

# Influence of Heat Pump Integration into Geothermal Heat Plant System

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## Abstract

The present paper assesses the operation of a geothermal heat plant cooperating with an absorption heat pump. The heat plant system is presented in detail together with parameters characterizing its work: the most important relations used in calculations, results of calculations, and conclusions resulting from the accomplished analysis. Calculations have been presented for a heat plant localized in the first climatic zone with accounts of different temperatures of extracted geothermal water. Additionally, the analysis considered is variation of parameters characteristic of heat recipients such as supply and return temperature, type and participation of particular heat receivers. Such an approach enabled us to determine how the considered parameters influence the effectiveness of operation of the considered heat plant installation. In the present paper neither costs nor economic analysis was carried out for such types of installations. These will be topics for future activities.

**Keywords:** renewable energy, geothermal energy, geothermal heating plant, absorption heat pump, high-temperature heating, low-temperature heating

## Introduction

Economic development, increasing consumption of energy, and terminal resources of conventional fuels, together with the necessity to reduce greenhouse gases, are only a selection of arguments to increase the energy acquisition from renewable sources of energy. In Poland there are already installations harnessing renewable sources of energy such as hydropower plants, wind farms, geothermal heat plants, and biomass burning. But their representation in the total production of energy, both electricity and heat, is rather small. One of the reasons for that are definitely the investment costs in cases of such installations and hence the significant risk and long payback times. However, despite these and other difficulties in the years to come there will be new projects focused on utilizing renewable sources of energy.

A significant part of Poland's renewable energy potential is geothermal energy [1]. The amount of geothermal resources and their appropriate documentation renders such sources of energy to be regarded as prospective.

Such background was used in selecting the topic of the present paper, in which we present the system enabling utilization of energy contained in geothermal waters for production of heat energy for central heating.

Geothermal energy is the accumulated energy in waters trapped in gaps and porous rock massifs under the surface of the ground, the temperature of which exceeds 20°C [2]. Energy contained in geothermal water, in relation to its temperature, can be managed in a variety of ways, starting from fish breeding, balneology, food processing, the heating sector, and finally electricity production [3]. Polish resources of geothermal energy are mostly waters not exceeding 80°C, but resources higher than 80°C also are available, and in the case of layers placed at higher depths

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the temperatures reach even 120°C [2]. As mentioned earlier, the present paper deals with the possibility of utilizing geothermal water for production of heat for central heating purposes and, as known, in Poland such systems are in the majority for high-temperature heating installations. That renders the geothermal source itself as not capable of covering the entire heat demand and hence in heat plants there have to be present peak-time boilers to increase parameters of network water to the required level.

### Characteristics of the Geothermal Power Plant

In the proposed project of the geothermal heat plant it has been assumed that it cooperates with the so called geothermal doublet, that is the two-hole exploitation system. In such a system the geothermal water is acquired with an extraction well and, following the heat recovery, is directed to the basin with a pumping well. The necessity of using such a system of geothermal energy acquisition is dictated by the impossibility of removing mineralized water to the surface reservoirs. The fact of water mineralization also requires use of a multi-plate, counter-current geothermal heat exchanger in the system. In such a way the corrosive interaction of water and heat plant elements are limited. In the case when extracted geothermal water has small mineralization, then following its treatment it can be directed to the network water. An example of such an installation can be the geothermal company in Mszczonów [4-6].

Due to the not too high thermal parameters of geothermal water, we propose including the absorption heat pump into the heat plant system, which significantly increases the parameters of network water and increases the utilization of geothermal energy. An example of such an installation where the heat pump is used is the heat plant in Pyrzyce.

A schematic of such a heat plant together with operational parameters can be found on the company's website [7].

The application of absorption heat pumps is caused by the low demand of these pumps for electrical energy (the driving energy in these pumps is heat). These pumps' reliability is the second reason, plus they are simple in operation.

As presented the application of the heat pump, to a significant extent, increases the effectiveness of heat plant operation, particularly in lower temperatures of geothermal water and high shares of high temperature receivers.

Fig. 1 presents a schematic diagram of a geothermal heat plant where two systems can be discerned: the system of acquisition of geothermal energy (incorporating the extraction well and a pumping well), geothermal water pumps, and a network of pipelines supplying geothermal water to the heat plant. The remaining part of the system is an assembly for utilization of geothermal energy consisting of network water circulation pumps, heating network distributing heat to recipients, high-temperature and low-temperature heat receivers, a gas-fired peak-load boiler, and an absorption heat pump. A common element combining these two systems is a multi-plate counter-current geothermal heat exchanger, for which the assumed temperature value difference between fluids is  $\Delta T=2K$ .

The presented geothermal heat plant cooperates with a district heating network supplying two groups of heat receivers (high- and low-temperature ones), assuming that both the heat plant and distribution network feature a qualitative regulation that is accomplished by changes of rotational velocity of network and geothermal water pumps. Under such regulation the temperatures of heating fluid at the heat receivers inlets and outlets do not depend on external temperatures, which means it is constant in the entire heating season.

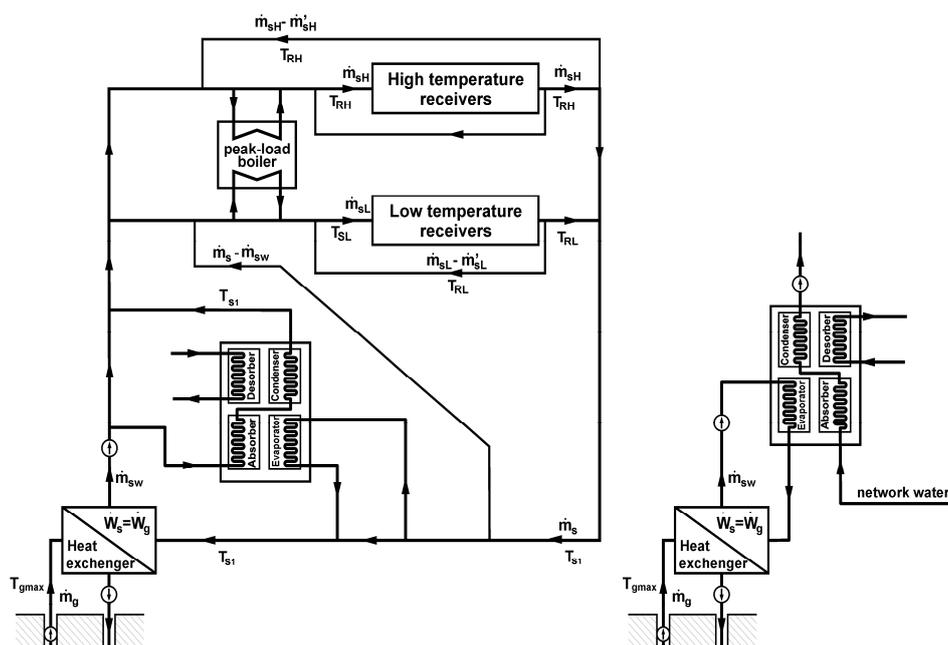


Fig. 1. Schematic of geothermal heat plant featuring an absorption heat pump (two variants of heat pump connection).

In order to cover the variable rate of heat demand to cover the needs for central heating, the mass flowrate of heating water is adequately adjusted in the function of external temperature. At the same time, in a close link to heating water control, the flowrate of geothermal water also undergoes qualitative control, assuming that in the counter-current geothermal heat exchanger the condition of equal thermal capacities between heating water and geothermal water is obeyed:

$$\dot{m}_s c_s = \dot{m}_g c_g \quad (1)$$

It has been assumed in calculations that maximum heat demand for heating purposes is  $Q_{co,max} = 8,000$  kW at minimum external temperature. The value of minimum external temperature results directly from the location of the heat plant and according to Polish Standards (PN-B-02403:1982), in case of objects located in the first climatic zone it is  $T_{z,min} = -16^\circ\text{C}$  [8]. The length of the heating season has been assumed at a level of 4,380 hours, assuming that it starts at the moment when external temperature drops below  $T_z = 12^\circ\text{C}$ , whereas in inner spaces it is sustained at a level of  $20^\circ\text{C}$ . Analysis has been conducted for three values of temperatures of extracted geothermal water  $T_{g,max}$ : 40, 60,  $80^\circ\text{C}$ , and a flow rate of  $200 \text{ m}^3/\text{h}$ . In calculations we also considered different values of network water return temperature and different shares of heat receivers.

In order to limit the negative influence of the heat plant in a local environment the authors assumed that a gas boiler and absorption heat plants will be the devices that increase temperature of network water in the heat plant. The boiler in such a system plays a dual role: increasing network water temperature and delivering steam to drive the heat pump.

Fig. 1 presents only two of many possible ways of connecting a heat pump to the heat plant system (such ways are dependent on operational parameters of the heat plant).

### Methodology of Calculations

In order to estimate the amount of used geothermal energy in the system of a heat plant cooperating with a heat pump knowledge of its operational parameters is necessary. We assume that in such a power plant an absorption heat pump will be installed (available on domestic market and offered by the company SANYO). The range of operation of such devices is limited by the temperature characteristics (Fig. 2) [12], and hence the parameters of pump operation were adjusted in such a way as to assure its appropriate operation. The temperature of network water leaving the heat pump was at all times determined based on presented temperature characteristics, whereas the remaining operational parameters were found on the basis of catalogue data and calculations such as a pump's heat balance, etc.

The rate of heat  $\dot{Q}_{co}$  required for central heating purposes in the case of a given external temperature  $T_z$  or a minimum external temperature  $T_{z,min}$  is, respectively:

$$\dot{Q}_{co} = \dot{Q}_{coH} + \dot{Q}_{coL} \quad (2)$$

$$\dot{Q}_{co,max} = \dot{Q}_{coH,max} + \dot{Q}_{coL,max} \quad (3)$$

The shares of high temperature heaters  $\phi_H$  and low temperature heaters  $\phi_L$  have been defined below:

$$\phi_H = \frac{\dot{Q}_{coH}}{\dot{Q}_{co}} = \frac{\dot{Q}_{coH,max}}{\dot{Q}_{co,max}} \quad (4)$$

$$\phi_L = \frac{\dot{Q}_{coL}}{\dot{Q}_{co}} = \frac{\dot{Q}_{coL,max}}{\dot{Q}_{co,max}} \quad (5)$$

Flowrates of heating water in the case of both heat receivers depend on external temperature  $T_z$  and vary linearly according to the formula:

$$\dot{m}_s = \alpha + \beta T_z \quad (6)$$

...where:  $\alpha = \alpha_H + \alpha_L$ ,  $\beta = \beta_H + \beta_L$ .

The relation presented below determined the rate of required heat for central heating purposes:

$$\dot{Q}_{co} = \dot{Q}_{co,max} \frac{T_w - T_z}{T_w - T_{z,min}} \quad (7)$$

...where:  $T_w$  – room temperature (assumed to be  $20^\circ\text{C}$ ).

Heat demand for central heating purposes is covered by the heat receivers at a given flowrate of heating water and assumed supply  $T_s$  and return  $T_R$  temperatures. This is described by the relation:

$$\dot{Q}_{co} = \dot{m}_s c_s (T_s - T_R) \quad (8)$$

Relations (6) and (8) can be used for calculating high or low temperature heating using the relevant indices H or L.

Using relations (4), (5), (6), (7), and (8), it is possible to determine coefficients  $\alpha$  and  $\beta$  for both groups of heat receivers using the expressions presented below [9-11]:

- in the case of high-temperature heating

$$\alpha_H = \frac{\phi_H Q_{co,max} T_w}{(T_w - T_{z,min}) c_s (T_{SH} - T_{RH})} \quad (9)$$

$$\beta_H = \frac{-\phi_H Q_{co,max}}{(T_w - T_{z,min}) c_s (T_{SH} - T_{RH})} \quad (10)$$

- in the case of low-temperature heating the above coefficients have analogous form, but index H should be changed to index L.

The total mass flowrate of heating water can be determined from relation (6) or from the formula presented below:

$$\dot{m}_s = \dot{m}_{sH} + \dot{m}_{sL} \quad (11)$$

Due to the fact that the maximum flowrate of water through the geothermal heat exchanger is limited, the relationship between  $\dot{m}_s$  and  $\dot{m}_{sw\ max}$  should be discerned as calculation cases A and B: first, if  $\dot{m}_s < \dot{m}_{sw\ max}$  then the flowrate of network water flows entirely through the heat exchanger; second, if  $\dot{m}_s > \dot{m}_{sw\ max}$ , where only part of network water flows through the heat exchanger, whereas the remaining part of the network water  $\Delta \dot{m}_s$  flows through a bypass around the heat exchanger.

The regulation diagram showing both cases is presented in Fig. 2.

Methodology of calculation of heat, including utilized geothermal energy in the heat plant is precisely described in several earlier works [9-11]. So we present only the heat balance equation for the heat pump, a schematic of which (together with temperature characteristics) is presented in Fig. 2.

$$\begin{aligned} \dot{m}_w \cdot i_{w1} + \dot{m}_p \cdot i_p + \dot{m}_{od} \cdot i_{od1} &= \\ = \dot{m}_w \cdot i_{w2} + \dot{m}_p \cdot i_w + \dot{m}_{od} \cdot i_{od2} \end{aligned} \quad (12)$$

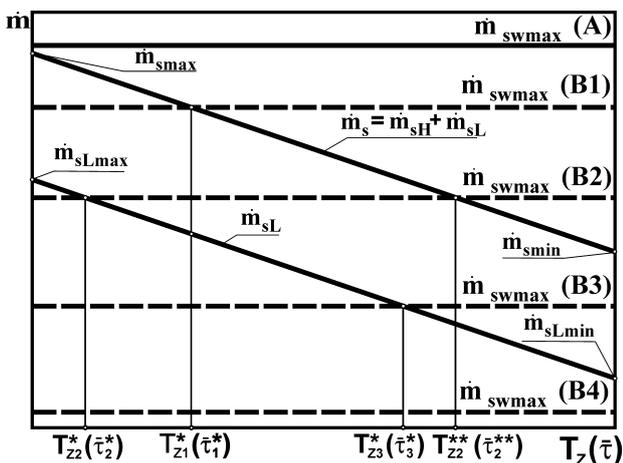


Fig. 2. Regulation charts for variants A and B.

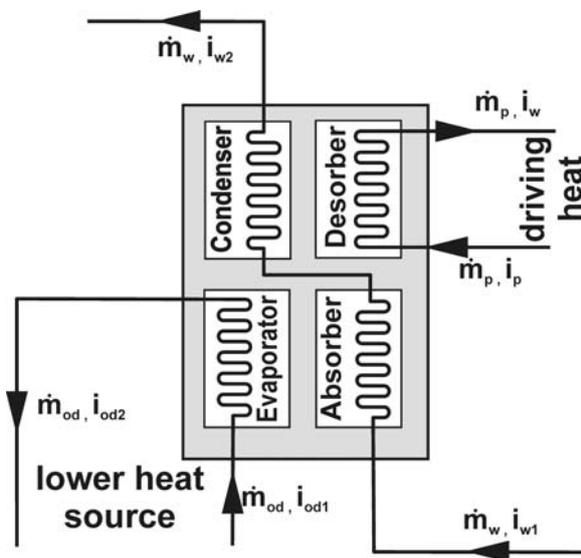


Fig. 3. Schematic and temperature characteristics of absorption heat pump.

In order to simplify calculations we assumed that the heat pump attains the same coefficient of performance in the entire range of regulation (even at loads significantly different from nominal ones). This results from catalogue data [12] that such a coefficient is equal to  $E=1.7$  whereas the temperature drop of the heat carrier in the lower heat source reservoir is 10 K. For such values, on the basis of heat pump balance and its temperature characteristics, the amount of heat required to drive the pump and heat recovered from the lower heat source reservoir has been determined. Such data, in combination with data related to the power plant itself, enabled determination of the amount of geothermal energy that later served as a basis for heat assessment of the effectiveness of geothermal plant operation.

Explained below is the way to determine heat pump parameters on the basis of temperature characteristics (Fig. 3). On the basis of these characteristics, having knowledge of temperatures of lower heat source reservoir and heated water supplying the pump, the temperature of water leaving the heat pump can be determined. For example, when the lower heat source reservoir temperature is 26°C (temperature beyond the evaporator 16°C) and temperature of water supplying the heat pump is 40°C, then temperature of water leaving the heat pump has a value of 54°C.

### Results of Calculations

For the case of the considered heat plant it has been calculated that the total amount of heat resulting from the heat demand for the entire season is  $Q_c=15,855$  MWh (15.85G Wh). A part of that heat is covered by the geothermal heat source  $Q_{geo}$ , whereas the remaining part, in relation to the system, is supplied in the peak-load boiler or a heat pump and a peak-load boiler.

In order to determine the influence of particular parameters on the amount of utilized geothermal energy the

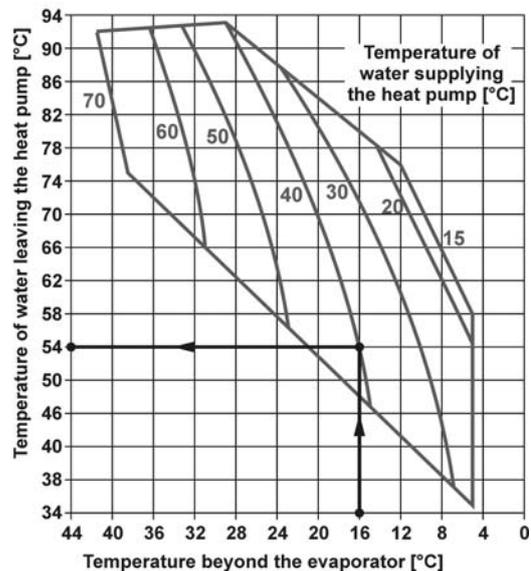


Table 1. Percentage share of geothermal energy in total amount of heat produced in geothermal heat plant in relation to operational parameters.

	Share Φ <sub>L</sub>	T <sub>SL</sub> /T <sub>RL</sub>												
		40/25	40/30	50/25	50/30	40/25	40/30	50/25	50/30	40/25	40/30	50/25	50/30	
T <sub>SH</sub> /T <sub>RH</sub> 90/50	1	73.7	49.7	51.6	38.3	100	99.8	100	99.8	100	100	100	100	100
		<b>84.5</b>	<b>70.4</b>	<b>71.5</b>	<b>63.7</b>	-	-	-	-	-	-	-	-	-
	0.5	43.3	40.0	26.0	20.0	60.0	60.0	60.0	60.0	60.0	85.0	85.0	85.0	85.0
		<b>50.7</b>	<b>50.6</b>	<b>44.6</b>	<b>42.7</b>	<b>75.4</b>	<b>75.4</b>	<b>75.4</b>	<b>75.4</b>	<b>75.4</b>	-	-	-	-
	0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0	70.0	70.0	70.0	70.0
		<b>29.3</b>	<b>29.3</b>	<b>29.3</b>	<b>29.3</b>	-	-	-	-	-	-	-	-	-
T <sub>SH</sub> /T <sub>RH</sub> 90/40	1	73.7	49.7	51.6	38.3	100.0	99.8	100.0	99.8	100	100	100	100	
		<b>84.5</b>	<b>70.4</b>	<b>71.5</b>	<b>63.7</b>	-	-	-	-	-	-	-	-	
	0.5	43.3	40.0	26.0	20.0	68.0	68.0	68.0	68.0	68.0	88.0	88.0	88.0	88.0
		<b>55.6</b>	<b>56.0</b>	<b>47.9</b>	<b>47.7</b>	<b>71.3</b>	<b>71.3</b>	<b>71.3</b>	<b>71.3</b>	<b>71.3</b>	-	-	-	-
	0	0.0	0.0	0.0	0.0	36.0	36.0	36.0	36.0	36.0	76.0	76.0	76.0	76.0
		<b>40.7</b>	<b>40.7</b>	<b>40.7</b>	<b>40.7</b>	<b>42.6</b>	<b>42.6</b>	<b>42.6</b>	<b>42.6</b>	<b>42.6</b>	-	-	-	-
T <sub>SH</sub> /T <sub>RH</sub> 80/50	1	73.7	49.7	51.6	38.3	100	99.8	100	99.8	100	100	100	100	
		<b>84.5</b>	<b>70.4</b>	<b>71.5</b>	<b>63.7</b>	-	-	-	-	-	-	-	-	
	0.5	43.3	40.0	26.0	20.0	63.3	63.3	63.3	63.3	63.3	96.7	96.7	96.7	96.7
		<b>55.0</b>	<b>51.2</b>	<b>44.7</b>	<b>40.8</b>	<b>83.9</b>	<b>83.8</b>	<b>83.9</b>	<b>83.8</b>	<b>83.8</b>	-	-	-	-
	0	0.0	0.0	0.0	0.0	27.0	27.0	27.0	27.0	27.0	92.2	92.2	92.2	92.2
		<b>38.9</b>	<b>38.9</b>	<b>38.9</b>	<b>38.9</b>	-	-	-	-	-	-	-	-	-
T <sub>SH</sub> /T <sub>RH</sub> 80/40	1	73.7	49.7	51.6	38.3	100.0	99.8	100.0	99.8	100	100	100	100	
		<b>84.5</b>	<b>70.4</b>	<b>71.5</b>	<b>63.7</b>	-	-	-	-	-	-	-	-	
	0.5	43.3	40.0	26.0	20.0	72.5	72.5	72.5	72.5	72.5	97.5	97.5	97.5	97.5
		<b>59.1</b>	<b>59.6</b>	<b>51.8</b>	<b>51.4</b>	<b>76.6</b>	<b>76.6</b>	<b>76.6</b>	<b>76.6</b>	<b>76.6</b>	-	-	-	-
	0	0.0	0.0	0.0	0.0	45.0	45.0	45.0	45.0	45.0	93.8	93.8	93.8	93.8
		<b>40.7</b>	<b>40.7</b>	<b>40.7</b>	<b>40.7</b>	<b>53.2</b>	<b>53.2</b>	<b>53.2</b>	<b>53.2</b>	<b>53.2</b>	-	-	-	-
T <sub>gmax</sub> = 40°C					T <sub>gmax</sub> = 60°C					T <sub>gmax</sub> = 80°C				

T<sub>SL</sub>/T<sub>RL</sub> – parameters of low temperature receivers (supply/return).

T<sub>SH</sub>/T<sub>RH</sub> – parameters of high temperature receivers (supply/return).

Φ<sub>L</sub> – share of low temperature receivers.

coefficient of utilization of geothermal energy E<sub>g</sub> has been defined as:

$$E_g = \frac{Q_{geo}}{Q_c} \cdot 100 \tag{13}$$

Introduction of this coefficient enables a clear presentation of results as well as their easy interpretation. Coefficient E<sub>g</sub>=100% when the total amount of heat required for central heating is covered from a geothermal source. On the other hand, if E<sub>g</sub>=0, then heat is entirely covered by the peak-load boiler.

The results of calculations for different parameters characterizing the geothermal heat plant are presented in Table 1.

Values presented in Table 1 denote the percentage share of geothermal heat in total heat produced in the heat plant. For specified parameters characterizing the heat plant presented are two values of geothermal energy share, the upper one refers to the heat plant and the lower one to the heat plant supported by installed heat pump (bold font). Due to this, it can also be read from the Table about how much increased the utilization of geothermal energy following installation in the given heat plant of the heat pump, which on the other hand enables a quick assessment of effective-

ness of such a system and the effect obtained as a result of heat pump utilization.

### Conclusions

It results from the presented calculations that the effectiveness of a geothermal heat plant, assessed on the basis of the share of geothermal energy in total energy production, is very good at high parameters of geothermal water ( $T_{gmax} = 80^{\circ}\text{C}$ ), independently from values of analyzed network parameters. In such a case the heat pump improves utilization of geothermal energy in a small amount and for several analyzed cases there is no need for its installation in the heat plant system, as the entire heat is covered by geothermal energy. Very good utilization of energy also is obtained in cases where there is a higher share of low-temperature heat receivers ( $\varphi_L=1$ ), even at low temperatures of geothermal water ( $T_{gmax} = 40^{\circ}\text{C}$ ). However, as mentioned earlier, the majority of individual heat receivers in Poland are equipped with high-temperature receivers and hence in further part of conclusions attention will be focused on cases where the total share is taken entirely by the high-temperature heat receivers. As results from data presented in Table 1 for such cases, the highest rate of utilization of geothermal energy, due to the application of the heat pump, is attained at lower temperatures of the heat pump. In some cases only the installation of a heat pump allowed utilization of geothermal energy. Such a situation is present when geothermal water temperature is  $T_{gmax} = 40^{\circ}\text{C}$ , accompanied by temperature of return water from high temperature heating  $T_{RH} > 38^{\circ}\text{C}$ . An important issue also is adequate incorporation of the heat pump to the heat plant system, as its inappropriate combination can result with unexpected opposing effects and as a result reduction of geothermal energy share utilization can be found. Another important issue is to test whether after incorporation of the heat pump into the heat plant system the parameters of pump operation (temperatures of fluids and temperature characteristics) will fall into the range provided by the producer, enabling, as a consequence, its correct operation.

### Nomenclature

$c$	– heat capacity of water
$\dot{m}_g$	– geothermal water mass flowrate
$\dot{m}_s$	– municipal water mass flowrate
$\dot{m}_{sw\ max}$	– limiting value of flowrate of water flowing through geothermal heat exchanger
$T_{SH}$	– temperature of supply water for high-temperature heating
$T_{RH}$	– temperature of return water from high- temperature heating
$T_{SL}$	– supply heating water temperature for low-temperature heating

$T_{RL}$	– temperature of return water from low- temperature heating
$T_w$	– internal temperature ( $20^{\circ}\text{C}$ )
$T_z$	– external temperature
$T_{z\ min}$	– minimum external temperature
$\dot{Q}_{co\ max}$	– maximum heat demand for heating purposes
$\dot{Q}_{co}$	– heat demand for central heating purposes
$\dot{Q}_{geo}$	– amount of utilised geothermal heat
$\dot{V}_{g\ max}$	– volumetric flowrate from geothermal heat source

### Greek Letters

$\alpha$	– linear coefficient
$\beta$	– linear coefficient
$\varphi$	– operational participation of heat receivers
$\tau_0$	– time period of heating season
$\bar{\tau}$	– reduced time
$\Delta T$	– temperature difference between fluids for geothermal heat exchangers

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