Analysis and comparison of methods for the preparation of domestic hot water from district heating system, selected renewable and non-renewable sources in low-energy buildings

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Abstract. The article presents an economic analysis and comparison of selected (district heating, natural gas, heat pump with renewable energy sources) methods for the preparation of domestic hot water in a building with low energy demand. In buildings of this type increased demand of energy for domestic hot water preparation in relation to the total energy demand can be observed. As a result, the proposed solutions allow to further lower energy demand by using the renewable energy sources. This article presents the results of numerical analysis and calculations performed mainly in MATLAB software, based on typical meteorological years. The results showed that system with heat pump and renewable energy sources Is comparable with district heating system.

1 Introduction

Low-energy and passive constructions are a result of the introduction of new ideas in building design process. Their main objective is to achieve a significant reduction in demand for non renewable primary energy, necessary to cover the needs of these buildings, mostly related to their heating, ventilation and domestic hot water. [1, 2]

Buildings of this type are characterized by increased demand of energy for domestic hot water preparation in relation to the total energy demand compared to existing buildings.

Research [3] shows that, the use of renewable sources such as wind and solar energy significantly reduces the primary energy demand in the building.

Electricity generated by wind turbines with vertical axis of rotation and photovoltaic cells can be used to heat the hot water in the tank through the warmer or as a source of electrical energy for the motive of a heat pump to prepare domestic hot water. Combining in one building, installations using these two types of renewable energy sources will provide benefits of mutual complementarity, when the energy generation in one of these installations will disappear or will be reduced. In the autumn and winter period, when the possibilities of solar energy are significantly reduced, wind turbines will produce much more energy than photovoltaic cells due to usually occurring windy weather in this time.

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This situation is changing in the summer period, when the photovoltaic cells produce more energy, due to the longer day and much greater intensity of solar radiation. In the summer months, while the air masses are not moving too quickly, in result, it is observed lower wind speeds and therefore wind turbines produce limited amounts of power.

Application of the above described installations, which use renewable energy sources, can allow to cover a significant demand for electricity, that is required to power the heat pump [4, 5] working for purposes of heating and domestic hot water. In case of excess electricity and the lack of heating needs, this energy can be used to heat the hot water in the tank. The use of heat pump in the above-mentioned system, will reduce the energy demand for primary fuels used to generate electricity.

In case of disadvantageous wind and solar conditions, the installation of renewable energy sources may be uneconomical, then the preparation of domestic hot water from district heating system [6] or natural gas installation [7] should be analyzed.

The basis for the analysis is the installation with the priority of hot water preparation. Building heat losses exist, but for the purposes of this analysis they are omitted.

The main purpose of the article is to present an economic analysis and comparison of selected methods for the preparation of domestic hot water in a building with low energy demand. This article also presents the results of numerical analysis and calculations performed in MATLAB software, based on typical meteorological years and the results, which presents that the system with heat pump and renewable energy can be economically justified.

2 The assumptions for the analysis and simulation (heat pump system)

Table 1. The assumptions for the analysis and simulation. (study of Author)

Description	Assumption
Building type	Multifamily, modernized, low energy building
Location	Legnica, Poland (Polish third climatic zone) [8]
Inhabitants	30 people
Hot water tank	2*0.75 m^3
Wind turbines	Selected 1 wind turbine with power 1 kW
Photovoltaic cells	Selected 4 photovoltaic cells with power 300 W each (orientation S45^0)
Heat pumps	Selected 2 heat pumps with power 11 kW each

On the basis of the typical demand for hot water for 30 people in a multi-family building (Fig. 1), the typical heat demand for domestic hot water purposes has been calculated in the following months of the year. (Fig. 2). Heat demand for hot water purposes in installation with water tank is based on calculation procedure given in Polish standard [9]

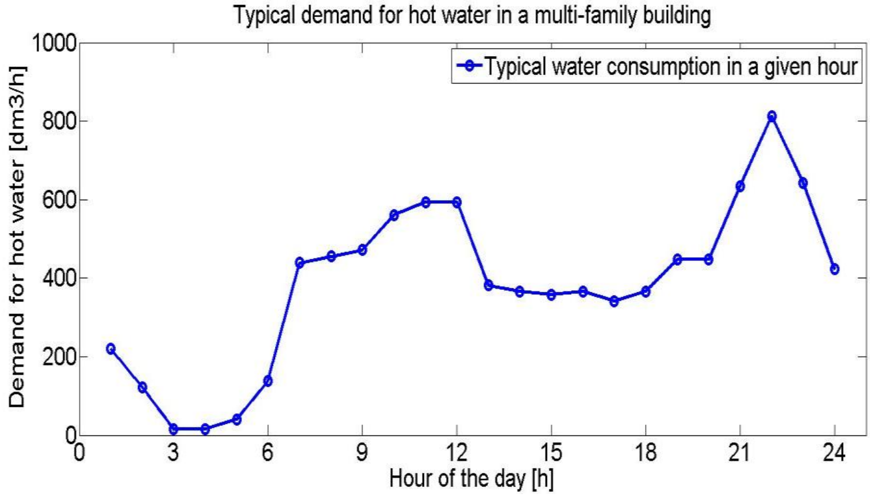

Fig 1. Typical demand for hot water for 30 people in a multi-family building. (study of Author)

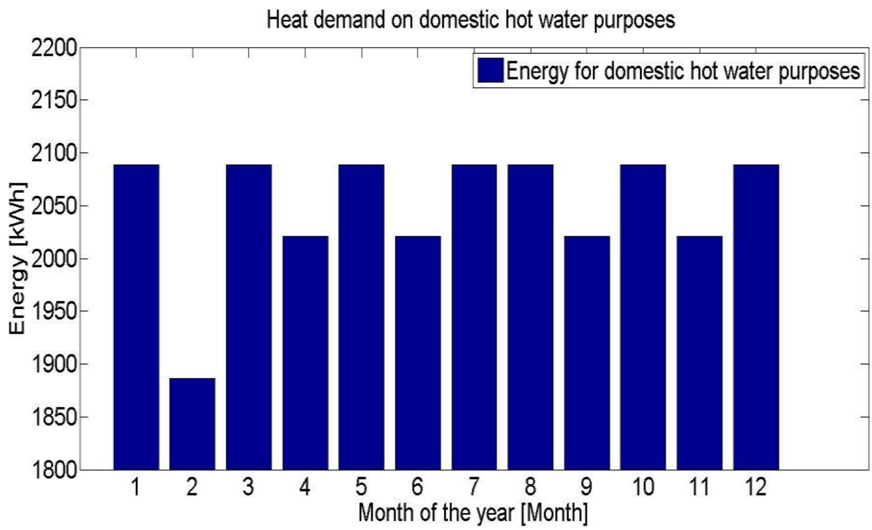

Fig 2. Typical heat demand on domestic hot water purposes during the year. (study of Author)

3 Domestic hot water from district heating system

One of the alternatives of supplying buildings with heat is district heating system [3]. In this case, heat is generated outside of the heated building and it supplied to the building via high-parameter pipe network, and then by a heat exchanger directed to the specific receivers. Particular advantage of district heating is the lack of a heat source at the customer, therefore, are not emitted to the environment any contaminants associated with combustion of non-renewable sources.

District heating substation is located in the building of the user, converts the high parameter of the heating medium, on the primary side, through a heat exchanger to the required parameter of hot water on the secondary side. District heating substation completely covers the energy demand for heating purposes. The heat demand is variable and adjusted by using the weather controller. Weather controller is changing the primary power supply parameters. Fees for the heat from the district heating network are calculated according to the current tariff and an indication of the heat meter is in a district heating substation.

Table 2. Tariff for consumers, which are supplied with heat in the form of hot water from district heating network in Legnica - B1-Lg. [10]

Tariff group	Heat production		Transmission and distribution	
	Annual fee for ordered thermal power	Cost of heat	Constant annual fee for heat transmission services	Variable fee rate for heat transmission services
	PLN/MW/year	PLN/GJ	PLN/MW/year	PLN/GJ
B1-Lg.	65486.01	25.25	19125.58	14.79

Thermal power of system with a tank of water, based on the maximum hourly water flow, multifamily, modernized, low energy building (30 people) amounts 13 kW.

The ordered thermal power amounts 0.013 MW. Based on typical consumption of hot water in the building (Fig. 2), annual demand of energy for domestic hot water in low energy building will amount 74.2 GJ per year.

On the basis of the district heat supplier tariff data (Tab. 2), annual operating costs for domestic hot water purposes are shown in the Tab. 3.

Table 3. The annual cost of hot water preparation according to the current WPEC Legnica tariff for heat from district heating network. (study of Author)

Description	PLN/year
Annual fee for ordered thermal power	851.32
Cost of heat	1873.63
Constant annual fee for heat transmission services	248.63
Variable fee rate for heat transmission services	1097.47
Summary (EC)	4071.05

4 Domestic hot water from renewable sources – heat pump powered by wind turbines and photovoltaic cells

Heat pump [4, 5] can be powered by electricity from wind turbines [11] and photovoltaic cells and it will reduce the energy demand for primary fuels used to generate electricity. In case of insufficient amounts of energy from renewable sources, the heat pump will be supplied from electrical network.

The use of the heat pump significantly reduces the need for energy for domestic hot water.

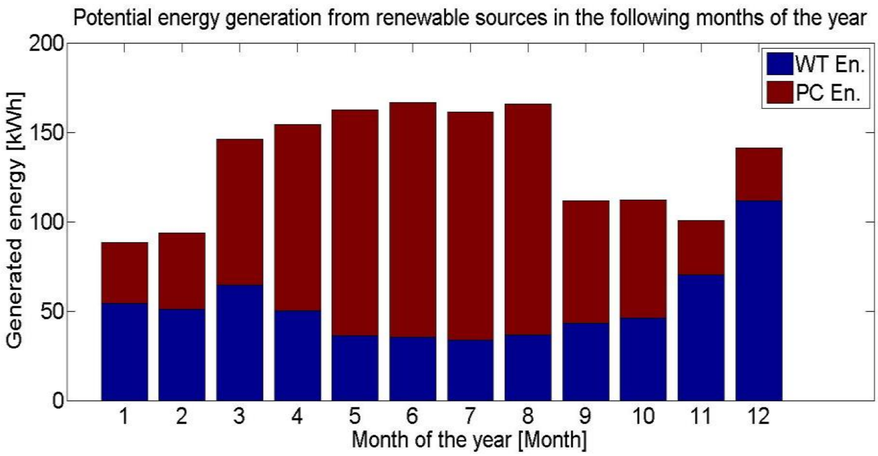

Fig 3. Potential energy generation from wind turbines and photovoltaic cells in the following months of the year. (study of Author)

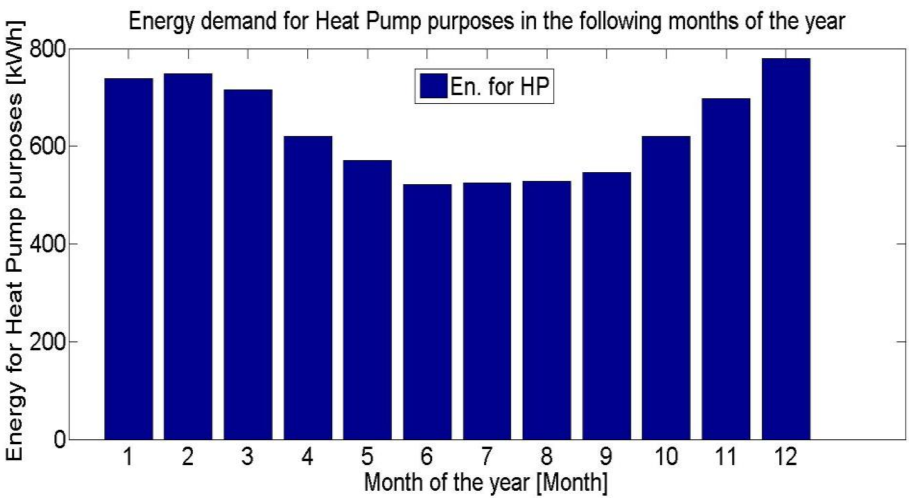

Fig 4. Electrical energy demand for heat pump purposes (motive power) in the following month of the year. (study of Author) , [12]

Fig. 3 shows the potential energy produced by renewable energy sources [12] in the analyzed system, the real value is weather dependent. Compared to Fig. 2, there can be observed a large energy deficit that must be covered by the electrical network.

The system with the heat pump [13] is able to fully cover the demand for domestic hot water. Energy demand for hot water purposes has been reduced by using an air-to-water heat pump [14] Economically, energy from renewable sources is not able to provide the total heat pump needs (Fig. 4), so the remaining energy must be provided from electrical network (Tab. 4).

Table 4. Electrical energy tariff [15] and the annual cost of hot water preparation in system with heat pump, powered by wind turbines and photovoltaic cells. (study of Author)

Description	Results
Generated energy from renewable sources	1604 kWh

Annual energy demand for heat pump, preparing domestic hot water	7601 kWh
Cost of energy daily tariff	0.316 PLN/kWh
Cost of energy night tariff	0.164 PLN/kWh
Annual summary costs (EC)	1350.29 PLN/year

5 Domestic hot water from non-renewable sources – natural gas

In this study is described a heating system powered by condensing gas boiler. Natural gas is the kind of ecological source of energy. As consequence of combustion of natural, it is being created a carbon dioxide and water vapour. The heat generated by the combustion of natural gas allows quick preparation of domestic hot water with minimal maintenance of the system. [16]

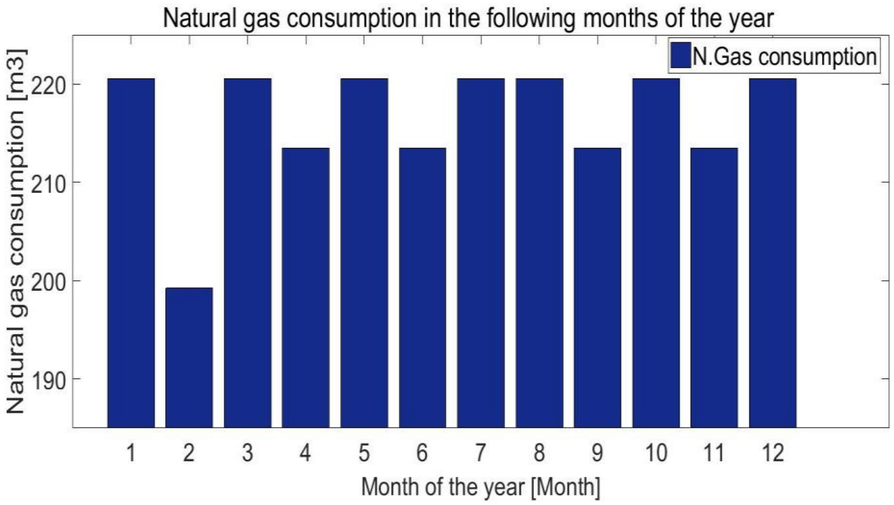

Fig 5. Natural gas consumption in the following months of the year. (study of Author)

Natural gas is one of the most expensive non-renewable energy sources. The amount of gas consumed during combustion depends on its caloric value and the efficiency of the gas boiler. The gas condensing boilers are characterized by the highest efficiency [7].

Natural gas consumption (Fig. 5) in the following months of the year can be calculated as follows:

$$V_{\mathrm{NGpM}} = \frac{E_{DHWP} * 3{,}6}{C_{VNG}} * \frac{1}{\eta} \tag{1}$$

where:

V_{NGpM} - natural gas consumption in the following month of the year, m3/month

E_{DHWP} - energy for domestic hot water purposes in the following month of the year, kWh/month
C_{VNG} - caloric value of natural gas, MJ/m3
η - total efficiency of the domestic hot water preparation system

Gas installation is able to quickly prepare the proper amount of hot water, but this carries an economic consequences. (Tab. 5)

Table 5. Natural gas parameters [17] and the annual cost of hot water preparation in system with gas condensing boiler. (study of Author)

Description	Results
Caloric value of natural gas	35.5 MJ/m3
Efficiency of the system	96%
Annual natural gas consumption	2597 m3
Natural gas cost	2.40 PLN/m3
Annual summary costs (EC)	6233.27 PLN/year

6 Investment costs of analyzed systems

Investment costs are included without any subsidies (especially for renewable sources and heat pumps) and with discounts from individual manufacturers. A summarized costs of the analyzed systems are comparised on Fig. 6.

The analysis includes the cost of purchasing individual components such as wind turbines and photovoltaic cells, domestic hot water tanks, gas condensing boilers and heat pumps. Assembly costs for individual installations are also included.

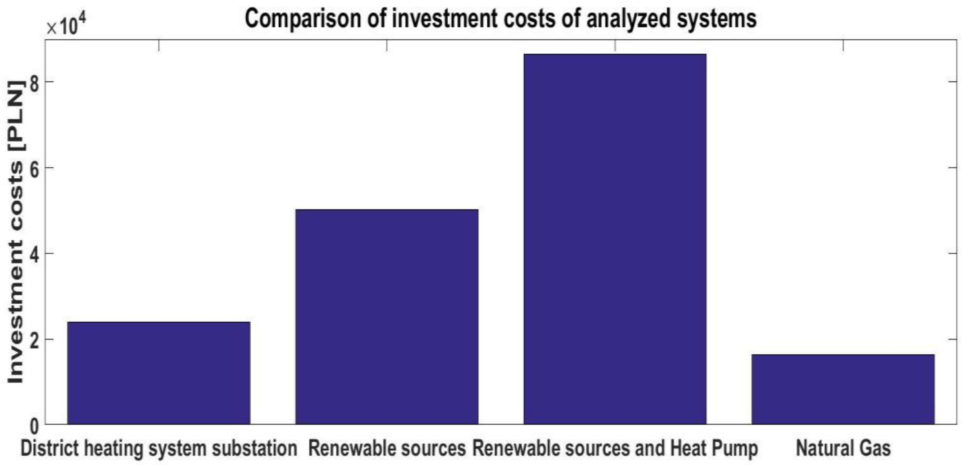

Fig 6. Comparison of investment costs of analyzed systems (IC_{SYS}). (study of Author)

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7 Summary - calculations

The aim of the study was an analysis and comparison of the results of domestic hot water preparation from district heating system, renewable sources, non-renewable sources and heat pump powered by electricity from renewable sources in low-energy buildings. The economic effect of analysis can be observed comparing the mentioned systems together. In an article, for the analysis and comparison, it has been deliberately disregarded coal due to significant emissions to the atmosphere and considerable participation in the formation of smog in Polish cities.

The duration of the analysis is 15 years (photovoltaic cells warranty + 5 years). It has been taken into account the annual increase in the price of fuel (natural gas) and electricity by 1%.

Investment and operating costs (Fig. 7) in the analyzed period of time of the year can be calculated as follows:

$$EC_{(i+1)} = EC_{(i)} * 1{,}01 \tag{2}$$

where:
$EC_{(i)}$ - operating costs in the following year, PLN/year
$EC_{(i+1)}$ - operating costs in the next year, PLN/year
i - following year of the analysis, $i \in <1,15>$

$$C_{SYS(i)} = -IC_{SYS} - EC_{(1)} - \sum_{i=2}^{n=15}(-EC_{(i)}) \tag{3}$$

where:
C_{SYS} - investment and operating costs in the following year of the analysis, PLN
IC_{SYS} - investment costs of the analyzed system, PLN
$EC_{(1)}$ - operating costs in the first year of analysis, PLN
$EC_{(i)}$ - operating costs in the following year, PLN
i - following year of the analysis, $i \in <1,15>$

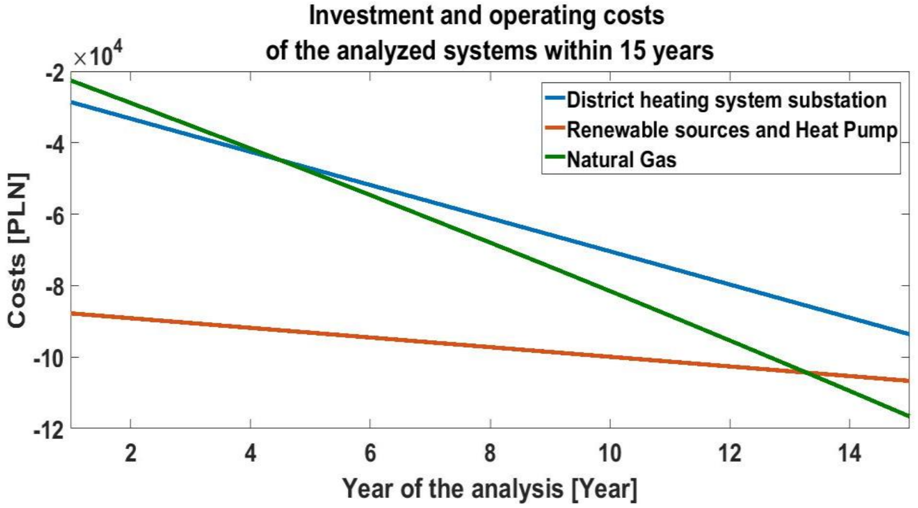

Fig 7. Investment and operating costs of the analyzed systems within 15 years. (study of Author)

The simulation (electrical energy generation by wind turbines and photovoltaic cells, based on typical meteorological years) and analysis in MATLAB software [12] allow to conclude that, it is preferable to use renewable energy sources which produce electricity to motive heat pumps or district heating system, if it is possible, because not all city units have a district heating network. The economic effect of analysis can be observed comparing the mentioned systems together (Fig. 7).

Considering the investment and operating costs, a better economic effect is achieved by district heating system compared to the gas system . A better result is achieved after 4 years of operation (Fig. 7).

Analyzing the system with renewable energy sources and comparing it with the gas system, better result is achieved after 13 years of operation (Fig. 7).

8 Summary - discussion

Research [18, 19] shows that, individual gas or oil boilers today and could be substituted by district heating or a more efficient individual heat sources as heat pumps powered by renewable sources. In such overall perspective, the best solution will be to combine a gradual expansion of district heating with individual heat pumps in the buildings with obsolete heating systems.

In the analyzed period, economically and ecologically as the research [20, 21] shows, the best choice is district heating system. The second system, based on the heat pump does not take into account the subsidy and is weather dependent. In the analyzed case (Fig. 3), can be observed that the wind turbines have a poor performance in comparison to the price.

Studies [22] shows that each different arrangement of Savonius rotor affects its performance.

In the case of using photovoltaic cells, instead of a wind turbine the results could be more energy efficient. Other studies [23] shows that the usage of photovoltaic cells can also be advantageous from the energetic point of view.

This article presents results that renewable energy sources, can allow to cover a significant demand for electricity, that is required to power the heat pump and it is economically justified, in comparison to natural gas system and in comparison to district heating system it is not significantly different.

Article draws attention to the process of proper selection of the domestic hot water preparation system. Proper selection should be preceded by a thorough analysis of the prevailing weather conditions and the recognition of the use of district heating network.

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