Tomasz SZUL
University of Agriculture in Kraków, Faculty of Production and Power Engineering
ul. Balicka 116b, 31-149 Kraków, Poland
e-mail: t.szul@urk.edu.pl

Received: 2018-07-25 ; Accepted: 2018-11-27

TECHNICAL AND ECONOMIC EVALUATION OF A HEATING SYSTEM BASED ON AIR-TO-WATER HEAT PUMPS WITH PHOTOVOLTAIC - MICRO-INSTALLATION WITHIN THE PROSUMENT PROGRAM

Summary

For an exemplary single-family residential building, final energy consumption for heating and domestic hot water preparation was calculated using an air / water heat pump, consumption of electricity for household purposes (lighting, household appliances, RTV, etc.) was also calculated as based on statistical summaries. On this basis, power was selected and the annual production volume was determined by a photovoltaic micro-installation working in the ON-GIRD system pursuant to prosumer regulations contained in the Act on Renewable Energy. Then, an economic analysis was carried out basing on such static and dynamic methods as SPBT, PBP, NPV, IRR and CCE. The calculations were made for two variants, i.e.: the investment costs of the system are borne entirely by the investor, or the installation is purchased within the "EKOkredyt Prosument II" NFEP&WM program. As a result of the calculations, it was found that the investment in PV micro-installation will be profitable only if the support instruments offered by the NFEP&WM program are used. If the investor uses co-financing, the investment will pay back within 16 years at the latest and if he wants to invest his own funds, the waiting period for the return on investments can be extended to up to 21 years, which, given the twenty-five year period of operation, can turn out to be the risk that the funds invested can never be returned.
***Key words**: final energy consumption in a building, air / water heat pumps, PV micro-installation, Prosumer program, economic analysis.*

OCENA TECHNICZNO-EKONOMICZNA SYSTEMU GRZEWCZEGO OPARTEGO NA POMPACH CIEPŁA TYPU POWIETRZE WODA WSPÓŁPRACUJĄCEGO Z MIKROINSTALACJĄ FOTOWOLTAICZNĄ W RAMACH PROGRAMU PROSUMENT

Streszczenie

Dla przykładowego budynku mieszkalnego jednorodzinnego obliczono zużycie energii końcowej do ogrzewania i przygotowania ciepłej wody użytkowej za pomocą pompy ciepła typu powietrze/woda. Określono również w oparciu o zestawienia statystyczne wielkość zużycia energii elektrycznej na cele bytowe (oświetlenie, AGD , RTV, itp.) Na tej podstawie dobrano moc i określono roczną wielkość produkcji przez mikroinstalację fotowoltaiczną pracującą w systemie ON-GIRD w ramach przepisów dotyczących prosumentów zawartych w ustawie o OZE. Następnie przeprowadzono analizę ekonomiczną w oparciu o metody statyczne i dynamiczne takie jak: SPBT, PBP, NPV, IRR oraz CCE. Obliczenia wykonano dla dwóch wariantów, tj.: koszty inwestycyjne systemu ponoszone są w całości przez inwestora, lub instalacja jest zakupiona w ramach programu NFOŚiGW „EKOkredyt Prosument II". W wyniku przeprowadzonych obliczeń stwierdzono, że inwestycja w mikroinstalację PV będzie opłacalna jedynie w przypadku skorzystania z instrumentów wsparcia oferowanych przez program NFOŚiGW. Jeżeli inwestor skorzysta z dofinansowania to inwestycja zwróci się najpóźniej w ciągu 16 lat, natomiast jeżeli będzie chciał zainwestować środki własne okres oczekiwania na zwrot nakładów może wydłużyć się nawet do 21 lat, co przy zakładanym dwudziestopięcioletnim okresie eksploatacji może okazać się, że inwestycja ta będzie niosła za sobą ryzyko, iż zainwestowane środki mogą się nie zwrócić.
***Słowa kluczowe:** zużycie energii końcowej w budynku, pompy ciepła typu powietrze/woda, mikroinstalacja PV, program Prosument, analiza ekonomiczna.*

1. Introduction

The prosumer energy industry in Poland is being talked about while developing renewable energy. Renewable energy sources, in accordance with the Polish Energy Policy adopted by the government by 2030, are to constitute 20% of the total energy produced in Poland. On a global scale, it is estimated that prosumers will generate approx. 10% of supplies, while in individual regions this share can be much larger. Market participants decide for themselves whether they want to buy energy from the network or to produce it for their own use.

One of the main directions of the development of the electricity market in the world, in Europe and in Poland can be a departure from the so-called system energy for the benefit of local distributed energy, the behavior of active energy consumers – prosumers is the main determinant of changes, with particular emphasis on investments in small micro-RES sources.

The Act on Renewable Energy Sources [15] (the implementation of the Directive on the promotion of the use of energy from renewable sources [3] and on energy efficiency [4]) introduced rules and conditions for conducting activities in the field of electricity generation from renewable energy sources as well as mechanisms and instruments supporting the production of electricity from renewable energy sources. The concept of micro-installation - that is, a renewable energy source installation with a total installed electric power of no more than 40 kW, connected to the power grid (ON-GIRD) with a rated voltage lower than 110 kV, has been defined. When using micro-installations, the energy produced in the first place is used to satisfy the current consumption at home. If a Prosumer produces more energy than its current consumption, a surplus will be created and transferred to the power grid. Pursuant to the RES Act, the so-called net-metering, or a periodic billing system, in the form of an invoice discount is used. The Seller shall inform the Prosumer about the amount of energy settled in accordance with the periods adopted in the comprehensive contract. The system of settlements for Prosumers enables the receipt of produced surplus energy sent to the network in the period up to 365 days from the date of billing reading within the proportion depending on the installed capacity in a given installation:

- for installations up to 10 kW: 0.8 kWh (energy consumed) for each 1 kWh of energy generated,
- for installations greater than 10 kW: 0.7 kWh (energy consumed) for each 1 kWh of energy generated. Both active electricity and distribution fees for variable components are subject to a discount.

In addition, it is encouraging by the fact that the National Fund for Environmental Protection and Water Management (NFEP&WM) together with Bank for Environmental Protection (BOŚ) also joined the promotion of renewable energy systems. The "EKOkredyt Prosument II" program introduced support mechanisms for investors wishing to purchase a photovoltaic micro-instanlations. Individuals can apply for an investment in the form of the redemption of a loan in the value of 30%. The loan interest rate is determined in advance by the fund at 1%. You must pay an income tax of 18% on the amount borrowed from your subsidy. The maximum funding period is 15 years. The subsidy can be used only to cover qualified investment costs (a purchase and installation of a photovoltaic system). As the NFEP&WM and the Bank for Environmental Protection (BOŚ) emphasize, an important condition for obtaining a loan with a subsidy is to care for the non-oversizing the installation – the design and installation should follow the energy needs of the residents.

Despite many incentives, the economic calculation is the basic criterion determining the installation of a specific energy system [11]. Energy analysis can not be a decisive factor in the choice of a solution to be used in practice. A potential user wishing to install a photovoltaic micro-installation should evaluate both the technical and economic aspects of each of the considered systems and choose the one that will be the most beneficial in the perspective of the total service life. In the literature on the subject, you can find technical and economic information and an analysis concerning PV micro-installations producing energy for the needs of individual consumers (households) with a capacity of 3 - 10 kW [13]. However, there are no studies on the co-operation of PV micro-installations with heating systems including heat pumps. The implementation of this type of a system can turn out to be an interesting alternative to the traditional sources of heat (e.g. gas) due to the beneficial system of the settlements of the energy generated by a prosumer - the surplus of electricity generated in the summer by PV micro-installations can be received (with a corresponding discount) during the heating season to feed the heat pump compressor. Therefore, the aim of the work was to determine the profitability of the PV installation which will generate energy to cover the living requirements (lighting, household appliances, RTV, etc.) and the heating requirements, such as heating the building and preparing hot usable water. The scope of work includes a calculation of power demand for heating and hot water preparation, a calculation of annual final energy consumption in the facility, power selection and the estimation of annual energy generation by the PV micro-installation. The economic analysis [1, 2, 11] includes the calculation of the value of assessment indices, as based on such static and dynamic methods as SPBT, PBP, NPV, IRR and CCE. The calculations were made for two financing options, i.e. the investment costs of the system are borne entirely by the investor, or the installation is purchased under the NFEP&WM "EKOkredyt Prosument II" program.

2. Materials and methods

The facility subject to the simulation study is typical for rural areas of the Kraków poviat [11], a detached single-family residential building with a usable area of 153 m^2, with the heated volume of 560 m^3, located in the third climatic zone (Kraków Balice climate station) with natural ventilation, inhabited by four people. The building density ratio A/V_e is 0.96 [1/m]. The building envelope is made in accordance with the guidelines regarding the maximum values of the U_{max} heat transfer coefficient contained in WT2013 [9]. Basing on the PN-EN 12831 standard [7], the heating demand of the building, which is 9.3 kW, was calculated. The power of the device for the preparation of domestic hot water in a tank system was calculated according to PN-EN 15450 [8], it equals 1.86 kW. Domestic hot water in the building will be distributed to dredging points in the circulation system. A heat pump with a capacity of approx. 12 kW and a seasonal efficiency factor COP = 2.6 (heat pump air/water 55/45) were selected for the analysis. The heat pump will operate in a central heating system with radiators (operating at 55/45^{o}C). The final stage of the technical analysis included the calculation of the final energy consumption of the building in the standard heating season (including energy consumption for heating, hot water preparation and the feed of ancillary equipment of the heating system). The calculations were made in accordance with the methodology included in the Regulation of the Minister of Infrastructure on the energy performance of buildings [10]. The data regarding the consumption of electricity for residential purposes in a household located in the rural areas of the Kraków poviat (lighting, household appliances, RTV, etc.) were adopted based on the lists contained in the Central Statistical Office of 2016 data [5], it is at the level of 3874 kWh for a family of four. The total annual electricity consumption in the building is summarized in Table 1.

Table 1. Value of the final energy demand index
Tab. 1. Wartość wskaźnika zapotrzebowania na energię końcową

Specification	Living needs	Heating	Hot water	Auxiliaries	Total
MWh	3.87	5.14	2.06	0.5	11.57
participation %	33	45	18	4	100

Source: own work / Źródło: opracowanie własne

The total electricity consumption in the analyzed facility is approximately 11.6 MWh/year.

The selection of the power of PV micro-installations was the next stage of the analysis.

The photovoltaic system power was calculated using the following formula [6]:

$$P_{PV} = \frac{(E_k \cdot a) + \left(\frac{E_k \cdot b}{O_e}\right)}{U_{PV_j}} \quad \text{kWp (1)}$$

where:
E_k – the amount of energy consumed annually, kWh;
a – percentage share of the current own consumption, %;
b – percentage share of the amount of energy delivered to the grid, %;
O_e – discount, up to 10 kW 0.8 over 0.7;
U_{PVj} – annual energy generation from 1 kWp of the installed capacity by PV installation [kWh].

The PV installation power calculation was based on the following assumptions:
- annual energy consumption E_k= 11570 kWh,
- the percentage share of the current own consumption varies in the range of 20 to 30% and therefore the average value was taken into account for calculations, i.e. a = 25%, thus the b parameter = 75%,
- discount O_e = 0.7,
- annual energy generation with 1 kWp for the Kraków-Balice climate station is U_{PVj} = 994 kWh.

For the above-mentioned assumptions, the P_{PV} photovoltaic power is equal to 15.3 kWp.

Then, the amount of the energy obtained from photovoltaic modules for long-term average conditions that prevail in the vicinity of Kraków was calculated. Energy for individual months has been calculated using the "Selfa PV calculator" program (http:/www.selfa-pv.com), however, due to the fact that the assumed operation time of the micro-installation is 25 years, the calculations assume that conversion efficiency over time decreases by 0.8% for each year of the installation operation [6]. The results of calculations are shown in Fig. 1.

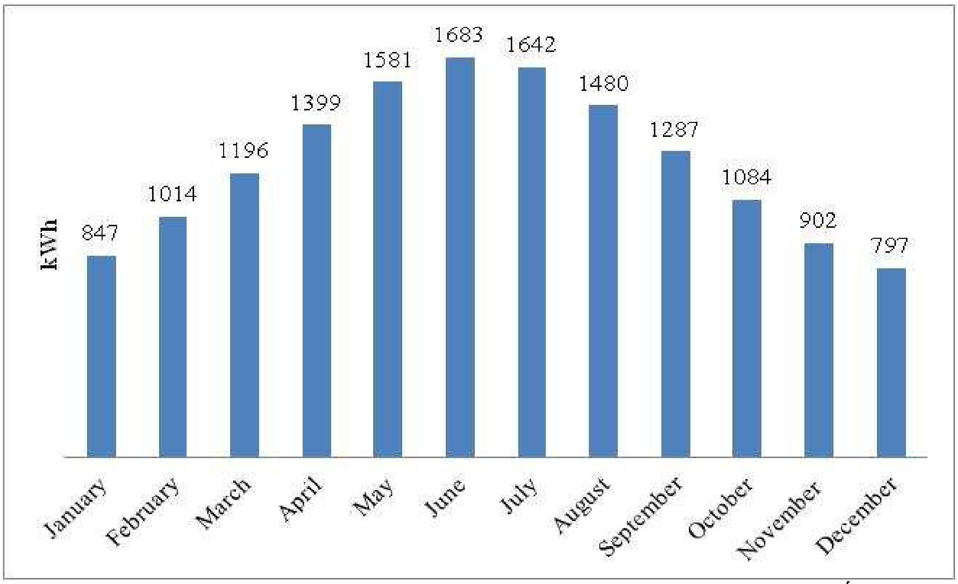
The average annual electricity generation for 15.3 kWp micro-installations is 14912 kWh. The greatest amount of sunshine occurs in the summer period from April to September. In these months, we obtain the largest profit from the energy generated. Due to the fact that these months are not in the heating season, most of the energy produced will be sent to the grid during this time. In the remaining months (during the heating season), the facility will take energy from the grid due to the small solar yield (4 times smaller than in the summer).

Having the data on the amount of energy used in the household and the energy yield from PV micro-installations, calculations were made to determine the amount of the annual costs of electricity consumption in the building. The results of the calculations for the PV micro-installation generation balance are shown in Fig. 2, while the generation and consumption balance (with discount) for electricity is shown in Fig. 3.

Basing on the calculations made, it can be concluded that on an annual basis, approx. 12 thousand kWh of the electricity generated by the PV installation will be transferred to the power grid. Approximately 2.9 thousand kWh of the energy will be used for the building's own needs, of which about 66% will be consumed by the heating system.

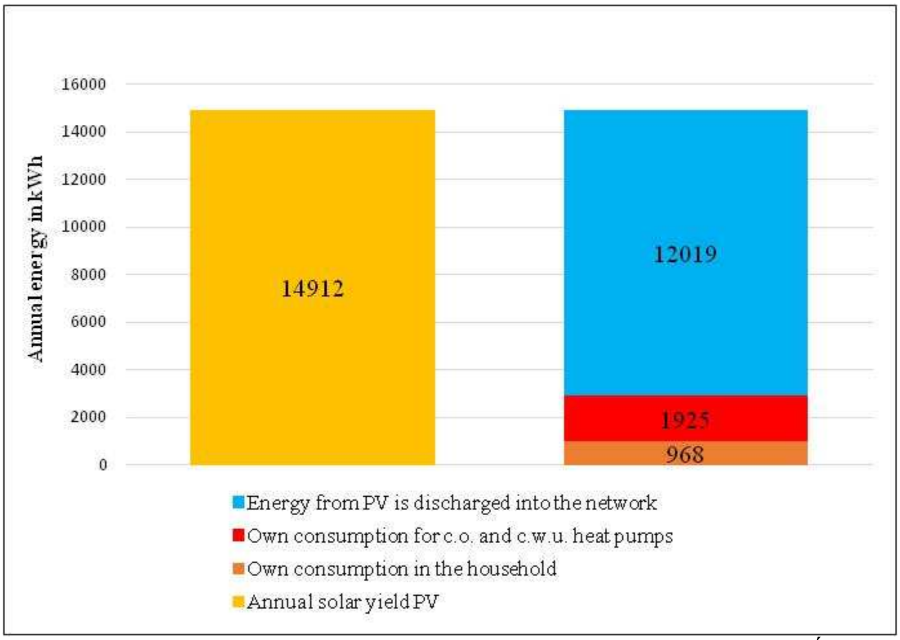
Taking into account the discount (30%), the amount of energy that can be "recovered" from the network was estimated - for the analyzed facility it will amount to approx. 8.4 thousand kWh, which, together with the total electricity consumption from the network amounting to approx. 8.68 thousand kWh, will result in the need to purchase approx. 267 kWh of electricity from the grid. This value, with a total energy consumption of 11.6 thousand kWh, is only 2.3% - so the PV micro-installation covers nearly 98% of the energy needs of the analyzed facility.

Taking into account the cost of electricity at the level of 0.65 PLN/kWh and the fee for renewable energy (3.7 PLN/MWh) for the energy collected, the estimated annual cost incurred for the purchase of electricity will amount to 206 PLN. If the building did not have a PV micro-installation - the annual costs incurred for the purchase of electricity would be PLN 7560.



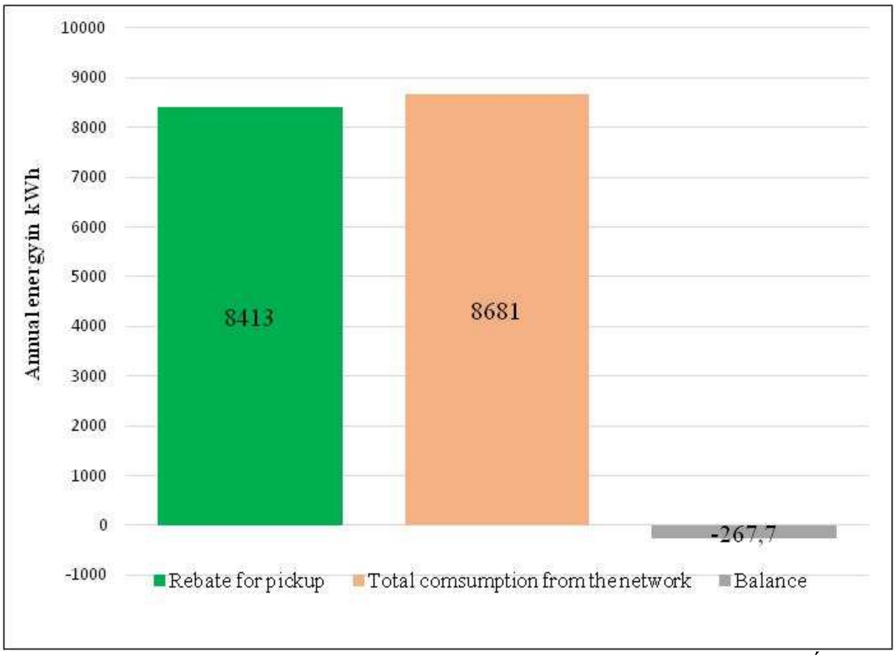
Source: own work / Źródło: opracowanie własne

Fig. 1. Electricity generation in the period of 12 months
Rys. 1. Produkcja energii elektrycznej w okresie 12 miesięcy



Source: own work / Źródło: opracowanie własne

Fig. 2. Energy generation balance of the PV micro-installation
Rys. 2. Bilans produkcji energii przez mikroelektrownię PV



Source: own work / Źródło: opracowanie własne

Fig. 3. Net-metering balance in the analyzed building
Rys. 3. Bilans Net-meteringu dla analizowanego obiektu

To estimate the investment costs, an offer inquiry was sent to ten companies dealing in the distribution of photovoltaic systems meeting operational and technical requirements consistent with the provisions of the energy law [13]. The inquiry concerned micro-systems with a capacity of 15-15.5 kWp with assembly, both on the roof slope and on the ground. On the basis of the offers received, the investment costs were determined as the average value of the proposed amounts. Capital expenditures can be covered by the investor's own funds, it is also possible to benefit from funding from the NFEP&WM in the "EKOkredyt Prosument II" program. Taking into account the interest rate on the loan, the financing period of 15 years, the redemption rate and the fact that a tax of 18% should be paid on the subsidy received. The actual subsidy amount was calculated, which is 19% (with a redemption of 30%).

In addition to installation costs, such operating costs as service and maintenance are very important for every investor, as well as insurance costs for the installation. It was assumed that the costs would account for 1.5% of capital expenditures per year. No less important - and often overlooked - is the depreciation of the solar photovoltaic installation. The assumption was linear depreciation spread over 25 years.

The economic assumptions for the calculation together with the estimated value of the annual benefits (*WRK*) resulting from the use of PV micro-installations are presented in Table 2.

Table 2. Basic assumptions for economic calculations
Tab. 2. Podstawowe założenia do obliczeń ekonomicznych

Specification	Value	
NI – expenditure, [PLN thousand]	*PV15*	*PV15*$_{d30}$
	61	49.4
n – total number of the years of operation	25	
o – service, repairs and insurance costs 1.5% of investment costs (annually), [PLN thousand]	0,9	
a – depreciation of photovoltaic installations, [PLN thousand]	2,4	
unit price (gross) of energy according to operator's tariffs	electricity tariff G11 (PLN 0.65/kWh)	
i– discount rate	3 %	
Pb – annual cost avoided purchase of electricity), [PLN thousand]	7,3	
Ke,o – annual costs of using the installation (o + a), [PLN thousand]	3,3	
WRK –value of annual benefits (*Pb-Ke, o*), [PLN thousand]	4	

Source: own work / Źródło: opracowanie własne

3. Indicators of economic evaluation of photovoltaic micro-installations

The choice of a particular system should be based on objective selection criteria. It is commonly believed that this criterion is the surplus of effects over the inputs [12, 13]. The economic analysis was made on the basis of simple and complex methods of property investment assessment, based on the interest rate (discount rate), taking into account the change in the value of money over time.

The methods are [1, 2, 11]:

- simple payback period SPBT (simple pay-back period).

Quotient of investment outlays and total savings (benefits).

$$SPBT = \frac{NI}{WRK} \text{ [years]} \tag{2}$$

- discounted payback period of PBP expenditures (pay-back period).

The period in which the discounted cash flows cover the investment outlays incurred. The discounted payback period includes the variable value of the invested amount over time:

$$PBP = \frac{\ln\left[\dfrac{1}{1-\left(\dfrac{NI}{WRK}\right)\cdot i}\right]}{\ln(1+i)} \text{ [years]} \tag{3}$$

- NPV net present value (net present value).

It is the sum of all future revenues for the lifetime of investments brought in to the current year and reduced by the investment outlays incurred (3):

$$NPV = \sum_{n=1}^{n=t} \frac{WRK_n}{(1+i)^n} - NI \text{ [PLN thousand]} \tag{4}$$

- internal rate of return of IRR (Internal Rate of Return) investment outlays.

This is the value of the discount rate at which the NPV net present value is equal to zero. The condition of investment profitability meets the criterion: *IRR* > *i*.

$$\sum_{n=1}^{n=t} \frac{WRK_n}{(1+IRR)^n} - NI = 0 \tag{5}$$

- cost of energy saved CCE (Cost of Conserved Energy).

If the cost of saved energy is less than or equal to the price paid for energy, there are indications that the investment is profitable.

$$CCE = \frac{NI \cdot \dfrac{i}{1-(1+i)^{-n}} + Ke,o}{\Delta E} \text{ [zł/kWh]} \tag{6}$$

where:
NI – initial costs (purchase and commissioning costs) [PLN thousand],
Ke,o –annual costs of using the installation (service, insurance and depreciation of installations),
t – another year of installation use,
i – discount rate,
n – 1..25 another year of costs (n = 25 years of installation life expectancy),
NI – investment expenditure,
WRK – the value of annual benefits [PLN thousand],
ΔE – annual energy saving [kWh].

4. Analysis of study results

The calculations made based on the economic assessment indicators allowed to determine the legitimacy of investing in solar micro-installations on farms, which additionally wanted to heat the building with a heat pump.
The results of the economic analyzes carried out for individual variants are presented in Table 3.

Table 3. Results of an economic analysis for individual financing options
Tab. 3. Wyniki analizy ekonomicznej dla poszczególnych wariantów finansowania

Specification	*PV3*	*PV3*$_{d30}$
SPBT [years]	15.3	12.4
PBP [years]	20.7	15.7
NPV [PLN thousand]	8.6	20.2
IRR [%]	4.2	6.3
CCE [PLN/kWh]	0.6	0.54

Source: own work / Źródło: opracowanie własne

Assuming that the investment in a PV micro-installation is financed on the basis of the investor's own resources, the size of the economic assessment indicators indicates that it would be on the verge of profitability. The installation's return period will be at the earliest between 15 and 21 years. After the return of the installation, the investor can save approx. PLN 8.6 thousand. However, the cost of the saved energy is only PLN 0.05 less than the price of purchase.

Significantly better values of would be recorded if the investor benefited from the NFEP&WM "Ekokredyt Prosument" program. In such a case, the investment would be returned within 12 to 16 years. After the return, the investor could save approx. PLN 20 thousand. The cost of the energy saved is clearly lower (PLN 0.11) than the price of purchase. The profitability of this investment is also demonstrated by the value of the internal rate of return ratio, 6.3%.

5. Discussion

For the example of the residential building located in the rural areas of the Kraków poviat, inhabited by a family of four, calculations were made for the power demand for heating and domestic hot water preparation. On this basis, a 12 kW air / water heat pump was selected, which would be the main source of heat for the facility. Then, seasonal electricity consumption was calculated for heating and domestic hot water preparation, as well as for feeding heating system auxiliaries (central heating + domestic hot water), approx. 7.7 MWh in the standard heating season. Electricity consumption for lighting, household appliances and audio / video devices was assumed on the basis of the data available in the Central Statistical Office (GUS) and for a family of four it is an average of 3.87 MWh. The total electricity consumption in the facility is approximately 11.6 MWh/year. On the basis of energy consumption, the power of photovoltaic micro-installations was selected, that should amount to 15.3 kWp. It is estimated that this installation can generate approx. 14.9 MWh of electricity per year. According to the provisions of the Renewable Energy Act, the excess energy generated can be transferred to the power grid, so that it could be recovered with a discount of 1:0.7 in the period of increased demand. The calculations showed that the PV micro-installation can cover approx. 98% of the energy needs of the facility. This would result in savings of PLN 7.3 thousand/year in relation to the costs incurred for the purchase of electricity in the event there is no PV installation. In order to determine the reasonableness of installing a solar installation to cover the building's energy needs, an economic analysis was made based on such assessment indicators as a simple and discounted payback period (SPBT, PBT), net present value (NPV), internal rate of return (IRR) and the cost of energy saved (CCE). For the needs of the economic analysis, the investment and operating costs related to the use of PV micro-installation were estimated. The economic analysis was made for two assumptions: the investment costs will be fully covered with the investor's funds and the investor will benefit from the EKOkredyt Prosument II program, thanks to which he will be able to get a 30% redemption of the eligible costs incurred for the investment (provided that he will benefit from a preferential loan from the Bank for Environmental Protection (BOŚ)**).** Basing on made calculations, it can be concluded that a better solution for the investor will be to use the offer of support under the "EKOkredyt Prosument II" program - this is evidenced by the values of all economic assessment indicators. If the investor uses the co-financing, the investment will pay back within 16 years at the latest and if he wants to invest his own funds, the waiting period for the return can be extended to up to 21 years, which, given the twenty-five year period of operation, can turn out to be the risk that the funds invested can never pay back. Similar conclusions can be drawn by analyzing the value of the cost of the energy saved indicator, which clearly indicates that the cost of the saved energy is only PLN 0.05 lower than the cost of purchasing energy from the grid.

6. References

[1] Bartnik R., Bartnik B. 2014. Rachunek ekonomiczny w energetyce. Wydawnictwo WNT.

[2] Bławat F. 2001. Analiza Ekonomiczna. Wydawnictwo Politechniki Gdańskiej.

[3] Dyrektywa Parlamentu Europejskiego i Rady 2009/28/WE z dnia 23 kwietnia 2009 r. w sprawie promowania stosowania energii ze źródeł odnawialnych (Dz. Urz. UE L 140 z 05.06.2009, str. 16, z późn. zm.).

[4] Dyrektywa Parlamentu Europejskiego i Rady 2012/27/UE z dnia 25 października 2012 r. w sprawie efektywności energetycznej (Dz. Urz. UE L 315 z 14.11.2012, str. 1).

[5] Główny Urząd Statystyczny. 2018. Bank Danych Regionalnych. Zużycie energii elektrycznej na wsi łącznie ze zużyciem na produkcję rolną w roku 2016. http://www.stat.gov.pl.

[6] Knaga J., Nęcka K., Szul T. 2014. Analysis of solar radiation for the purpose of implementation of photovoltaic systems in municipal facilities. Bioenergy and Other Renewable Energy Technologies and Systems, 1, 67-74.

[7] PN-EN ISO 12831:2006. Instalacje grzewcze w budynkach - Metoda obliczania obciążenia cieplnego.

[8] PN-EN 15450:2007. Instalacje ogrzewcze w budynkach - Projektowanie instalacji centralnego ogrzewania z pompami ciepła.

[9] Rozporządzenie Ministra Infrastruktury z dnia 17 lipca 2015 r. w sprawie w sprawie warunków technicznych jakim powinny odpowiadać budynki i ich usytuowanie (Dz.U. z 2015 r., poz. 1422).

[10] Rozporządzenie Ministra Infrastruktury z dnia 27 lutego 2015 r. w sprawie metodologii obliczania charakterystyki energetycznej budynku i lokalu mieszkalnego lub części budynku stanowiącej samodzielną część techniczno-użytkową oraz sposobu sporządzania i wzorów świadectw ich charakterystyki energetycznej. (Dz. U. 2015., poz. 376).

[11] Szul T. 2018. Ocena efektywności energetycznej budynków: wybrane zagadnienia z przykładami. Wydawnictwo Naukowe Intellect. ISBN 978-83-950526-3-7.

[12] Szul T. 2016. Ocena techniczno-ekonomiczna systemów grzewczych wykorzystujących energię elektryczną. Technika Rolnicza Ogrodnicza Leśna, 1, 12-15.

[13] Szul T. 2015. Prosumer Energy - a Benefit or Loss for Beneficiaries in the Light of the Act on Renewable Sources of Energy. Barometr Regionalny. Analizy i Prognozy, 13/2, 101-116.

[14] Ustawa z dnia 10 kwietnia 1997 prawo energetyczne (Dz.U. 1997 Nr 54 poz. 348, z późn. zm.).

[15] Ustawa z dnia 22 czerwca 2016 roku o odnawialnych źródłach energii (Dz.U. 2016 poz. 925).

Acknowledgments:

The study was financed from a subsidy granted by the Ministry of Science and Higher Education for its statutory activities