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OPTIMIZATION WITH THE USE OF GENETIC ALGORITHMS OF THE LOCATION DEPTH OF HORIZONTAL GROUND HEAT EXCHANGERS

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Summary. The objective of the paper was to prepare a method describing a minimum depth for installation of a ground heat exchanger in the heat pumps systems. The lower is the location depth of the horizontal ground heat exchangers (HGHE), the lower are the geothermal installation costs with the horizontal ground heat exchanger and consequently the higher cost-effectiveness of an investment. A task of two-criteria optimization was formulated – i.e. determination of the minimum depth and a diameter of the HGHE pipes assuming a particular temperature of the operational factor on the output from the HGHE. Reduction of the depth of the HGHE translates into the decrease of installation costs. The module of genetic algorithms from MatLab application was used to carry out optimization. Within the calculations, which were carried out, validity of optimization of the installation depth of HGHE and no reason for optimization of the pipes diameter were confirmed.

Key words: genetic algorithm, optimization, horizontal ground heat exchangers, heat pumps

Introduction

In the age of the increasing power industry crisis, conventional thermal energy sources for heating households are becoming more and more expensive. Owners of buildings more frequently search for alternative thermal energy sources, e.g. from renewable energy sources (RES). In case of individual investors, the most important case at such investment is a return period of the incurred inputs. In case of big investments, e.g. construction of biogas plants 1 MW_e, the investment was assessed as cost-effective under the condition that it would obtain funds in the amount of at least 50% of the investment costs – i.e. inputs will be returned in few years [Niemczewska 2010; Szlachta Fugol 2009]. In many studies, in case of 100% of financing investments, included to RES, the rate of return exceeds 15 years [Pasierb et al. 2010; Dobrzański 2010]. This paper deals with thermal energy obtained from a heat pump with the horizontal ground heat exchangers (HGHE). Cost-effectiveness of exploitation of the whole systems was researched (e.g. [Dąbrowski, Hutnik

2010]). Since, investment costs have the biggest impact on cost-effectiveness of the RES investments [Pasierb et. al. 2010], searching for solutions enabling their minimization seems to be justified. Designing the HGHE constitutes the highest cost of the whole investment. The paper presents a method enabling determination of the smallest depth of placing the HGHE in relation to the required temperature of the operational factor, flowing out of the exchanger to the supply of the heat pump evaporator. Solving this problem will enable lowering the costs of installing the HGHE, which has a positive impact on cost-effectiveness of the investment and the return period of the incurred costs. The problem formulated in this way is an optimization issue. Genetic algorithms from MatLab packet were used as a device enabling performance of the task.

Optimization of the pipes arrangement in vertical exchangers, with the use of genetic algorithms (GA) was presented in the paper of [Sayyaadi et. al. 2009] as well as [Sanaye, Niroomand 2009]. Similar analyses were carried out in the heat pumps systems for recovery of heat from ground waters [Matott 2011]. Economic and energy analysis concerning the heat pump systems supplied from the HGHE may be found in the paper [Sanaye, Niroomand 2010].

The objective and the scope of the study

The objective of the paper was to find the smallest depth of placing the HGHE at the required temperature of the operational factor, flowing out of the exchanger to the heat pump evaporator and determination of the depth, at which a unitary heat flux charged by the HGHE will reach the maximum value. A mathematical model was used in order to carry out the aim, describing heat exchange in the pipe-ground system, which combines the mentioned sizes.

Research methodology

The model of heat exchange in the ground was presented in figure 1 (according to [Zalewski 2001]).

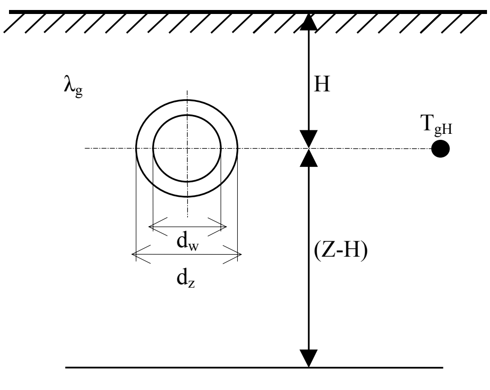


Fig. 1. Assumptions for construction of a model of heat exchange in the ground (symbols in the text)

Rys. 1. Założenia do budowy modelu wymiany ciepła w gruncie (oznaczenia w tekście)

Source: author's own study based on Zalewski 2001

From the analysis presented in the paper [Rubik 2011] it appears that at the models constructed on the basis of Fourier equation in the determined and undetermined conditions of heat exchange, average volume of heat flux charged from the ground in the whole heating season is similar and reaches 16 $W \cdot m^{-2}$ [Rubik 2011]. A good compliance with a model constructed on the basis of figure 1, was obtained applying a simplified formula (1) [Rubik 1999], enabling determination of the exchanger length:

$$L = \frac{Q_O \, ln \dfrac{4H}{d_z}}{2\pi\lambda_g (T_{gH} - T_m)} \quad [m] \tag{1}$$

where:

L – length of exchanger pipes [m],
Q_0 – heat power charged from the ground [W],
H – depth of placing the HGHE from the ground surface [m],
d_z – outside diameter of a pipe [m],
λ_g – coefficient of conducting ground heat [$W \cdot m^{-1} \cdot K^{-1}$],
T_{gH} – ground temperature at the H depth in a relevant month of the heating season [°C],
T_m – temperature of the heat carrier flowing out of an exchanger – supply of the pump evaporator [°C].

Since [Rubik 2011]:

$$Q_O = q_L \cdot L \quad [W] \tag{2}$$

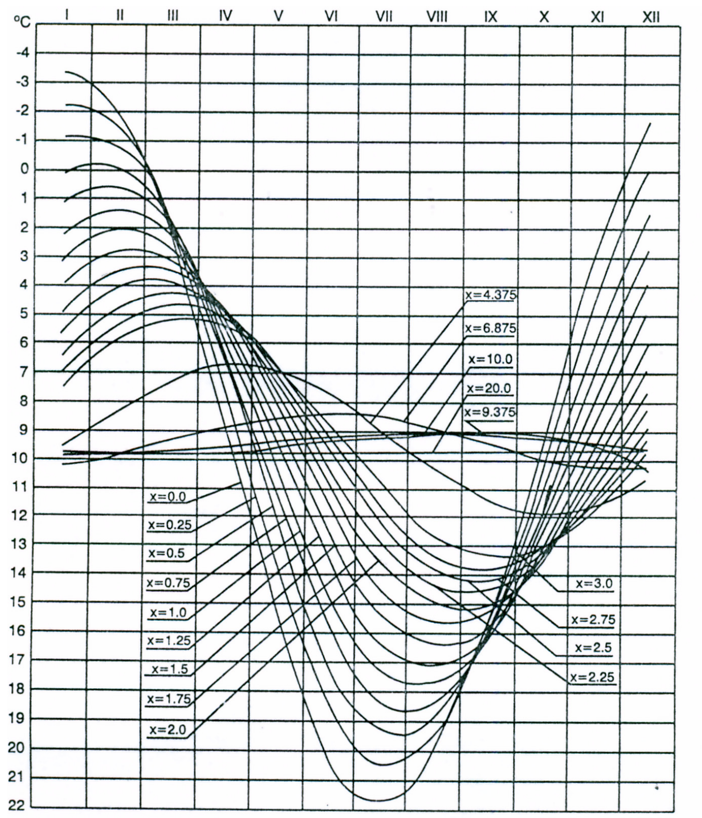
stands for a unitary heat flux collected by a pipe from the ground q_L [$W \cdot m^{-1}$] is:

$$q_L = \frac{2\pi\lambda_g (T_{gH} - T_m)}{ln\left(\dfrac{4H}{d_z}\right)} \quad [W \cdot m^{-1}] \tag{3}$$

Formula (3) was selected to carry out optimization of the depth of placing the HGHE since it combines the selected physical quantities, i.e. a unitary heat flux collected from the ground, depth of placing the HGHE and the outside diameter of the HGHE pipe.

In order to determine the ground temperature (T_{gH}) at the depth H – equation combining these two quantities was applied for this purpose. For this purpose, quantities from a nomogram at fig. 2 [Adamczyk 1994] and regression equation was found $T_{gH}=f(H)$ for temperature distribution in the ground at the turn of January and February at $R^2 = 0.9986$ and significance level $p \leq 0.05$:

$$T_{gH} = 0.0206H^3 - 0.548H^2 + 4.7457H - 3.2997 \tag{4}$$



Source: Adamczyk 1994

Fig. 2. Temperature distribution in the ground
Rys. 2. Rozkład temperatury w gruncie

Coefficient of ground heat conduction was accepted according to EN ISO 13370, which is 2 for sand or gravel.

Considering equation 3 and 4 at the accepted value $\lambda_g = 2$ and the fact that genetic algorithms in MatLab always search for minimum – and in this case a maximum must be found (reverse function should be applied), we obtain equation enabling finding a maximum value of function of two variables with the use of AG; this equation in the utility form for MatLab takes the following form:

$$q_L = \frac{-12.68 \cdot (0.0206x_1^3 - 0.548x_1^2 + 4.7457x_1 - 3.2997) - T_m}{ln\frac{4x_1}{x_2}}$$

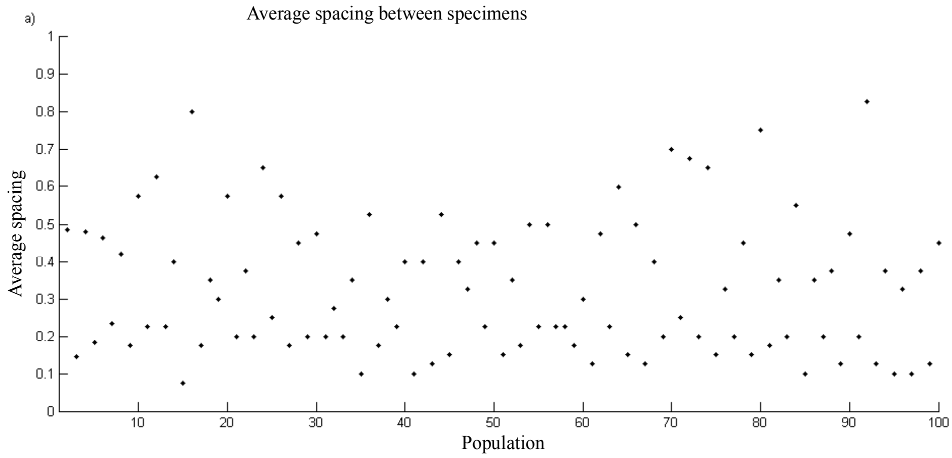
$x_1 = H$, $x_2 = d_z$, and the remaining symbols as in equation 1.

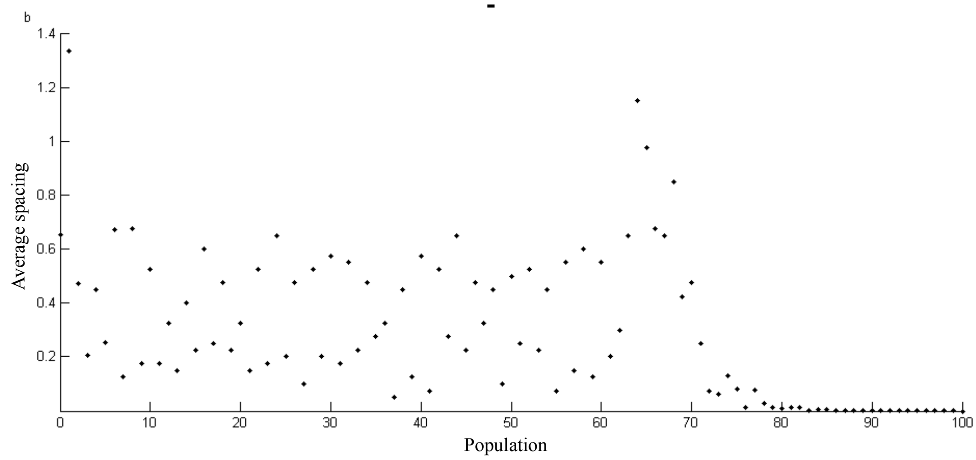
The function prepared in such a way was subjected to optimization with the use of genetic algorithm for two variables and T_m = 5, 0 and -5.

Review of the research results

For the function defines in this way, we search for a depth, at which according to the accepted model, a unitary heat flux (q_L – equation 3, z – equation 5) will be the highest. Since the function described with the equation 5 is discontinuous along the straight line $x_2=4x_1$ therefore a field of particular variables should be described. For the depth of placing HGHE underground H equal to 0.5 to 10 m (in the model x_1) was accepted and for the outside diameter d_z 0.01 do 0.04 m (in the model x_2). We look for the lowest value of function 5 in the above mentioned limits. The accepted values of limits comply with real applicable values H and d_z used in the construction of HGHE.

MatLab environment, version 7.11.0 with the optimization toolbox was used for calculations. Initially, arrangement of genetic algorithms parameters were tested in order to select such at which we will obtain proper results in the fastest way for the presented issue, i.e. value x_1 andx_2 for which the function reaches a minimum value in the set boundaries at the lower number of calculations. Exemplary changes of average distance between specimens of a population for first 100 generations were presented in figure 3a and b depending on the method of crossbreeding – 3a with a single point, 3b with a double crossbreeding point. Then, all tests of optimization were carried out at the same arrangements of parameters, i.e. the initial size of a population, the size of a population in next generations, degree of crossbreeding and mutation, the amount of generations, etc. for which, the fastest way of obtaining a correct result (after the lower number of generations) was determined.

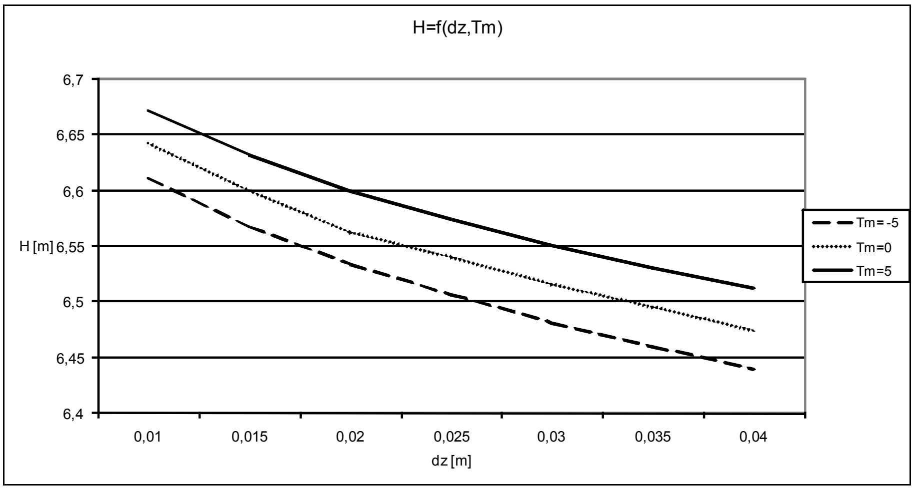




Source: author's own study

Fig. 3. Average changes of distance between population specimens for the first 100 generations; a) single crossbreeding; b) double crossbreeding
Rys. 3. Średnie zmiany odległości pomiędzy osobnikami populacji dla pierwszych 100 pokoleń; a) krzyżowanie pojedyncze; b) krzyżowanie podwójne

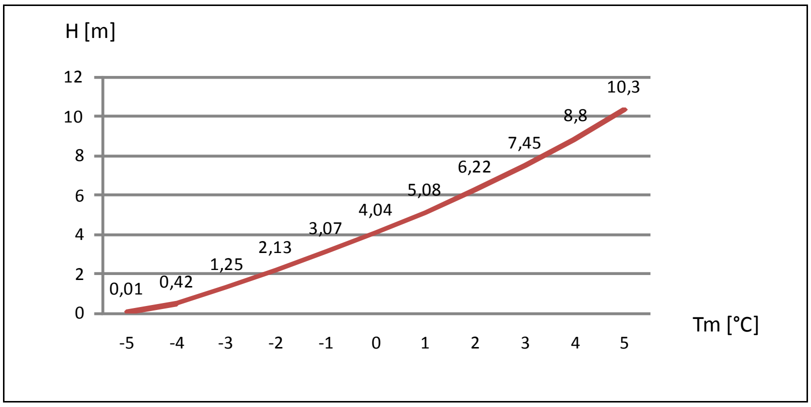
The highest unitary heat flux was obtained for the researched model, at the diameter of exchanger pipes of d_z = 0.04 m and the average depth of 6.5 depending on the accepted value T_m – fig. 4.



Source: author's own study

Fig. 4. Results obtained during optimization $H=f(d_z, T_m)$
Rys. 4. Uzyskane w czasie optymalizacji wyniki $H=f(d_z, T_m)$

Simultaneously, it was calculated (for the determined value q_L), what depth of the HGHE must be accepted to obtain particular temperature of the operational factor at the output T_m – the obtained results were presented in figure 5.



Source: author's own study

Fig. 5. Diagram of the obtained relation $H=f(T_m)$
Rys. 5. Wykres uzyskanej zależności $H=f(T_m)$

The obtained values of the HGHE (H) location depth in relation to the determined temperature of the operational factor (T_m) on the output from the ground show a strong correlation – coefficient $R^2=0.9859$.

Summary and conclusions

Calculations and simulations, which were carried out, indicate that the selected tool (genetic algorithms) is suitable for solving the issue of the most advantageous selection of the HGHE location depth. However, the issue may be solved with mathematical analysis obtaining a detailed solution.

It was decided to use genetic algorithms becasue the paper constitutes an introduction to research, which aim is to determine the most advantageous HGHE location depth but with the simultaneous use of the ground as a thermal accumulator (charged in summer - during the system operation as air conditioning). A real process of heat exchange in the pipe-ground system may be described with Fourier's equation (at the assumed permanent temperature of a carrier inside the exchanger pipe we obtain two-dimensional equation of conducting heat) solved with numerical methods e.g. finite elements [Rubik 2011]. Therefore, a model describing the phenomena of collecting and returning heat to the ground during a year, including also heat losses from the ground to air (in the moment of accumulating heat in the ground), will be more complex and difficult or completely insolvable with other methods. Therefore, a simpler issue was solved with the use of genetic algorithms, such for which the obtained results may be easily checked. The function described with equation

5 in the accepted boundaries is constant and differentiable. It achieves minimum value for *y* assuming the highest value (equal to boundary value) but for the value *x* inside the range determined with boundaries. A solution to the presented issue enabled learning a new program, possibilities of its use at the simultaneous verification of the correctness of the obtained results.

The lower is the depth of the position of the horizontal ground heat exchangers, the lower are the geothermal installation costs with the horizontal ground heat exchangers and consequently the higher cost-effectiveness of an investment. Simultaneously, the obtained results prove that the highest unitary heat flux is not obtained at the maximum assumed acceptable depth (10m) but at the depth of 6.5 m.

Moreover, the minimum depth of the HGHE, at which the operational factor reaches the set temperature at the output from the cycle of HGHE, was determined - in practice this depth is between 1 and 2 m (depending on the freezing zone of the ground - which causes that the operational factor during exploitation reaches a negative temperature [Zalewski 2001]

In case of using this tool in real conditions:

– coefficient of the ground heat conduction (λ_g) shall be selected in relation to the real type of the ground (sand, gravel, clay etc.) and humidity;
– temperature distribution shall be adjusted to the local conditions and a climatic zone.

At the further stage of the research, economic and energy optimization for the whole geothermal installation may be carried out because despite higher costs of an investment at the deeper installation of the HGHE, pump efficiency will be higher which will translate into lower costs of exploitation; such economic and energy analysis for the systems with vertical heat exchangers was presented in the paper [Sanaye, Niroomand 2009].

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OPTYMALIZACJA ZA POMOCĄ ALGORYTMÓW GENETYCZNYCH GŁĘBOKOŚCI POŁOŻENIA POZIOMYCH GRUNTOWYCH WYMIENNIKÓW CIEPŁA

Streszczenie. Celem pracy było opracowanie metody określenia minimalnej głębokości zainstalowania gruntowego, poziomego wymiennika ciepła w układach pomp ciepła. Im mniejsza głębokość usytuowania PGWC, tym niższe koszty instalacji geotermicznej z poziomym gruntowym wymiennikiem ciepła, a co za tym idzie większa opłacalność inwestycji. Sformułowano zadanie optymalizacji dwukryterialnej – określenie minimalnej głębokości i średnicy rur PGWC przy założeniu określonej temperatury czynnika roboczego na wyjściu z PGWC. Zmniejszenie głębokości PGWC przekłada się na zmniejszenie kosztów wykonania instalacji. Do przeprowadzenia optymalizacji wykorzystano moduł algorytmów genetycznych z programu MatLab. W ramach przeprowadzonych obliczeń potwierdzono zasadność optymalizacji głębokości instalacji PGWC i brak sensowności optymalizacji średnicy rur.

Słowa kluczowe: algorytmy genetyczne, optymalizacja, poziomy gruntowy wymiennik ciepła, pompy ciepła

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