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Analysis of the geothermal energy use in powering various hybrid systems

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Abstract: *Analysis of the geothermal energy use in powering various hybrid systems.* The paper presents results of investigation of two different systems powered by the geothermal energy and different kind of energy – electrical or chemical. The electricity-geothermal board Geotermia Mazowiecka S.A. has been analysed first and the part of geothermal energy in the input heat flux is about to 25–30%. Then the small detached house powering with heat pump and electricity was analysed in comparison with the other house using only conventional fuel. The investment in geothermal energy source has been more expensive, but the using of such an installation started pay off during several months.

Key words: geothermic, geothermal energy, hybrid systems, heat pump

INTRODUCTION

Environmental and economic considerations influence the search for solutions that increasingly take into account renewable energy sources in power systems. More and more popular is the use of biomass [Bloch-Michalik and Gaworski 2015, Jacek and Litwińczuk 2016]. Due to the specifics of renewable energy sources (RES), they often have to cooperate with other, usually conventional, sources of energy, creating hybrid systems. The widespread presence and renewability of geothermal energy, as well as the lack of dependence on changing climatic conditions, make it possible to exploit geothermal potential in many installations. for heating of rooms and for preparing hot water, agricultural applications, fish farming [Suslov et al. 2015], balneotherapy and recreation [Pająk and Bujakowski 2016]. Geothermal energy is often used as the lower heat source in a heat pump [Hepbasli and Akdemir 2004], often in hybrid systems that also use solar energy [Ozgener and Hepbasli 2007]. A dynamic increase in the number of installations with heat pumps can be observed [Sanner et al. 2003]. Utilizing the energy of the interior of the Earth gives the opportunity to use a stable source of heat, no matter what time of the year, and also emissionless, due to the environment [Self et al. 2013]. Prospects for the development of geothermal resources in Central and Eastern Europe (also in Poland) in the next 10–20 years are presented in [Pająk et al. 2016]. The direct use of geothermal energy in Poland is presented in Figure 1 according to data

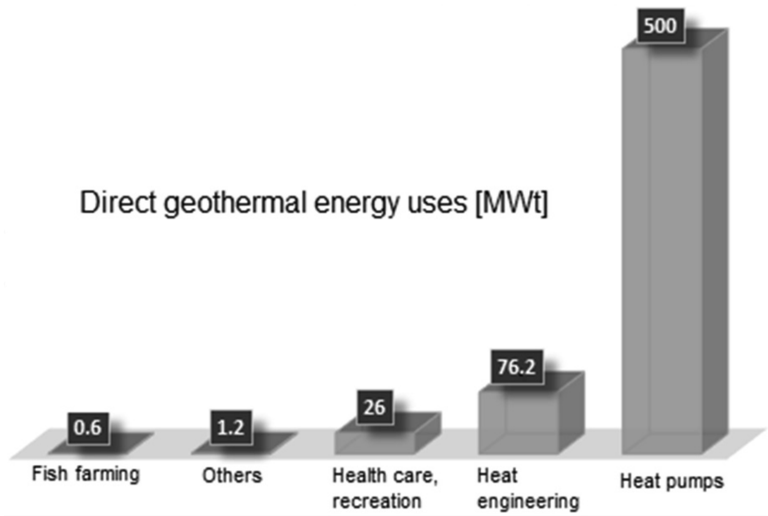

FIGURE 1. The geothermal energy uses in Poland, 2015

collected in Kępińska [2016]. This is a structure close to the world structure, where 70.9% is produced by heat pumps [Lund and Boyd 2016], compared to 82.78% in Poland.

Heat pumps are used in agriculture, for example as the heat source in the pump can be used heat exchanger at the positions where the pigs are located [Nawrocki and Myczko 1998]. An example of the use of heat pumps in milk production may be the recovery of waste heat from chilled milk and its use for the heating of technological or usable water [Kupczyk et al. 2001]. The heat pump is most often used for heating, and this is particularly true in rural areas where there is no access to district heating.

The aim of this paper is to present and compare the use of geothermal energy in hybrid power systems in two different systems. The first issue concerns the Geotermia Mazowiecka Power Plant in Mszczonów (51°58′28″ N 20°30′45″ E), the second one-family house in the Płock area. Due to the specific nature of each of these issues and the possibility of obtaining relevant data, the presented analysis will be of a different nature for each of the considered cases.

MATERIAL AND METHODS

Analysis of individual dependencies concerning the Geotermia Mazowiecka S.A. were based on data obtained from the power plant [Balcer 2010]. These include monthly reports such as average and daily values showing the instantaneous values recorded every hour. Each of these reports was further subdivided into separate sections to give a quick overview of how the whole system works. All types of reports cover the outside temperature, which directly affects the change in input and output fluxes. The data in the geothermal section of the reports illustrate the flow of geothermal water. The water flow value is expressed in $m^3 \cdot h^{-1}$.

The analysis for a single-family house equipped with a heat pump was carried out, comparing the costs of assembly and use of the boiler room together with the equipment based on the heat pump in relation to heating with heating oil.

RESULTS AND DISCUSSION

Geotermia Mazowiecka S.A. extracts geothermal water and uses it for heating, recreational purposes (in thermal pools) and for drinking water. The Geothermal Power Plant in Mszczonów is able to provide heat to the inhabitants of the city only by geothermal water at 42°C, deriving from a depth of about 1,700 m until the air temperature drops below –5°C. Water is then heated with the use of gas boilers (Fig. 2).

The technology used in Mszczonów is based on the recovery of heat from geothermal water by means of a 2.7 MW absorption heat pump powered by a high-temperature gas fired boiler (1.8 MW). In addition, this system works with two low-temperature gas boilers, each with a capacity of 2.4 MW, which are "peak hours heating technology" [Balcer 2002]. The heat pump uses the old Geological Institute's research borehole from 1977, which was used to search for oil and gas. The Mszczonów IG-1 borehole was reconstructed and adapted for geothermal water exploitation, which significantly contributed to the reduction of investment costs [Bujakowski 2015]. The borehole has a depth of 4,000 m. At this level, the geothermal water temperature is about 70°C, but it is highly mineralized. That's why it was decided to take water from a depth of 1,602–1,714 m. Despite its lower temperature, it has the quality of drinking water, which allows it to be injected into the same hole and significantly reduces the operating costs.

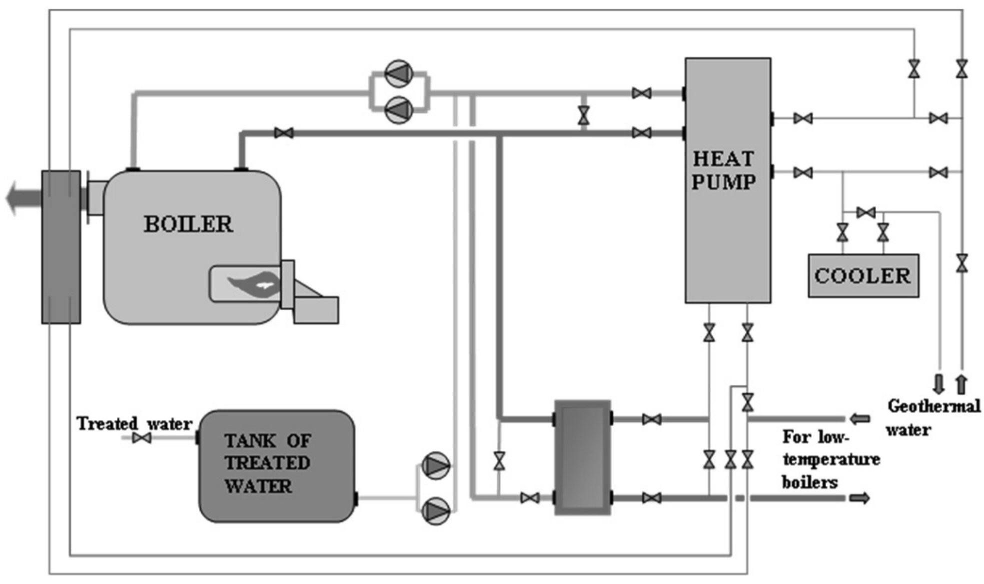

FIGURE 2. Diagram of the installation at the Geotermia Mazowiecka S.A.

The water from the investigated intake does not contain any components of natural origin that are potentially toxic, in concentrations considered to be harmful to health. Laboratory tests conducted using membrane water concentration methods from the studied intake indicated the possibility of obtaining specific concentrates which could be used to produce mineral water [Tomaszewska et al. 2016]. Currently water purified from excess of iron compounds is directed to urban waterworks [Balcer 2015].

Geothermal water is extracted from the IG-1 intake using a multi-stage borehole pump. Then it is pumped into the centre of Mszczonów, where the geothermal power plant is located. From the economizer, which receives heat from the furnace gas from the high-temperature boiler, the geothermal water goes to the absorption heat pump (Fig. 2). The next step is to cool it through the fan cooler to a temperature of 20–30°C, depending on the current needs of the Mszczonów heating system. The heat exchanger installed in the system allows additional heating of the municipal water leaving the heating pump. During the winter, the auxiliary power supply is automatically switched on: two low-temperature boilers support the operation of the pump. Their upper heat source is a gas boiler with an economizer. Natural gas is supplied to the boiler, which burns when mixed with the supplied air. Hot furnace gases such as nitrogen, carbon dioxide, water vapor and small amounts of oxygen flow through the boiler, where in the heat exchanger give up a part of its heat [Gałusza and Paruch (Eds) 2008]. The water, supplied to the boiler, flows in the economizer, where it cools the furnace gas, condenses it and reheats itself. The heat generated in this process is used to heat up the primary water. Reducing the furnace gas temperature from 260° to 120°C results in a 6% lower furnace gas loss. In June 2008, the town of Mszczonów put into operation thermae with a complex of pools of 2.1 ha. Pool water is heated by a nearby geothermal intake.

The structure of geothermal energy utilization in the presented power plant was analysed using the calculation of the total energy components powered the plant (referred to as the input heat flux). The input heat flux consists of the sum of individual energies:

- chemical of gas coming from a high temperature boiler or/and two low--temperature boilers;
- economizer, which receives heat from the furnace gas:
  - before economizer (geothermal part),
  - behind the economizer (part of the urban heat distribution network);
- geothermal to the heat pump.

Figure 3a shows the changes in geothermal energy share throughout the installation before and after the construction of the pools. It has increased several times when another source of heat reception was used, such as pool basins. At that time, the highest share of geothermal energy in the system was achieved, amounting to about 35%. During the holiday season, the geothermal system operates at about 25–30% of the total installed capacity (Fig. 3b).

The values of the input heat flux are dependent on the outside temperature. When the temperature drops, the reaction of the input heat flux is noticeable (Fig. 4). As the temperature decreases,

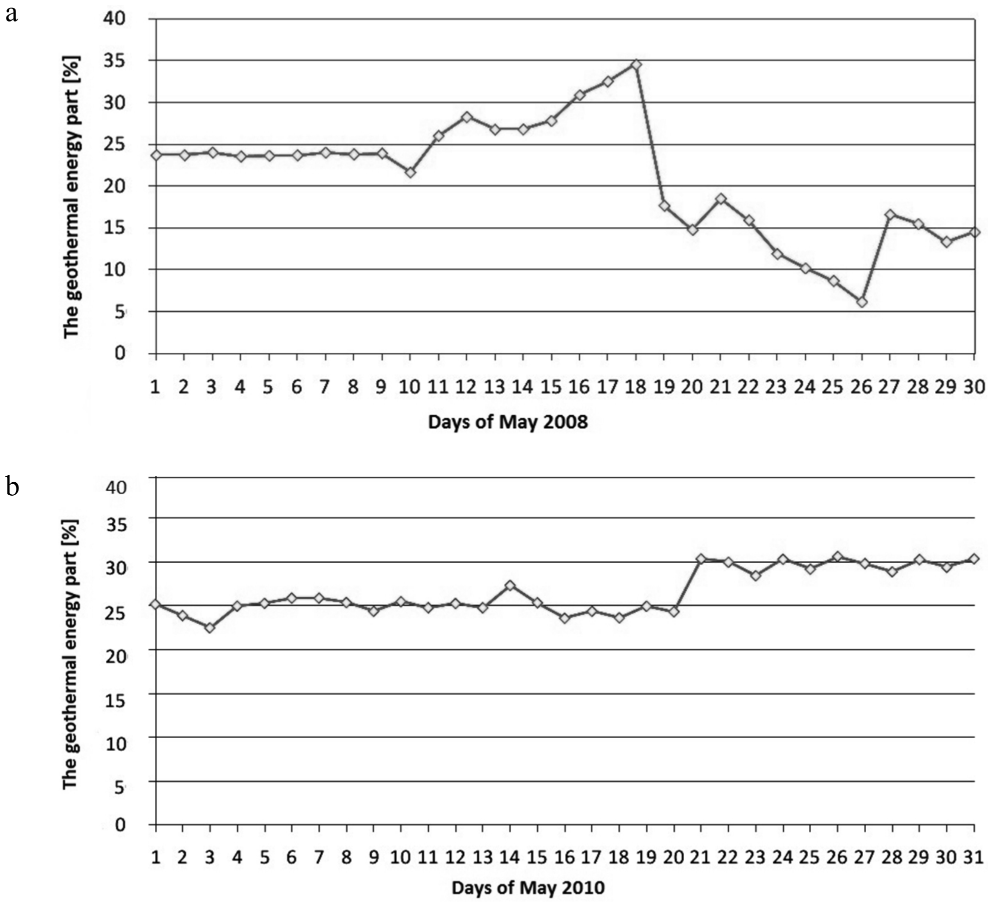

FIGURE 3. Share of geothermal part in the heat balance in May 2008 (a) and May 2010 (b)

the demand for heat (used for heating purposes) increases. Initially, it could be assumed that daily flows are significantly influenced by morning and evening hours. However, the study shows that the increase in demand for usable purposes only slightly increases the input heat flux.

Figure 5 shows the response of the input flux to the change in ambient temperature throughout the year 2005. At negative temperatures, this flux is rising due to the increasing demand for heat and hot water by consumers. In the summer, the geothermal segment is switched off and the input flux is kept constant at about 40 GJ and is caused by the heating of one of the two boilers. Since the pool complex was built in 2008, with three basin pools, its summer share has increased significantly compared to previous years (Fig. 6).

For installations using a heat pump, it is important to accurately estimate the cost of purchasing the equipment and the total installation. For example, in

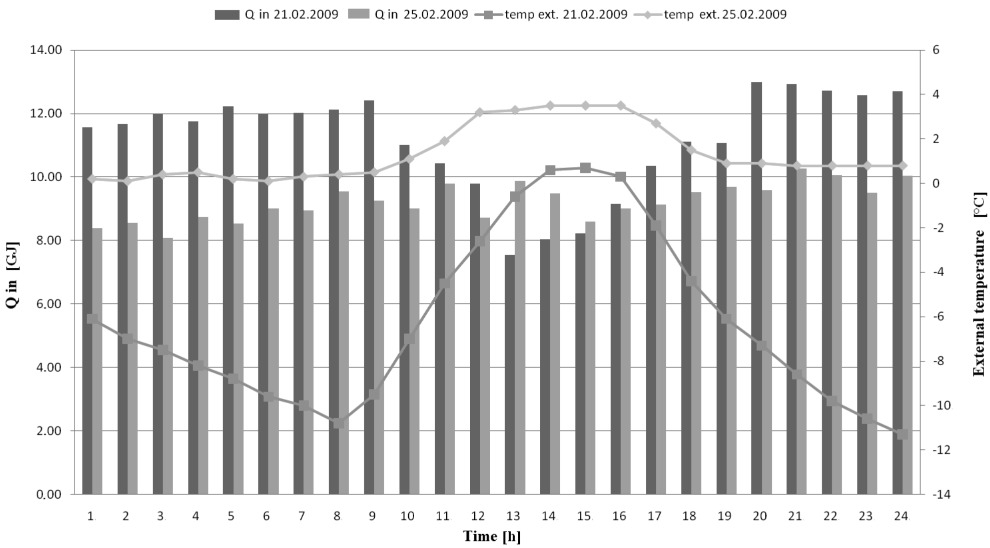

FIGURE 4. Daily course of input heat flux 21 and 25 February 2009

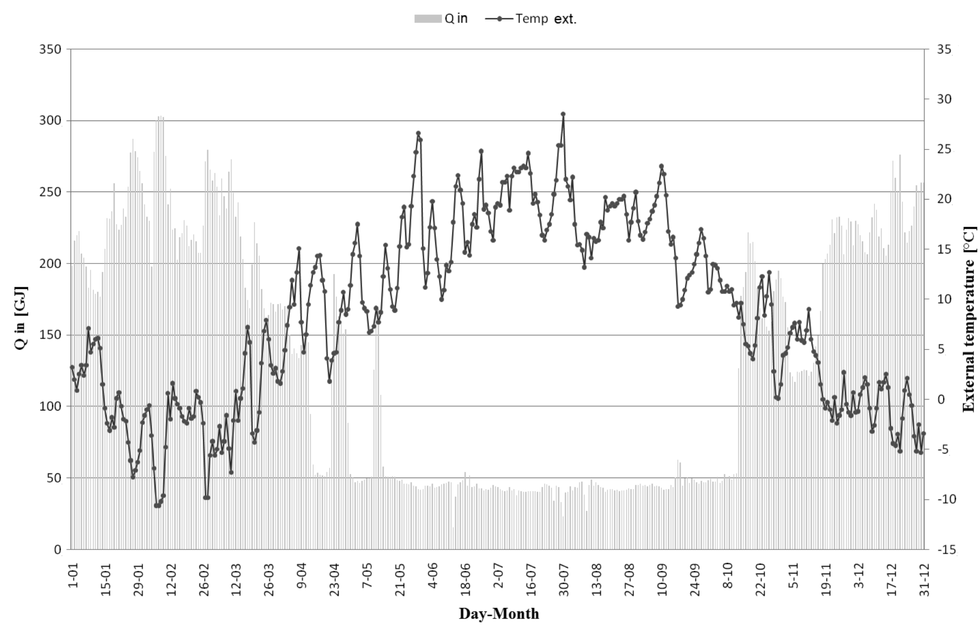

FIGURE 5. Courses of input heat flux and outside temperature in 2005

Joniec [2012] the cost calculation for an exemplary home of 180 m^2 is presented, while in the author's study in 2012 the total cost of installing a heat pump in the present building was bigger by about PLN 40,000 compared with the heating variant based on the boiler room equipped with a traditional heat source in

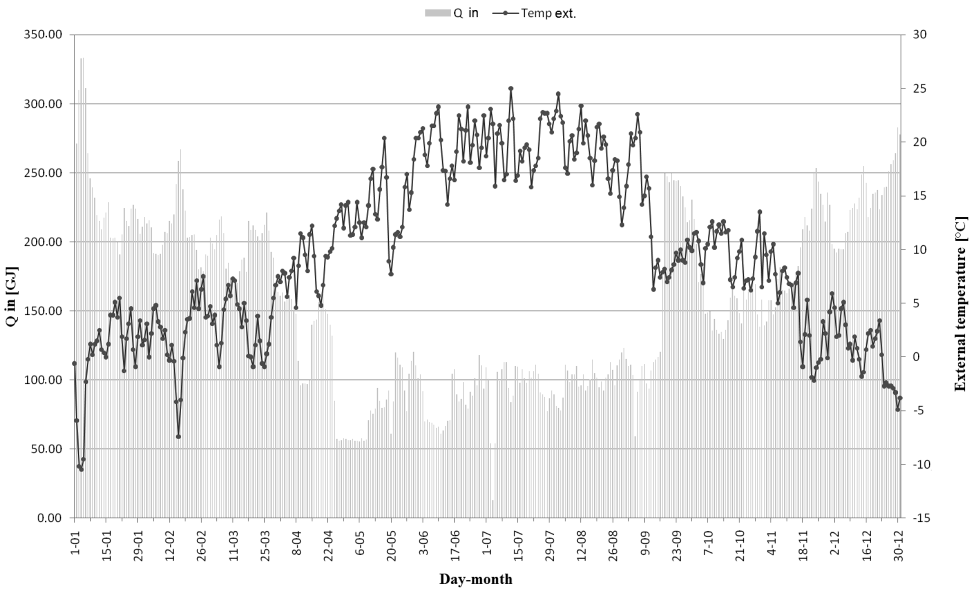

FIGURE 6. Courses of the input heat flux and outside temperature in 2008

the form of heating oil. Considering the appropriateness of using the heat pump for heating instead of the conventional fuel oil, a single-family detached house with a total area of 228.2 m^2, occupied by 4 people, situated near Płock has been taken into consideration. The central heating system is based on the technology of the heat pump engine room together with the lower source of heat. The water engine room utilizes a heat pump with a nominal power of 6.0 kW and a built-in storage tank with a capacity of 160 l of hot usable water (huw). The additional equipment of the pump is a 9-kW electric heater, which ensures a full-time operation of the system. To improve the comfort of the building, a passive cooling system is provided, realized by the lower source and the air cooler mounted on the ventilation duct of mechanical ventilation with heat recovery. The heat pump, through quality control, directly supplies the underfloor heating system of 7.7 kW and the ladder radiators of 0.5 kW. The adjustment consists in using the floor regulator from the outdoor temperature sensor mounted on the north side of the building in a place without sun exposure, balancing energy with the priority of production of huw. It is implemented according to the temperature sensor built into the tank via a three-way valve. When the hot water tank is filled, the valve switches to the heating system. The heat pump is then controlled according to the selected heating curve, using an outdoor temperature sensor in combination with a built-in heating sensor. The heat pump as a compact device has built-in circulation pumps of the lower and upper sources. The 2 × 65 m vertical sondes with the collector well were selected as the lower source. The whole installation of the heat source closed cycle is filled with aqueous propylene glycol solution. A comparison of the costs of installation and use of the boiler room with the heat pump-based instrumentation compared to the heating oil was carried out (the Table), assuming: annual heating demand 14,250 kWh, annual electricity consumption for heating 2,591 kWh, annual energy demand for huw: 2,670 kWh.

TABLE. Selected components of installation and operating costs, prices in 2012

Specification	Heating system [PLN/EUR]	Total operating costs for the year [PLN/EUR]	Total cost [PLN/EUR]
Heating system with heat pump	53 411 / 1 277	2 780 / 665	56 241 / 13 454
Heating system – oil furnace	30 000 / 7 177	4 846 / 1 159	38 671 / 9 251

Comparing the design assumptions of the proposed solutions, the lower cost of the whole was found in the solution based on the operation of a boiler room equipped with a traditional heat source in the form of heating oil. The difference is PLN 15,551. The differences between the costs of complex assembly of the proposed equipment and the costs of exploitation are analysed in the following. In case of purchase and installation of traditional equipment, the cost is lower by PLN 23,411. In the case of operating costs, a solution based on the heat pump is more advantageous from the design point of view. The annual operating cost is lower by PLN 7,860.

Analysing all the design assumptions, a solution based on the heat pump operation was taken. The decision-making in this case was the fact that the difference in operating costs of individual devices was high. It was assumed that with such a high operating cost difference after two years, the investment with the heat pump would be subject to the same total costs as in the case of a heating solution, i.e. both investments would be subject to the same total cost. Economically attractive will be the next few years when using a solution based on heat pump operation. Figure 7 shows a graph of the operating costs incurred in this home and the comparison of operating costs in a home heated with heating oil.

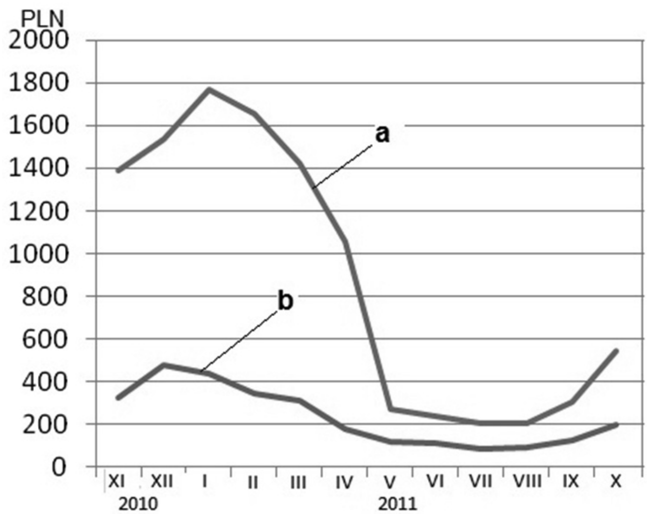

FIGURE 7. Operating costs incurred in home heating by heating oil (a) and heat pump (b)

CONCLUSIONS

In both presented examples of the use of geothermal energy, we can observe multifaceted benefits, associated not only with economic profits (sometimes achievable only after a long time from the investment), but also with so needed now saving natural resources and no emission of harmful substances into the environment (atmosphere, water). These benefits are visible especially in the case of such a large investment, which is Geotermia Mazowiecka S.A., in which the share of geothermal energy in the input stream is maintained at around 30% in the summer season. It is also very interesting to use geothermal water as drinking water and planned as mineral water. On the other hand, using a heat pump to heat the house brings economic benefits only after two years from the installation. Then its operating cost compared to the oil boiler operation is significantly lower.

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Streszczenie: *Analiza wykorzystania energii geotermalnej w zasilaniu różnych układów hybrydowych.* W pracy zaprezentowano analizę dwóch przypadków zastosowania energii geotermalnej w hybrydowych układach zasilania. Ze względu na specyfikę zagadnień i charakter możliwych do pozyskania danych każdy z tych przypadków był analizowany w inny sposób. Dla zakładu Geotermia Mazowiecka S.A. analizowano raporty wieloletnie, które zawierały dane obejmujące parametry eksploatacyjne oraz temperaturę zewnętrzną. Stwierdzono udział energii geotermalnej w strumieniu ciepła wejściowego na poziomie około 30% w lecie. Tak duży udział jest również konsekwencją uruchomienia basenów i całorocznego wykorzystywania ujęcia geotermalnego. Dla jednorodzinnego domu analizowano dwa przypadki inwestycji i eksploatacji: układu zasilanego pompą ciepła oraz układu zasilanego złożonego jedynie z kotła olejowego. Koszt inwestycji w pompę ciepła był większy, mniejsze były zaś koszty eksploatacji. Analiza obu przypadków wskazuje na zasadność inwestycji korzystających z energii geotermalnej, zwłaszcza przy planowanym długim użytkowaniu tego układu zasilania.

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