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Deep thermomodernization of three residential buildings in Kryvyi Rih, Ukraine

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Abstract. This article presents the energy balance conditions of three multi-family residential buildings located in Kryvyi Rih, Ukraine. These buildings were built more than 40 years ago and are not insulated. A significant amount of energy is lost by the external partitions. The building's heating is powered by municipal natural gas. A proposal for several thermomodernization variants for selected facilities are presented in the article. These variants of deep thermomodernization include an upgrade of the heating installation, insulation of external walls and roof, and the replacement of windows and doors in common areas. In view of the recent increases in the gas prices, the internal building's temperature is maintained below the thermal comfort. The presented variants include the proposal to leave the internal temperature at the present level, as well as to increase it to 20 °C. Heat transfer coefficients were calculated based on of the PN-EN 6946 standard and the heat demand for the buildings was estimated in the standard reference year in accordance with the PN-EN ISO 13790 standard. Results are compared with real values. The buildings' models were prepared in the Audytor OZC 6.7. Pro software. The impact of appropriately sized photovoltaic system for each of the objects was also analyzed and the solar irradiation data has been taken from the RETScreen 4 software.

1 Introduction

This work analyzes the energy balance of the three selected, characteristic residential buildings belonging to housing communities in Ukraine, located in Kryvyi Rih. This analysis and its results may translate into larger scale projects in the future, even considering the whole city, in which most of the buildings are similar to those described in this article. Like in most countries around the world, the problems with increasing energy demand and environmental pollution are real in Ukraine. One of the main ways to reduce energy consumption and greenhouse gas emissions is by improving energy efficiency. From among all sectors, one of the most energy-intensive in this country, and at the same time almost unmodernized, is the building sector. The majority of buildings in Ukraine have not undergone any energy upgrades. They are not insulated, heating systems are outdated, while natural gas prices are still growing. In Ukraine, at on the 1st of July 2016,

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the natural gas price had doubled. This resulted in the need to reduce spending on heat. The reduction of energy consumption has been achieved by lowering the temperature maintained indoors, even below thermal comfort. For many people living in residential apartment buildings, the costs of utility bills are a significant portion of the whole financial balance of the flat. Even though they get special subsidies, it is not enough to encourage people to maintain thermal comfort in their homes.

In Ukraine, as in other countries, the most sensible solution seems to be a deep thermomodernization of the whole group of buildings. This investment will result in reducing the energy demand for those buildings, while simultaneously allowing reduction of unit costs for each building. The three selected multi-family residential buildings in this analysis were deliberately chosen, as each of them represents a specific type of building common in Kryvyi Rih. Performing an energy balance analysis for these facilities may be the basis for determining the costs of modernization of all local residential buildings and for carrying out a thermomodernization of the whole city.

There is a support system in Ukraine promoting the use of renewable energy sources. Therefore, it was decided to also consider installation of a photovoltaic system on each building. Some electricity can cover shared energy consumption in buildings and the remaining energy can be sold to the grid. All prices and costs given in this article are gross value.

The DREEAM project, financed by Horizon 2020 (http://dreeam.eu/), whose Polish partner is the National Energy Conservation Agency, encourages such deep, multi-building thermomodernization combined with the use of renewable energy. The DREEAM project aims to show that thermomodernization of buildings on a larger scale, combined with the use of renewable energy sources is more profitable than the traditional method of modernization of individual facilities. The project indicates activities that may reduce energy demand by up to 75%. The project consists of two parts. One is devoted to practical actions that will result in a deep thermomodernization in three pilot European locations: Padiham in Great Britain, Treviso in Italy and Berlin in Germany. The second part of the project assumes the preparation of energy audits in other locations that will show the potential of saving energy in different European countries, including Ukraine. The results are intended to prove that regardless of the climate, cultural differences or institutional activities the ideas included in this project can bring enormous benefits, and therefore it is encouraged to replicate this approach across Europe. The results of the project can be the basis for creation of nationwide thermomodernization support programs, fitting to the specific local conditions.

2 Basic information on the examined buildings

In the city of Kryvyi Rih in Ukraine there are thousands of buildings and most of them are not insulated. Three buildings were selected for this analysis. Each of them belongs to one of three groups. Each group consists of a different set of objects specific for this region. The first group includes 3–4-storey buildings made of bricks (further referred as building 1). The second group are 4–5-storey buildings made of reinforced concrete slabs (further referred as building 2), and the third one is over 6-story buildings (further referred as building 3), also made of reinforced concrete slabs. The examined buildings do not have a central hot water distribution system, it was not considered in this analysis. Table 1 contains the most important information about selected buildings.

Table 1. General information about the examined buildings.

Number of building group	**Unit**	**Building 1**	**Building 2**	**Building 3**
Year of construction	[year]	1954	1968	1970
Number of floors	[no.]	5	5	9
Number of people living in the building	[no.]	33	165	431
Heated area	[m^2]	1,070.7	4,222.1	10,592.0

3 Methodology and examination results

3.1 Thermomodernization of selected buildings

The considered buildings are characterized by lack of external partitions thermal insulation and lack of heating installation pipes insulation. It should be considered which modernization variants to carry out, so that the costs incurred can be repaid by the difference in the heat bills. Calculation of the heat demand for buildings in the standard reference year were made using monthly balance method based on PN-EN ISO 13790 [2]. Heat transfer coefficients were calculated on the basis of the PN EN 6946 standard [3]. Computer models of the buildings were made in the Audytor OZC 6.7 Pro software. In addition, the designated results were compared with results from the program which confirmed the correctness of the calculations made. Figures 1, 2 and 3 contain visualizations of buildings modeled in this program.

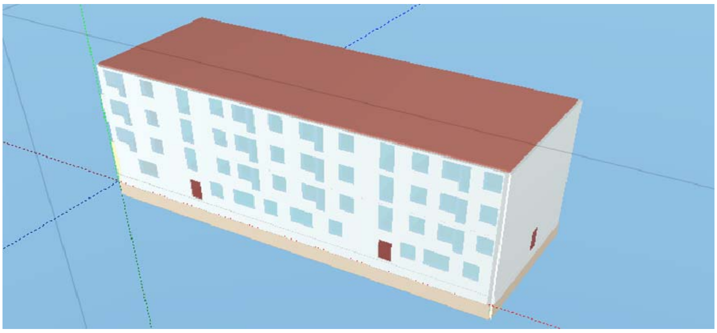

Fig. 1. Building 1 - visualization made in the Audytor OZC 6.6 Pro program.

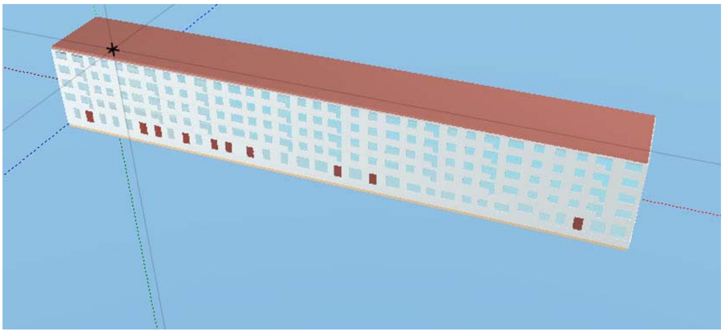

Fig. 2. Building 2 - visualization made in the Audytor OZC 6.6 Pro program.

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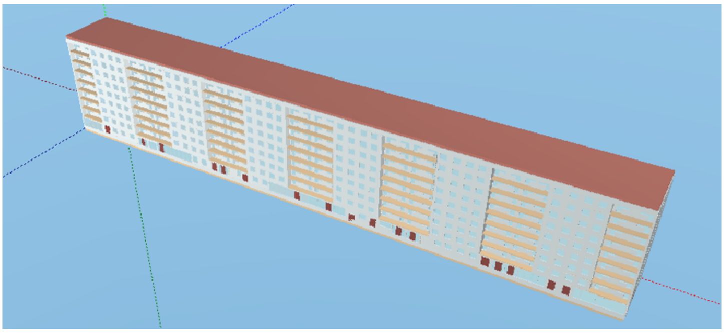

Fig. 3. Building 3 - visualization made in the Audytor OZC 6.6 Pro program.

The calculations were made with the assumption that the internal temperature in buildings is kept at 20°C. Both measured temperature and the buildings' residents indicated however, that in reality temperature is kept at a lower level. In order to verify this, the amount of usable energy was converted into final energy and then compared with the actual energy consumption in buildings. Then the variants with different temperatures were analyzed, which indicated that the temperature in the buildings is about 17°C. Further calculations assumes this temperature.

Therefore, at the beginning, two variants were proposed for each of the buildings. Both modernization variants assume the same basic state before thermomodernization, in which the average internal temperature is 17°C. A list of possible upgrades is identical for all the buildings and includes: insulation of walls and roofs, replacement of window and door carpentry in common areas and modernization of heating installations.

In order to select the most economical solution, several upgrade variants were analyzed for each thermomodernization activity. The costs of individual thermomodernization measures and the annual financial savings resulting from their implementation were listed. The upgrade variants in which the quotient of cost and savings was the lowest (the lowest SPBT - Simple Pay Back Time) were selected. Selected solutions are summarized below:

- insulation of external walls with mineral wool (with a thermal conductivity coefficient $\lambda = 0.031$ W/m·K), thickness of 13 cm (buildings 1 and 3) and 14 cm (building 2) - change in the heat transfer coefficient from approximately 1.2–1.3 W/m^{2}K to 0.19 W/m^{2}K;
- insulation of the ventilated flat roof with granular mineral wool (with a thermal conductivity coefficient $\lambda = 0.040$ W/m·K), thickness of 23 cm - change in the heat transfer coefficient from approximately 0.95 W/m^{2}K to 0.15 W/m^{2}K;
- replacement of staircase windows with a heat transfer coefficient of 2.9 W/m^{2}K for new plastic windows (U = 0.9 W/m^{2}K);
- replacement of old doors with a heat transfer coefficient of 2.85 W/m^{2}K for aluminum doors (U = 1.3 W/m^{2}K);
- modernization of the heating installation - increase in the total system efficiency from 0.5852 to 0.7524 (partial efficiency was determined based on the Polish Regulation [1]).

Figure 4 presents the demand for usable and final energy consumption in the buildings in the state before and after deep thermomodernization. The cost of 1 GJ of final energy was set at 339 UAH/GJ. The gross price of UAH/GJ was taken after 1st July 2016 (after price increases). Final energy consumption in buildings 1 and 3 (in terms of kWh/m^2/year) is at a similar level. This value in building 2 is lower and it is due to the fact that over 74% of the building's surface is heated (in buildings 1 and 3 this value is around 55–60%), and the energy consumption indicator is related to the unit of the heated area.

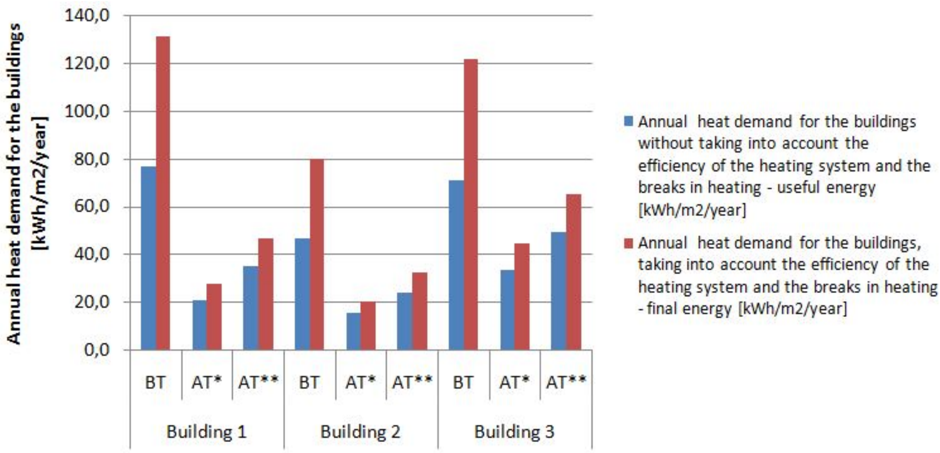

Fig. 4. Annual heat demand for the buildings.
BT – before thermomodernization, AT – after thermomodernization.
* with assumption that internal temperature is 17°C before and after thermomodernization.
** with assumption that internal temperature is 17°C before and 20°C after thermomodernization.

Due to the still growing prices of thermomodernization materials in Ukraine and a very difficult assessment of how much these prices will change after thermomodernization, it was decided to set the costs of selected modernizations at the current prices level in Poland (in subsequent calculations 1 PLN = 6.72 UAH - average exchange rate of the National Bank of Poland for April 12th 2017). The predicted total costs of labor and materials, as well as estimated savings depending on the variant, are presented in table 2. Assuming that after thermomodernization the temperature in buildings will remain at the level before thermomodernization the theoretical reduction in final energy demand will go down to approx. 64% in building 3, 74% in building 2 and 79% in building 1. In variant which assures increasing indoor temperature to 20 °C the total demand for final energy compared to the value from before thermomodernization is lower approx. 46% in building 3, 57% in building 2 and 64% in building 1.

Table 2. Economic characteristics of the optimal variant of the thermomodernization project.

Description	Unit	Building 1	Building 2	Building 3
Planned total costs	[UAH]	3,753,023	9,037,879	21,118,701
Annual theoretical final energy cost savings*	[UAH/year]	135,058	306,659	998,965
Annual theoretical reduction in final energy demand*	[%]	78.7	74.3	63.4
Simple Pay Back Time (SPBT) *	[years]	27.8	29.5	21.1
Annual theoretical final energy cost savings**	[UAH/year]	110,107	246,080	728,511
Annual theoretical reduction in final energy demand**	[%]	64.2	59.6	46.3
Simple Pay Back Time (SPBT) **	[years]	34.1	36.7	29.0

* with assumption that internal temperature is 17°C before and after thermomodernization
** with assumption that internal temperature is 17°C before and 20°C after thermomodernization

The demand for final energy in buildings in Figure 4 is lower than in buildings characterized by similar external partitions parameters. This is mainly due to the fact that analyzed buildings have internal temperatures lower than 20°C (approximately 17°C), ventilation is very poor (ventilation airflow limited by users) and the demand of hot water preparation is not considered in results. In recent years the value of Ukrainian Hryvna is unstable, beacuse of it the polish prices of materials and labor were used in calculations (these Polish prices are even twice as high). Because of this fact the SPBT of selected thermo-modernization measures are high (Table 2).

Table 3 presents the share of the costs of individual thermomodernization actions, which are summarized in Table 3.

Table 3. Economic characteristics of the optimal variant of the thermomodernization project.

Kind of modernization	**Participation in the entire thermomodernization**					
	Building 1		**Building 2**		**Building 3**	
	UAH	%	UAH	%	UAH	%
Insulation of external walls	1,834,890	48.9	5,048,215	55.9	12,675,888	60.0
Insulation of external walls of cellar	173,074	4.6	0	0.0	0	0.0
Insulation of the roof	595,741	15.9	1,340,816	14.8	2,132,096	10.1
Staircase window replacement	86,930	2.3	243,855	2.7	735,437	3.5
Staircase door replacement	61,907	1.6	296,675	3.3	358,047	1.7
Modernization of the heating installation	870,480	23.2	1,978,318	21.9	5,087,233	24.1
Documentation	130,000	3.5	130,000	1.4	130,000	0.6
Sum	3,753,023	100.0	9,037,879	100.0	21,118,701	100.0

In all three buildings, the highest share of cost of thermomodernization actions is the insulation of external walls. The larger the building and the greater the ratio of the wall area to the entire surface of the whole external partitions, the greater the share of the wall insulation cost in the whole cost, which in the case of building 3 is 60% of the total cost of thermomodernization. In all buildings, the costs of modernizing the heating system have a similar share in the total costs, which results from the adopted assumption of dependency of the price of such an operation on the number of heaters in the facility.

As shown in table 2, in variants that assume improvement of thermal comfort, including increase of the internal temperature from 17°C to 20°C, the energy and financial savings are reduced in comparison to the variants in which this temperature is not increased. However, it is recommended to improve this situation. Simple Pay Back Time (SPBT), assuming a fixed price of heat in time, are at the level of 30–34 years.

As an additional thermomodernization activity, a photovoltaic installation can be also considered. Despite the fact that this type of installation is used to produce electricity, the resulting financial gains can be used to repay thermomodernization activities reducing heat demand. The selection of photovoltaic installations is presented in the chapter 3.2.

3.2 Selection of photovoltaic installations

In this chapter, the selection of a photovoltaic (PV) system for each building was analyzed. PV systems will supply electricity for the common parts of the buildings while the surplus energy will be sold to the grid. Electricity usage in the common parts of the building results mostly from demand for lighting, which is energy-efficient. In addition, there are lifts in building 3. There is a support system for photovoltaic installations currently in force in Ukraine. According to the support system it is possible to install a PV system with a power not exceeding the ordered power for the building, but no more than 30 kW_p. In both analyzed buildings ordered power is lower than 30 kW_p. However, it was assumed that if the roof surface is large enough it will be possible to increase this power to 30 kW_p. It was estimated that 20 kW_p of photovoltaic panels could be installed in the first building and 30 kW_p in the remaining buildings. Use of typical polycrystalline modules with nominal power of 250 W_p and 15.3% efficiency was assumed for each system. In order to maximize solar profits, PV panels should be placed on the roof on a frame at an angle of 35° and directed towards the south. Calculations of electricity amount produced by PV installations for the considered buildings were made using the solar irradiation values taken from the RETScreen program. In all three buildings, the rate for purchasing electricity in 2016 was 1.68 UAH/kWh. According to the Ukrainian law in case of buildings like those assessed the principle of monthly energy balancing and settlements with the energy producer applies. If the monthly amount of energy produced by PV installations is greater than the amount of energy for the building's own needs the surplus is rewarded with a "green tariff", the value of which depends on the period in which the installation was installed. For the period 1st January 2017 – 31st December 2019, it is – 6.2271 UAH/kWh. The average annual production of electricity in the proposed photovoltaic installations gives an efficiency of 1,168 kWh/kW_p per year. The financial balances were calculated by comparing the above data with the demand for electricity in common parts of the buildings. The outcomes are summarized in Table 4. For further calculations, the total PV installation price was assumed at 43,680 UAH/kW_p.

Table 4. Electricity usage in common areas in the buildings calculated for 2016.

Building	Electricity consumption by the common parts of the buildings		Electricity saving – electricity production by the PV		Surplus electricity sold to the network		Yearly profit
	UAH	kWh	UAH	kWh	UAH	kWh	UAH
Building 1	7,379	4,392	7,379	4,392	118,116	18,968	125,494
Building 2	2,409	1,434	2,409	1,434	209,268	33,606	211,677
Building 3	31,518	18,761	27,362	16,287	116,777	18,753	144,139

Building 1 and building 2 do not have a lift and in these cases the electricity demand is much lower than the value of electricity produced by the PV installation. Therefore, the greater part of the energy is sold to the network, and the income for its sale is higher. In the elevator-equipped building 3 the situation is different and variant is less profitable than in 1-st and 2-nd building. In every case monthly balances of electricity and the excess energy is sold to the network are created. "The green tariff" is almost four times higher than the price of energy purchased in the network. Thus, the most advantageous solution that brings the fastest return on investment is the variant in which the building consumes the least amount of electricity and sells to the network as much electricity as possible. Below in Figures 4–6, the monthly breakdown of electricity demand in the common parts of buildings 1-3 and the production from photovoltaic installations designed for these buildings are listed.

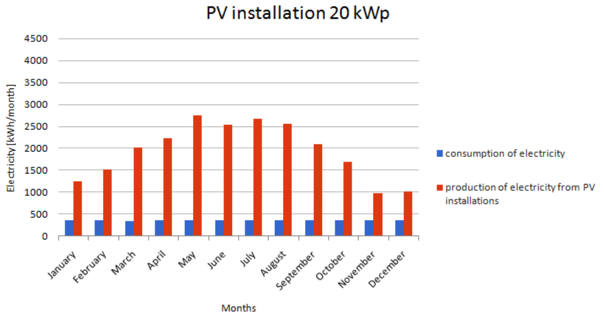

Fig. 4. Consumption of electricity by the Building 1 and production electricity from 20 kW_p photovoltaic installation.

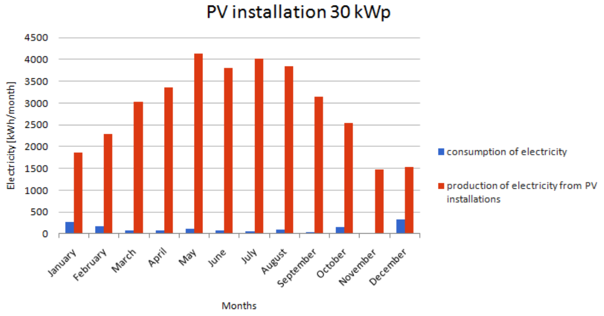

Fig. 5. Consumption of electricity by the Building 2 and production electricity from 30 kW_p photovoltaic installation.

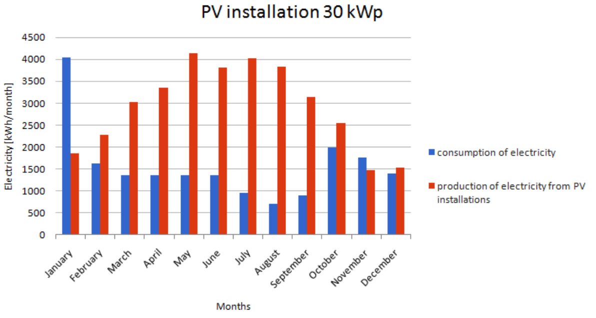

Fig. 6. Consumption of electricity by the Building 3 and production electricity from 30 kW_p photovoltaic installation.

3.3 Thermomodernization and photovoltaics

In this chapter the data related to the variants assuming only thermomodernization and variants assuming thermomodernization expanded with photovoltaic installations is collected and presented. The data is presented in Table 5. Inclusion of heating and electricity into joint analysis is not typical, however it serves an important function in calculation of potential financial savings, both resulting from the reduction of heat consumption and from the electricity sold to the grid. Money obtained from the sale of electricity can be used not only to pay off the solar installation, but also to other thermomodernization activities. A detailed description of the main conclusions is given in Chapter 4.

Table 5. Energy specification of the buildings (heat + electricity for common parts).

Description	Unit	Building 1		Building 2		Building 3	
		BT	AT	BT	AT	BT	AT
Annual heating demand for heating the building without taking into account the efficiency of the heating system and the breaks in heating - final energy*	[kWh/year]	140,556	29,889	338,278	87,000	1,290,333	471,778
	[UAH/year]	171,534	36,476	412,834	106,175	1,574,723	575,758
Annual heating demand for heating the building without taking into account the efficiency of the heating system and the breaks in heating - final energy**	[kWh/year]	140,556	50,333	338,278	136,639	1,290,333	693,389
	[UAH/year]	171,534	61,427	412,834	166,754	1,574,723	846,212
Electricity demand for common parts of the building	[kWh/year]	4,392	0	1,434	0	18,761	0
	[UAH/year]	7,379	0	2,409	0	31,518	0
Electricity sold to the grid	[kWh/year]	0	18,968	0	33,606	0	18,753
	[UAH/year]	0	118,116	0	209,268	0	116,777
Final energy + electricity*	[kWh/year]	144,948	29,889	339,712	87,000	1,309,094	471,778
	[UAH/year]	178,913	-81,639	415,243	-103,093	1,606,241	458,981
Final energy + electricity**	[kWh/year]	144,948	50,339	339,709	136,652	1,309,103	695,851
	[UAH/year]	178,913	-56,689	415,243	-42,514	1,606,241	729,435

BT – before thermomodernization, AT – after thermomodernization
* with assumption that internal temperature is 17°C before and after thermomodernization
** with assumption that internal temperature is 17°C before and 20°C after thermomodernization

4 Analysis of results and conclusions

Collection of all the results presented in the tables in Chapter 3 allowed the final analysis and conclusions. The most important data was selected and summarized in Table 6. Each proposed modernization variant brings savings, both in terms of energy and money.

Table 6. Summary of the most important parameters: energy costs, energy savings, SPBT for individual investments.

Description	Unit	Building 1	Building 2	Building 3
The cost of thermomodernization	[UAH]	3,753,023	9,037,879	21,118,701
The cost of PV installation	[UAH]	873,600	1,310,400	1,310,400
Reduction of energy charges (only heating) - without PV *	[UAH/year]	135,058	306,659	998,965
Reduction of energy charges (heating and electricity) - with PV *	[UAH/year]	260,552	518,336	1,147,260
Reduction of energy charges (only heating) - without PV **	[UAH/year]	110,107	246,080	728,511
Reduction of energy charges (heating and electricity) - with PV **	[UAH/year]	235,601	457,757	876,806
SPBT (only heating) - without PV *	[years]	27.8	29.5	21.1
SPBT (heating and electricity) - with PV *	[years]	17.8	20.0	19.6
SPBT (only heating) - without PV **	[years]	34.1	36.7	29.0
SPBT (heating and electricity) - with PV **	[years]	19.6	22.6	25.6

* with assumption that internal temperature is 17°C before and after thermomodernization
** with assumption that internal temperature is 17°C before and 20°C after thermomodernization

As previously indicated in chapter 3.1, for thermomodernization containing all the indicated variants reducing the heat demand and bringing the indoor temperature of buildings to 20°C, SPBT was at the level of 30–34 years. The photovoltaic system can improve combined financial results. Under the assumptions presented in sub-chapter 3.2, PV installations will cover 100% of the electricity demand for common parts in the analyzed buildings and additional energy will be sold to the electricity grid. It will allow obtaining additional income that will reduce SPBT. Variants assuming this option reduce SPBT to 20–26 years. It is a long payback period but it is acceptable assuming that PV installations are designed for a long technical lifetime and the thermomodernization measures carried out will bring beneficial effects for even longer periods of time. An additional unknown, which may favorably affect the proposed investments, are the costs of electricity and heat, which in Ukraine are systematically growing, much faster than in other countries in this region.

Comprehensive thermomodernization activities in old, uninsulated buildings are needed and they can bring visible effects. Both operating costs and energy consumption can be reduced by up to 3-4 times. Additional benefits may come from the use of renewable energy sources. The combination of all these activities at once, on a multi-building scale, reduces unit costs of the entire investment while simultaneously improving the comfort of use of the buildings.

References

1. Regulation of Minister of Infrastructure and Economic Development (21 February, 2015) *on the methodology for determining the energy performance of building or part of the building and energy performance certificates*
2. PN EN ISO 13790 : *Energy performance of buildings -- Calculation of energy use for space heating and cooling*
3. PN EN ISO 6946: *Building components and building elements -- Thermal resistance and thermal transmittance -- Calculation method*