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The autonomic energy system of the residential building based on renewable energy sources

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Abstract

The work presents the concept of a single-family building which is supplied only with the energy from local renewable energy source, the one which does not have a possibility of cooperation with the national energy system or with the local heat supply company. Only commonly occurring and available renewable energy resources are taken into account, that is solar radiation and kinetic energy obtained from wind, so technologies connected with burning were switched off, with the emission of carbon dioxide. Due to the stochastic nature of abundance of the materials, periodic production and accumulation are provided and, if necessary, the recovery of energy from batteries. There was a selection of devices performing the conversion of energetic resources into electricity and heat. Among those devices we can enumerate: wind turbines, photovoltaic cells and photothermal absorbers. In order to accumulate the heat, the water-battery was selected. It was thermally isolated from the surrounding. In order to accumulate electricity, the chemical battery was used. During the first part of the heating season, the building was heated on the basis of an exchange of heat between the heat accumulator and the building. In the second part of the heating season, for the purpose of heating, the heat pump was turned on. For this pump, the water-battery was the bottom heat source. During its work, the heat pump was powered by the chemical battery which accumulates electricity.

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1 Introduction

The energy produced in the world is used in the sector of residential building and public utility buildings to a significant extent. The effectiveness improvement of the use of produced energy should include the building industry in the wide scope. In order to do this, mechanisms were introduced promoting the improvement of the energetic quality of already existing buildings as well as the promotion of energy-saving construction and the use of renewable energy sources in construction to a large extent [6]. There are two main reasons which force the wider use of renewable energy sources. The first reason is the excessive emission of harmful gases produced in the process of burning and especially carbon dioxide, which is considered the reason for intensifying housewarming effect.

The other reason forcing the introduction of energy-saving solutions in construction are decreasing resources of fossil energy resources and,what is connected with this, the constant increase in their price.

2 Characteristics of the building under consideration

The energetic demand of the building includes two groups of needs: the first one is to provide the required thermal comfort of the building use, which requires the supply to the building or the collection from the building of the defined amount of heat, the other one are the needs connected with the maintenance of the utilitarian function of the building such as the preparation of warm utilisation water or the supply of receivers with electric energy.

The typical single-family building of the area of 140 m^2 resided by the 4-member family was chosen to analyse the energetic needs of the building and the possibilities to satisfy them on the basis of renewable energy sources. The building is situated in the area exposed to wind with the average annual wind speed of 5 m/s. The bungalow with the utilisable attic without cellars. In the neighbourhood of the analysed building there are not any elements which could shade solar collectors.

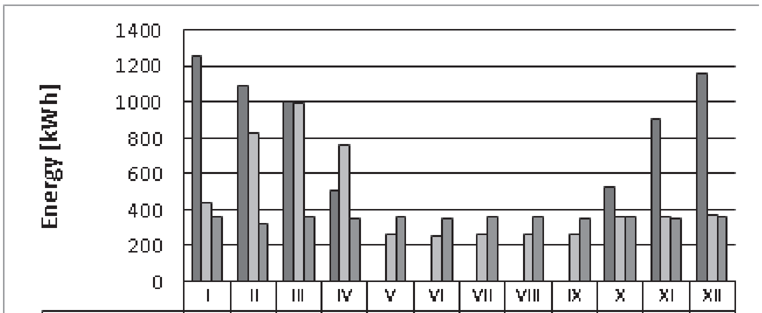
The data of outer temperatures of the heating season presented in the paper [3] were used as a model of the climate of the surrounding for the given residential building for which the calculations of heat demand to warm the building were made. The calculations of heat demand were made in accordance with [9]. The seasonal heat demand amounted to 46 kWh/(m^2a), which is 6440 kWh/a, therefore the low-energy house is being considered.

The heat demand to obtain warm utilisation water was calculated from the commonly known dependence in thermodynamics between heat, mass, specific heat and temperature for the accepted supply amounting to 50 l per day per person. The required amount of heat is 4246 kWh/a for four inhabitants while warming water from 10 °C (the temperature of water in the water supply system) to 60 °C (the temperature of water in the collection battery).

The electrical energy demand was estimated on the basis of the accepted way of the building use by a four-member family for the standard equipment of the building. It was assumed that the building is equipped with lighting and other electrical appliances of the high quality characterised by the low use of electrical energy and that the cooker and the stove are electric. The calculations were made according to the requirements defined in the paper [10].

It was also assumed that heat for heating purposes will be stored in the heat accumulator in which water will be heated with the use of solar collectors in the summertime and this container will be the lower source of heat for the heat pump but only during a part of the heating season. For the significant part of the heating season, i.e., about half of it, the amount of heat collected in the accumulator enables to heat the building with the heat collected in the accumulator without the use of the heat pump which means on the basis of the heat exchange forced only with the circulating pump. In about the middle of the heating season the temperature of water in the accumulator will decrease to such a value that it is not possible to warm the building due to the heat exchange between the heat accumulator and the heated building. Then, the heat pump will be included in the heating process of the building for which the accumulator will be the lower source of heat. It will result in the increase in the demand for electrical energy in the other half of the heating season including a part of January, February, March and a part of April [2].

Figure 1 illustrates the demand for electrical energy and heat in individual months of the year for the building under consideration. The demand for energy in the building is characterised by big seasonal differences which results from lower outer temperatures and shorter time intervals between the sunrise and the sunset. The total demand for electrical energy and heat for the building under consideration is presented in Tab. 1.



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
central heating	1260	1090	1000	504	0	0	0	0	0	523	908	1155
electricity	441	831	993	759	265	258	266	267	263	364	360	368
hot water	360	325	360	348	360	348	360	360	348	360	348	360

Figure 1: The demand for electrical energy and heat for the analysed building.

Table 1: The demand for electrical energy and heat for the basic building.

Demand for heat	central heating	6440 kWh/a year
	warm utilisation water	4246 kWh/m^2
Demand for electrical energy	5450 kWh/m^2	

3 Resources of renewable energy sources in the surrounding of the analysed building

In order to satisfy all the needs of the building, solar radiation energy and kinetic energy of wind were foreseen. The production of electrical energy and heat were calculated on the basis of solar radiation energy and average daily wind speed included in the paper [3]. The unit values (per a unit of the area) of solar radiation energy and the unit kinetic energy of wind for next months in a year obtained in the experiment are presented in Fig. 2.

4 Analysis of possibilities to provide all the energetic needs of the building

Having the defined needed amount of heat for heating purposes, the constructional parameters and work parameters of practicable water heat accumulators can be defined [4].

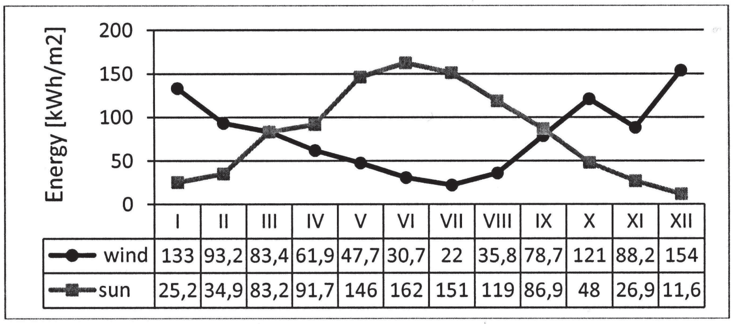


Figure 2: Unit value of solar radiation energy and wind energy.

The accumulators differ in the water capacity, i.e., heat capacity and heat transfer coefficients through their walls, but each of them provides an amount of heat needed to warm the building which is defined in point 2. It was assumed in each of these variants of the accumulator that the heat pump will be cooperating with thermally insulated water heat accumulator. The technical data of these accumulators are presented in Tab. 2.

Table 2: Technical parameters of practicable heat accumulators.

Water capacity in the accumulator [m^3]	80	110	130
Heat transfer coefficient U through the walls of the accumulator should not be higher than [W/m^2K]	0.05	0.1	0.2
Heat possible to be collected [kWh]	8 300	11 450	13 550
Heat loss [kWh]	1 860	5 010	7 110

The water heat accumulator with the capacity of 110 m^3 and the heat transfer coefficient U through the walls of the accumulator amounting to 0.1 (Tab. 2) was adopted for the considered building.

Having chosen the accumulator, the choice of needed collectors cooperating with it should be done. On the basis of [5] it was assumed that the average annual conversion efficiency of solar radiation energy into heat in absorbers should amount to 60% for the vacuum collector. The required area of absorbers was defined on the basis of the total values of solar radiation energy, efficiency of collectors, demand for heat and efficiency of heat recovery from the accumulator. In order to provide heat for warming purposes and obtain warm utilisation water, 40 m^2 of vacuum collectors are needed. Figure 3 depicts the production of heat

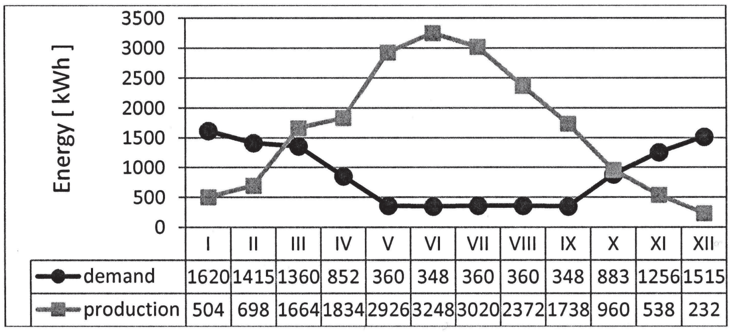


Figure 3: Comparison of the course of the heat production by solar vacuum collectors of the area of 40 m^2 and the demand for heat for warming purposes during the year.

together with the demand for heat.

Moreover, heat loss in conductors between the collectors and the heat accumulator should be taken into consideration while indicating the total area of the absorber. Approximately, each next 10 m of these conductors increases the area of the collectors by 8–10% [8].

The provision of the needed amount of electrical energy will be possible with the use of the system of monocrystalline photoelements with the power of 10 kW and the area of 70 m^2 [11] or the wind turbine with the area marked with the blades amounting to 8 m^2 [1]. Then, the system of photoelements should produce about 10 000 kWh of electrical energy and the wind turbine about 7 600 kWh (Fig. 4).

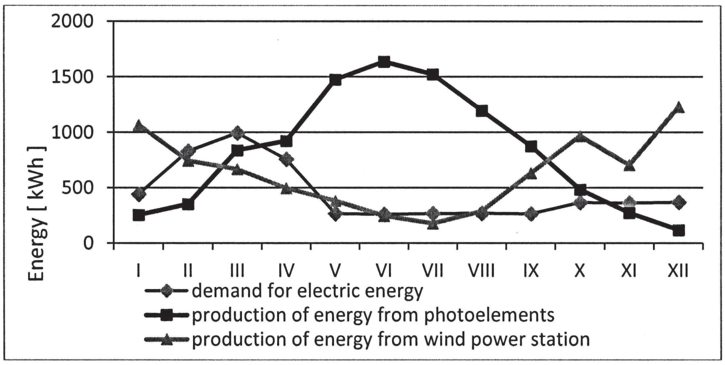


Figure 4: Comparison of the course of the electrical energy production by solar photoelements and the wind turbine with the course of the demand for electrical energy.

On the basis of the balance of energy defined as a difference between the supplied energy by the system of solar photoelements with the power of 10 kW and the wind turbine and the energy used systematically (Fig. 5), the capacity of the needed chemical electrical accumulator was defined.

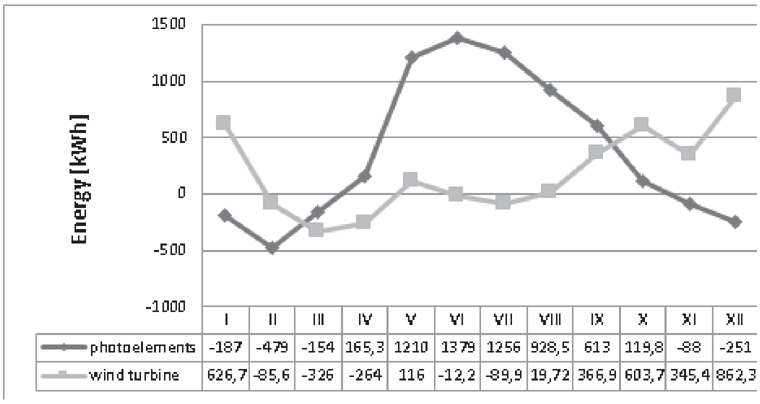


Figure 5: Electrical energy balance.

Among the accumulators for the collection of electrical energy produced from renewable energy sources, the lead-acid batteries, whose efficiency of energy recovery is 70%, are the most popular in the market.

If the solar photoelements have been chosen, the capacity of the chemical accumulator should be 169 440 Ah, which is, for example, 737 accumulators with the capacity of 230 Ah and 12 V, and if the wind turbine is chosen, the capacity of the accumulator is smaller and amounts to 71 575 Ah, which is 311 accumulators with the capacity of 230 Ah and 12 V. The smaller capacity of the chemical accumulator while choosing the wind turbine results from the compatibility of the changes of the wind energy flow with the changes of electrical energy demand for the building.

5 The economic effectiveness ratios of an investment for the energy system of the building based exclusively on local resources of renewable energy sources

This part of the article presents the evaluation of the economic effectiveness of investment in the wind turbine, photovoltaic cells and solar collectors with power providing the complete demand for electricity and heat of the discussed building.

The prices of all the appliances were taken according to the present list prices [12,14].

It should be emphasized that one part of the energy system based on one energy raw material and one energy technology is not often cost-effective, whereas the complex application of several technologies and sources of energy as a whole can already be profitable. Also, it should be considered that there are other conditions not only the economic ones to implement some solutions. In case of power industry there are mostly ecological condition.

The calculations of the economic effectiveness ratios the following influences were taken into consideration the changes in energy prices in two variants:

- variant I – the price of energy increases by the value of 0.05 PLN/kWh during the year starting the output level 0.40 PLN/kWh,
- variant II – 5% of the annual increase in the prices starting the output level 0.40 PLN/kWh.

The analysis was made adopting:

- wind turbine STORM [14] with the power of 5 kW,
- solar collectors Roto Sunroof [14] with the effective area of 2.12 m^2,
- monocrystalline solar batteries 220 Wp.

Table 3 presents a the prices of the elements of the energy systems and the production of energy and heat with their use.

Table 3: Investment cost of the systems for the considered building and the production of energy and heat with their use.

Elements of the energy system	Power/area	Cost of the purchase	Cost of installation	Production of energy [kWh]
Wind turbine	5 kW	35 000	15 000	7 600
Solar collectors	19 collectors=40 m^2	64 000*	5 000	25 000
Photovoltaic cells	70 m^2 = 10 kW= 46 modules	119 600	10 000	10 000

*only the collector

The results of the economic calculations are presented in the form of the diagrams illustrating the dependence between the planned cash flow and the simple time of expenditure return the net cash flow (NCF), (simple payback time of the investment – SPBT). The 25-year calculating period of exploitation and viability of appliances was accepted.

5.1 The economic effectiveness ratios when the produced electricity and heat are used online – without accumulation

When the production of heat and electricity is used on a regular basis, in other words, it is not stored in rechargeable batteries or accumulators of heat, the pay-

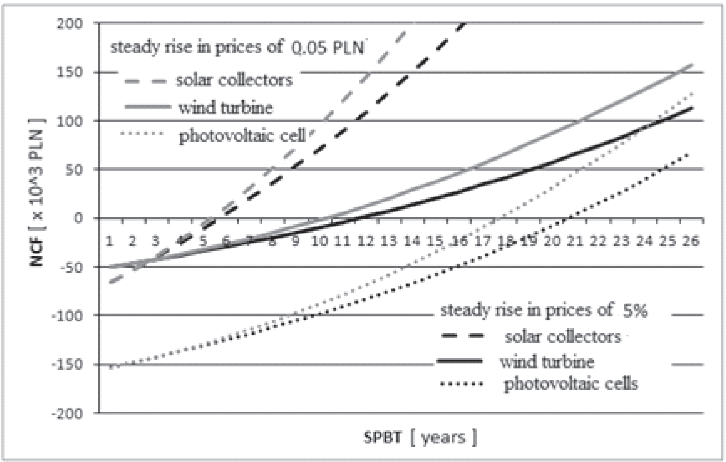


Figure 6: Payback period of the invested capital in the wind turbine, solar collectors and photovoltaic cells for two tendencies of the increase in the energy prices.

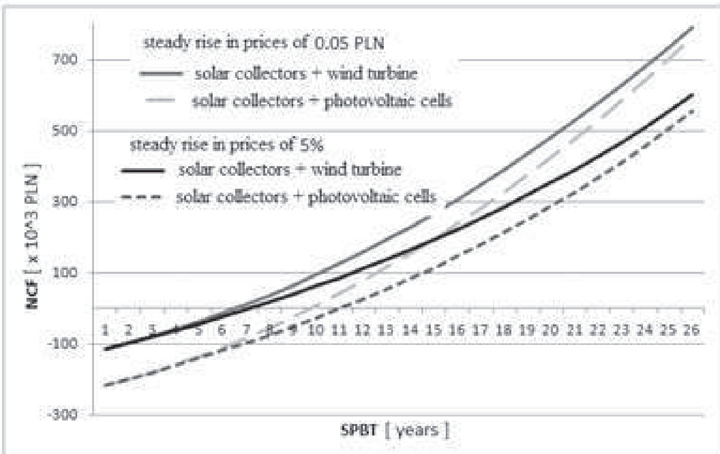


Figure 7: Payback period of the capital invested in the connected systems (wind turbine +collectors and cells + collectors) for two tendencies of the increase in the energy prices.

back time of those investments (Figs. 6 and 7) is much shorter than when electricity and heat is accumulated (Figs. 8–11).

If we take into consideration all these investments separately, the payback time will be (Fig. 6):

- 5–6 years for solar panels,
- 11–12 years for wind turbines,
- 17–20 years for solar photovoltaic cells.

However, if these systems are joined into hybrid systems, the payback time will be (Fig. 7):

- about 7 years for solar panels and wind turbines,
- 10–12 years for solar panels and solar photovoltaic cells.

5.2 The economic effectiveness ratios when there is a necessity to apply the accumulation of the produced energy

Table 4 demonstrates the approximate cost of the systems taking the costs of the battery purchase, the invertor, the loading regulator and the construction of the water heat battery into consideration, as well as the list of the amount of the energy and heat production in these systems.

Table 4: Total cost of autonomic systems.

Elements of the energy system	Cost of batteries together with the supportive appliances	Total cost of the investment	Energy production after the deduction of losses of transfer and accumulation
Wind turbine	1 460 000	1 510 000	5 500
Photovoltaic cells	1 980 000	2 109 600	5 500
Solar collectors	100 000	169 000	10 700

Since the viability of the batteries designed for renewable energy sources is about 12 years [12], which means by half shorter than the viability of the solar cells and the wind turbines, therefore the economic analysis took the exchange of the set of batteries during the exploitation of the energy system into consideration.

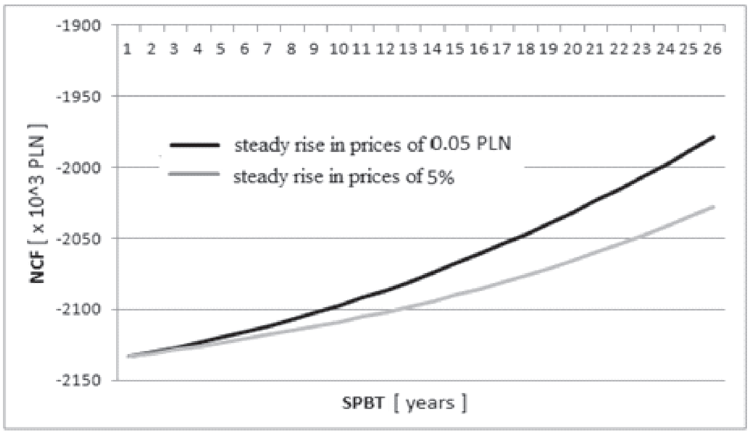


Figure 8: Payback period of the capital invested in the photovoltaic cells together with the electricity battery for two tendencies of the increase in the energy prices.

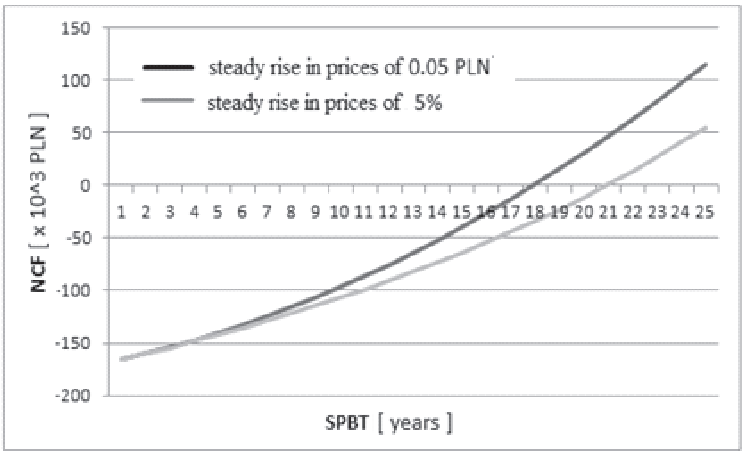


Figure 9: Payback period of the capital invested in the solar collectors together with the heat battery for two tendencies of the increase in the energy prices.

The received results of the simple payback time of the investment (SPBT) allow to draw conclusions that currently, from the economic point of view, the investment solar photovoltaic cells and wind turbines with electricity accumulators is unprofitable as the payback time of the investment is longer than the viability of the object (Figs. 8, 10 and 11).

As it can be noticed, the time after which the investment expenditure would

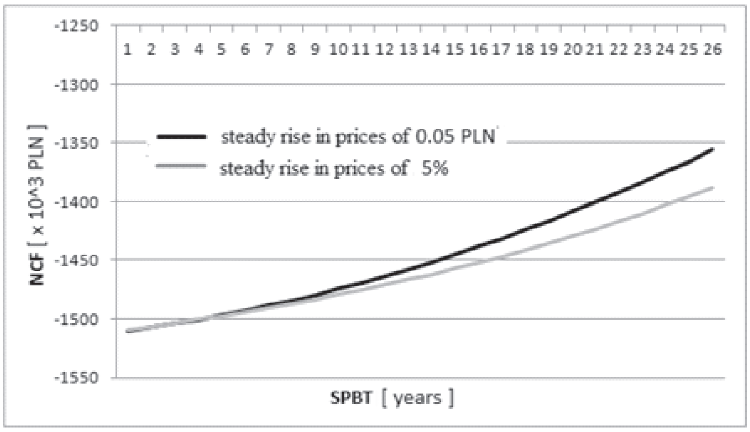


Figure 10: Payback period of the capital invested in the wind turbine together with the electricity battery for two tendencies of the increase in the energy prices.

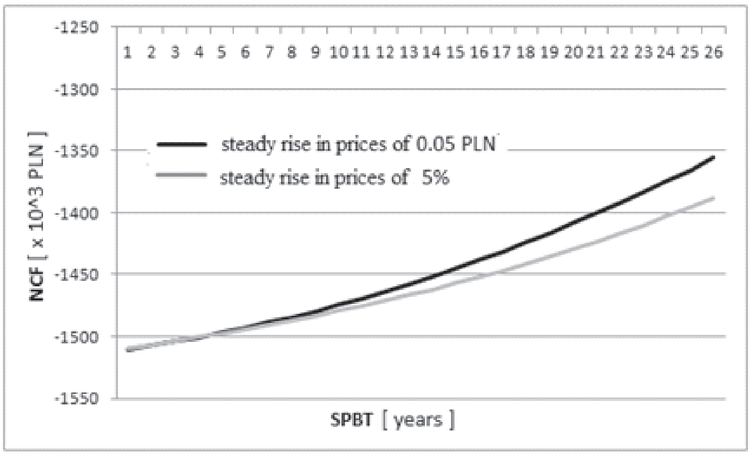


Figure 11: Payback period of the capital invested in the energy systems for two tendencies of the increase in the energy prices. (One of the systems consists of the wind turbine, collectors and batteries, and the other one of the solar photoelements, collectors and batteries).

be balanced by the income from the made investment is significantly shorter when there is no necessity to store electricity and heat. Only investing in the solar collectors without storing heat in the longer period of time (for example, for the whole winter) is economically justified (Fig. 9).

It should be noticed that while investing in renewable energy sources, i.e., ecological power industry, raising funds from the EU or some national institutions can be counted on. It can lower the cost of the investment and consequently, it will result in shortening time after which there will be the return of incurred investment outlays.

Apart from that after 2012 the industry in Poland will be able to emit only 209 million tonnes of carbon dioxide into the atmosphere annually without being punished. If the Electricity Boards do not manage to limit the carbon dioxide emission, the companies will have to buy additional limits in the open market or they will be forced to pay fines. The costs connected with the limitation of the carbon dioxide emission will be incurred proportionally to the amount of the emission in a given country. In Poland 92% of electricity is produced from coal and lignite, thus the high emissivity. Brussels calculated that as a result of climatic package energy in the countries of the Community will be more expensive by 22% on average, but in Poland the prices will be doubled, and Sweden will not report changes as it has the minimal emission level [13].

The increase in the energy and heat prices increases the investment profitability in the systems using renewable energy sources. Certainly, ecological benefits have always existed.

Although the investments in wind turbines and solar power plants are characterised by not too beneficial ratios of economic effectiveness because of quite a long payback time of the investment, they are more and more popular all over the world. After increasing the expenditures connected with the investment, electricity and heat will be received at the costs close to zero (the cost of the system exploitation), which is making them more and more popular.

6 Conclusions

The conducted research and the analysis showed that there is a possibility to build residential buildings supplied with the autonomous energetic systems based on the local resources of renewable energy sources. They will be the buildings with the zero emission of pollution into the atmosphere in the form of combustion products and incombustible admixtures which are in fuels. The low-energy building has been considered.

Considering the stochastic character of the appearance of renewable energy sources and big time-lags between the periods of the biggest demand for energy and the periods of the biggest possibilities to use renewable energy sources, the energy produced from them has to be accumulated periodically and if it is needed, it has to be recovered from the accumulators with the big capacity from time to time. The efficiency of the electrical energy and heat recovery from the accumulators significantly deviating from 100% causes that the amount of energy produced from renewable sources have to be significantly higher than the energetic needs of the building. The water heat accumulator insulated thermally from the surrounding in the shape of the cube with the edge amounting to about 5 m can accumulate heat needed to warm the building for half of the heating season through the exchange of heat between the accumulator and the building. In the other half of the heating season the water heat accumulator which already has the temperature too low to warm the building through the heat exchange can make the lower source for the heat pump. The solar and wind hybrid system is the most beneficial for the electrical energy production because wind energy demand reaches the maximum value when the demand for the solar radiation energy is minimal and vice versa. The provision of the building demand for electrical energy taking the drive of the circulating pumps transporting heat and the heat pump into consideration and taking the admissible level of the low battery into account requires the use of chemical accumulators with the capacity higher in case of the choice of solar photoelements and lower in case of the wind turbine.

The autonomous energetic system of the residential building has to influence its appearance significantly – covering with photoelements and absorbers, and its cubature – the provision of a place for heat accumulators and electrical energy.

Summing up, it should be emphasized that currently the production of heat and energy on the basis of renewable energy sources is not justified economically. Energy technologies based on renewable energy sources are developing owing to the subsidies. The justification of development of these technologies is now solely ecological.

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