof insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.7. Classrooms

Roof insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 8,343 kWh/a, which gives 36.72% reduction in the building.

2.6.1.8. Sport halls

Roof insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 2,741 kWh/a, which gives 12.12% reduction in the building.

2.6.1.9. Canteen

Roof insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 379 kWh/a, which gives 1.72% reduction in the building.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, Photovoltaic installation of power up to 40 kWp is defined as a small installation and can be connected to the grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 15% of the roof – 660 m^2. In Warsaw the productivity of PV is about 950 kWh/kWp so this installation would provide 38,000 kWh a year.

2.8. Lighting system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total the installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 92 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	101,938	40,775	61,163
Primary energy [kWh/a]	305,814	122,326	183,488
CO_2 emission [Mg/a]	73.19	29.28	43.91

Table 93 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4,552	101,599	22

Financial savings from lighting modernisation are about 4,500 EUR and payback time is 22 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 45,578 kWh/a, which gives 24.82% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 8,532 kWh/a, which gives 4.72% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,954 kWh/a, which gives 1.62% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing an automatic control which is based on the amount of light from the outside and presence of people in a room. In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 94 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	101,938	70,315	31,623
Primary energy [kWh/a]	305,814	210,946	94,868
CO_2 emission [Mg/a]	73.19	40.49	22.71

Table 95 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,353	84,666	36

Investment cost of the modernisation is about 85 000 EUR. Payback time of the measure is rather reasonable with the level of 36 years. As this option decreases electricity consumption, primary energy savings are relatively high, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 23,565 kWh/a, which gives 24.82% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 4,411 kWh/a, which gives 4.72% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,527 kWh/a, which gives 1.62% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the first variant is limited by foundation program specifications and the second variant is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the second variant the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control. Users should be trained how to use the system, so that it would work effectively and properly.

In the first variant it is the heating which is, as the only system, controlled automatically. This means that users can turn off the lighting only manually. The last person leaving specific room ought to always remember to turn off the lights. Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 5 parameters: size of the school, amount of energy it consumes/ loses by specific element, number of heaters and annual usage cost and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service. Heating control automation has an annual fee that is charged for this service.

Table 96 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	External walls insulation	1 m^2	42	-
2.	Windows modernisation	1 m^2	233	-
3.	Roof insulation	1 m^2	35	-
4.	Heating source modernisation	1 heater	134	11,628
5.	Lighting modernisation	1 W	1.74	-
6.	Heating control automation	Annual usage	233	2,326
7.	Mechanical ventilation with heat	1 m^2	47	-

	recovery			
8.	Lighting control automation	1 W	0.58	-
9.	Photovoltaic system	1 kWp	1628	-

2.12.2. Accuracy

During the process of measures evaluation a few simplifications have been implemented. Firstly, the analytical model was adjusted so that it consumes possibly similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the actual savings can be a bit lower, while energy consumption would be lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, in reality they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), heat – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Insulation of external walls and roof - experience from the Polish market shows that huge share of total costs is labour and materials, however scaffolding and equipment may represent up to 30% of total costs. Accuracy level is around 80%.

Windows modernisation – In this case the main cost are new windows. Accuracy level can be estimated at 90%.

Heating source modernisation and control automation – Prices found on a website of a company providing such solutions. Accuracy level is around 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs per about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy is around 90%.

Mechanical ventilation – based on author's experience and expert opinions, however estimation is not easy due to the variety of situations when vent ducts cannot be installed. Accuracy level is around 80%.

Photovoltaic system – this price is standard on the Polish market, so the accuracy is around 95%.

2.12.3. Methods and standards used

Most of methods were based on author's experience, knowledge and internet offers from companies providing specific solutions.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the *Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building* separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 97 Standards used during energy audit

	Applied version	English version
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements
2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings - Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczeń."	EN ISO 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods
6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków - Wymiana ciepła przez grunt - Metody obliczania."	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach - Liniowy współczynnik przenikania ciepła - Metody uproszczone i wartości orientacyjne."	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia."	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane - Właściwości cieplno-wilgotnościowe - Tabelaryczne wartości obliczeniowe i procedury określania deklarowanych i obliczeniowych wartości cieplnych"	ISO 10456:2007 Building materials and products -- Hydrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania"	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system"	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 "Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance"	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 98 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit

	termo modernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	
3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metody obliczania oszczędności energii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency audit card and methods for calculating energy savings
5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) - raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) - raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme - 1st variant

3.1. Aim of the renovation plan

The aim of the first renovation plan is to modernize the building so that it meets Polish building standards and consumes less energy. As the result the costs of maintenance of the school will be lower. Such modernisation plan was chosen due to the possibility of getting funds from the BGK thermal-modernisation and renovation program, which is a national programme supporting thermal modernisation of buildings in Poland.

The first variant includes the following measures:

- External walls insulation
- Windows modernisation
- Roof insulation
- Heating source modernisation
- Lighting modernisation

The extent of each measure incudes meeting the minimum requirements, despite the costs or payback time. There are no other boundaries to renovate this building in a way proposed above.

3.2. Criteria for ranking energy efficiency improvement measures

The main criterion was to meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 W/m^2•K
- heat transfer coefficient of windows: U = 1.1 W/m^2•K
- heat transfer coefficient of roofs: U = 0.18 W/m^2•K

Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not.

Last criterion is the improvement of thermal comfort in the building. This however cannot be measured, but it is important to remember that sometimes it is more important to improve comfort than to save money.

3.3. Potential interactions with other proposed recommendation

The only affected parameter is the heating source. Each modernisation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. The impact of interactions between measures have been considered in the Variants (see row “Total” in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions. Lighting has no effect on any of other renovations.

3.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls – the most efficient way is to use 4 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23W/ m^2•K.

Roof insulation – the best option is to use, depending on the roof, 2, 4, 6 or 10 cm or of polystyrene with thermal conductivity parameter of λ=0,04. Added to existing state it allows to meet required standard of U = 0.18 W/m²•K

Replacement of windows – In this case there is no other option but to replace all old windows with new ones with heat transfer coefficient with 1.1 W/m²•K value

Heating source improvements – Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs to LED ones.

When it comes to lighting and heating source both money and final energy savings were considered. LEDs are one of the eco-friendliest lighting choices whilst also their high efficiency leads to economical savings. When it comes to the heating source, installing heating source automation decreases the usage of heating when it is not necessary (weekends and nights), so it improves the system`s efficiency.

The measures considered in the 1st variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 99 Measures included in the 1st variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating source modernisation	32,142	28,928	10.11	972	11,628	12
2.	Lighting modernisation	61,163	183,488	43.91	4,552	101,599	22
3.	Windows modernisation	142,046	127,842	44.66	4,294	267,430	62
4.	External walls insulation	74,909	34,295	11.98	2,265	148,163	65
5.	Roof insulation	25,232	22,709	7.93	763	152,302	200
	Total	284,376	384,380	118.08	11,300	681,122	60

The most beneficial option, with 12 years payback time, is heating source modernisation due to its really low investment cost. Of course, after insulation of walls and the roof, its impact will be much lower because losses of heat will be reduced significantly. The roof modernisation is the least profitable. This is because the roof is already in good condition.

3.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	140.7	91.3
Primary energy consumption - heating [kWh/m²a]	79.2	53.4
Primary energy consumption - DHW [kWh/m²a]	22.2	22.2

Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	39.3	15.7
Final energy consumption - total [kWh/m²a]	119.7	83.2
Final energy consumption - heating [kWh/m²a]	82.6	54.0
Final energy consumption - DHW [kWh/m²a]	24.0	24.0
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	13.1	5.23
CO_2 emissions - total [kg/m²a]	44.83	29.67
CO_2 emissions - heating [kg/m²a]	25.51	15.99
CO_2 emissions - DHW [kg/m²a]	9.92	9.92
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	9.39	3.76

The 1st renovation variant allows reducing final energy consumption by around 284 MWh/a and primary energy consumption by around 384 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 681 000 EUR and the estimated payback time is at the level of 101 years. The EP factor of the building after implementing the proposed measures would achieve about 91.33 kWh/m²/a, which makes the building much more efficient.

4. Renovation scheme - 2nd variant

4.1. Aim of the renovation plan

The aim of the second renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The second variant includes all measures of the 1st variant with the following additional renovations:

- Heating control automation
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

4.2. Criteria for ranking energy efficiency improvement measures

The aim of the second variant is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows for large final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

4.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation, heating control automation, etc.) affects the work of a boiler/heat exchanger. The better the condition of a building, the less heat needs to be provided. Also, changes in usage time of the heating system influences other measures decreasing the heat consumption – turning the heating off during nights and weekends decreases energy savings from walls and roof insulation as well as windows modernisation or mechanical ventilation with heat recovery, as the time they work and generate savings is also shorter.

Lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions.

4.4. Suggested measures (optimal implementation plan)

Based on previous paragraphs the implementation plan includes the following measures:

Insulation of external walls – the most efficient way is to use 4 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23W/m^2•K.

Roof insulation – the best option is to use, depending on the roof, 2, 4, 6 or 10 cm or of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K.

Replacement of windows – In this case there is no other option but to replace all old windows with new ones with heat transfer coefficient with 1.1 W/m^2•K value.

Heating source improvements –Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs for LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the weather forecast control system (e.g. Egain/Promar etc.), which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used to 0 m3/h.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the 2nd variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 100 Measures included in the 2nd variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating control automation	56,900	51,210	17.89	1,488	2,326	2
2.	Heating source modernisation	32,142	28,928	10.11	972	11,628	12
3.	Lighting modernisation	61,163	183,488	43.91	4,552	101,599	22
4.	Photovoltaic system	-	114,000	-	2,828	65,116	23
5.	Lighting control automation	31,623	94,868	22.71	2,353	84,666	36
6.	Windows modernisation	142,046	127,842	44.66	4,294	267,430	62
7.	External walls insulation	74,909	34,295	11.98	2,265	148,163	65
8.	Mechanical ventilation with heat recovery	117,682	37,901	13.24	3,558	362,372	102
9.	Roof insulation	25,232	22,709	7.93	763	152,302	200
	Total	481,355	520,211	188.42	20,409	1,195,603	59

The shortest payback time (typically 1-3 years) is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view. The roof modernisation is the least profitable. This is because the roof is already in good condition.

4.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	140.7	59.3
Primary energy consumption - heating [kWh/m²a]	79.2	40.9
Primary energy consumption - DHW [kWh/m²a]	22.2	22.2
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	39.3	10.8
Final energy consumption - total [kWh/m²a]	119.7	57.9
Final energy consumption - heating [kWh/m²a]	82.6	30.3
Final energy consumption - DHW [kWh/m²a]	24.0	24.0
Final energy consumption - cooling [kWh/m²a]	n/a	n/a

Final energy consumption - lighting [kWh/m²a]	13.1	3.6
CO_2 emissions - total [kg/m²a]	44.83	20.64
CO_2 emissions - heating [kg/m²a]	25.51	8.13
CO_2 emissions - DHW [kg/m²a]	9.92	9.92
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	9.39	2.59

The 2nd renovation variant allows reducing final energy consumption by around 481 MWh/a and primary energy consumption by around 520 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 1 119 000 EUR and the estimated payback time is at the level of 99 years. The EP factor of the building after implementing the proposed measures would achieve about 59.3 kWh/m²/a, which makes the building much more efficient. The total cost of the maximum efficiency variant is significantly higher than the 1st variant, also in reference to the energy savings. Thus, the 1st variant is more realistic and is proposed as the basic one.

5. Attachments

No attachments.

V. Building #5 SP 77 (ul. Samogłoska 9, 01-980 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building was built in 1963. In 2017 the building has been completely modernized, including thermal modernization and adding a new storey over a part of a building. The building envelope is new. A thermal modernization included an insulation of the building, which has been performed with graphite polystyrene. Insulation parameters are very good. Windows have been exchanged with 3-glazed ones. The building is heated with its own gas boiler, which is also planned to be exchanged to a new condensing boiler during the upcoming summer. Pipes transporting heat are insulated, a boiler is located in the non-heated basement with separate entrance from the outside of the building. The boiler generates heat for a central heating and domestic hot water preparation. There is an accumulation tank in the system of 500 dm^3. A heat distribution system in the school is new and all plate convectors are equipped with thermostats, however most of convectors are covered with shield with holes for safety issues. This decreases the efficiency of radiant heating of plate heaters. A sport hall is heated and ventilated with two fans with heating coils transferring fresh air into the room. Most of the building is ventilated naturally with assist of small exhaust fans in toilets, except the sport hall, new classrooms in the recently added part of the building and the kitchen. There are two classrooms that have air conditioning units. In the whole building there is an energy efficient fluorescent lighting installed. Most of the fittings are 2x58W, some are 2x36W. There are a few individual CLFs in the small rooms (sanitary etc.) The sport hall is equipped with 3x36W fittings. There is one general switch for lighting that is used during the unoccupied period. The building does not have any BMS system, however it has well organized security monitoring system.

The School owns also a balloon-covered football field that is heated with the gas heater mounted on the pressurizing fan for the balloon.

The general overview of the building allowed for giving very good opinion about energy efficiency of the building. Thus, it is surprising that the final energy indicator for heating in 2017 reached 162.08 kWh/m^2a, which is very high as for the building after recent thermal modernization. This might be explained by including to the calculation the heat for the sport field covered with the balloon, owned by the school. Another issue is that in the beginning of 2017 the school was before the renovation, which might have had an impact on the calculations.

1.2. Summary table: existing state of the building

Category	Value
Building type[13]	Educational building

[13] Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

Constriction year / major reconstruction year	1963 / 2017
Building fabric[14]	Concrete and reinforced concrete blocks
Building useful area [m^2]	2,919.59
Useful area of the audited zone [m^2]	Classrooms: 1,001.63 m2 Sport hall: 159.00 m2 Canteen: 159.45 m2 (with facilities)
Shape factor - building [1/m]	0.298
Building volume [m^3]	9,781 m^3
Volume of the audited zone [m^3]	Classrooms: 3225.3 m^3 Sport hall: 1033.5 m^3 Canteen: 454.4 m^3 (with facilities)
Shape factor - audited zone [1/m]	Classrooms: 0.308 1/m Sport hall: 0.154 1/m Canteen: 0.351 1/m (with facilities*)*
Number of floors	3
Number of building users	700
Heating system	Gas boiler + accumulation tank (500 dm^3) + water convectors with thermostats
Domestic hot water (DHW) system	Boiler heating, the same source as the central heating
Cooling system	Two units in two classrooms of southern exposition, used only when needed
Lighting system	Fluorescent bulbs
Primary energy consumption - total [kWh/m^2a]	157.6
Primary energy consumption - heating [kWh/m^2a]	92.4
Primary energy consumption - DHW [kWh/m^2a]	22.6
Primary energy consumption - cooling [kWh/m^2a]	n/a
Primary energy consumption - lighting [kWh/m^2a]	42.5
Final energy consumption - total [kWh/m^2a]	112.8
Final energy consumption - heating [kWh/m^2a]	79.5
Final energy consumption - DHW [kWh/m^2a]	19.2
Final energy consumption - cooling [kWh/m^2a]	n/a
Final energy consumption - lighting [kWh/m^2a]	14.2

[14] E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

CO_2 emissions - total [kg/m²a]	**42.956**
CO_2 emissions - heating [kg/m²a]	**26.417**
CO_2 emissions - DHW [kg/m²a]	6.365
CO_2 emissions - cooling [kg/m²a]	n/a
CO_2 emissions - lighting [kg/m²a]	10.174

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to total energy savings after applying measures together.

As the school was recently (2017) completely modernised, there is no typical thermal modernisation variant proposed. All the walls and windows as well as the roof were renovated, and they meet Polish building standards.

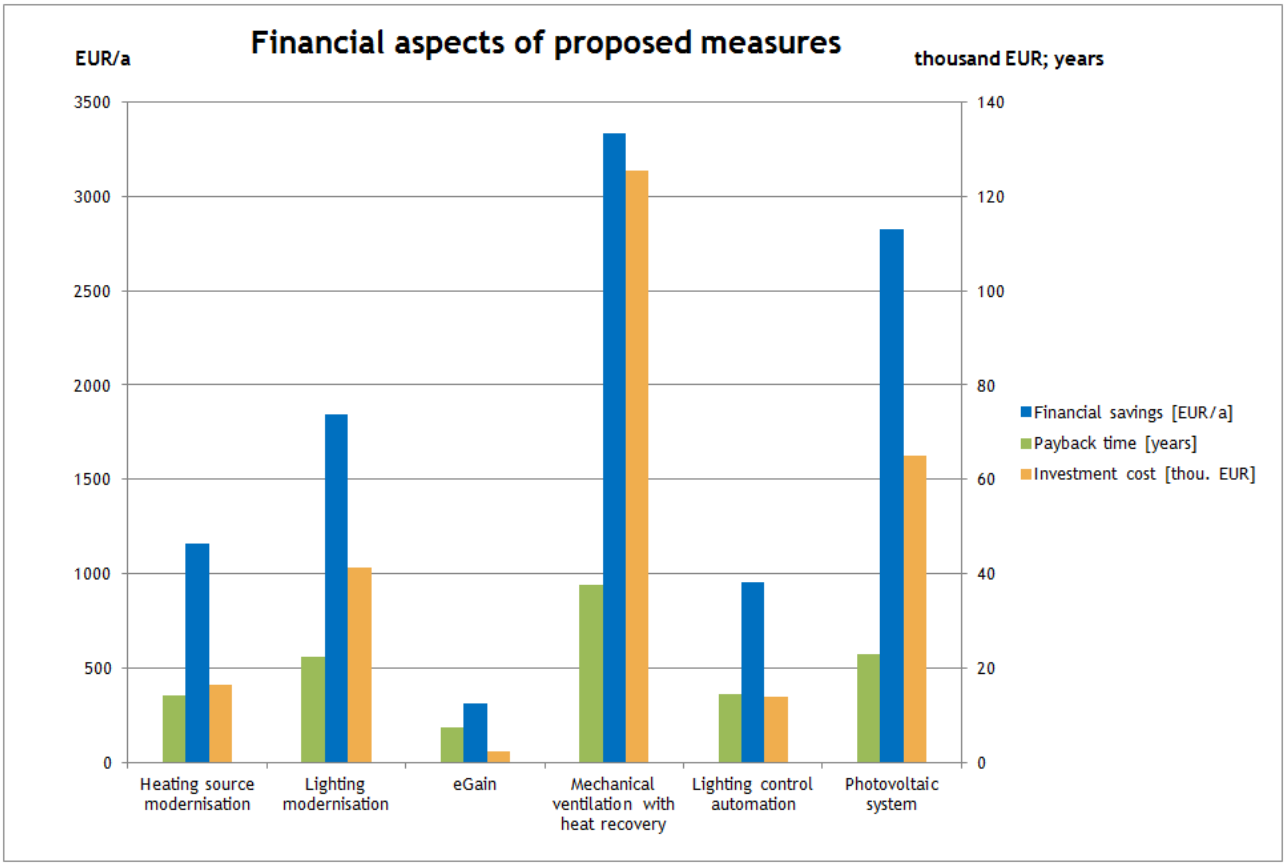
The proposed renovation scheme is the maximum efficiency variant, which is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values even lower than 0 kWh/m²a. This value however is only achieved because of energy consumption calculation in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

The table presented in section 1.4 contains all analysed measures. For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

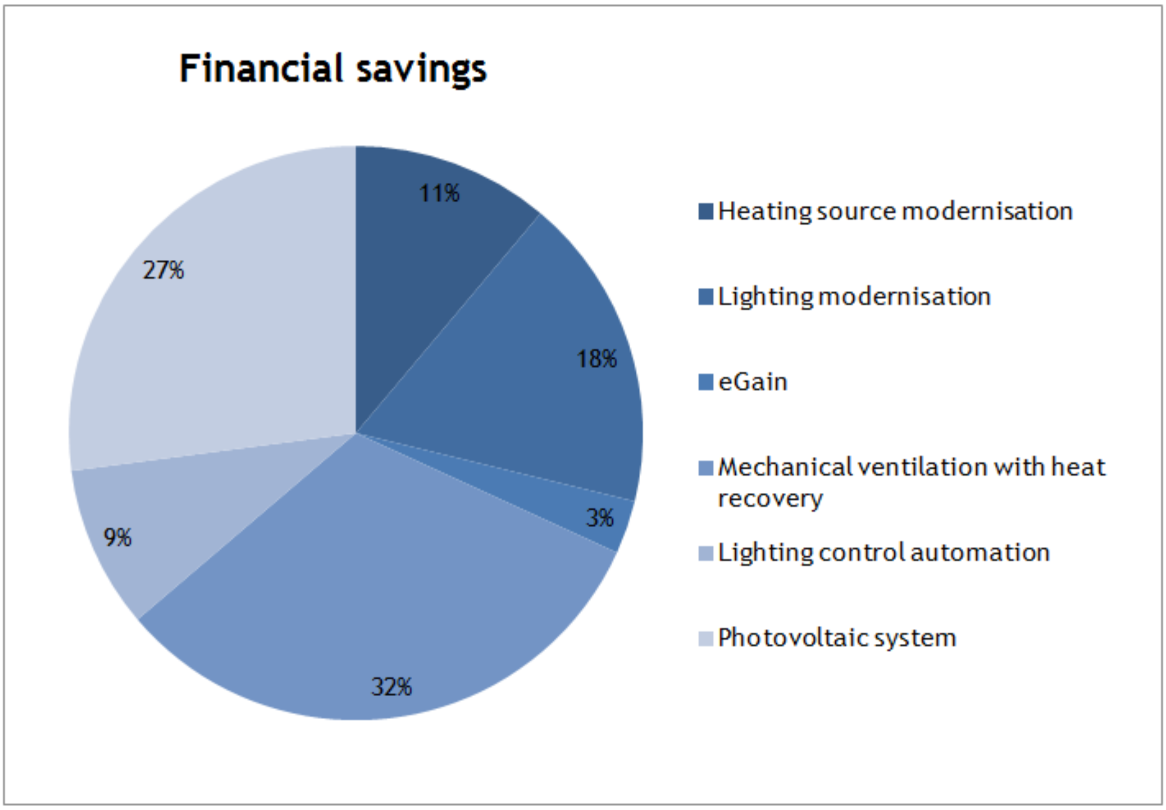
1.4. Summary table: suggested measures, energy savings, financial savings

	Measure	**Final energy savings [kWh/a]**	**Primary energy savings [kWh/a]**	**CO_2 reduction [Mg/a]**	**Financial savings [EUR/a]**	**Investment costs [EUR/a]**	**Payback time [years]**
1.	Heating source modernisation	25,104	27,615	8.342	759	16,279	14
2.	Lighting modernisation	24,821	74,466	17.821	1,847	41,232	22
3.	Heating control automation	18,084	19,893	6.009	314	2,326	7
4.	Mechanical ventilation with heat recovery	110,231	98,977	36.628	3,333	125,433	38
5.	Lighting control automation	12,833	38,501	9.214	955	13,744	14

6.	Photovoltaic system	-	173,736	-	2,828	65,116	23



The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. The most profitable option is the heating source modernisation combined with the heating system automation. High investment cost of installing the mechanical ventilation system in combination with technical difficulties makes it an additional option usually not considered in a typical thermal modernisation plan.



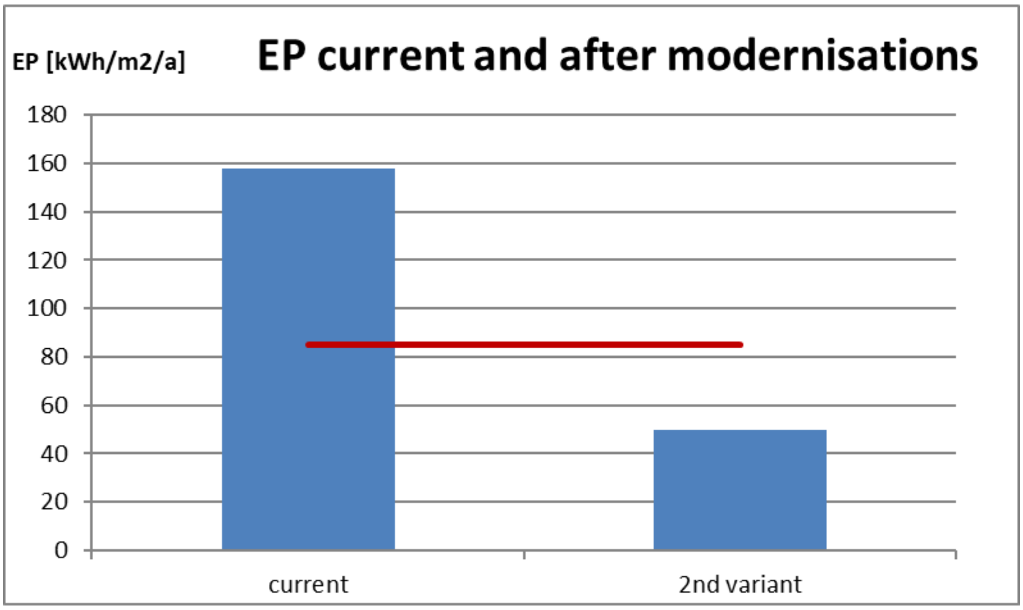
The graph above presents the percentage of financial savings after implementing each measure regardless of the others. Implementing all the measures at once decreases the savings from individual measures and might change the percentage because of the interactions between options. As seen on the graph, the biggest savings are generated by mechanical ventilation with heat recovery and photovoltaic system. Low percentage of the heating control automation results from the annual fee while the system is installed, the investment cost and the energy savings from this measure are satisfactory, though.

In the table below, the shares of primary energy savings due to analysed measures in each space have been presented.

Table 101 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen	Rest of the building
1.	Heating source modernisation	13%	13%	27%	47%
2.	Lighting modernisation	35%	3%	6%	56%
3.	Heating control automation	27%	10%	16%	46%
4.	Mechanical ventilation with heat recovery	29%	0%	18%	53%
5.	Lighting control automation	35%	3%	6%	56%
6.	Photovoltaic system	-	-	-	-

Total primary energy consumption before and after implementations of measures according to 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

Heat for the building is produced with a traditional gas boiler, which declared efficiency equals 90%. It will be exchanged in the upcoming season (summer 2019) with a condensing gas boiler (Bosch model Condens 700 F), which is already bought and is waiting for the summer to be installed. After the renovation the efficiency will achieve 95%. Another problem is the poor condition of the insulation of the pipes. Many parts are even lacking a thermal insulation, which causes large heat loss. A better insulation of the pipes would increase the system`s efficiency to 96%.

The modernisation also includes changes in time usage of the boiler. Currently it produces heat 24 hours a day, 7 days a week, leading to inefficiency of the heating system. When no lessons are held nor the sport hall is unoccupied, the space heating is unnecessary.

The heat distribution system in the school is new and all convectors are equipped with thermostats. Most of the heaters are covered with shields for safety issues, this however decreases the efficiency of radiant heating. It is recommended to consider another means of preventing the children from burning, so that it improves the heat distribution in the building.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 102 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	329,407	290,996	38,411
Primary energy [kWh/a]	460,145	417,893	42,252
CO_2 emission [Mg/a]	125.413	112.650	12.763

Table 103 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,161	16,279	14

Estimated payback time is around 14 years and the investment cost is around 16,000 EUR. The modernisation will improve the system`s efficiency, reducing the heat consumed in the form of gas.

The heating source modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.1.1. Classrooms

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 3,590 kWh/a, which gives 13% reduction in the building.

2.1.1.2. Sport halls

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 3,590 kWh/a, which gives 13% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 7,456 kWh/a, which gives 27% reduction in the building.

2.1.2. Heating control automation

The weather forecast control system (for example Egain or Promar) is used to control the heating system, based on the local weather forecasts. It reduces the time when building becomes overheated, during some periods when there are high external temperature amplitudes during the day. This solution increases the efficiency of the system`s regulation allowing for energy savings. The calculated total efficiency of the system would increase from the current 0.85, to 0.93, according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building. Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 104 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	329,407	311,323	18,084

Primary energy [kWh/a]	460,145	440,252	19,893
CO_2 emission [Mg/a]	125.413	119.404	6.009

Table 105 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
314	2,326	7

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however is around 1-3 years. Longer estimated payback time might result from the condition of the heating system`s regulation, which is already good.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 5,371 kWh/a, which gives 27% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 1,989 kWh/a, which gives 10% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 3,183 kWh/a, which gives 16% reduction in the building.

2.2. Water and sewage system

No changes to the sewage system are considered.

2.3. HVAC

Most of the building is ventilated naturally, with several fans exhausting air from “dirty” zones like toilets. The only exceptions are: sport hall, three classrooms with adjacent corridors and facilities located in the newest part of the building, close to the sport hall and the canteen’s kitchen, which have mechanical ventilation with dedicated air handling units.

Installing the mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows a reduction in final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 106 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	329,407	219,176	110,231
Primary energy [kWh/a]	460,145	361,168	98,977
CO_2 emission [Mg/a]	125.413	88.785	36.628

Table 107 Financial savings and investment cost of mechanical ventilation with heat recovery

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,333	125,433	38

In practical terms installing additional mechanical ventilation system in the existing building might be problematic and is usually not considered in a typical thermal modernisation scheme. As the school was recently modernised, only the maximum efficiency variant is considered, so this measure is also included in the proposed renovation scheme.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

Primary energy in the amount of 28,703 kWh/a would be saved in classrooms, while 0 kWh/a would be saved in the Sport hall and 17,816 kWh/a would be saved in the canteen and its facilities.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in the building is not a commonly used installation, but only used in selected circumstances. There are only two air conditioning units in the school, one in a computer classroom and one in a classroom of south exposition.

2.5. Electric system

In the existing state of the building, it has been estimated that the lighting consumes around 41,000 kWh of energy. According to the invoices provided by the school staff, total annual consumption of electricity in the past year was 57,497 kWh. This difference is caused by the fact that aside from the lighting there are many devices using electricity, like computers, projectors and mechanical ventilation in the newest part of the building.

The modernisation of the lighting system includes the ones and installing automatic control which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is a possibility of decreasing the electrical power which will reduce electricity costs. This however will not decrease the energy consumption.

2.6. Building envelope

As the school was recently completely modernised, the heat parameters of the external partitions meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 W/m^2•K
- heat transfer coefficient of windows: U = 1.1 W/m^2•K

- heat transfer coefficient of roofs: U = 0.18 $W/m^2 \cdot K$

Thus, no measures including the building envelope renovation were considered.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, Photovoltaic installation of power up to 40 kWp is defined as a small installation and can be connected to the grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 52% of the roof – 660 m^2. In Warsaw the productivity of PV is about 950 kWh/kWp so this installation would provide 38,000 kWh a year.

2.8. Lighting system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 108 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	329,407	304,586	24,821
Primary energy [kWh/a]	460,145	385,679	74,466
CO_2 emission [Mg/a]	125.413	107.592	17.821

Table 109 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,847	41,232	22

Financial savings from lighting modernisation are about 1,850 EUR and payback time is 22 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 26,063 kWh/a, which gives 35% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 2,234 kWh/a, which gives 3% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,468 kWh/a, which gives 6% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing automatic control which is based on the amount of light from the outside and presence of people in a room. In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 110 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	329,407	316,574	12,833
Primary energy [kWh/a]	460,145	421,644	38,501
CO_2 emission [Mg/a]	125.413	116.199	9.214

Table 111 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
955	13,744	14

Investment cost of the modernisation is about 14 000 EUR. Payback time of the measure is relatively low with the level of 14 years. As this option decreases electricity consumption, primary energy savings are relatively high, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 13,475 kWh/a, which gives 35% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 1,155 kWh/a, which gives 3% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,310 kWh/a, which gives 6% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the renovation scheme is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the proposed maximum efficiency variant, the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control.

Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 4 parameters: size of the school, amount of energy it consumes/ loses by specific element, annual usage cost and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service.

Table 112 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	Heating source modernisation	1 heater	134	11,628
2.	Lighting modernisation	1 W	1.74	-
3.	Heating control automation	Annual usage	233	2,326
4.	Mechanical ventilation with heat recovery	1 m^2	47	-
5.	Lighting control automation	1 W	0.58	-
6.	Photovoltaic system	1 kWp	1628	-

2.12.2. Accuracy

During the process of evaluation, a few simplifications have been done. Firstly, the analytical model was adjusted so that it consumes similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. In this case there were big discrepancies between the data from the invoices and the results of the calculations. This however is caused by the fact that the invoices summarized the energy consumption in 2017, while the modernisation was implemented in the same year, significantly changing the efficiency of the building. Thus, the energy consumption in the model is smaller than the amount following the invoices. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the calculated savings can be a bit lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), natural gas – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Heating source modernisation and control automation – Prices found on one of the companies` website. Accuracy level 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs for about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy 90%.

Mechanical ventilation – based on author's experience and expert opinions but estimation is not easy because of variety of every school. Accuracy level on 80%.

2.12.3. Methods and standards used

Most of methods were based on author's experience, knowledge and internet offers from companies.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the *Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building* separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 113 Standards used during energy audit

	Applied version	English version
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements
2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings – Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczeń."	EN ISO 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation

		methods
6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków - Wymiana ciepła przez grunt - Metody obliczania.”	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach - Liniowy współczynnik przenikania ciepła - Metody uproszczone i wartości orientacyjne.”	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia.”	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane - Właściwości cieplno-wilgotnościowe - Tabelarycznewartościobliczenioweiproceduryokreślaniadeklarowanychiobliczeniowychwartościcieplnych"	ISO 10456:2007 Building materials and products -- Hydrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania”	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system”	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 “Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance”	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 114 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia termo modernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit
3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metody obliczania oszczędności energii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency

		audit card and methods for calculating energy savings
5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) - raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) - raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme

3.1. Aim of the renovation plan

The aim of the renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The variant includes the following renovations:

- Heating source modernisation
- Lighting modernisation
- Heating control automation
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

3.2. Criteria for ranking energy efficiency improvement measures

The aim of the renovation scheme is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows big final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

3.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (heating control automation, mechanical ventilation with heat recovery) affects the work of the boiler. The better the condition of a building, the less heat needs to be provided. Also, changes in usage time of the heating system influences other measures decreasing the heat consumption – turning the heating off during nights and weekends decreases energy savings from exchanging the boiler with a new one or insulating the pipes, as the time they work and generate savings is also shorter.

The lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2). Tables in chapters 3.5 include impact of interactions.

3.4. Suggested measures (optimal implementation plan)

Based on previous paragraphs the implementation plan includes the following measures:

Heating source improvements - replacing the old boiler with a new one. Installing a better insulation of the pipes. Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used. Some of the heaters in the corridors are covered with shields for safety issues, this however decreases the efficiency of radiant heating. It is recommended to consider another means of preventing the children from burning, so that it improves the heat distribution in the building.

Lighting – Exchange of fluorescent bulbs for LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the Egain/Promar etc. system, which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used to 0 m3/h.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the scheme, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 115 Measures ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]

1.	Heating control automation	18,084	19,893	6.009	314	2,326	**7**
2.	Heating source modernisation	25,104	27,615	8.342	759	16,279	**14**
3.	Lighting control automation	12,833	38,501	9.214	955	13,744	**14**
4.	Lighting modernisation	24,821	74,466	17.821	1,847	41,232	**22**
5.	Photovoltaic system	-	173,736	-	2,828	65,116	**23**
6.	Mechanical ventilation with heat recovery	110,231	98,977	36.628	3,333	125,433	**38**
	Total	**151,271**	**315,036**	**61.819**	**5,897**	**264,130**	**45**

The shortest payback time is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view. The longest payback time is achieved in case of installing the mechanical ventilation system. The total payback time is longer than the payback time of each measure. This is caused by the fact that total final energy savings and, consequently, financial savings are lower than the sum of the savings from the measures implemented separately.

3.5. Impact of the renovation scheme

	Existing	**After implementation**
Primary energy consumption - total [kWh/m^2a]	157.6	49.7
Primary energy consumption - heating [kWh/m^2a]	92.4	55.4
Primary energy consumption - DHW [kWh/m^2a]	22.6	21.6
Primary energy consumption - cooling [kWh/m^2a]	n/a	n/a
Primary energy consumption - lighting [kWh/m^2a]	42.5	11.7
Final energy consumption - total [kWh/m^2a]	112.8	61.0
Final energy consumption - heating [kWh/m^2a]	79.5	38.9
Final energy consumption - DHW [kWh/m^2a]	19.2	18.2
Final energy consumption - cooling [kWh/m^2a]	n/a	n/a
Final energy consumption - lighting [kWh/m^2a]	14.2	3.9
CO_2 emissions - total [kg/m^2a]	42.956	21.782
CO_2 emissions - heating [kg/m^2a]	26.417	12.930
CO_2 emissions - DHW [kg/m^2a]	6.365	6.045
CO_2 emissions - cooling [kg/m^2a]	n/a	n/a
CO_2 emissions - lighting [kg/m^2a]	10.174	2.807

The renovation scheme allows reducing final energy consumption by around 151 MWh/a and primary energy consumption by around 315 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 264,000 EUR and the estimated payback time is at the level of 45 years. The EP factor of the building after implementing the proposed measures would achieve about 49.7 kWh/m^2/a, which makes the building much more efficient.

4. Attachments

No attachments.

VI. Building #6 SP 28 (ul. Gościeradowska 18/20, 93-535 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building was built in 1964. The building envelope is well preserved, however it has not been modernized since the original state, so the heat parameters of external partitions are poor. Windows were changed around 2000-2002 and have an acceptable heat transfer coefficient, however some of them are leaky. In 1994 the heat source in the building has been modernized and exchanged with insulated district heating heat exchanger. Pipes with heating factor are insulated since then. The insulation condition is satisfactory. Old iron ribbed convectors in classrooms and corridors have not been exchanged since the original state and they lack thermostats. Only sport hall heating units have been changed to plate convectors and are now equipped with thermostats. The building does not have any HVAC systems except a dedicated mechanical ventilation in the kitchen and cooling unit in the computer server room. The whole building is equipped with traditional T8 fluorescent bulbs manually controlled by users. The building does not have any BMS system.

The general overview of the building allowed for giving a poor opinion about energy efficiency of the building. The measured final energy indicator for heating in previous year is 147.53 kWh/m^{2}a, which is high.

1.2. Summary table: existing state of the building

Category	**Value**
Building type[15]	**Educational building**
Constriction year / major reconstruction year	**1964/ 1994 (heating source exchange)**
Building fabric[16]	**Aerated brick, steel reinforced concrete (roof), aerated concrete slabs (roof)**
Building useful area [m^2]	**3,521.2 m^2**
Useful area of the audited zone [m^2]	**Classrooms: 1 224.58 m^2** **Sport hall: 288.00 m^2** **Canteen: 113.25 m^2 (with facilities)**
Shape factor - building [1/m]	**0.291**

[15]Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

[16]E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

Building volume [m³]	12,129 m³
Volume of the audited zone [m³]	Classrooms: 4,131.6 m³ Sport hall: 1,548.0 m³ Canteen: 385.1 m³ (with facilities)
Shape factor - audited zone [1/m]	Classrooms: 0.296 1/m Sport hall: 0.182 1/m Canteen: 0.290 1/m (with facilities)
Number of floors	3, partially with basement
Number of building users	450
Heating system	District heating + radiators without thermostats (except sport hall)
Domestic hot water (DHW) system	District heating, the same source as the central heating
Cooling system	One unit in the server room, Toshiba RAS-167SAV-E5
Lighting system	2xT8 fittings with 2x36W fluorescent bulbs
Primary energy consumption - total [kWh/m²a]	180.1
Primary energy consumption - heating [kWh/m²a]	118.6
Primary energy consumption - DHW [kWh/m²a]	14.7
Primary energy consumption - cooling [kWh/m²a]	n/a
Primary energy consumption - lighting [kWh/m²a]	46.9
Final energy consumption - total [kWh/m²a]	158.8
Final energy consumption - heating [kWh/m²a]	128.3
Final energy consumption - DHW [kWh/m²a]	14.9
Final energy consumption - cooling [kWh/m²a]	n/a
Final energy consumption - lighting [kWh/m²a]	16.6
CO_2 emissions - total [kg/m²a]	58.801
CO_2 emissions - heating [kg/m²a]	42.628
CO_2 emissions - DHW [kg/m²a]	4.952
CO_2 emissions - cooling [kg/m²a]	n/a
CO_2 emissions - lighting [kg/m²a]	11.222

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to total energy savings after applying measures together in Variant 1 and Variant 2.

The recommended Variant 1 is a typical thermal modernisation scheme applied in Poland, that is usually introduced when the owner of the building is applying for financial subsidies for thermal modernisation. Application of all measures allows to meet current technical requirements for buildings, namely maximum U-values for external walls, roof, and windows.

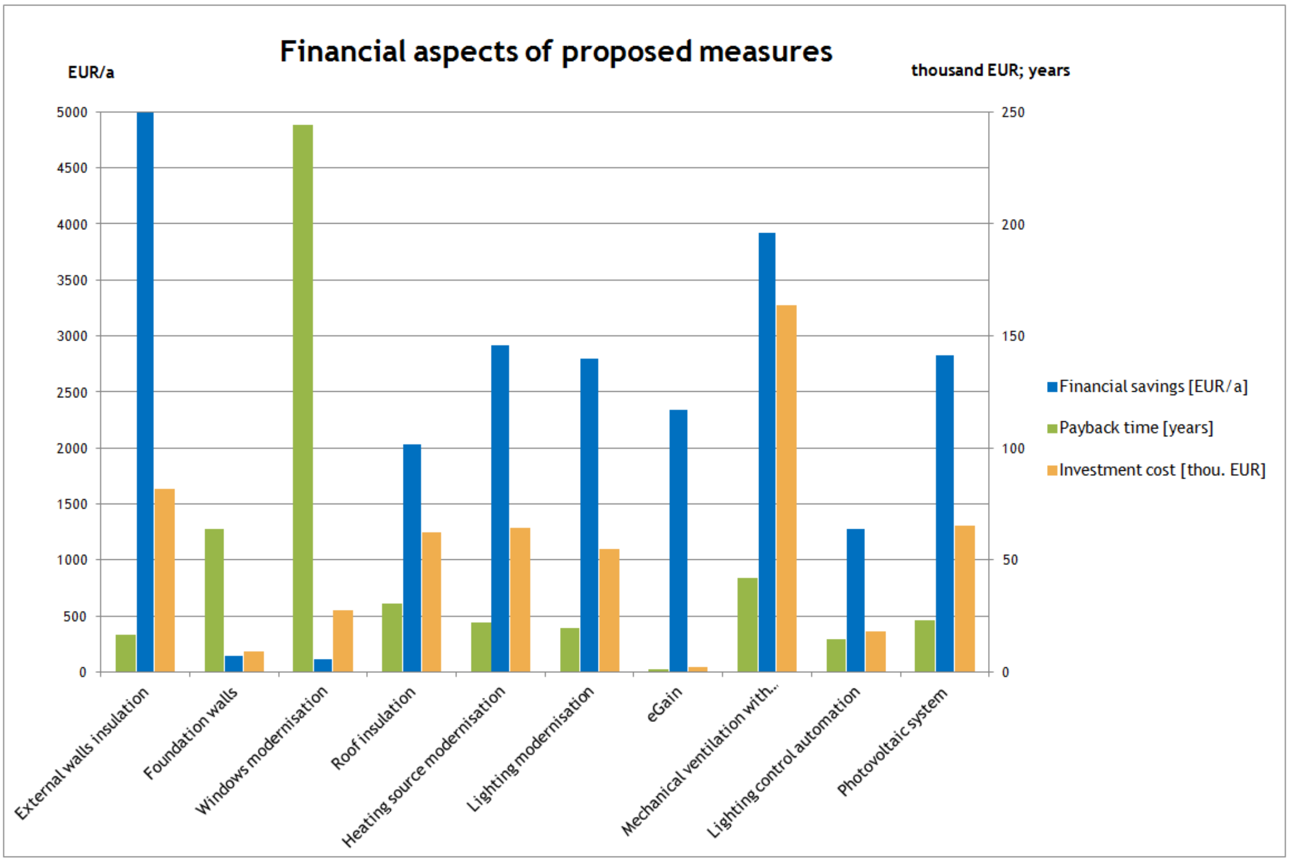
The maximum efficiency Variant 2 is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values lower than 0 kWh/m^{2}a. This value however is only achieved because of energy consumption in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

The table presented in section 1.4 contains all analysed measures. Measures 1-6 are considered as a basic modernisation (Variant 1). In order to achieve the nZEB standard, measures 7-10 are added.

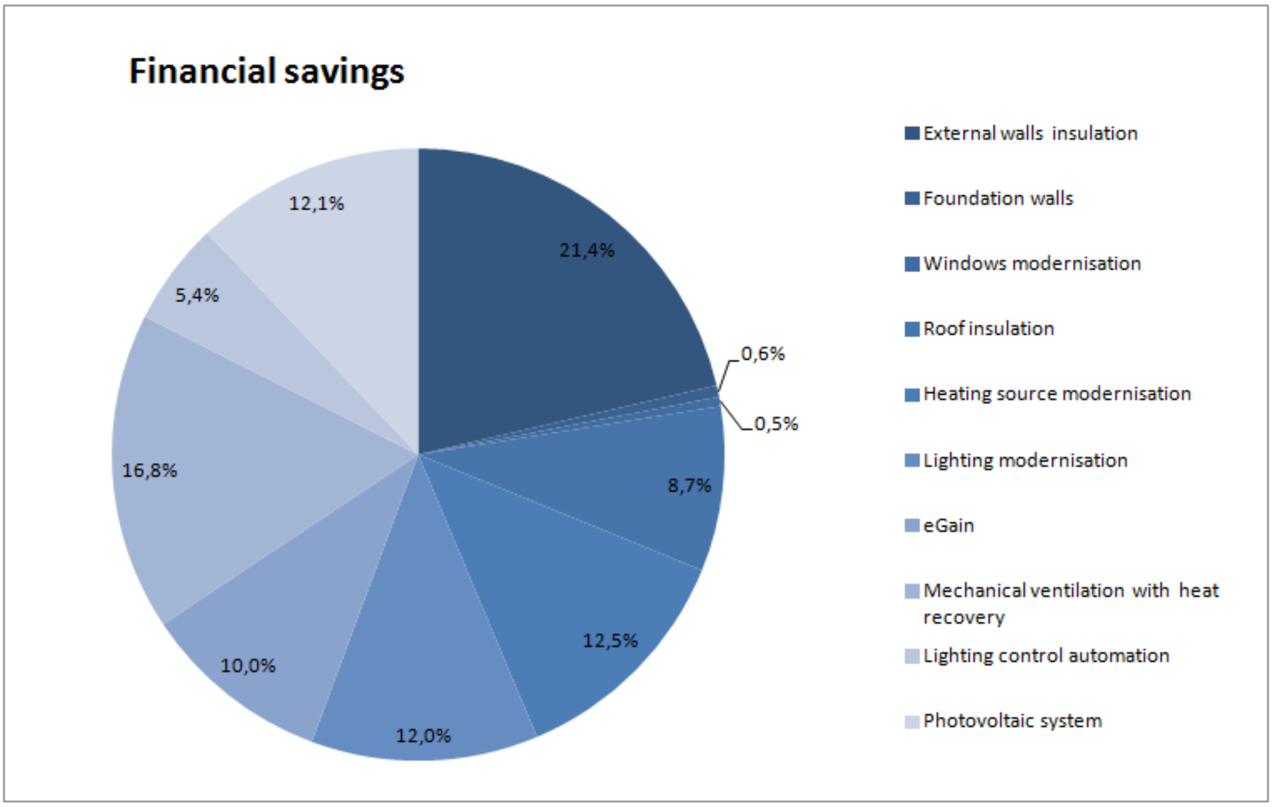
For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

1.4. Summary table: suggested measures, energy savings, financial savings

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	165,048	148,543	54.842	4,990	81,664	16
2.	Foundation walls	4,765	4,289	1.583	144	9,220	64
3.	Windows modernisation	3,720	3,349	1.236	112	27,473	244
4.	Roof insulation	67,177	60,460	22.322	2,031	62,390	31
5.	Heating source modernisation	96,546	86,892	32.080	2,919	64,093	22
6.	Lighting modernisation	37,612	103,192	27.005	2,799	54,850	20
7.	Heating control automation	85,009	76,509	28.247	2,337	2,326	1
8.	Mechanical ventilation with heat recovery	129,718	85,169	43.103	3,922	163,777	42
9.	Lighting control automation	17,072	51,216	12.258	1,270	139,753	14
10.	Photovoltaic system	-	114,000	-	2,828	65,116	23



The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. Considering this, the best measure is the external walls insulation, which is one of the basic options proposed as a part of a thermal modernisation plan. The extremely long payback time of the windows modernisation results from the fact that the assumed heat transfer coefficient of the windows in the sport hall, which are proposed to be exchanged, is not very high (U=1.4 W/m^2•K compared to 1.1 W/m^2•K after renovation). However, the windows are leaky, and this causes a noticeable problem with highly ventilated and cold sport hall, so the measure is considered in both modernisation variants. High investment cost of installing the mechanical ventilation system in combination with technical difficulties makes it an additional option considered only as a part of the maximum efficiency variant.



The graph above presents the percentage of financial savings after implementing each measure regardless of the others. Implementing all the measures at once decreases the savings from individual measures and might change the percentage because of the interactions between options. As seen on the graph, the biggest savings are generated by external walls insulation. Low value of savings from windows modernisation results from the fact that only in the sport hall windows are proposed to be exchanged. Also, foundation walls are a small part of all the building`s walls, which causes low percentage of savings from this measure.

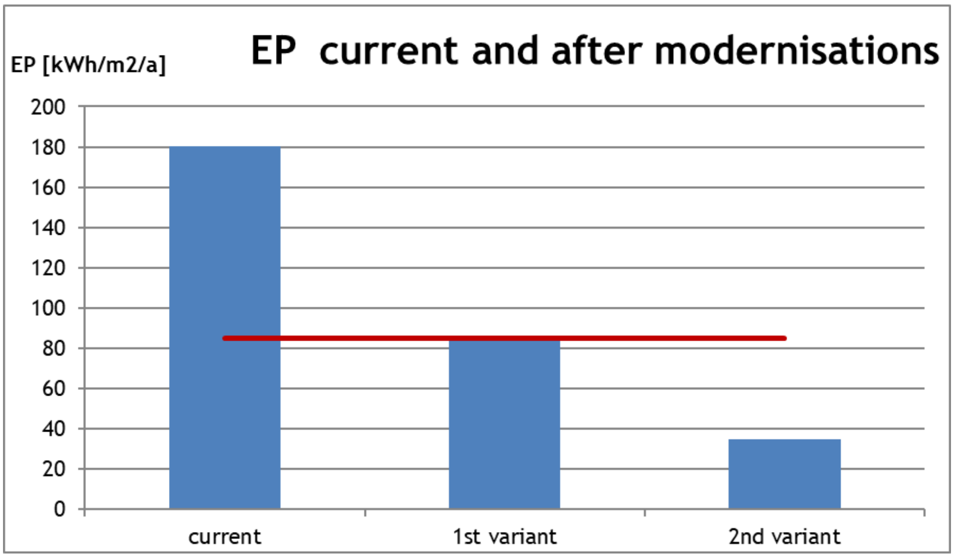
In the table below, the shares of primary energy savings due to analysed measures in each space have been presented.

Table 116 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen	Rest of the building
1.	External walls insulation	43%	10%	3%	44%
2.	Foundation walls	0%	0%	0%	100%
3.	Windows modernisation	0%	100%	0%	0%
4.	Roof insulation	36%	15%	0%	48%
5.	Heating source modernisation	39%	7%	2%	52%
6.	Lighting modernisation	33%	9%	7%	51%
7.	Heating control automation	41%	5%	3%	52%
8.	Mechanical ventilation with heat recovery	35%	7%	3%	56%

9.	Lighting control automation	34%	10%	3%	53%

Total primary energy consumption before and after implementations of measures according to 1st and 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

The main problem with the heating system is the lack of thermostats on the old plate heaters. This causes frequent overheating of the building, which results in heat waste due to ventilation by windows opening and decreases thermal comfort of the building`s users as well. The only part of the building where heaters are equipped with thermostats is the sport hall.

The proposed renovation of the heating system includes an exchange of the old iron ribbed convectors with new plate heaters with thermostats.

The modernisation includes changes in time usage of a district heating heat exchanger. Currently it produces heat 24 hours a day, 7 days a week, leading to inefficiency of the heating system. When no lessons are held nor the sport hall is unoccupied, the space heating is unnecessary. Installation of traditional heating control allowing for night and weekend temperature reduction could allow for significant energy savings with low investment cost. Also, in case there is already a controller installed, it is recommended to perform heating system rinsing and regulation. The calculated total efficiency of the system would increase from the current 0.85, to 1.05[17], according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

[17] Efficiency >1.0 is caused by applying temperature reduction in nights and weekends.

Table 117 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	559,236	462,690	96,546
Primary energy [kWh/a]	634,340	547,448	86,892
CO_2 emission [Mg/a]	207.050	174.970	32.080

Table 118 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,919	64,093	22

Estimated payback time is around 22 years. The investment cost is around 64 000 EUR, however this will improve comfort and will result in reduced number of interventions of the technical staff than in defective current installation. After the modernisation the problems with overheating and aerated heaters on the top floor corridors will be solved.

The heating source modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.1.1. Classrooms

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 33,888 kWh/a, which gives 39% reduction in the building.

2.1.1.2. Sport halls

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 6,082 kWh/a, which gives 7% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,738 kWh/a, which gives 2% reduction in the building.

2.1.2. Heating control automation

The weather forecast control system (for example Egain or Promar) is used to control the heating system, based on the local weather forecasts. It reduces the time when building becomes overheated, during some periods when there are high external temperature amplitudes during the day. This solution increases the efficiency of the system`s regulation allowing for energy savings. The calculated total efficiency of the system would increase from the current 0.85, to 0.93, according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building. Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 119 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction

Final energy [kWh/a]	559,236	474,227	85,009
Primary energy [kWh/a]	634,340	557,831	76,509
CO_2 emission [Mg/a]	207.050	178.803	28.247

Table 120 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,337	2,326	1

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however is around 1-3 years.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 31,369 kWh/a, which gives 41% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 3,825 kWh/a, which gives 5% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,295 kWh/a, which gives 3% reduction in the building.

2.2. Water and sewage system

No changes to the sewage system are considered.

2.3. HVAC

The whole building is now ventilated naturally, except the kitchen which is equipped with the mechanical exhaust ventilation.

Installing the mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows a reduction in final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 121 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	559,236	429,518	129,718
Primary energy [kWh/a]	634,340	549,171	85,169
CO_2 emission [Mg/a]	207.050	163.947	43.103

Table 122 Financial savings and investment cost of installing the mechanical ventilation with heat recovery

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,922	163,777	42

In practical terms installing the mechanical ventilation system in the existing building might be problematic and is not considered in a typical thermal modernisation scheme. This measure is proposed as a part of maximum efficiency Variant 2, which aims at fulfilling requirement for newly designed buildings.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.3.1.1. Classrooms

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 29,809 kWh/a, which gives 35% reduction in the building.

2.3.1.2. Sport halls

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 5,962 kWh/a, which gives 7% reduction in the building.

2.3.1.3. Canteen

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,555 kWh/a, which gives 3% reduction in the building.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in the building is not a commonly used installation, but only used in selected circumstances. There is only one cooling unit in the school, dedicated for the computer server room.

2.5. Electric system

In the existing state of the building, it has been estimated that the lighting consumes around 55 000 kWh of energy. According to the invoices provided by the school staff, total annual consumption of electricity is 110 284 kWh. This difference is caused by the fact that aside from the lighting there are many devices using electricity, like computers or projectors. It is also significant that there is a server room working 24 hour 7 days a week, and it is being cooled all the time by cooling unit.

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones and installing automatic control which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is a possibility of decreasing the electrical power which will reduce electricity costs. This however will not decrease the energy consumption.

2.6. Building envelope

2.6.1. External walls insulation

Thermal modernisation of the building includes insulation of the external walls, foundation walls and the roof, as well as windows modernisation. It is usually most profitable when all of the thermal modernisation measures are performed together, as a large share of costs is associated with preparation of construction field, ex. construction of scaffoldings etc.

External walls insulation decreases the heat transfer coefficient, which influences heat loss through the walls. The building envelope has not been modernised since the original state and the heat transfer coefficient is estimated at 0.95 W/m^2•K, which is high. Thermal modernisation of the building assumes insulation of the external walls with 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K.

The heat resistance of the insulation material is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

Where d – thickness [m], λ - thermal conductivity [W/m•K]

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the external walls' parameters are presented in the table below.

Table 123 Heat parameters of the external walls

Current heat transfer coefficient [W/m^2•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m^2•K/W]	Heat transfer coefficient [W/m^2•K]
0.95	0.04	0.14	3.50	0.23

The heat transfer coefficient of the external walls after the proposed modernisation equals 0.23 W/m^2•K.

Values of the energy savings, CO_2 reduction as well as the savings are presented in the tables below.

Table 124 Energy savings and CO_2 reduction after external walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	559,236	394,188	165,048
Primary energy [kWh/a]	634,340	485,797	148,543

CO_2 emission [Mg/a]	207.050	152.208	54.842

Table 125 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4,990	81,664	16

The investment cost of the external walls' insulation is relatively high, the financial savings though are satisfactory, which results in payback time of 16 years. Thus, this measure is treated as one of the basic options considered in a typical thermal modernisation scheme.

External walls insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.1. Classrooms

External walls insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 63,873 kWh/a, which gives 43% reduction in the building.

2.6.1.2. Sport halls

External walls insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 14,854 kWh/a, which gives 10% reduction in the building.

2.6.1.3. Canteen

External walls insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,456 kWh/a, which gives 3% reduction in the building.

2.6.2. Foundation walls insulation

Foundation walls insulation, the same way as external walls insulation, improves the heat parameters and decreases heat loss to the ground. The modernisation assumes insulation of the foundation walls with 10 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. The heat transfer coefficient of the foundation walls depends on the depth under the ground level. This influence is included in the equivalent heat transfer coefficient. Information on the external walls' parameters are presented in the table below.

Table 126 Heat parameters of the foundation walls

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]	Equivalent heat transfer coefficient [W/m²•K]
0.99	0.04	0.10	2.50	0.28	0.23

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 127 Energy savings and CO_2 reduction after foundation walls insulation

	Existing	After implementation	Savings/reduction

Final energy [kWh/a]	559,236	554,471	4,765
Primary energy [kWh/a]	634,340	630,051	4,289
CO_2 emission [Mg/a]	207.050	205.467	1.583

Table 128 Financial savings and investment cost of foundation walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
144	9,220	64

Foundation walls are a small part of all the building walls, which causes low percentage of financial savings from this measure. The payback time at the level of 64 years is relatively high, however when all the measures are considered together, implementing foundation walls insulation does not have much impact on the payback time of the whole modernisation in both variants. This results of the investment cost, which percentage in the total cost of the modernisation is not high.

Foundation walls would result in a reduction of primary energy consumption in zones located in the basement. In the basement there are not any classrooms, canteens or sport halls.

2.6.3. Windows modernisation

Windows modernisation includes an exchange of the windows in the sport hall with new ones of U=1.1 W/m^2•K. In the existing state the windows in the sport hall are leaky and their heat transfer coefficient equals 1.4 W/m^2•K. Windows in the rest of the building were exchanged between 2000 and 2002 and their parameters are good. The proposed measure could solve the problem with highly ventilated and too cold sport hall.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 129 Energy savings and CO_2 reduction after windows modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	559,236	555,516	3,720
Primary energy [kWh/a]	634,340	630,991	3,349
CO_2 emission [Mg/a]	207.050	205.814	1.236

Table 130 Financial savings and investment cost of windows modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
112	27,473	244

The extremely long payback time of the windows modernisation results from the fact that the assumed heat transfer coefficient of the windows in the sport hall, which are proposed to be exchanged, is not very high (U=1.4 W/m^2•K compared to 1.1 W/m^2•K after renovation). However, the windows are leaky, and this causes a noticeable problem with highly ventilated and cold sport hall, so the measure is considered in both modernisation variants.

Windows modernisation would result in a reduction of primary energy consumption sport hall.

Windows modernisation would result in a reduction of primary energy consumption only in the Sport hall. Primary energy consumption reduction in the Sport hall equals 3,349 kWh/a, which gives 100% reduction in the building.

2.6.4. Roof insulation

Roof insulation allows the improvement of heat parameters, which decreases heat loss. In the proposed modernisation variant, the insulation with 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K is considered.

The overall heat resistance is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the roof materials and parameters are presented in the table below.

Table 131 Heat parameters of the roof

Current heat transfer coefficient [W/m^2•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m^2•K/W]	Heat transfer coefficient [W/m^2•K]
0.50	0.04	0.14	3.50	0.18

The heat transfer coefficient of the roof after the proposed modernisation equals 0.18 W/m^2•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 132 Energy savings and CO_2 reduction after roof insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	559,236	492,059	67,177
Primary energy [kWh/a]	634,340	573,880	60,460
CO_2 emission [Mg/a]	207.050	184.728	22.322

Table 133 Financial savings and investment cost of roof insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,031	62,390	31

Annual financial savings from the roof insulation are about 2,000 EUR. The payback time is 31 years. The measure will also improve the thermal comfort in the building and is considered as one of the basic options proposed as a part of typical thermal modernisation.

Roof insulation would result in a reduction of primary energy consumption in classrooms and sport halls.

Primary energy in the amount of 21,766 kWh/a would be saved in classrooms, while 9,069 kWh/a would be saved in the Sport hall and 0 kWh/a would be saved in the canteen and its facilities.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, Photovoltaic installation of power up to 40 kWp is defined as a small installation and can be connected to the grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 37% of the roof – 660 m^2. In Warsaw the productivity of PV is about 950 kWh/kWp so this installation would provide 38,000 kWh a year.

2.8. Lighting system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 134 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	559,236	521,624	37,612
Primary energy [kWh/a]	634,340	531,148	103,192
CO_2 emission [Mg/a]	207.050	180.045	27.005

Table 135 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,799	54,850	20

Financial savings from lighting modernisation are about 2,800 EUR and payback time is 20 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 34,053 kWh/a, which gives 33% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 9,287 kWh/a, which gives 9% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 7,223 kWh/a, which gives 7% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing automatic control which is based on the amount of light from the outside and presence of people in a room. In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 136 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	559,236	542,164	17,072
Primary energy [kWh/a]	634,340	583,124	51,216
CO_2 emission [Mg/a]	207.050	194.792	12.258

Table 137 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,270	18,283	14

Investment cost of the modernisation is about 18,000 EUR. Payback time of the measure is relatively low – at a level of 14 years. As this option decreases electricity consumption, primary energy savings are relatively high, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 17,413 kWh/a, which gives 34% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 5,122 kWh/a, which gives 10% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,536 kWh/a, which gives 3% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the first variant is limited by foundation program specifications and the second variant is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the second variant the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control. Users should be trained how to use the system, so that it would work effectively and properly.

In the first variant it is the heating which is, as the only system, controlled automatically. This means that users can turn off the lighting only manually. The last person leaving specific room ought to always remember to turn off the lights. Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 5 parameters: size of the school, amount of energy it consumes/ loses by specific element, number of heaters and annual usage cost and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service.

Table 138 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	External walls insulation	1 m^2	42	-
2.	Foundation walls	1 m^2	105	-
3.	Windows modernisation	1 m^2	233	-
4.	Roof insulation	1 m^2	35	-
5.	Heating source modernisation	1 heater	134	11,628
6.	Lighting modernisation	1 W	1.74	-
7.	Heating control automation	Annual usage	233	2,326

8.	Mechanical ventilation with heat recovery	1 m^2	47	-
9.	Lighting control automation	1 W	0.58	-
10.	Photovoltaic system	1 kWp	1628	-

2.12.2. Accuracy

During the process of evaluation, a few simplifications have been done. Firstly, the analytical model was adjusted so that it consumes similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the calculated savings can be a bit lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), heat – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Insulation of external walls and roof - experience from the Polish market shows that huge share of total costs is labour and materials, however scaffolding and equipment may represent up to 30% of total costs. Accuracy level is around 80%.

Insulation of foundation walls – similar as the insulation of the external wall. However, in this case the work is much more difficult to do so the cost of labour is even higher. Approximately about 90%.

Windows modernisation – In this case the main cost are new windows. Accuracy level can be estimated at 90%.

Heating source modernisation and control automation – Prices found on one of the companies` website. Accuracy level 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs for about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy 90%.

Mechanical ventilation – based on author’s experience and expert opinions but estimation is not easy because of variety of every school. Accuracy level on 80%.

2.12.3. Methods and standards used

Most of methods were based on author’s experience, knowledge and internet offers from existing companies.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the *Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building* separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 139 Standards used during energy audit

	Applied version	English version
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements
2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings – Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczeń."	EN ISO 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods
6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków - Wymiana ciepła przez grunt - Metody obliczania."	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach - Liniowy współczynnik przenikania ciepła - Metody uproszczone i wartości orientacyjne."	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia."	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane -- Właściwości cieplno-wilgotnościowe -- Tabelaryczne wartości obliczeniowe i procedury określania deklarowanych i obliczeniowych wartości cieplnych"	ISO 10456:2007 Building materials and products -- Hygrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania"	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system"	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 "Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance"	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 140 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit

	termomodernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	
3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metody obliczania oszczędności energii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency audit card and methods for calculating energy savings
5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) - raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) - raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme - 1st variant

3.1. Aim of the renovation plan

The aim of the first renovation plan is to modernize the building so that it meets Polish building standards and consumes less energy. As the result the costs of maintenance of the school will be lower. Such modernisation plan was chosen due to the possibility of getting funds from the BGK thermal-modernisation and renovation program, which is a national programme supporting thermal modernisation of buildings in Poland.

The first variant includes the following measures:

- External walls insulation
- Windows modernisation
- Roof insulation
- Heating source modernisation
- Lighting modernisation

The extent of each measure incudes meeting the minimum requirements, despite the costs or payback time. There are no other boundaries to renovate this building in a way proposed above.

3.2. Criteria for ranking energy efficiency improvement measures

The main criterion was to meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 W/m^2•K
- heat transfer coefficient of windows: U = 1.1 W/m^2•K
- heat transfer coefficient of roofs: U = 0.18 W/m^2•K

Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not.

Last criterion is the improvement of thermal comfort in the building. This however cannot be measured, but it is important to remember that sometimes it is more important to improve comfort than to save money.

3.3. Potential interactions with other proposed recommendation

The only affected parameter is the heating source. Each modernisation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation) affects the work of a heat exchanger. The better the condition of a building, the less heat needs to be provided. The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions. Lighting has no effect on any of other renovations.

3.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls and foundation walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.23W/ m^2•K.

Roof insulation – the best option is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K.

Replacement of windows – In this case there is no other option but to replace all old windows with new ones with heat transfer coefficient of 1.1 W/m^2•K.

Heating source improvements – Replacing old iron ribbed convectors with new plate heaters with thermostats. Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs to LED ones.

When it comes to lighting and heating source both money and final energy savings were considered. LEDs are one of the eco-friendliest lighting choices whilst also their high efficiency leads to economical savings. When it comes to the heating source, replacing old iron ribbed convectors with new plate heaters with thermostats is the best economical option, which will also have definite impact on the thermal comfort in the building. Some of the heaters in the corridors are covered with shields for safety issues, this however decreases the efficiency of radiant heating. It is recommended to consider another means of preventing the children from burning, so that it improves the heat distribution in the building. Installing heating source automation decreases the usage of heating when it is not necessary (weekends and nights), so it improves the system`s efficiency.

The measures considered in the 1st variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 141 Measures included in the 1st variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	165,048	148,543	54.842	4,990	81,664	16
2.	Lighting modernisation	37,612	103,192	27.005	2,799	54,850	20
3.	Heating source modernisation	96,546	86,892	32.080	2,919	64,093	22
4.	Roof insulation	67,177	60,460	22.322	2,031	62,390	31
5.	Foundation walls insulation	4,765	4,289	1.583	144	9,220	64
6.	Windows modernisation	3,720	3349	1.236	112	27,473	244
	Total	294,892	334,745	110.723	10,374	299,689	29

The most beneficial option is the external walls insulation, despite high investment cost, as both energy savings and financial savings are the highest of all the measures, resulting in the shortest payback time of 16 years. The windows modernisation has the longest payback time, however, as indicated in previous paragraphs, it has another significant advantage, such as solving the problem with cold and highly ventilated sport hall. The foundation walls insulation is concerned despite long payback time, as it does not have much impact on the total cost and payback time of the whole modernisation variant.

3.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	180.1	85.1
Primary energy consumption - heating [kWh/m²a]	118.6	51.7
Primary energy consumption - DHW [kWh/m²a]	14.7	14.7
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	46.9	18.8
Final energy consumption - total [kWh/m²a]	158.8	75.1
Final energy consumption - heating [kWh/m²a]	128.3	53.9
Final energy consumption - DHW [kWh/m²a]	14.9	14.9

Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	15.6	6.3
CO_2 emissions - total [kg/m²a]	58.801	
CO_2 emissions - heating [kg/m²a]	42.628	
CO_2 emissions - DHW [kg/m²a]	4.952	
CO_2 emissions - cooling [kg/m²a]	n/a	
CO_2 emissions - lighting [kg/m²a]	11.222	

The 1st renovation variant allows reducing final energy consumption by around 295 MWh/a and primary energy consumption by around 335 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 300,000 EUR and the estimated payback time is at the level of 29 years. The EP factor of the building after implementing the proposed measures would achieve about 85 kWh/m²/a, which makes the building much more efficient.

4. Renovation scheme - 2nd variant

4.1. Aim of the renovation plan

The aim of the second renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The second variant includes all measures of the 1st variant with the following additional renovations:

- Heating control automation
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

4.2. Criteria for ranking energy efficiency improvement measures

The aim of the second variant is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows for large final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

4.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation, heating control automation, etc.) affects the work of the heat exchanger. The better the condition of a building, the less heat needs to be provided. Also, changes in usage time of the heating system influences other measures decreasing the heat consumption – turning the heating off during nights and weekends decreases energy savings from walls and roof insulation as well as windows modernisation or mechanical ventilation with heat recovery, as the time they work and generate savings is also shorter.

Lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions.

4.4. Suggested measures (optimal implementation plan)

Based on previous paragraphs the implementation plan includes the following measures:

Insulation of external walls and foundation walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0,04. Added to existing state it allows to meet required standard of U = 0.23W/m^2•K.

Roof insulation – the best option is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0,04. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K.

Replacement of windows – In this case there it is suggested to replace all old windows with new ones with heat transfer coefficient with 1.1 W/m^2•K value.

Heating source improvements - Replacing old iron ribbed convectors with new plate heaters with thermostats. Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs for LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the Egain/Promar etc. system, which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used to 0 m3/h.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the 2nd variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 142 Measures included in the 2nd variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]

1.	Heating control automation	85,009	76,509	28.247	2,337	2,326	1
2.	Lighting control automation	17,072	51,216	12.258	1,270	139,753	14
3.	External walls insulation	165,048	148,543	54.842	4,990	81,664	16
4.	Lighting modernisation	37,612	103,192	27.005	2,799	54,850	20
5.	Heating source modernisation	96,546	86,892	32.080	2,919	64,093	22
6.	Photovoltaic system	-	114,000	-	2,828	65,116	23
7.	Roof insulation	67,177	60,460	22.322	2,031	62,390	31
8.	Mechanical ventilation with heat recovery	129,718	85,169	43.103	3,922	163,777	42
9.	Foundation walls insulation	4,765	4,289	1.583	144	9,220	64
10.	Windows modernisation	3,720	3,349	1.236	112	27,473	244
	Total	384,828	512,450	143.242	13,395	549,191	41

The shortest payback time (typically 1-3 years) is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view. The windows modernisation has the longest payback time, however, as indicated in previous paragraphs, it has another significant advantage, such as solving the problem with cold and highly ventilated sport hall.

4.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	180.1	34.6
Primary energy consumption - heating [kWh/m²a]	118.6	39.4
Primary energy consumption - DHW [kWh/m²a]	14.7	14.7
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	46.9	12.9
Final energy consumption - total [kWh/m²a]	158.8	49.5
Final energy consumption - heating [kWh/m²a]	128.3	30.3
Final energy consumption - DHW [kWh/m²a]	14.9	14.9
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	15.6	4.3
CO_2 emissions - total [kg/m²a]	58.801	18.121
CO_2 emissions - heating [kg/m²a]	42.628	10.074

CO_2 emissions - DHW [kg/m²a]	4.952	4.952
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	11.222	3.096

The 2nd renovation variant allows reducing final energy consumption by around 385 MWh/a and primary energy consumption by around 398 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 550 000 EUR and the estimated payback time is at the level of 41 years. The EP factor of the building after implementing the proposed measures would achieve about 34.6 kWh/m²/a, which makes the building much more efficient. The total costs of the maximum efficiency variant are significantly higher than the 1st variant, also in reference to the energy savings. Thus, the 1st variant is more realistic and is proposed as the basic one.

5. Attachments

No attachments.

VII. Building #7 SP 277 (ul. Suwalska 29, 03-252 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building was built in 1970. Since then, there were a few modernizations of the building envelope and systems: a modernization of a district heating heat exchanger in 1980, a modernization of windows and walls in a sport hall in 1995 (walls were insulated), exchange of windows in the rest of the building in 2000. In 2005 there was a modernization of the roof in the sport hall and it was thermally insulated. Heat parameters of external partitions are poor. New PVC windows are leaky, and it is often cold in the building. The installation of the central heating system is old, and it often gets aerated, so the city hall technical crew must intervene even a few times during the heating season. The building is heated with the district heating, the system is weather controlled, and the heating schedules are applied. Old iron ribbed convectors in the classrooms and corridors have never been exchanged and they lack thermostats. The building does not have any HVAC systems except dedicated mechanical ventilation in the kitchen and one cooling unit in the computer room. The whole building is equipped with traditional fluorescent bulbs manually controlled by users. The building does not have any BMS system.

The general overview of the building allowed for giving a poor opinion about energy efficiency of the building. The measured final energy indicator for heating is 172.77 kWh/m^{2}a, which is high.

In 2013 there was a new investment near the school building. The pre-school barrack was connected to the main building, however it is not treated as a typical building. It does not consume any heat energy, as it is fully powered by electricity, and thus the heating parameter concerns only the main school building.

1.2. Summary table: existing state of the builiding

Category	Value
Building type[18]	Educational building
Constriction year / major reconstruction year	1970
Building fabric[19]	Brick, steel reinforced concrete (roof), aerated concrete slabs (roof)
Building useful area [m^2]	3,753 m^2
Useful area of the audited zone [m^2]	Classrooms: 1,638 m^2

[18] Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

[19] E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

	Sport hall: 191 m^2 Canteen: 245 m^2 (with facilities)
Shape factor - building [1/m]	0.307
Building volume [m^3]	12,209 m^3
Volume of the audited zone [m^3]	Classrooms : 5 242 m^3 Sport hall: 1,146 m^3 Canteen: 784 m^3 (with facilities)
Shape factor - audited zone [1/m]	Classrooms :0.313 1/m Sport hall: 0.167 1/m Canteen: 0.313 1/m (with facilities)
Number of floors	4
Number of building users	900
Heating system	District heating+iron ribbed radiators without thermostats
Domestic hot water (DHW) system	District heating, the same source as the central heating
Cooling system	One unit for the computer classroom
Lightning system	2xT8 fittings with 2x36W fluorescent bulbs, switched on manually when needed
Primary energy consumption - total [kWh/m^2a]	184.4
Primary energy consumption - heating [kWh/m^2a]	136.1
Primary energy consumption - DHW [kWh/m^2a]	14.6
Primary energy consumption - cooling [kWh/m^2a]	n/a
Primary energy consumption - lighting [kWh/m^2a]	33.7
Final energy consumption - total [kWh/m^2a]	173.1
Final energy consumption - heating [kWh/m^2a]	147.0
Final energy consumption - DHW [kWh/m^2a]	14.9
Final energy consumption - cooling [kWh/m^2a]	n/a
Final energy consumption - lighting [kWh/m^2a]	11.2
CO_2 emissions - total [kg/m^2a]	61.858
CO_2 emissions - heating [kg/m^2a]	48.852
CO_2 emissions - DHW [kg/m^2a]	4.939
CO_2 emissions - cooling [kg/m^2a]	n/a
CO_2 emissions - lighting [kg/m^2a]	8.067

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to total energy savings after applying measures together in Variant 1 and Variant 2.

The recommended Variant 1 is a typical thermal modernisation scheme applied in Poland, that is usually introduced when the owner of the building is applying for financial subsidies for thermal modernisation. Application of all measures allows to meet current technical requirements for buildings, namely maximum U-values for external walls, roof, and windows.

The maximum efficiency Variant 2 is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values lower than 0 kWh/m^{2}a. This value however is only achieved because of energy consumption in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

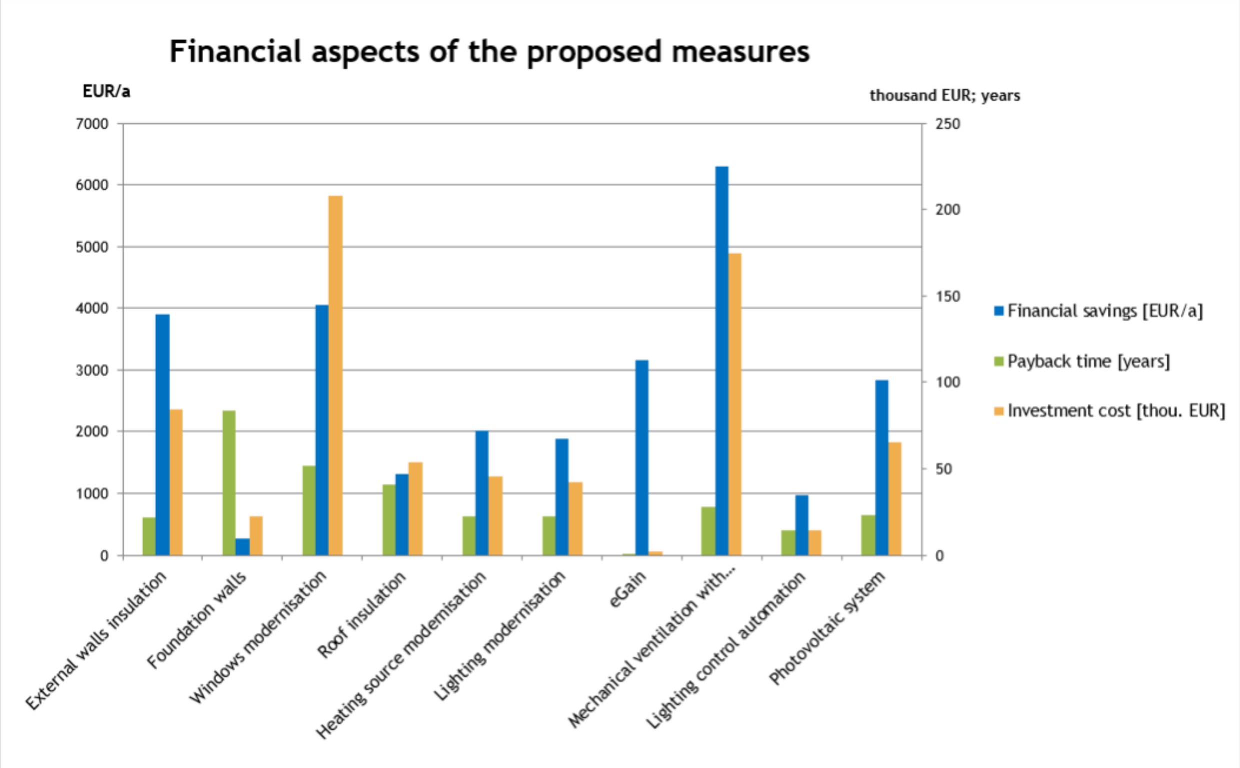
The table presented in section 1.4 contains all analysed measures. Measures 1-6 are considered as a basic modernisation (Variant 1). In order to achieve the nZEB standard, measures 7-10 are added.

For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

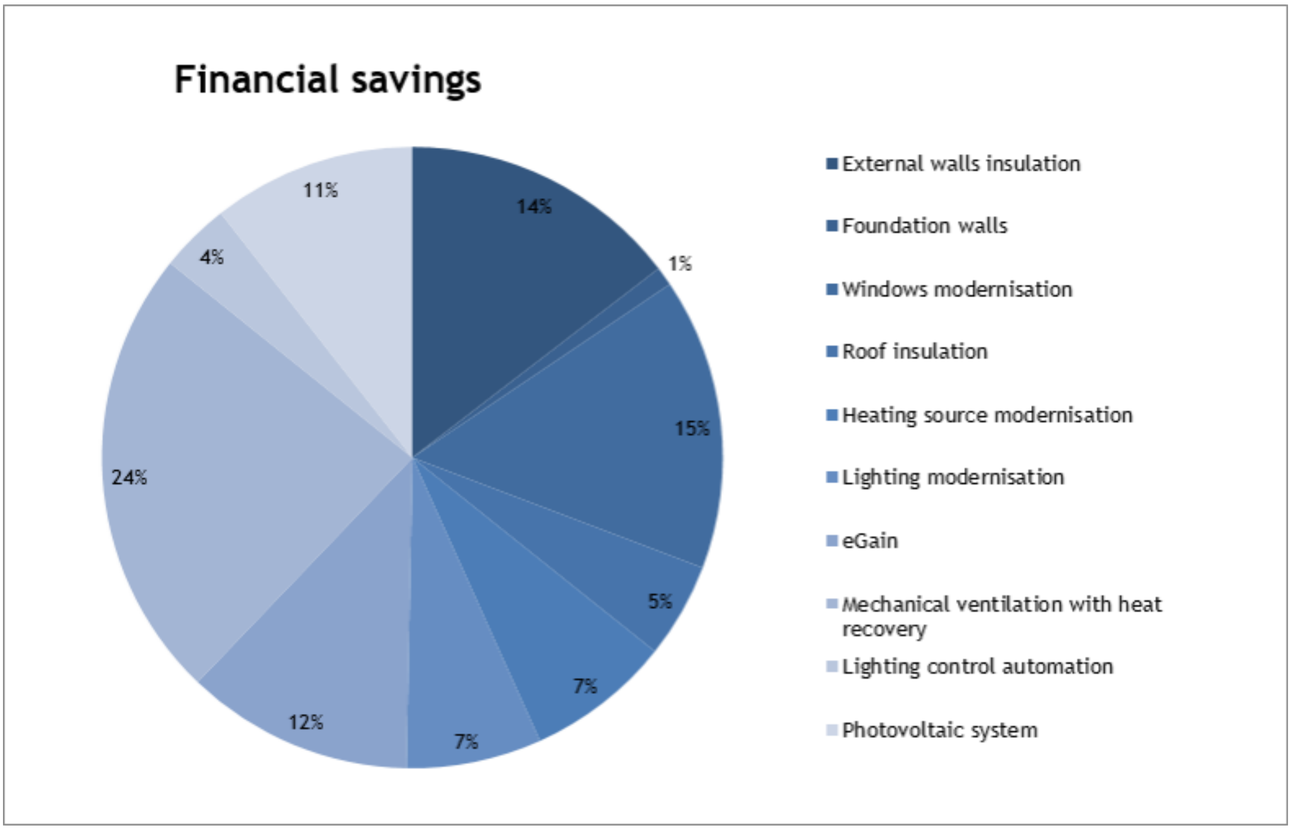
1.4. Summary table: suggested measures, energy savings, financial savings

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	128,852	115,966	42.815	3,896	84,384	22
2.	Foundation walls	8,730	7,857	2.901	264	22,160	84
3.	Windows modernisation	134,206	120,785	44.594	4,057	208,391	51
4.	Roof insulation	43,764	39,388	14.542	1,323	53,829	41
5.	Heating source modernisation	66,548	59,893	22.113	2,012	45,395	23
	Lighting modernisation	25,300	75,901	18.165	1,883	42,027	22
7.	Heating control automation	112,371	101,133	37.339	3,165	2,326	1
8.	Mechanical ventilation with heat recovery	208,526	151,956	69.289	6,304	174,558	28

9.	Lighting control automation	13,081	39,243	9.391	973	14,009	14
10.	Photovoltaic system	-	114,000	-	2,828	65,116	23



The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. Considering this, the best measures are the external walls insulation and heating source modernisation, which is one of the basic options proposed as a part of a thermal modernisation plan. Relatively long payback time and investment cost of the windows modernisation might result from the fact that the assumed heat transfer coefficient of the windows does not change after the renovation. However, the windows are very leaky, and this causes a noticeable problem as cold air gets through draughty windows lowering the thermal comfort in the classrooms. Thus, the measure is considered in both renovation variants.



The graph above presents the percentage of financial savings after implementing each measure regardless of the others. Implementing all the measures at once decreases the savings from individual measures and might change the percentage because of the interactions between options. As seen on the graph, the biggest savings would be generated by installing the mechanical ventilation. This however requires big investment costs and might be problematic from technical point of view. The external walls and windows modernisation are beneficial options, which are treated as the basic ones. Foundation walls are a small part of all the building`s walls, which causes low percentage of savings from this measure.

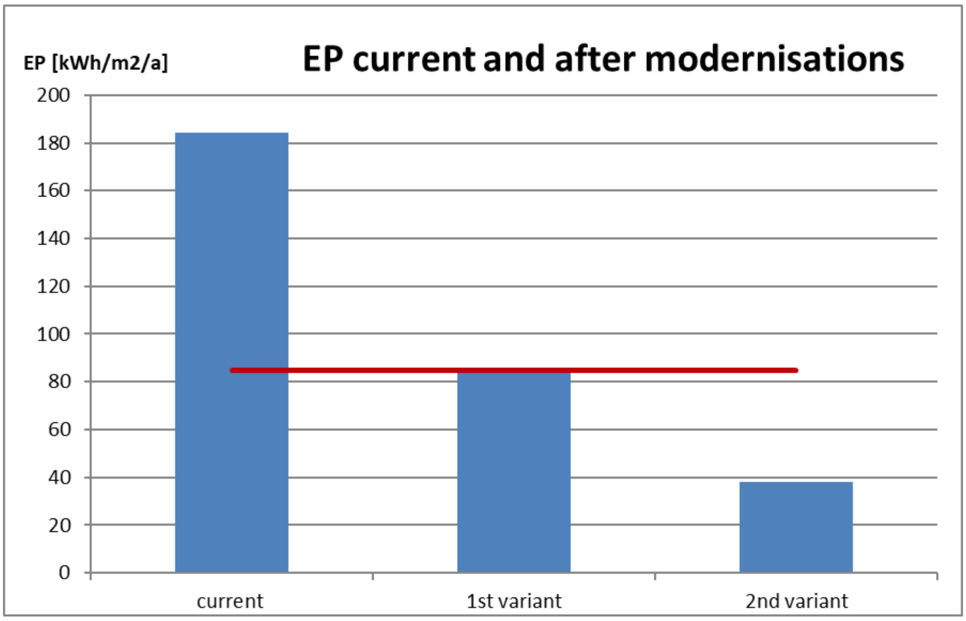
In the table below the shares of primary energy savings due to analysed measures in each space are presented.

Table 143 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen	Rest of the building
1.	External walls insulation	43%	8%	3%	46%
2.	Foundation walls	32%	0%	0%	68%
3.	Windows modernisation	44%	5%	6%	46%
4.	Roof insulation	46%	7%	0%	47%
5.	Heating source modernisation	43%	5%	4%	49%
6.	Lighting modernisation	44%	5%	7%	45%
7.	Heating control automation	42%	8%	4%	47%
8.	Mechanical ventilation with heat	43%	4%	8%	45%

	recovery				
9.	Lighting control automation	44%	5%	7%	45%

Total primary energy consumption before and after implementations of measures according to 1st and 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

One of the problems with the heating system is the lack of thermostats on the old plate heaters. This results in a big heat waste due to ventilation by windows opening and decreases thermal comfort of the building`s users as well. It is usually too cold in the whole building, which is caused mainly by leaky windows and faulty heating installation that often gets aerated and needs to be serviced.

The proposed renovation of the heating system includes an exchange of the old iron ribbed convectors with new plate heaters with thermostats.

The heating system is equipped with PROMAR technology for the control of the heating source and comfort parameters in the building, thus it is assumed that heating is not used during weekends and nights. No changes in the usage time of the system are proposed

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 144 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	583,174	66,548
Primary energy [kWh/a]	691,927	632,034	59,893
CO_2 emission [Mg/a]	232.154	210.041	22.113

Table 145 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,012	45,395	23

Estimated payback time is around 23 years. The investment cost is around 45,000 EUR, however this will improve comfort and will result in reduced number of interventions of the technical staff than in defective current installation. After the modernisation the problems with too cold rooms and aerated heaters will be solved.

The heating source modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.1.1. Classrooms

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 25,754 kWh/a, which gives 43% reduction in the building.

2.1.1.2. Sport halls

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 2,995 kWh/a, which gives 5% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,396 kWh/a, which gives 4% reduction in the building.

2.1.2. Heating control automation

The weather forecast control (for example Egain or Promar) system is used to control the heating system provided by the local weather forecasts. This solution increases the efficiency of the system`s regulation. It is possible that PROMAR device installed in the system already has a possibility of using the weather control algorithm. We advice to contact Promar company in order to apply this algorithm in the controler.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 146 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	537,351	112,371
Primary energy [kWh/a]	691,927	590,793	101,133
CO_2 emission [Mg/a]	232.154	194.82	37.339

Table 147 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,165	2,326	1

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however is around 1-3 years.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 42,476 kWh/a, which gives 42% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 8,091 kWh/a, which gives 8% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,045 kWh/a, which gives 4% reduction in the building.

2.2. Water and sewage system

No changes will be added to the water and sewage system.

2.3. HVAC

The whole building is now ventilated naturally, except the kitchen which is equipped with the mechanical exhaust ventilation.

Installing the mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows a reduction in final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 148 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	441,195	208,526
Primary energy [kWh/a]	691,927	539,970	151,956
CO_2 emission [Mg/a]	232.154	162.865	69.289

Table 149 Financial savings and investment cost of mechanical ventilation with heat recovery

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
6,304	174,558	28

In practical terms installing the mechanical ventilation system in the existing building might be problematic and is not considered in a typical thermal modernisation scheme. This measure is proposed as a part of maximum efficiency Variant 2, which aims at fulfilling requirement for newly designed buildings.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.3.1.1. Classrooms

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 65,341 kWh/a, which gives 43% reduction in the building.

2.3.1.2. Sport halls

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 6,078 kWh/a, which gives 4% reduction in the building.

2.3.1.3. Canteen

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 12,156 kWh/a, which gives 8% reduction in the building.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in the building is not a commonly used installation, but only used in selected circumstances. There is only one cooling unit in the school, dedicated for the computer classroom, which is used only when needed.

2.5. Electric system

In the existing state of the building, it has been estimated that the lighting consumes around 42,000 kWh of energy. According to the invoices provided by the school staff, total annual consumption of electricity is 220,599 kWh. This however includes energy consumption of barracks with pre-school. Because energy consumption of these units is not separated from each other, it is impossible to separate the energy used strictly by the building of SP 277.

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones and installing automatic control, which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is a possibility of decreasing the electrical power which will reduce electricity costs. This however will not decrease the energy consumption.

2.6. Building envelope

2.6.1. External walls insulation

Thermal modernisation of the building includes insulation of the external walls, foundation walls and the roof, as well as windows modernisation. It is usually most profitable when all of the thermal modernisation measures are performed together, as a large share of costs is associated with preparation of construction field, ex. construction of scaffoldings etc.

External walls insulation decreases the heat transfer coefficient, which influences heat loss through the walls. There were a few modernisations of the building envelope since the original state, the heat parameters of the external partitions are poor though. The heat transfer coefficient of the walls in the sport hall is 0,61 $W/m^2 \bullet K$ and in the other parts of the building it equals 0.95 $W/m^2 \bullet K$, which is high. Thermal modernisation of the building assumes insulation of the external walls with 14 cm of polystyrene with thermal conductivity parameter of λ=0,04 W/m•K in the whole building except the sport hall. In the sport hall the insulation of 8 cm of polystyrene with thermal conductivity parameter equal λ=0,04 W/m•K is proposed.

The heat resistance of the insulation material is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

Where d – thickness [m], λ - thermal conductivity [W/m•K]

The overall heat transfer coefficient is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the external walls' parameters are presented in the table below.

Table 150 Heat parameters of the external walls

Current heat transfer coefficient [$W/m^2 \bullet K$]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [$m^2 \bullet K/W$]	Heat transfer coefficient [$W/m^2 \bullet K$]
0.95	0.04	0.14	3.50	0.23

Table 151 Energy savings and CO_2 reduction after external walls insulation

Current heat transfer coefficient [$W/m^2 \bullet K$]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [$m^2 \bullet K/W$]	Heat transfer coefficient [$W/m^2 \bullet K$]

0.61	0.04	0.08	2.00	0.23

The heat transfer coefficient of the external walls in the whole building after the proposed modernisation equals 0.23 W/m²•K.

Values of the energy savings, CO_2 reduction as well as the savings are presented in the tables below.

Table 152 Energy savings and CO_2 reduction after external walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	520,870	128,852
Primary energy [kWh/a]	691,927	575,960	115,966
CO_2 emission [Mg/a]	232.154	189.339	42.815

Table 153 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
3,896	84,384	22

The investment cost of the external walls' insulation is relatively high, the financial savings though are satisfactory, which results in payback time of 22 years. Thus, this measure is treated as one of the basic options considered in a typical thermal modernisation scheme.

External walls insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.1. Classrooms

External walls insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 49,865 kWh/a, which gives 43% reduction in the building.

2.6.1.2. Sport halls

External walls insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 9,277 kWh/a, which gives 8% reduction in the building.

2.6.1.3. Canteen

External walls insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 3,479 kWh/a, which gives 3% reduction in the building.

2.6.2. Foundation walls insulation

Foundation walls insulation, the same way as external walls insulation, improves the heat parameters and decreases heat loss to the ground. The modernisation assumes insulation of the foundation walls with 10 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. The heat transfer coefficient of the foundation walls depends on the depth under the ground level. This influence is included in the equivalent heat transfer coefficient. Information on the external walls' parameters are presented in the table below.

Table 154 Heat parameters of the foundation walls

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]	Equivalent heat transfer coefficient [W/m²•K]
0.98	0.04	0.10	2.50	0.28	0.23

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 155 Energy savings and CO_2 reduction after foundation walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	640,992	8,730
Primary energy [kWh/a]	691,927	684,070	7,857
CO_2 emission [Mg/a]	232.154	119.253	2.901

Table 156 Financial savings and investment cost of foundation walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
264	22,160	84

Foundation walls are a small part of all the building walls, which causes low percentage of financial savings from this measure. The payback time at the level of 84 years is high, however when all the measures are considered together, implementing foundation walls insulation does not have much impact on the payback time of the whole modernisation in both variants. This results of the investment cost, which percentage in the total cost of the modernisation is not high.

Foundation walls would result in a reduction of primary energy consumption in classrooms and other zones.

Primary energy in the amount of 2 514 kWh/a would be saved in classrooms, while 0 kWh/a would be saved in the Sport hall and 0 kWh/a would be saved in the canteen and its facilities.

2.6.3. Windows modernisation

Windows modernisation includes an exchange of the windows with new ones. In the existing state the windows are very leaky and this causes a big heat loss by increasing the air flow in the whole building. Despite the fact that current heat transfer coefficient equals 1.1 $W/m^2 \cdot K$, the proposed renovation scheme includes an exchange of all the windows in the building. The energy savings were calculated by decreasing the airflow from 0,00112 $m^3/s/m^2$ to 0,00056 $m^3/s/m^2$ after the renovation.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 157 Energy savings and CO_2 reduction after windows modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	515,515	134,206
Primary energy [kWh/a]	691,927	571,142	120,785
CO_2 emission [Mg/a]	232.154	187.56	44.594

Table 158 Financial savings and investment cost of windows modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4 057	208 391	51

Relatively long payback time of the windows modernisation might result from the fact that the assumed heat transfer coefficient of the windows does not change after the renovation. However, the windows are leaky, and this causes a noticeable problem as cold air gets through draughty windows lowering the thermal comfort in the classrooms. It often happens that water flows through windows during heavy rains, so this modernisation is considered in both modernisation variants.

Windows modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.3.1. Classrooms

Windows modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 53,145 kWh/a, which gives 44% reduction in the building.

2.6.3.2. Sport halls

Windows modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 6,039 kWh/a, which gives 5% reduction in the building.

2.6.3.3. Canteen

Windows modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 7,247 kWh/a, which gives 6% reduction in the building.

2.6.4. Roof insulation

Roof insulation allows the improvement of heat parameters, which decreases heat loss. In the proposed modernisation variant, the insulation with 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K is considered in the whole building except the sport hall. In the sport hall the insulation of 10 cm of polystyrene with thermal conductivity parameter equal λ=0.04 W/m•K is proposed.

The overall heat resistance is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

The overall heat transfer coefficient is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the roof materials and parameters are presented in the table below.

Table 159 Heat parameters of the roof

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.50	0.04	0.14	3.50	0.18

Table 160 Heat parameters of the roof

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.33	0.04	0.10	2.50	0.18

The heat transfer coefficient of the roof in the whole building after the proposed modernisation equals 0.18 W/m²•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 161 Energy savings and CO_2 reduction after roof insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	605,957	43,764
Primary energy [kWh/a]	691,927	652,539	39,388
CO_2 emission [Mg/a]	232.154	217.612	14.542

Table 162 Financial savings and investment cost of roof insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,323	53,829	41

Annual financial savings from the roof insulation are about 1 300 EUR. The payback time is 41 years. The measure will also improve the thermal comfort in the building and is considered as one of the basic options proposed as a part of typical thermal modernisation.

Roof insulation would result in a reduction of primary energy consumption in classrooms and sport hall.

Primary energy in the amount of 18,118 kWh/a would be saved in classrooms, while 2,757 kWh/a would be saved in the Sport hall and 0 kWh/a would be saved in the canteen and its facilities.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, Photovoltaic installation of power up to 40 kWp is defined as a small installation and can be connected to the grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 43% of the roof – 660 m^2. In Warsaw the productivity of PV is about 950 kWh/kWp so this installation would provide 38,000 kWh a year.

2.8. Lightning system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 163 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	624,421	25,300
Primary energy [kWh/a]	691,927	616,026	75,901
CO_2 emission [Mg/a]	232.154	213.988	18.165

Table 164 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,883	42,027	22

Financial savings from lighting modernisation are about 1,900 EUR and payback time is 22 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 33,396 kWh/a, which gives 44% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 3,795 kWh/a, which gives 5% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 5,313 kWh/a, which gives 7% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing automatic control which is based on the amount of light from the outside and presence of people in a room. In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 165 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	649,721	636,640	13,081
Primary energy [kWh/a]	691,927	652,684	39,24
CO_2 emission [Mg/a]	232.154	222.762	9.391

Table 166 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
973	14,009	14

Investment cost of the modernisation is about 14,000 EUR. Payback time of the measure is relatively low with the level of 14 years. As this option decreases electricity consumption, primary energy savings are high in reference to final energy savings, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 17,267 kWh/a, which gives 44% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 1,962 kWh/a, which gives 5% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,747 kWh/a, which gives 7% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the first variant is limited by foundation program specifications and the second variant is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the second variant the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control. Users should be trained how to use the system, so that it would work effectively and properly.

In the first variant it is the heating which is, as the only system, controlled automatically. This means that users can turn off the lighting only manually. The last person leaving specific room ought to always remember to turn off the lights. Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 5 parameters: size of the school, amount of energy it consumes/ loses by specific element, number of heaters and annual usage cost and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service.

Table 167 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	External walls insulation	1 m^2	42	-
2.	Foundation walls	1 m^2	105	-
3.	Windows modernisation	1 m^2	233	-
4.	Roof insulation	1 m^2	35	-
5.	Heating source modernisation	1 heater	134	11,628
6.	Lighting modernisation	1 W	1.74	-
7.	Heating control automation	Annual usage	233	2,326
8.	Mechanical ventilation with heat recovery	1 m^2	47	-
9.	Lighting control automation	1 W	0.58	-

10.	Photovoltaic system	1 kWp	1,628	-

2.12.2. Accuracy

During the process of evaluation, a few simplifications have been done. Firstly, the analytical model was adjusted so that it consumes similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. In case of electricity there were big discrepancies between the calculations and the data following the invoices. This however results from the fact that the energy consumption of the school and the barracks of pre-school is not separated. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the calculated savings can be a bit lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), heat – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Insulation of external walls and roof - experience from the Polish market shows that huge share of total costs is labour and materials, however scaffolding and equipment may represent up to 30% of total costs. Accuracy level is around 80%.

Insulation of foundation walls – similar as the insulation of the external wall. However, in this case the work is much more difficult to do so the cost of labour is even higher. Approximately about 90%.

Windows modernisation – In this case the main cost are new windows. Accuracy level can be estimated at 90%.

Heating source modernisation and control automation – Prices found on one of the companies` website. Accuracy level 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs for about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy 90%.

Mechanical ventilation – based on author’s experience and expert opinions but estimation is not easy because of variety of every school. Accuracy level on 80%.

2.12.3. Methods and standards used

Most of methods were based on author’s experience, knowledge and internet offers from existing companies.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the *Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building* separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 168 Standards used during energy audit

	Applied version	English version
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements
2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings – Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczeń."	EN ISO 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods
6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków - Wymiana ciepła przez grunt - Metody obliczania."	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach - Liniowy współczynnik przenikania ciepła - Metody uproszczone i wartości orientacyjne."	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia."	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane -- Właściwości cieplno-wilgotnościowe -- Tabelaryczne wartości obliczeniowe i procedury określania deklarowanych i obliczeniowych wartości cieplnych"	ISO 10456:2007 Building materials and products -- Hygrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania"	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system"	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 "Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance"	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 169 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit

	termomodernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	
3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metody obliczania oszczędności energii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency audit card and methods for calculating energy savings
5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) - raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) - raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme - 1st variant

3.1. Aim of the renovation plan

The aim of the first renovation plan is to modernize the building so that it meets Polish building standards and consumes less energy. As the result the costs of maintenance of the school will be lower. Such modernisation plan was chosen due to the possibility of getting funds from the BGK thermal-modernisation and renovation program, which is a national programme supporting thermal modernisation of buildings in Poland.

The first variant includes the following measures:

- External walls insulation
- Windows modernisation
- Roof insulation
- Heating source modernisation
- Lighting modernisation

The extent of each measure incudes meeting the minimum requirements, despite the costs or payback time. There are no other boundaries to renovate this building in a way proposed above.

3.2. Criteria for ranking energy efficiency improvement measures

The main criterion was to meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 W/m^2•K
- heat transfer coefficient of windows: U = 1.1 W/m^2•K
- heat transfer coefficient of roofs: U = 0.18 W/m^2•K

Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not.

Last criterion is the improvement of thermal comfort in the building. This however cannot be measured, but it is important to remember that sometimes it is more important to improve comfort than to save money.

3.3. Potential interactions with other proposed recommendations

The only affected parameter is the heating source. Each modernisation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation) affects the work of a heat exchanger. The better the condition of the building, the less heat needs to be provided. The impact of interactions between measures have been considered in the Variants (see row “Total” in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions. Lighting has no effect on any of other renovations.

3.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls and foundation walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0,04 W/m•K in the whole building except the sport hall. In the sport hall the insulation of 8 cm of polystyrene with thermal conductivity parameter equal λ=0,04 W/m•K is proposed. In case of the foundation walls 10 cm of polystyrene should be installed. Added to existing state it allows to meet required standard of U = 0.23W/ m^2•K

Roof insulation – the best option is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K in the whole building except the sport hall. In the sport hall the insulation of 10 cm of polystyrene with thermal conductivity parameter equal λ=0,04 W/m•K is proposed. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K

Replacement of windows – In this case it is suggested to replace all old windows with new ones with heat transfer coefficient of 1.1 W/m^2•K.

Heating source improvements – Replacing old iron ribbed convectors with new plate heaters with thermostats.

Lighting – Exchange of fluorescent bulbs to LED ones.

In case of the windows the standards are already fulfilled, however their condition is poor significantly decreasing thermal comfort of the building`s users, so the measure was considered as the part of the 1st variant.

When it comes to lighting and heating source both money and final energy savings were considered. LEDs are one of the eco-friendliest lighting choices whilst also their high efficiency leads to economical savings.

When it comes to the heating source, replacing old iron ribbed convectors with new plate heaters with thermostats is the best economical option, which will also have definite impact on the thermal comfort in the building. Some of the heaters in the school are covered with shields for safety issues, this however decreases the efficiency of radiant heating. It is recommended to consider another means of preventing the children from burning, so that it improves the heat distribution in the building. Installing heating source automation decreases the usage of heating when it is not necessary (weekends and nights), so it improves the system`s efficiency.

The measures considered in the 1st variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 170 Measures included in the 1st variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	128,852	115,966	42.815	3,896	84,384	22
2.	Lighting modernisation	25,300	75,901	18.165	1,883	42,027	22
3.	Heating source modernisation	66,548	59,893	22.113	2,012	45,395	23
4.	Roof insulation	43,764	39,388	14.542	1,323	53,829	41
5.	Windows modernisation	134,206	120,785	44.594	4,057	208,391	51
6.	Foundation walls	8,730	7,857	2.901	264	22,160	84
7.	**Total**	361,354	378,350	129.829	12,043	456,186	38

The most beneficial option is external walls insulation, but the savings and, in consequence, the payback time will be longer when there are no problems with leaky windows after modernisation. The windows modernisation has a long payback time, however, as indicated in previous paragraphs, it has another significant advantage, such as solving the problem with cold and highly ventilated rooms. The foundation walls insulation is concerned despite the long payback time, as it does not have much impact on the total cost and payback time of the whole modernisation variant. It may however affect positively the construction of the building in the future and also improve comfort in the basement classrooms.

3.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	184.4	83.6
Primary energy consumption - heating [kWh/m²a]	136.1	55.5
Primary energy consumption - DHW [kWh/m²a]	14.6	14.6
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lightning [kWh/m²a]	33.7	13.5
Final energy consumption - total [kWh/m²a]	173.1	76.8

Final energy consumption - heating [kWh/m²a]	147.0	57.5
Final energy consumption - DHW [kWh/m²a]	14.9	14.9
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lightning [kWh/m²a]	11.2	4.5
CO_2 emissions - total [kg/m²a]	61.858	27.265
CO_2 emissions - heating [kg/m²a]	48.852	19.098
CO_2 emissions - DHW [kg/m²a]	4.939	4.939
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lightning [kg/m²a]	8.067	3.227

The 1st renovation variant allows reducing final energy consumption by around 361 MWh/a and primary energy consumption by around 378 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 456,000 EUR and the estimated payback time is at the level of 38 years. The EP factor of the building after implementing the proposed measures would achieve about 84 kWh/m²/a, which makes the building much more efficient.

4. Renovation scheme - 2nd Variant

4.1. Aim of the renovation plan

The aim of the second renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The second variant includes all measures of the 1st variant with the following additional renovations:

- Heating control automation
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

4.2. Criteria for ranking energy efficiency improvement measures

The aim of the second variant is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows for large final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

4.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation, heating control automation, etc.) affects the work of the heat exchanger. The better the condition of a building, the less heat needs to be provided.

Lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions.

4.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls and foundation walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0,04 W/m•K in the whole building except the sport hall. In the sport hall the insulation of 8 cm of polystyrene with thermal conductivity parameter equal λ=0,04 W/m•K is proposed. In case of the foundation walls 10 cm of polystyrene should be installed. Added to existing state it allows to meet required standard of U = 0.23W/ m^2•K

Roof insulation – the best option is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K in the whole building except the sport hall. In the sport hall the insulation of 10 cm of polystyrene with thermal conductivity parameter equal λ=0,04 W/m•K is proposed. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K

Replacement of windows – In this case it is suggested to replace all old windows with new ones with heat transfer coefficient of 1.1 W/m^2•K.

Heating source improvements – Replacing old iron ribbed convectors with new plate heaters with thermostats.

Lighting – Exchange of fluorescent bulbs to LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the Egain/Promar etc. system, which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used to 0 m3/h.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the 2nd variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 171 Measures included in the 2nd variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]

1.	Heating control automation	112,371	101,133	37.339	3,165	2,326	1
2.	Lighting control automation	13,081	39,243	9.391	973	14,009	14
3.	External walls insulation	128,852	115,966	42.815	3,896	84,384	22
4.	Lighting modernisation	25,300	75,901	18.165	1,883	42,027	22
5.	Heating source modernisation	66,548	59,893	22.113	2,012	45,395	23
6.	Photovoltaic system	-	114,000	-	2,828	65,116	23
7.	Mechanical ventilation with heat recovery	208,526	151,956	69.289	6,304	174,558	28
8.	Roof insulation	43,764	39,388	14.542	1,323	53,829	41
9.	Windows modernisation	134,206	120,785	44.594	4,057	208,391	51
10.	Foundation walls	8,730	7,857	2.901	264	22,160	84
	Total	452,014	549,216	161.972	15,015	712,195	47

The shortest payback time (typically 1-3 years) is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view. The windows modernisation has a long payback time, however, as indicated in previous paragraphs, it has another significant advantages, such as solving the problem with cold and highly ventilated rooms.

4.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	184.4	38.0
Primary energy consumption - heating [kWh/m²a]	136.1	44.5
Primary energy consumption - DHW [kWh/m²a]	14.6	14.6
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lightning [kWh/m²a]	33.7	9.3
Final energy consumption - total [kWh/m²a]	173.1	52.7
Final energy consumption - heating [kWh/m²a]	147.0	34.7
Final energy consumption - DHW [kWh/m²a]	14.9	14.9
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lightning [kWh/m²a]	11.2	3.1
CO_2 emissions - total [kg/m²a]	61.858	18.700
CO_2 emissions - heating [kg/m²a]	48.852	11.535
CO_2 emissions - DHW [kg/m²a]	4.939	4.939

CO_2 emissions - cooling [kg/m^{2}a]	n/a	n/a
CO_2 emissions - lightning [kg/m^{2}a]	8.067	2.226

The 2nd renovation variant allows reducing final energy consumption by around 452 MWh/a and primary energy consumption by around 435 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 712,000 EUR and the estimated payback time is at the level of 47 years. The EP factor of the building after implementing the proposed measures would achieve about 38 kWh/m^2/a, which makes the building much more efficient. The total costs of the maximum efficiency variant are significantly higher than the 1st variant, also in reference to the energy savings. Thus, the 1st variant is more realistic and is proposed as the basic one.

5. Attachments

No attachments.

VIII. Building #8 SP 26 (ul. Miedziana 8, 00-814 Warszawa)

1. Summary of the energy performance of the building and suggested improvement options

1.1. Summary of the existing state of the building

The building consists of two parts. The first one was built around 1890, and was later modernized around 1933, however the precise history of the building is not well known. During the World War II a huge part of the buildings was damaged and rebuild in the next few years. Around 1960 a new part of the building has been added and finally between 2002 and 2007 the whole building has been renovated and the newest part with a new sport hall has been added. A heat distribution system has been modernized and new water convectors with thermostats were installed. It is supposed that the building was refurbished according to construction requirements as of 1960. Therefore, U-value of external partitions U-value equals 1.35 W/(m^{2}K) for external walls and 0.87 W/(m^{2}K) for a flat roof. Windows has been exchanged with new ones around 2002-2004 with the declared U-value of 1.1 W/(m^{2}K). There is only a natural ventilation in the building, except a part of building with the sport hall and changing rooms, where air handling units with heat recovery are installed. Furthermore, a canteen has its own air handling unit. The only room with air conditioning is a computer classroom. Most of the building is equipped with T8 36W fluorescent bulbs controlled manually. The building does not have any BMS system.

The general overview of the building allowed for giving a good opinion about energy efficiency of the building, concerning its age and a fact that only a moderate amount of insulation can be applied for thermal modernization of the external partitions. Nevertheless, there are still some measures that can be taken into account to decrease the energy consumption. The measured final energy indicator for heating previous year is 114.27 kWh/m^{2}a, which is quite good for this kind of building.

1.2. Summary table: existing state of the builiding

Category	Value
Building type[20]	Educational building
Constriction year / major reconstruction year	1890/1960/2002-2007
Building fabric[21]	No documentation available
Building useful area [m^2]	5,593.53
Useful area of the audited zone [m^2]	Classrooms: 1,346.0 m2 Sport hall: 745 m2 Canteen: 198 m2 (with facilities)
Shape factor - building [1/m]	0.252

[20] Single-family house, Apartment block, Office, Educational building, Hospital, Hotels and restaurants, Sport facilities, Wholesale and retail trade services buildings

[21] E.g. Building Fabric, Brick wall with cavity wall, Brick wall without cavity wall, Double-skin façade, Curtain wall, Concrete wall, Stone Wall, Sheet panel, Concrete block wall, Prefabricated, Mainly Glass facade

Building volume [m^3]	22,155 m^3
Volume of the audited zone [m^3]	Classrooms: 4,307 m^3 Sport hall: 6,593 m^3 Canteen: 515 m^3 (with facilities)
Shape factor - audited zone [1/m]	Classrooms: 0.313 1/m Sport hall: 0.113 1/m Canteen: 0.385 1/m (with facilities)
Number of floors	4
Number of building users	450
Heating system	District heating + water convectors with thermostatic valves
Domestic hot water (DHW) system	District heating, the same source as the central heating
Cooling system	Two units in a computer classroom
Lighting system	2xT8 fittings with 2x36W fluorescent bulbs (except the large sport hall - halogen fittings)
Primary energy consumption - total [kWh/m^2a]	156.1
Primary energy consumption - heating [kWh/m^2a]	110.5
Primary energy consumption - DHW [kWh/m^2a]	14.0
Primary energy consumption - cooling [kWh/m^2a]	n/a
Primary energy consumption - lighting [kWh/m^2a]	31.6
Final energy consumption - total [kWh/m^2a]	142.4
Final energy consumption - heating [kWh/m^2a]	117.2
Final energy consumption - DHW [kWh/m^2a]	14.7
Final energy consumption - cooling [kWh/m^2a]	n/a
Final energy consumption - lighting [kWh/m^2a]	10.5
CO_2 emissions - total [kg/m^2a]	51.380
CO_2 emissions - heating [kg/m^2a]	38.929
CO_2 emissions - DHW [kg/m^2a]	4.878
CO_2 emissions - cooling [kg/m^2a]	n/a
CO_2 emissions - lighting [kg/m^2a]	7.573

1.3. Suggested implementation programme and its expected results

Each energy measure analysis has been performed in reference to the actual state of the building. Thus, total energy savings after implementation of all measures together will have different impact on the whole energy consumption in the building than separately applied. For example, heating source efficiency improvement in reference to the actual energy consumption will have higher impact on energy consumption reduction, than it would have when applied together with thermal modernisation of the external partitions of the building. Even though the improvement of efficiency of the heating source will be the same in both cases, the reduction of energy consumption will be different. This is the reason why the sum of final energy and financial savings of measures is not equal to total energy savings after applying measures together in Variant 1 and Variant 2.

The recommended Variant 1 is a typical thermal modernisation scheme applied in Poland, that is usually introduced when the owner of the building is applying for financial subsidies for thermal modernisation. Application of all measures allows to meet current technical requirements for buildings, namely maximum U-values for external walls, roof, and windows.

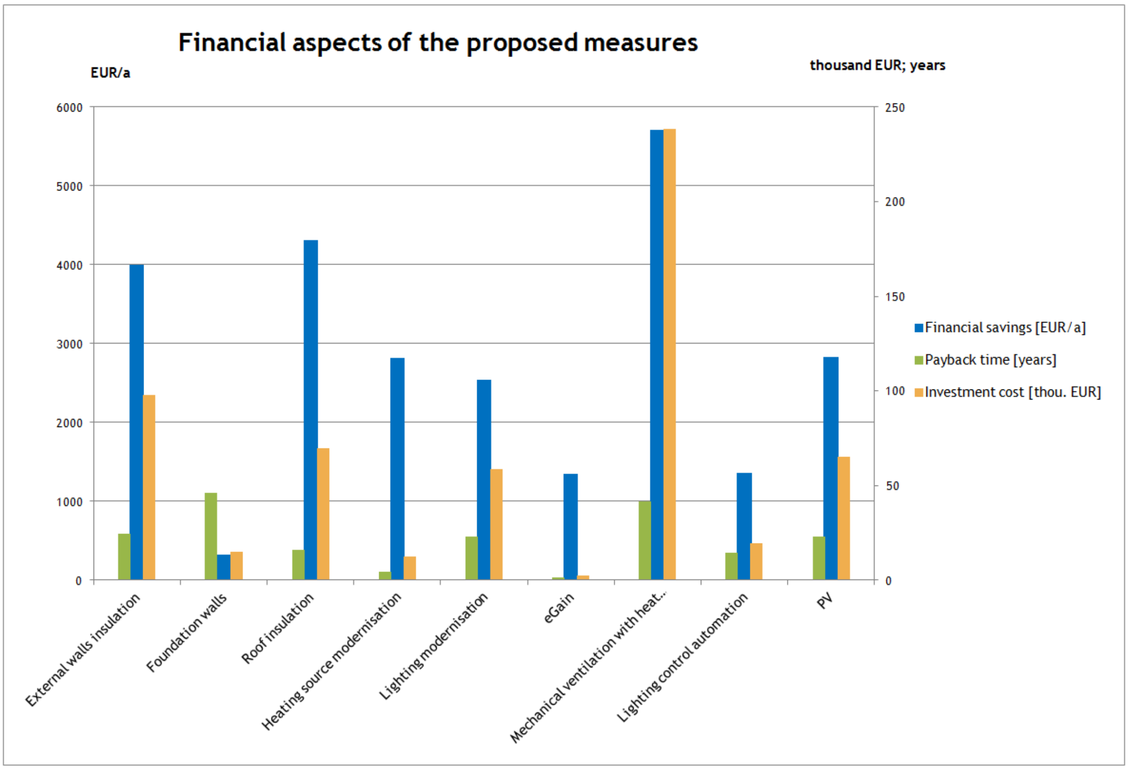
The maximum efficiency Variant 2 is a method for improving energy efficiency of the building that allows achieving the nZEB standard by the building (fulfilling requirements defined in Polish law for newly designed buildings) and presenting the minimum possible consumption of primary energy by building. Due to the fact that the Photovoltaic system is analysed, calculated final and primary energy indicator might achieve values lower than 0 kWh/m^{2}a. This value however is only achieved because of energy consumption in the whole-year balance. In fact, the building will still require having a heating source and electrical grid connection.

The table presented in section 1.4 contains all analysed measures. Measures 1-5 are considered as a basic modernisation (Variant 1). In order to achieve the nZEB standard, measures 6-9 are added.

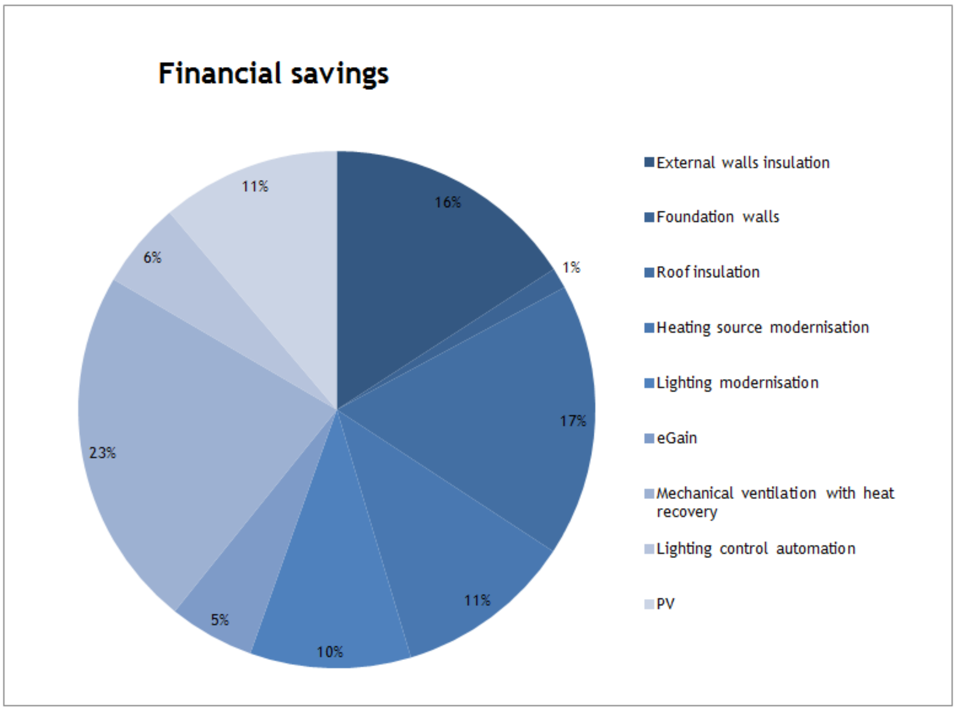
For each measure energy and financial savings, CO_2 reduction, investment cost and simple payback time are presented.

1.4. Summary table: suggested measures, energy savings, financial savings

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	External walls insulation	132,383	119,145	43.988	4,002	98,056	24
2.	Foundation walls	10,862	9,776	3.609	328	15,183	46
3.	Roof insulation	143,908	129,517	47.818	4,351	69,614	16
4.	Heating source modernisation	93,113	83,802	30.940	2,815	12,326	4
5.	Lighting modernisation	34,145	105,066	24.516	2,541	58,801	23
6.	Heating control automation	52,360	47,124	17.398	1,350	2,326	2
7.	Mechanical ventilation with heat recovery	189,010	128,403	62.804	5,714	238,234	42
8.	Lighting control automation	18,302	54,905	13.141	1,362	19,600	14
9.	Photovoltaic system	-	114,000	-	2,828	65,116	23



The graph above presents financial savings, investment costs and payback time of each proposed measure. The most beneficial are the options with short payback time and high financial savings. Considering this, the best measure is the modernisation is the heating control automation with low both investment cost and payback time. High investment cost of installing the mechanical ventilation system in combination with technical difficulties makes it an additional option considered only as a part of the maximum efficiency variant.



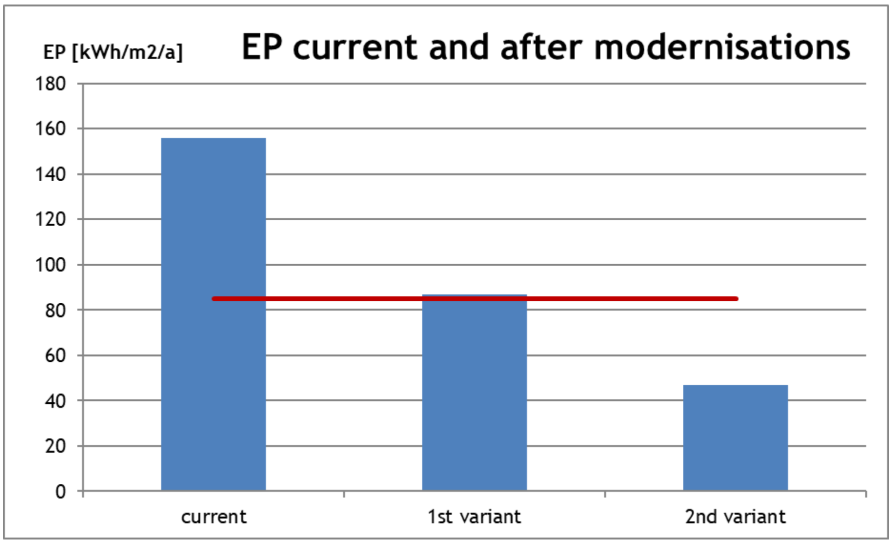
The graph above presents the percentage of financial savings after implementing each measure regardless of the others. Implementing all the measures at once decreases the savings from individual measures and might change the percentage because of the interactions between options. As seen on the graph, the biggest savings would be generated by installing the mechanical ventilation. This however requires big investment costs and might be problematic from technical point of view. The external walls and the roof insulation are beneficial options, which are treated as the basic ones. Foundation walls are a small part of all the building`s walls, which causes low percentage of savings from this measure.

In the table below, the shares of primary energy savings due to analysed measures in each space have been presented.

Table 172 Percentage of the primary energy savings from modernisations by zones

No.	Measure	Classrooms	Sport hall	Canteen	Rest of the building
1.	External walls insulation	51%	15%	4%	31%
2.	Foundation walls	0%	0%	5%	95%
3.	Roof insulation	22%	21%	0%	58%
4.	Heating source modernisation	24%	22%	2%	52%
5.	Lighting modernisation	26%	8%	3%	63%
6.	Heating control automation	26%	19%	3%	51%
7.	Mechanical ventilation with heat recovery	21%	23%	3%	53%
8.	Lighting control automation	26%	8%	4%	63%

Total primary energy consumption before and after implementations of measures according to 1st and 2nd variant has been presented below. The red line represents the EP of the nZEB level.



2. Energy efficiency improvement options

2.1. Heating system

2.1.1. Heating system modernisation

According to both the economic manager of the school and the technical staff leader, the thermal comfort in the building is well preserved. The heating system is in a good condition. The only part of the building, where there are no thermostatic valves on the convectors, is the canteen.

The proposed renovation includes installation of thermostatic valves in the canteen.

The modernisation also includes changes in time usage of a district heating heat exchanger. Currently it produces heat 24 hours a day, 7 days a week, leading to inefficiency of the heating system. When no lessons are held nor the sport hall is unoccupied, the space heating is unnecessary. Installation of traditional heating control allowing for night and weekend temperature reduction could allow for significant energy savings with low investment cost. Also, in case there is already a controller installed, it is recommended to perform heating system rinsing and regulation. The calculated total efficiency of the system would increase from the current 0.85, to 1.05[22], according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 173 Energy savings and CO_2 reduction after the heating system modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	703,323	93,113
Primary energy [kWh/a]	873,327	789,525	83,802
CO_2 emission [Mg/a]	287.396	256.456	30.940

Table 174 Financial savings and investment cost of the heating system modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,815	12,326	4

Estimated payback time is around 4 years. The investment cost is around 12,000 EUR. Short payback time results from the fact that only several thermostats would be installed not generating much investment cost, while the changes of the heating system`s usage cause significant energy savings.

The heating source modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.1.1. Classrooms

[22] Efficiency >1.0 is caused by applying temperature reduction in nights and weekends.

The heating source modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 20,112 kWh/a, which gives 24% reduction in the building.

2.1.1.2. Sport halls

The heating source modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 18,436 kWh/a, which gives 22% reduction in the building.

2.1.1.3. Canteen

The heating source modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,676 kWh/a, which gives 2% reduction in the building.

2.1.2. Heating control automation

The weather forecast control (for example Egain or Promar) system is used to control the heating system provided by the local weather forecasts, reducing the time when building becomes overheated during some periods when there are high external temperature amplitudes during the day. This solution increases the efficiency of the system`s regulation allowing for energy savings. The calculated total efficiency of the system would increase from the current 0.85, to 0.93, according to the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building. Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 175 Energy savings and CO_2 reduction after implementation of weather forecast control

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	744,076	52,360
Primary energy [kWh/a]	873,327	826,203	47,124
CO_2 emission [Mg/a]	287.396	269.998	17.398

Table 176 Financial savings and investment cost of implementation of weather forecast control

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,350	2,326	2

The investment cost is estimated and may vary depending on easiness of heating system adjustment, also there is an annual fee while the system is installed. Typical payback time however is around 1-3 years.

The heating control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.1.2.1. Classrooms

The heating control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 12,252 kWh/a, which gives 26% reduction in the building.

2.1.2.2. Sport halls

The heating control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 8,954 kWh/a, which gives 19% reduction in the building.

2.1.2.3. Canteen

The heating control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 1,414 kWh/a, which gives 3% reduction in the building.

2.2. Water and sewage system

No changes to the sewage system are considered.

2.3. HVAC

The old part of the building is now ventilated naturally. The new large sport hall with facilities and the canteen are equipped with the mechanical ventilation. The kitchen is equipped with mechanical ventilation hoods used only during food processing

Installing the mechanical ventilation system with heat recovery allows decreasing heat loss by recovering heat from extract air to incoming fresh air in a heat exchanger. It is assumed that at a current state, the air permeability of the building (n50 value) equals 3.0 h^{-1}. The heat savings are defined by the heat recovery efficiency of the system, which is assumed to be 75%. Installation of the mechanical ventilation system decreases the air flow in the building after working hours to 0 m^3/h as well. This allows a reduction in final energy consumption for heating.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 177 Energy savings and CO_2 reduction after installing the mechanical ventilation with heat recovery

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	607,426	189,010
Primary energy [kWh/a]	873,327	744,924	128,403
CO_2 emission [Mg/a]	287.396	224.592	62.804

Table 178 Financial savings and investment cost of mechanical ventilation with heat recovery

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
5,714	238,234	42

In practical terms installing the mechanical ventilation system in the existing building might be problematic and is not considered in a typical thermal modernisation scheme. This measure is proposed as a part of maximum efficiency Variant 2, which aims at fulfilling requirement for newly designed buildings.

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.3.1.1. Classrooms

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 26,965 kWh/a, which gives 21% reduction in the building.

2.3.1.2. Sport halls

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 29,533 kWh/a, which gives 23% reduction in the building.

2.3.1.3. Canteen

Mechanical ventilation with heat recovery would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 3,852 kWh/a, which gives 3% reduction in the building.

2.4. Cooling system

No cooling system measures are being considered, as a cooling system in the building is not a commonly used installation, but only used in selected circumstances. The only cooling system in the building is a computer classroom air conditioning.

2.5. Electric system

In the existing state of the building, it has been estimated that the lighting consumes around 59,000 kWh of energy. According to the invoices provided by the school staff, total annual consumption of electricity is around 101000 kWh. This difference is caused by the fact that aside from the lighting there are many devices using electricity, like computers and projectors, also there is mechanical ventilation in a pat of a building.

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones and installing automatic control which is based on amount of light from the outside and presence of people in a room.

After the lighting exchange, there is a possibility of decreasing the electrical power which will reduce electricity costs. This however will not decrease the energy consumption.

2.6. Building envelope

2.6.1. External walls insulation

Thermal modernisation of the building includes insulation of the external walls, foundation walls and the roof, except the oldest part of the building. The oldst part of the building is treated as a historic building, thus it's elevation cannot be modernised from the outside. It is usually most profitable when all of the thermal modernisation measures are performed together, as a large share of costs is associated with preparation of construction field, ex. construction of scaffoldings etc.

External walls insulation decreases the heat transfer coefficient, which influences heat loss through the walls. The U-values are supposed to reach around 1.35 W/(m^{2}K) for external walls in the part of the building that was built around 1960. Thermal modernisation assumes insulation of these external walls with 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. The newest part of the building connected to the new sport hall was built in 2005. According to regulations of that time, both external walls and flat roofs were required to have U-value not higher than 0.3 W/(m^{2}K). Thermal modernisation assumes insulation of these walls with 4 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. The oldest part of the building is treated as historical so applying external walls insulation in this part is not considered.

The heat resistance of the insulation material is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

Where d – thickness [m], λ - thermal conductivity [W/m•K]

The overall heat transfer coefficient is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the external walls' parameters are presented in the table below.

Table 179 Heat parameters of the external walls in the part of the building from 1960

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
1.35	0.04	0.14	3.50	0.23

Table 180 Heat parameters of the external walls in the newest part of the building

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.3	0.04	0.04	1	0.23

The heat transfer coefficient of the external walls after the proposed modernisation equals 0.23 W/m²•K.

Values of the energy savings, CO_2 reduction as well as the savings are presented in the tables below.

Table 181 Energy savings and CO_2 reduction after external walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	664,053	132,383
Primary energy [kWh/a]	873,327	754,182	119,145
CO_2 emission [Mg/a]	287.396	243.408	43.988

Table 182 Financial savings and investment cost of external walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4,002	98,056	24

The investment cost of the external walls' insulation is relatively high. The payback time is aroun 24 years. Thus, this measure is treated as one of the basic options considered in a typical thermal modernisation scheme.

External walls insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.6.1.1. Classrooms

External walls insulation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 60,764 kWh/a, which gives 51% reduction in the building.

2.6.1.2. Sport halls

External walls insulation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 17,872 kWh/a, which gives 15% reduction in the building.

2.6.1.3. Canteen

External walls insulation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 4,766 kWh/a, which gives 4% reduction in the building.

2.6.2. Foundation walls insulation

Foundation walls insulation, the same way as external walls insulation, improves the heat parameters and decreases heat loss to the ground. The modernisation assumes insulation of the foundation walls with 10 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K. The heat transfer coefficient of the foundation walls depends on the depth under the ground level. This influence is included in the equivalent heat transfer coefficient. Information on the external walls' parameters are presented in the table below.

Table 183 Heat parameters of the foundation walls

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]	Equivalent heat transfer coefficient [W/m²•K]
1.35	0.04	0.10	2.50	0.31	0.23

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 184 Energy savings and CO_2 reduction after foundation walls insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	785,574	10,862
Primary energy [kWh/a]	873,327	863,551	9,776
CO_2 emission [Mg/a]	287.396	283.609	3.609

Table 185 Financial savings and investment cost of foundation walls insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
328	15 183	46

Foundation walls are a small part of all the building walls, which causes low percentage of financial savings from this measure. The payback time at the level of 46 years is relatively high, however when all the measures are considered together, implementing foundation walls insulation does not have much impact on the payback time of the whole modernisation in both variants. This results of the investment cost, which percentage in the total cost of the modernisation is not high.

Foundation walls would result in a reduction of primary energy consumption in the Sport hall and other zones.

Primary energy in the amount of 0 kWh/a would be saved in classrooms, 0 kWh/a would be saved in the Sport hall and 489 kWh/a would be saved in the canteen and its facilities.

2.6.3. Roof insulation

Roof insulation allows the improvement of heat parameters, which decreases heat loss. In the proposed modernisation variant, the insulation with 18 cm of polystyrene with thermal conductivity parameter of λ=0.04 W/m•K is considered in the non-historical part of the building. In the oldest part of the school insulating the attic inside with 18 cm of mineral wool is proposed. The insulation in the historical part of the building must be located on the inside of the roof construction, and in this case mineral wool is recommended.

The overall heat resistance is calculated according to the following formula:

$$R_{insulation} = \frac{d}{\lambda}$$

The overall heat transfer coefficient after addition of new insulation is calculated according to the following formula:

$$U = \frac{1}{\frac{1}{U_{current}} + R_{insulation}}$$

Information on the roof materials and parameters are presented in the table below.

Table 186 Heat parameters of the roof

Current heat transfer coefficient [W/m²•K]	Polystyrene thermal conductivity λ [W/m•K]	Insulation thickness [m]	Insulation resistance [m²•K/W]	Heat transfer coefficient [W/m²•K]
0.87	0.04	0.18	4.50	0.18

The heat transfer coefficient of the roof after the proposed modernisation equals 0.18 W/m²•K.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 187 Energy savings and CO_2 reduction after roof insulation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	653,793	142,643
Primary energy [kWh/a]	873,327	744,949	128,378
CO_2 emission [Mg/a]	287.396	239.999	47.397

Table 188 Financial savings and investment cost of roof insulation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
4,312	69,614	16

Annual financial savings from the roof insulation are about 4,300 EUR. The payback time is 16 years. The measure is considered as one of the basic options proposed as a part of typical thermal modernisation.

Roof insulation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

Primary energy in the amount of 28,494 kWh/a would be saved in classrooms, while 27,199 kWh/a would be saved in the Sport hall and 0 kWh/a would be saved in the canteen and its facilities.

2.7. Renewable energy sources

In the existing state there are no renewable sources in the school at all.

The goal of the modernisation is to achieve 40 kWp using PV. In Polish law, Photovoltaic installation of power up to 40 kWp is defined as a small installation and can be connected to the grid on simplified rules, making it more profitable. Installation of 40 kWp of PV panels can be accomplished by placing panels on 31% of the roof – 660 m^2 in case of installing it on the flat part of the roof or 10% of the roof – 200 m^2 in case of using the sloping part of the roof. Costs of installation would be comparable, assuming that both installations requires steel frame for the construction. In Warsaw the productivity of PV is about 950 kWh/kWp so this installation would provide 38,000 kWh a year.

2.8. Lighting system

2.8.1. Lighting modernisation

The modernisation of the lighting system includes exchanging fluorescent bulbs with LED ones. In this way total installed power could be reduced to 40% of the current state.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 189 Energy savings and CO_2 reduction after lighting modernisation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	762,291	34,145
Primary energy [kWh/a]	873,327	768,261	105,066
CO_2 emission [Mg/a]	287.396	262.880	24.516

Table 190 Financial savings and investment cost of lighting modernisation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
2,541	58,801	23

Financial savings from lighting modernisation are about 2,500 EUR and payback time is 23 years. As the lighting modernisation decreases electricity consumption, primary energy savings are relatively high compared to the modernisations decreasing heat consumption. This makes this option beneficial from the ecological point of view.

Lighting modernisation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.1.1. Classrooms

Lighting modernisation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 27,317 kWh/a, which gives 26% reduction in the building.

2.8.1.2. Sport halls

Lighting modernisation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 8,405 kWh/a, which gives 8% reduction in the building.

2.8.1.3. Canteen

Lighting modernisation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 3,152 kWh/a, which gives 3% reduction in the building.

2.8.2. Lighting control automation

The maximum efficiency variant assumes installing automatic control which is based on the amount of light from the outside and presence of people in a room. In this way the unnecessary usage of lighting is reduced and therefore the energy consumption for lighting decreases.

Values of the parameters before and after modernisation as well as the savings are presented in the tables below.

Table 191 Energy savings and CO_2 reduction after implementation of lighting control automation

	Existing	After implementation	Savings/reduction
Final energy [kWh/a]	796,436	778,134	18,302
Primary energy [kWh/a]	873,327	818,422	54,905
CO_2 emission [Mg/a]	287.396	274.255	13.141

Table 192 Financial savings and investment cost of implementation of lighting control automation

Financial savings [EUR/a]	Investment cost [EUR]	Payback time [years]
1,362	19,600	14

Investment cost of the modernisation is about 19,600 EUR. Payback time of the measure is relatively low with the level of 14 years. As this option decreases electricity consumption, primary energy savings are relatively high, which makes the measure beneficial from the ecological point of view.

Lighting control automation would result in a reduction of primary energy consumption in classrooms, sport halls and canteen with facilities.

2.8.2.1. Classrooms

Lighting control automation would result in a reduction of primary energy consumption in Classrooms. Primary energy consumption reduction in Classrooms equals 14,275 kWh/a, which gives 26% reduction in the building.

2.8.2.2. Sport halls

Lighting control automation would result in a reduction of primary energy consumption in the Sport hall. Primary energy consumption reduction in the Sport hall equals 4,392 kWh/a, which gives 8% reduction in the building.

2.8.2.3. Canteen

Lighting control automation would result in a reduction of primary energy consumption in the canteen with facilities. Primary energy consumption reduction in the canteen with facilities equals 2,196 kWh/a, which gives 4% reduction in the building.

2.9. Other systems

There is no need for other systems to be introduced as the first variant is limited by foundation program specifications and the second variant is already vastly expanded and enables to achieve the nZEB standard.

2.10. User behaviour change

In the second variant the energy management is done automatically. Both heating and lighting devices should adjust to optimal parameters without manual control. Users should be trained how to use the system, so that it would work effectively and properly.

In the first variant it is the heating which is, as the only system, controlled automatically. This means that users can turn off the lighting only manually. The last person leaving specific room ought to always remember to turn off the lights. Training for all user groups could be organised in order to teach them how to use energy smartly and do not waste it. Impact of such a measure is however hard to estimate, so it is not included in further calculations.

2.11. Other suggestions

No other suggestions are recommended.

2.12. Assumptions used in calculating savings and the resulting accuracy of the recommendations

2.12.1. Assumptions

Assumptions were made based on 5 parameters: size of the school, amount of energy it consumes/ loses by specific element, number of heaters and annual usage cost and capacity (kWp) of the photovoltaic system. Costs of each installation has been estimated based on contractors' offers. Heating control automation has an annual fee that is charged for this service.

Table 193 Assumptions of modernisations' prices

No.	Measure	Unit measured	Price per unit [EUR/unit]	Additional cost [EUR]
1.	External walls insulation	1 m^2	42	-
2.	Foundation walls	1 m^2	105	-
3.	Roof insulation	1 m^2	35	-
4.	Heating source modernisation	1 heater	134	11628
5.	Lighting modernisation	1 W	1.74	-
6.	Heating control automation	Annual usage	233	2326

7.	Mechanical ventilation with heat recovery	1 m^2	47	-
8.	Lighting control automation	1 W	0.58	-
9.	Photovoltaic system	1 kWp	1628	-

2.12.2. Accuracy

During the process of evaluation, a few simplifications have been done. Firstly, the analytical model was adjusted so that it consumes similar amount of energy as the real building. It was done based on invoices provided by the school staff and documentation of the building. Secondly, the monthly method was adopted. Being a bit less accurate, there was no dynamic nor hourly documentation that could be used for the hourly method. Another aspect that may have impact on results is that a standard meteorological year was used in calculations. It is a bit colder than recent years so if the next ones are hotter, the calculated savings can be a bit lower. Also estimated time of usage of lighting or heating is taken as the mean of the usage in typical buildings of similar size. Therefore, they can be lower or higher depending on non-measurable parameters. Another uncertainty is energy price, which dynamically grows in recent years in Poland (electricity in particular). The following prices (variable component) have been included in calculations: electricity – 0.33 PLN/kWh (0.0767 EUR/kWh), heat – 0.13 PLN/kWh (0.0302 EUR/kWh).

Besides those, different modernisation measures have different accuracies.

Insulation of external walls and roof - experience from the Polish market shows that huge share of total costs is labour and materials, however scaffolding and equipment may represent up to 30% of total costs. Accuracy level is around 80%.

Insulation of foundation walls – similar as the insulation of the external wall. However, in this case the work is much more difficult to do so the cost of labour is even higher. Approximately about 90%.

Heating source modernisation and control automation – Prices found on one of the companies` website. Accuracy level 85%.

Lighting modernisation and control automation – Classical fluorescent bulbs can be replaced with fully automated LEDs for about 2.32 euro per 1 Watt. This price is rather constant on the Polish market and the chosen proportions were 75:25 for replacement. Estimated accuracy 90%.

Mechanical ventilation – based on author's experience and expert opinions but estimation is not easy because of variety of every school. Accuracy level on 80%.

2.12.3. Methods and standards used

Most of methods were based on author's experience, knowledge and internet offers from companies.

Calculations of the seasonal energy consumption for heating and domestic hot water were performed according to the *Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building* separately for each variants and modernisation considered in audit. Some of the coefficients, relations, approximations or specific methods (i.e. heat losses to the ground, impact of temperature setbacks during nights, etc.) were performed in compliance with documents listed below. Calculations were validated with measured consumption from the invoices using heating degree days method, and since results were covering real data with accuracy of +/- 15% authors assumed they are correct.

Table 194 Standards used during energy audit

	Applied version	English version
1	Norma PN-EN 16247-1 "Audity Energetyczne: Wymagania Ogólne"	EN 16247 Energy audits - Part 1: General requirements
2	Norma PN-EN 16247-2 "Audity Energetyczne Część 2: Budynki"	EN 16247 Energy audits - Part 2: Buildings
3	Norma PN-EN 16247-3 "Audity Energetyczne Część 3: Procesy"	EN 16247-3"Energy audits - Part 3: Processes
4	Polska Norma PN-EN 12831:2006 „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego."	EN 12831 Energy performance of buildings - Method for calculation of the design heat load
5	Polska Norma PN-EN ISO 6946:2008 „Elementy budowlane i części budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczeń."	EN ISO 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods
6	Polska Norma PN-EN ISO 13370 „Właściwości cieplne budynków - Wymiana ciepła przez grunt - Metody obliczania."	EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
7	Polska Norma PN-EN ISO 14683 „Mostki cieplne w budynkach - Liniowy współczynnik przenikania ciepła - Metody uproszczone i wartości orientacyjne."	ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
8	Polska Norma PN-EN ISO 13790:2009 „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii do ogrzewania i chłodzenia."	ISO 13790:2008 Energy performance of buildings -- Calculation of energy use for space heating and cooling
9	Polska Norma PN-EN ISO 10456:2009 "Materiały i wyroby budowlane - Właściwości cieplno-wilgotnościowe - Tabelaryczne wartości obliczeniowe i procedury określania deklarowanych i obliczeniowych wartości cieplnych"	ISO 10456:2007 Building materials and products -- Hydrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
10	Norma ISO 50001 „Systemy Zarządzania Energią. Wymagania i zalecenia użytkowania"	ISO 50001:2018 Energy management systems -- Requirements with guidance for use
11	Norma ISO 50004 „Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system"	ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system
12	Norma ISO 50006 "Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance"	ISO 50006 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

List of regulations used during the energy audit:

Table 195 Regulations used during energy audit

	Applied version	English version
1	Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej (Dz. U. 2016 Poz. 831 z późn. zm.)	Act of 20 May 2016 on energy efficiency
2	Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia	Regulation of the Minister of Infrastructure of 17 March 2009 on the scope of a building energy audit

	termo modernizacyjnego (Dz.U. nr 43, poz. 346 z późn. zm.).	
3	Rozporządzenie Ministra Infrastruktury z dn. 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. zm.)	Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions that buildings and their location should meet
4	Rozporządzenie Ministra Gospodarki z dnia 5 października 2017 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metody obliczania oszczędności energii (Dz.U. 2017 poz. 1912).	Regulation of the Minister of Economy dated 5th October 2017 on the detailed scope and method of preparation of the energy efficiency audit, model of the energy efficiency audit card and methods for calculating energy savings
5	Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2015 poz. 376 z późn. zm.)	Regulation of the Minister of Infrastructure and Development of 27 February 2015 on methodology for determining the energy performance of a building
6	KOBiZE (The National Centre for Emissions Management) - raport „Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2014 do raportowania w ramach Systemu Handlu Uprawnieniami do Emisji za rok 2017”	KOBiZE (The National Center for Emissions Management) - report "Calorific Values (WO) and CO2 emission factors (EC) in 2014 for reporting under the emission trading regulation scheme for 2017"
7	KOBiZE (The National Centre for Emissions Management) - raport „WSKAŹNIKI EMISYJNOŚCI CO2, SO2, NOx, CO i pyłu całkowitego DLA ENERGII ELEKTRYCZNEJ na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok”	KOBiZE (The National Center for Emissions Management) - report "CO2, SO2, NOx, CO and total dust EMISSION RATES FOR ELECTRICITY based on information contained in the National Database on greenhouse gas emissions and other substances for 2017"
8	Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE w sprawie efektywności energetycznej	Directive 2012/27/EU on energy efficiency

3. Renovation scheme - 1st variant

3.1. Aim of the renovation plan

The aim of the first renovation plan is to modernize the building so that it meets Polish building standards and consumes less energy. As the result the costs of maintenance of the school will be lower. Such modernisation plan was chosen due to the possibility of getting funds from the BGK thermal-modernisation and renovation program, which is a national programme supporting thermal modernisation of buildings in Poland.

The first variant includes the following measures:

- External walls insulation
- Roof insulation
- Heating source modernisation
- Lighting modernisation

As the oldest part of the building is treated as historical, no external walls insulation in this part is considered.

3.2. Criteria for ranking energy efficiency improvement measures

The main criterion was to meet Polish building standards. Those are:

- heat transfer coefficient of external walls: U = 0.23 $W/m^2 \bullet K$
- heat transfer coefficient of windows: U = 1.1 $W/m^2 \bullet K$
- heat transfer coefficient of roofs: U = 0.18 $W/m^2 \bullet K$

Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not.

Last criterion is the improvement of thermal comfort in the building. This however cannot be measured, but it is important to remember that sometimes it is more important to improve comfort than to save money.

3.3. Potential interactions with other proposed recommendations

The most affected parameter is the heating source. Each modernisation that leads to decreasing the heat consumption (exchange of windows, roof and walls insulation) affects the work of a heat exchanger. The better the condition of a building, the less heat needs to be provided. The impact of interactions between measures have been considered in the Variants (see row "Total" in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions. Lighting has no effect on any of other renovations.

3.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls and foundation walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 in the part from 1960 and 4 cm of polystyrene in the newest part of the building. Added to existing state it allows to meet required standard of U = 0.23 $W/m^2 \bullet K$.

Roof insulation – the best option is to use 18 cm of polystyrene with thermal conductivity parameter of λ=0.04 in in the non-historical part of the building. In the oldest part of the school insulating the attic inside with 18 cm of mineral wool is proposed. Added to existing state it allows to meet required standard of U = 0.18 W/m²•K.

Heating source improvements – Installing thermostats on the convectors in the canteen. Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs to LED ones.

When it comes to lighting and heating source both money and final energy savings were considered. LEDs are one of the eco-friendliest lighting choices whilst also their high efficiency leads to economical savings. When it comes to the heating source, replacing old iron ribbed convectors with new plate heaters with thermostats is the best economical option, which will also have definite impact on the thermal comfort in the building. Installing heating source automation decreases the usage of heating when it is not necessary (weekends and nights), so it improves the system`s efficiency.

The measures considered in the 1st variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 196 Measures included in the 1st variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating source modernisation	93,113	83,802	30.940	2,815	12,326	4
2.	Roof insulation	142,643	128,378	47.397	4,312	69,614	16
3.	Lighting modernisation	34,145	105,066	24.516	2,541	58,801	23
4.	External walls insulation	132,383	119,145	43.988	4,002	98,056	24
5.	Foundation walls	10,862	9,776	3.609	328	15,183	46
	All togther	348,096	387,623	129.319	12,088	253,979	21

The shortest payback time of 4 years is achieved in case of the heating source modernisation. This results from big energy savings from reducing heat consumption during nights and weekends. The foundation walls insulation is concerned despite long payback time, as it does not have much impact on the total cost and payback time of the whole modernisation variant.

3.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	156.1	86.8
Primary energy consumption - heating [kWh/m²a]	110.5	60.2

Primary energy consumption - DHW [kWh/m²a]	14.0	14.0
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	31.6	12.7
Final energy consumption - total [kWh/m²a]	142.4	80.2
Final energy consumption - heating [kWh/m²a]	117.2	61.3
Final energy consumption - DHW [kWh/m²a]	14.7	14.7
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	10.5	4.2
CO_2 emissions - total [kg/m²a]	51.380	28.261
CO_2 emissions - heating [kg/m²a]	38.929	20.353
CO_2 emissions - DHW [kg/m²a]	4.878	4.878
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	7.573	3.029

The 1st renovation variant allows reducing final energy consumption by around 348 MWh/a and primary energy consumption by around 388 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 254,000 EUR and the estimated payback time is at the level of 21 years. The EP factor of the building after implementing the proposed measures would achieve about 87 kWh/m²/a, which makes the building much more efficient.

4. Renovation scheme - 2nd variant

4.1. Aim of the renovation plan

The aim of the second renovation scheme is transforming the building into NZEB, which means improving the energy efficiency of the building to the maximum level so that it fulfils Polish requirements for newly designed buildings. As these requirements are not dedicated for already existing buildings, they might not be appropriate, and achieving the required level of energy consumption might not be possible with investment cost on an acceptable level.

The second variant includes all measures of the 1st variant with the following additional renovations:

- Heating control automation
- Mechanical ventilation with heat recovery
- Lighting control automation
- Photovoltaic system

The most problematic measure is installing the mechanical ventilation, which needs a dedicated infrastructure. This is not only problematic from a technical standpoint, but also may generate big investment costs.

4.2. Criteria for ranking energy efficiency improvement measures

The aim of the second variant is to achieve the maximum level of energy efficiency so that it meets the nZEB standard. Thus, final and primary energy savings were the most important criteria. Another criterion, usually the most important for the investor, is SPBT (Simple Payback Time). This may be the crucial indicator defining if the measure would be implemented or not. As environmental issues were considered as a priority, financial savings and payback time might not be positive and some of the proposed measures might not be beneficial from the economical point of view. The most noticeable case is the installation of mechanical ventilation, which allows for large final energy savings, but on the other hand requires also huge investment costs and might be problematic from the technical point of view.

4.3. Potential interactions with other proposed recommendations

Each renovation that leads to decreasing the heat consumption (roof and walls insulation, heating control automation, etc.) affects the work of the heat exchanger. The better the condition of a building, the less heat needs to be provided. Also, changes in usage time of the heating system influences other measures decreasing the heat consumption – turning the heating off during nights and weekends decreases energy savings from walls and roof insulation or mechanical ventilation with heat recovery, as the time they work and generate savings is also shorter.

Lighting renovation influences savings from lighting control automation, as the installed power after exchanging old bulbs with new LED ones is lower. Reducing the unnecessary usage of the lighting will generate less savings when the power of the bulbs is smaller.

The impact of interactions between measures have been considered in the Variants (see row “Total” in chapter 3.2 and 4.2). Tables in chapters 3.5 and 4.5 include impact of interactions.

4.4. Suggested measures (optimal implementation plan)

Based on the selection criteria mentioned above, the following energy efficiency measures have been proposed:

Insulation of external walls and foundation walls – the most efficient way is to use 14 cm of polystyrene with thermal conductivity parameter of λ=0.04 in the part from 1960 and 4 cm of polystyrene in the newest part of the building. Added to existing state it allows to meet required standard of U = 0.23W/ m^2•K.

Roof insulation – the best option is to use 18 cm of polystyrene with thermal conductivity parameter of λ=0.04 in in the non-historical part of the building. In the oldest part of the school insulating the attic inside with 18 cm of mineral wool is proposed. Added to existing state it allows to meet required standard of U = 0.18 W/m^2•K.

Heating source improvements – Installing thermostats on the convectors in the canteen. Changing the usage time of the heating system so that it does not work at night and during weekends when the building is not used.

Lighting – Exchange of fluorescent bulbs to LED ones. Implementation of lighting control automation so that it responds to the amount of sunlight and the presence of people in the room.

Heating control automation – implementation of the Egain/Promar etc. system, which improves the regulation of the heating system providing for the weather forecast.

Mechanical ventilation with heat recovery – the efficiency of the heat recovery at the level of 75% and decreasing the air flow when the building is not used.

Photovoltaic system – installing PV panels on the roof to achieve 40 kWp from the renewable energy source.

The measures considered in the 2nd variant, ranked by payback time, are presented in the table below. The payback time of each measure may vary in case of implementing all the options due to influences between measures.

Table 197 Measures included in the 2nd variant ranked by payback time

No.	Measure	Final energy savings [kWh/a]	Primary energy savings [kWh/a]	CO_2 reduction [Mg/a]	Financial savings [EUR/a]	Investment costs [EUR/a]	Payback time [years]
1.	Heating control automation	52,360	47,124	17.398	1,350	2,326	2
2.	Heating source modernisation	93,113	83,802	30.940	2,815	12,326	4
3.	Lighting control automation	18,302	54,905	13.141	1,362	19,600	14
4.	Roof insulation	142,643	128,378	47.397	4,312	69,614	16
5.	Lighting modernisation	34,145	105,066	24.516	2,541	58,801	23
6.	Photovoltaic system	-	114,000	-	2,828	65,116	23
7.	External walls insulation	132,383	119,145	43.988	4,002	98,056	24
8.	Mechanical ventilation with heat recovery	189,010	128,403	62.804	5,714	238,234	42
9.	Foundation walls	10,862	9,776	3.609	328	15,183	46
	Total	499,846	611,865	182.566	16,999	579,256	34

The shortest payback time (typically 1-3 years) is achieved in case of heating control automation, despite the fact that there is an annual fee while the system is installed. The measure is then worth considering. The lighting modernisation, including also installing automated technology, is a beneficial option both from economic and environmental point of view.

4.5. Impact of the renovation scheme

	Existing	After implementation
Primary energy consumption - total [kWh/m²a]	156.1	46.7
Primary energy consumption - heating [kWh/m²a]	110.5	44.4
Primary energy consumption - DHW [kWh/m²a]	14.0	14.0
Primary energy consumption - cooling [kWh/m²a]	n/a	n/a
Primary energy consumption - lighting [kWh/m²a]	31.6	8.7
Final energy consumption - total [kWh/m²a]	142.4	53.0
Final energy consumption - heating [kWh/m²a]	117.2	35.4

Final energy consumption - DHW [kWh/m²a]	14.7	14.7
Final energy consumption - cooling [kWh/m²a]	n/a	n/a
Final energy consumption - lighting [kWh/m²a]	10.5	2.9
CO_2 emissions - total [kg/m²a]	51.380	18.741
CO_2 emissions - heating [kg/m²a]	38.929	11.774
CO_2 emissions - DHW [kg/m²a]	4.878	4.878
CO_2 emissions - cooling [kg/m²a]	n/a	n/a
CO_2 emissions - lighting [kg/m²a]	7.573	2.090

The 2nd renovation variant allows reducing final energy consumption by around 500 MWh/a and primary energy consumption by around 498 MWh/a. These savings are not equal to the sum of the savings from each measure calculated separately, which results from the interactions indicated in the previous paragraphs. The total investment cost of the renovation is about 580 000 EUR and the estimated payback time is at the level of 34 years. The EP factor of the building after implementing the proposed measures would achieve about 46.7 kWh/m²/a, which makes the building much more efficient. The total costs of the maximum efficiency variant are significantly higher than the 1st variant, also in reference to the energy savings. Thus, the 1st variant is more realistic and is proposed as the basic one.

5. Attachments

No attachments.