THE ENERGY EFFICIENCY OF A SCHOOL BUILDING HYBRID HEATING SYSTEM WITH A HEAT PUMP. A CASE STUDY

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Key words: heat pump, COP, SPF, energy efficiency, hybrid system, renewable energy

Summary: This paper presents a hybrid heating system of a school building with a heat pump and a gas boiler, which replaced an old coal-gas system. The description of the test object, the concept of heating system and its construction, commissioning, selection of electricity tariff to supply the heat pump and auxiliary equipment, control system, economic effects of investments carried out and further research plans are also presented. It was also determined the energy efficiency of the heat pump by means of COP and SPF factors. The results obtained indicate the correctness of assumed solutions.

1. INTRODUCTION

For several years there has been observed in Poland a growing popularity heating sources for buildings, alternative to solutions based on burning of fossil fuels. One of them is a heat pump.

A typical compression heat pump is supplied by the electrical energy to drive compressor and auxiliary equipment. A growing number of these devices will be an additional load in the Polish Power System (PPS). This is particularly evident in winter, when demand for heating of buildings is high, and the system is the most loaded in a year. Therefore, the proper selection of heat pump for heating and cooling of buildings is more and more important issue. This action is desirable and beneficial, both for the user of the device, and for operation of the power system.

To improve the energy performance of heating systems with heat pumps, mixed (hybrid) systems [20], [21], consisting of two or more sources, are being built. Such systems increase the reliability of the heat supply, what is very important in public utility buildings, like school buildings.

2. HEAT PUMP MARKET IN POLAND AND ITS POTENTIAL

Geothermal energy resources, defined as the heat stored in rocks, soil and groundwater can be used for practical purposes, among which are mentioned most frequently medicine, recreation, heat and electricity production [19]. The utilization of geothermal resources depends largely on their temperature. In general, [1], [13], [19] the resources are divided into high temperature (> 150°C), medium temperature (between 100 and 150°C) and low temperature (< 100°C). Development of heat pump technology in the last twenty years, caused the separation of very low temperature geothermal resources (< 20°C). They are also known as shallow geothermal energy.

Very low temperature geothermal resources have in Poland a very good prospects for development on the base of heat pumps [10], [11]. Energy Policy [5], [16] gives the market potential for heat pumps equal to 755 MW of the installed thermal capacity and 8167 TJ heat production in the year 2020, and 1100 MW of the installed thermal capacity and 12000 TJ of heat production in 2030. The scale of potential investments in heat pumps over the period 2010-2020 is estimated on 286MWt in the amount of 172 million Euro [18]. It causes, that the Polish heat pump market is characterized by the dynamic growth, over thirty percent year to year (Fig. 1).

Fig. 1. The annual number of new installations of heat pumps in Poland, [17]

The market is dominated by earth-coupled (or closed-loop) heat pumps, representing approximately 2/3 of units sold. Behind them follows water-source (or open-loop) and air-source heat pumps. For example, according to [18], in 2007 there were installed in Poland 2200 ground source heat pumps, 1100 ground water, and 600 air-water. But according to [7], [8] in 2009, there were installed about 7300 new heat pumps ([17] gives a number of 5100 units). From this, 3750 closed-loop heat pumps; 2950 air-source heat pumps; 450 open-loop; 95 industrial systems; and 60 gas heat pumps. This trend continued in the year 2010 [15], when closed-loop heat pumps constituted 70% of sales, air-source - 20%, and
remaining 10% were open-loop units.

When it comes to the rated power, the market is dominated by [15] [17] devices with power 6-20kW (65%), followed units with power above 20 kW (30%). The smallest contribution have units with rated power below 5 kW (10%).

Concerning these data, it must be remembered that in Poland so far there are no instruments to support development of heat pump market. Hence, the growth of this market is limited and results from ongoing opportunities of investors.

3 LEGAL ENVIRONMENT OF HEAT PUMPS IN POLAND

3.1 Legislation

In the year 2009 was adopted by the European Parliament and Council the Directive 2009/28/EC on the promotion of energy from renewable sources [3]. From a legal point of view, it is only a guide to action for the Member States. However, the records proved to be very important for the heat pump industry and its development in Poland.

The first important change was the recognition of heat pumps as a renewable source. This was done with the simultaneous determination of minimum efficiency requirements of these devices. This was caused, among others, the case of France, where financial support for new heat pumps, without setting efficiency requirements, resulted in a high electricity consumption in the summer for air conditioning purposes. At the same time, nuclear power stations (base source of electricity in France) have the lowest efficiency, what caused problems in electricity supply. Therefore, there are promoted devices satisfying minimum requirements set out in the Commission Decision of 11.09.2007 establishing ecological criteria for the award of the Community eco-label to electrically driven, gas driven or gas absorption heat pumps [2].

This directive also imposed requirements on member states to develop national action plans to implement it by the deadline of 30 June 2010. In Poland this plan [14] was adopted by the Council of Ministers on 7 December 2010. Particularly strong emphasis was put on biomass and biogas. Heat pumps were treated marginally. It is pointed out [9], [12] that according to the adopted Action Plan in the intermediate scenario, in 2020 only 2% of heat and cold (about 150 ktoe) will be supplied by the heat pumps. They are at the end of the statement, after the biomass (78%), solar energy (9%), biogas (8%) and geothermal energy (3%). There is missing the evaluation of the current situation in the sector of heat pumps (for example, there was omitted a more and more popular type of air-source heat pump) and the prospects for market development and the impact of heat pump technology for general use of RES in the economy, particularly in the energy efficient housing. For these reasons, the potential for development of the heat pump sector in this document is significantly underestimated.

Another very important piece of legislation for the sector of heat pumps is a new version of the EPBD Directive No. 2010/31/EU [4]. It introduces the concept of a nearly zero energy building. It is an object of extremely high energy efficiency set by Annex I to the Directive. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including renewable energy produced on-site or nearby. In such objects heat pumps will have the wide opportunity to be used as sources of heat and cold.

Furthermore, according to the directive, member states shall ensure that for new buildings, before construction, should be considered and taken into account technical, environmental and economic feasibility of highly efficient alternative systems, such as, among others, heat pumps.

The growing importance of efficiency requirements for heat pumps and for buildings is evident. Therefore, this issue will have increasing importance in researches and applications.

3.2 The energy efficiency of heat pumps

Energy efficiency of compression heat pumps is defined by two coefficients: COP and SPF. COP is a coefficient of thermal efficiency of a heat pump. It is defined as the ratio of the heat put into the heating system and the energy supplied to the compressor. The SPF (Seasonal Performance Factor), takes into account the impact of the energy consumed by additional elements, like circulation pumps or electric heater in the hot water tank. The settlement period is 1 year. The minimum value of SPF is determined on the basis of the Directive 2009/28/EC and is:

$$SPF > 1,15 \cdot \frac{1}{\eta}$$  \hspace{1cm} (1)

where $\eta$ is the ratio between total gross production of electricity and the primary energy consumption for electricity production and shall be calculated as an EU average based on Eurostat data.

According to Eurostat data for 2009, $\eta = 0.438$ and the minimum value of SPF is 2.626. For comparison, the conversion efficiency $\eta$ only for Poland, according to CSO data [6], in the year 2009 amounted to $\eta = 0.4079$, and in 2010: $\eta = 0.4141$, what gives the SPF (2009) = 2.819, and SPF (2010) = 2.796.
4 DESCRIPTION OF THE INVESTMENT

4.1 Origin of the project

The idea of heat pumps installation in electricity consumers serviced by the Tarnów Power Company (ZET, now Tauron Polska Energia) arose in 2001. There was also planned a special tariff for "Eco-Heating". It was also appointed a special team, who began promoting the idea. The aim was to popularize this type of heating within electricity consumers in the region. This was to increase the electricity sales, increase of power lines load in rural and suburban areas and to improve the load profile of distribution lines. The team had to gain experience in the implementation of several pilot projects. The Power Company was supposed to invest its own funds in these devices and to assemble them in interested buyers and then sell to them the heat produced. There was also established the basis of special tariffs for heat pumps. The result of this work was a collection of papers on economic and technical aspects of heat pumps exploitation. Promising results led to the first pilot investment [20].

When selecting an object for the first project, the concern was primarily directed towards the location and geological conditions. A facility located on heavy and wet soils, characterized by good thermal conductivity was sought. There were also taken into account facilities where modernization of the heating system was planned.

These conditions were met by the facility proposed in 2002 by the Commune Office in Wojnicz near Tarnow. It was a school building in Wielka Wies. It was situated in the valley of the Dunajec river, on clay soils, and had an appropriate area next to the building, what could allowed for the construction of the ground heat exchanger. What is more, these areas are rich with shallow groundwater aquifers. It was also planned the modernization of the central heating system and boiler room during the summer of 2004. It was decided that ZET would finance a heat pump with necessary auxiliary equipment. Commune Authority declared to buy the heat produced by heat pump and to provide the necessary documentation.

4.2 Description of the object

The school building in Wielka Wies (Fig. 2) was built according to the traditional technology before the year 1987. It has a floor area of 1107 m² and a volume of 3538 m³.

The building is located in climat zone 3 according to the PN-EN 12831 standard. Heat losses for the northern and gable walls account for 70.4 kW, while for the southern walls: 35 kW. This gives a total demand for thermal power of 105.4 kW. The central heating installation was designed for 105 kW, and the heating water parameters of 90/70°C. Originally, the boiler room was equipped with a gas boiler with a capacity of 145 kW and the old coal stove. Central heating installation was performed in an open system from steel pipes, corroded, requiring replacement. Cast-iron radiators were equipped with a faulty radiator valves.

In order to reduce heat costs, there were replaced old windows and old cast iron radiators for steel panel radiators. There was also planned the modernization of the heating system and a central heating system.

4.3 Technical assumptions and the modernization

The basis for further analyzes were invoices for gas for the period 2000-2003 obtained from the Commune Office. The graph of the gas consumption for heating of the building is shown in Figure 3.

The gas boiler produced on average 565 GJ of heat per year. For further calculation purposes there were also assumed:
the peak thermal power: 105.4 kW
annual heat demand for heating: 565 GJ
efficiency of the gas boiler: 0.80
gas tariff: W4
the calorific value of the gas: 34.2 MJ/m³
Type of the heat pump: Vatra 32T/1A1
max. thermal power: 48.06 kW
continuous thermal power: 30 kW
COP = 3.15

These data were used to complete a feasibility study and a business plan. According to the design data, the length of the heating season in Wielka Wieś is 222 days (5328 h) and the average temperature is 2.5°C. The temperature observations from previous years showed that during the heating season is about 25 days with an average daily temperature below -5°C.

The main assumption of the heat pump selection was the work at the base of the load-duration curve [23]. It was planned that the heat pump would guarantee to cover the heat demand of the object for the outdoor temperature of about -5°C. This would guarantee continuous operation of this device over the heating season with constant, optimal parameters. As a result, the heat pump would work as the basis of demand with the power of 30 kW and an annual heat generation of about 255 GJ (Fig. 4). If there was a high demand for heat, the gas boiler would be turned on. It would ensure continuity of heat supply. Thanks to that, the Commune Authority was to receive a cheaper supply of heat, and ZET - its permanent sell.

![Fig. 4. Load duration curve for the heat pump and the gas boiler.](image)

The analysis also assumed that the heat pump, which is owned by ZET, in five years will have been sold to the local municipality (owner of the school building). On the basis of the agreement with the Community Office, there were assumed the price of heat from the heat pump on 37 zł/GJ (gross), about 10% lower than for the heat from the gas boiler, and giving return on investment costs under these conditions was nine years.

### 4.4 Implementation of the investment

It was assumed that the heat source for heat pump will be a ground collector in the square adjacent to the school. This concept has been changed because of the plan to build the gym-hall on this place. Then there was proposed construction of open-loop system (water well system). The argument for this solution was an old deep well next to the school building and the geological data about groundwater resources (10-15 m below the surface) in the valley of the Dunajec. For this purpose the geological project of wells was made and groundwater resources were identified. After obtaining necessary approvals, wells were drilled. Capacity of ground water deposit in the project was estimated at more than 10 m³/h, against the needs of heat pump of 6 m³/h.

When drilling the supplying well there was confirmed the arrangements of strata from geological studies. Impermeable layer of clay was to a depth of about 8 m below the surface. The next was the 3.5 m deep aquifer, containing coarse gravel with a high performance filtration. After that there was a layer of impermeable clay starting at about 12 m below the surface. The performed pumping test gave good results. The study confirmed the capacity of deposits compatible with the design data.

The study of the water composition in terms of mineral content showed a high content of iron, but did not exclude the use of heat pumps.

After tendering there was purchased OCHSNER Golf Maxi GMWW 38 heat pump. Its main technical data are shown in Table 1.

<table>
<thead>
<tr>
<th>Duty point</th>
<th>Maximum supplying temperature</th>
<th>Thermal power kW</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>W10/W35</td>
<td></td>
<td>37.6</td>
<td>5.7</td>
</tr>
<tr>
<td>W10/W50</td>
<td></td>
<td>34.7</td>
<td>3.7</td>
</tr>
</tbody>
</table>

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The next step was the assembling of hydraulic and electrical connections, installation of the water tank with a capacity of 1m³, the heat pump with auxiliary...
equipment, the heat meter on the output of the heat pump and the electricity meter (Fig. 5).

Fig. 5. The heating system diagram.

The last stage was the final approval of the work connected with the training of persons who have had to deal with the further exploitation of the heat pump.

5 OPERATION AND TESTING

5.1 Launching the boiler room

The system was put into operation in January 2005. Observations of heat pump performance in January and February, when outdoor temperature was reaching 20°C, showed the groundwater temperature stability and the stable operation of the system. In times of high demand for the heat, the outlet water temperature from the heat pump rose to 57°C.

Waveforms of the electrical power of the heat pump compressor's and outside temperature within first four months of 2005 are shown in Figure 6.

Fig. 6. The outdoor temperature and the heat pump electrical power from January 1 to April 30 2005
Fluctuations of the power in February resulted from a sharp transition from low outdoor temperatures (about -15...-20°C) to positive temperatures. It was so also due to the high temperature set on a gas boiler. A controller was switching on a gas boiler a short period, to maintain the temperature inside the boiler, but not in the system. This resulted in additional gas consumption and worsening of economic performance of investment. This effect was eliminated by assembling a new controller of the boiler.

Despite the very low outdoor temperatures, the heat pump worked stably in cooperation with the gas boiler. At temperatures down to -5°C the heat pump worked independently, covering the heat demand for the school.

Results of studies confirmed the correctness of technical assumptions of the new heating system. For the period January-April the average value of COP was 3.25. The SPF factor (taking into account the energy consumed by circulation pumps), was 2.93. Average temperatures in characteristic points of the heating system are shown in Table 2.

Table 2. Temperatures in heating system (I-III 2005).

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>Temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply well - inlet water for heat pump</td>
<td>11,0</td>
</tr>
<tr>
<td>Temperature drop - the heat pump exchanger</td>
<td>3,5</td>
</tr>
<tr>
<td>Flow temperature</td>
<td>51,5</td>
</tr>
<tr>
<td>Maximum flow temperature</td>
<td>55,0</td>
</tr>
<tr>
<td>Return water temperature</td>
<td>42,0</td>
</tr>
</tbody>
</table>

5.2 Selection of the electrical tariff for the heat pump

Element contributing significantly to the economic success of the new investment was the selection of the right electricity tariff for heat pump and other equipment of the heating system. Favored by a fairly regular and predictable nature of the use of the school. Thus, already by the first measurement data, an economic evaluation of using different power tariffs. The school building was powered by C12a tariffs by two measuring systems, ie: for the social needs and for the heat pump.

In the first quarter of 2005 the school consumed 5597 kWh. The electricity consumption by the heating system amounted to 20571 kWh. Heat pump demand for power, according to the measurements, was even throughout the day (Fig. 7), with an average of 9.8 kW.

Fig. 7. The heat pump load profile and energy tariffs

On the basis of the valid rates, the cost of energy for individual tariffs was calculated. It amounted to 8812.15 zł for the C11, 7648.54 zł for the C12a and 8011.30 zł for the C12b tariff. So, the choice of the C12a tariff was proper. Furthermore, the use of the new heating system resulted in the more than fourfold increase in the electricity consumption in the school. This significantly increased the the network utilization, particularly during nights.

5.3 Economic results for 2005

The main objective of the heat pump installation was to reduce the cost of heating of the school building. For the 2005 rates, the cost of the gas for heating purposes amounted to 17990 zł/year. As a result of the heat pump work, gas consumption has dropped from an average of approximately 20000 m³ to about 4200 m³ in 2005, of which for heating was about 2320 m³. This allowed for the change of the gas tariff from W3 to W4, where the share of fixed costs is smaller by 4%. Delivery of heat took place continuously for 24 h/day, and in 2005 was 458 GJ in total. The result was a decrease in costs of heating by about 9.2%, despite the heat production higher by 22 GJ. This gave a period of investment return less than 7 years.

The analysis based on a real data confirmed the proper selection of the equipment and good economic effects for the owner of the heat pump (ZET) and for the heat consumer (school).

5.4 Energy efficiency of heating system

Since its launch, after the necessary adjustments, the supply of heat still takes place continuously without any interruption. Periodically occurring increased heat demand was covered by the gas boiler. After the heating season, the primary heat source is gas boiler.

The heat pump is still monitored. The amount of the electricity consumed and the heat produced is stored in the memory of relevant counters. By 2009, the
installation was under the substantive supervision by the staff from from Energy Company in Tarnow. This allowed for a professional ongoing monitoring of the installation.

During that time the control algorithm of the heat pump was also modified. It was eaken into account an afternoon peak demand between the hours of 13 and 17, and end of lessons at school (Fig. 8), when the fee increases according to C12a tariff. There can be seen that the hourly power of heat pump is the smallest in the transitional months (April, September). Low values for February were such because the school holidays, when heating of the school worked with a reduced internal temperature. For the remaining months there can be seen a fairly regular waveforms of the diurnal variation of the electric power.

![Fig. 8. Hourly power of the heat pump compressor](image)

Several years of exploitation confirmed the good energy performance of the heating system expressed by SPF value, as shown in Figure 9 (solid black line represents SPF = 2.626). It is very important that the heat pump operated in a relatively unfavorable energy conditions. The heating system is the installation of a conventional radiators, requiring the temperature of the inlet water above 40°C, what causes that the heat pump operates with lower efficiency. The average value of SPF for months of heating for the period from January 2005 to December 2009 was 3.13. This allows to determine the efficiency of the heating system as good, over obligatory standards.

![Fig. 9. COP and SPF factors in 2005-2009 (2007/2008 data n.a.)](image)

In 2010, as a result of transformations in the energy sector in Poland, the installation with the heat pump became the property of the Commune Authority in Wojnicz. From this time the Department of Power Systems and Environmental Protection Facilities, AGH University of Science and Technology, take over the scientific supervision of the system. It is
planned to develop the energy monitoring of the heating system in characteristic points for a comprehensive metering and remote visualization of the heating system for the owner and for research purposes.

6 SUMMARY
This paper describes the conception, the construction and the operation of the heating system based on the heat pump and the gas boiler. As a result of the modernization and conversion of the coal-gas heating to the hybrid system there were obtained a number of benefits. The first was the decline in gas consumption by about 75% and the possibility of the transition to the gas tariff with lower fixed costs. The use of the appropriate electricity tariff to supply the heat pump and take into account the operation mode of the school, helped to reduce overall energy costs for heating. This happened despite the costs of depreciation of a new part of the system and lower unit price of heat from a heat pump in relation to the reference price of heat from the gas boiler.

Several years of faultless exploitation also showed a good energy-efficiency of the heat pump, measured by SPF factor. Its average value for the period from January 2005 to December 2009 (only heating months) was 3.131. It is therefore more than required by Directive 2009/28/EC minimum value SPF = 2.626. The average value of COP coefficient was 3.467. Thus, the work of the circulation pumps has substantial influence on the values of energy efficiency coefficients.

Further investigations are planned and the extension of energy monitoring of the heating system. They will allow for a more detailed assessment of the solutions, identification of opportunities to improve the energy efficiency of heat pumps and heating system as a whole in Polish climatic conditions.

7 REFERENCES
[8] Grochal B.: Instruments to support the development of heat pump market (in Polish), Workshop on "Effectiveness of support systems heat and cooling from renewable energy sources in Poland and other countries", Warszawa, 29 April 2010
EFEKTYWNOŚĆ ENERGETYCZNA HYBRYDOWEGO SYSTEMU OGRZEWANIA SZKOLNEGO Z POMPĄ CIEPŁA. STUDIUM PRZYPADKU

Słowa kluczowe: heat pump, COP, SPF, energy efficiency, renewable energy,

Streszczenie: W artykule przedstawiono hybrydowy system ogrzewania budynku szkolnego z pompą ciepła i kotłem gazowym, który zastąpił ogrzewanie węglowo-gazowe. Opisano obiekt badany, koncepcję systemu ogrzewania i jego budowę, uruchomienie, dobór taryfy energetycznej do zasilania pompy ciepła i urządzeń pomocniczych, funkcjonowanie systemu, efekty ekonomiczne przeprowadzonej inwestycji i dalsze plany badawcze. Określona została także efektywność energetyczna pompy ciepła za pomocą wskaźników COP oraz SPF. Uzyskane rezultaty wskazują na poprawność przyjętych rozwiązań.

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