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## HEAT PUMP AT SUBSOIL WATER FOR HEAT AND POTABLE WATER SUPPLY

Запропоновано новий підхід до вирішення проблеми видалення ґрунтових вод з подальшим їх використанням на базі теплового насоса для цілей теплопостачання та забезпечення питною водою. Розроблено методику розрахунку, що дозволяє визначити, виходячи із заданої потужності теплового насоса, глибину свердловини, кількість свердловин, з урахуванням швидкості і температури ґрунтових вод. Розроблено алгоритм розрахунку установки, реалізація якої показана на конкретному прикладі, що підтверджує її ефективність для забезпечення споживачів одночасно опаленням, питною водою, а також для запобігання підтоплення будинків ґрунтовими водами.

**Ключові слова:** тепловий насос, теплопостачання, водопостачання, ґрунтові води.

Предложен новый подход к решению проблемы удаление подпочвенных вод с последующим их использованием для обеспечения питьевой водой и теплоснабжения на базе теплового насоса. Разработана методика расчета, позволяющая определить, исходя из заданной мощности теплового насоса, глубину буровой скважины, количество скважин, с учетом скорости и температуры грунтовых вод. Разработан алгоритм расчета установки, реализация которой показана на конкретном примере, подтверждающем ее эффективность для обеспечения потребителей одновременно отоплением, питьевой водой, а также для предотвращения подтопления домов грунтовыми.

**Ключевые слова:** тепловой насос, теплоснабжение, водоснабжение, грунтовые воды.

Removal of groundwater with further use of it for potable water supply and heat supply with the use of heat pump is an important problem. A new revolutionary approach to the decision of energy and water saving that provides rational accommodation of groundwater boreholes ensuring the required flow rate of water through the heat pump evaporator with simultaneously high intensity of heat exchange process is proposed. The method of calculation which allows determining the necessary depth of borehole, quantity of boreholes, in consideration of flow rate and temperature of subsoil water determining capacity of heat pump installation is worked out. Realization and algorithm of calculation of subsoil water heat pump installation are developed. Results that confirms efficiency of its work for heat and water supply simultaneously are shown on concrete example.

**Keywords:** heat pump, subsoil water, heat supply, potable water supply

**Introduction.** Numerous regions of the world are under negative influence of subsoil water circulating near surface of the ground. That is why the purpose of the work is to estimate the prospects of implementation of the installation for removal of subsoil water from houses for further supply of potable water and heat to consumers at the base of heat pump [1]. This task is especially important in the autumn-winter period for regions with high level of subsoil water when danger of flooding of the buildings is grown considerably and deficiency of energy for heating increases simultaneously [2–5].

**A general material.** We offer new revolutionary approach to the decision of this task that provides rational accommodation of subsoil water boreholes

supporting the required flow rate of water for thermal needs of heat pump evaporator with high intensity of heat exchange process simultaneously. The circuit of heat pump installation with integrated purposes (preventing flooding of buildings during a high water period of time, heat and potable water supply) at base of subsoil water includes a borehole circuit and water purification circuit. Heat pump installation of potable water and heat supply at base of subsoil water has a special module for water purification [6].

Installation of potable water and heat supply (Figure 1) at base of heat pump 3 includes the evaporator 5, compressor 6, condenser 7 and throttle gate 8.

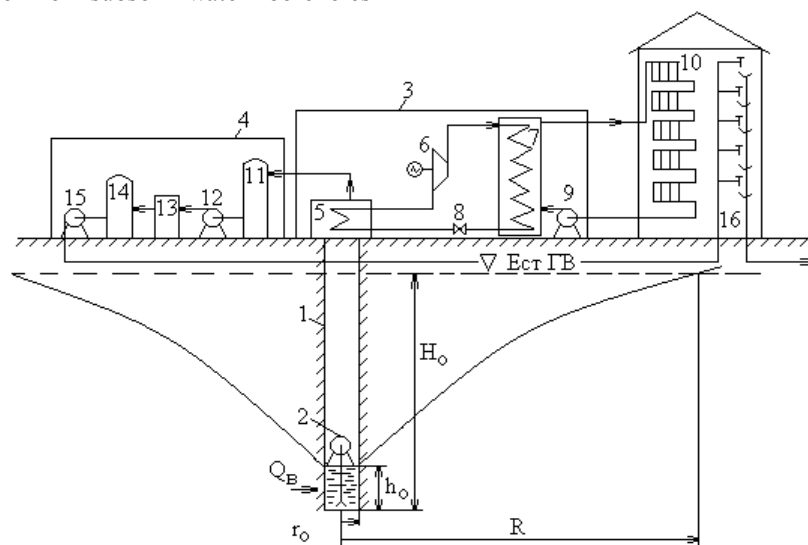


Figure 1. Installation of potable water and heat supply at base of subsoil water: 1 – borehole; 2, 9, 12, 15 – pump; 3 – heat pump; 4 – module of water purification; 5 – evaporator; 6 – compressor; 7 – condenser; 8 – throttle gate; 10 – heat consumer; 11 – subsoil water tank; 13 – tank for water purification; 14 – tank with potable water; 16 – potable water consumer

Evaporator 5 is placed in the circuit of circulation of subsoil water incoming from borehole 1 via pump 2. Condenser is placed in the circuit of circulation of heat consumer 10. The system of water purification 4 includes subsoil water tank 11, incoming through evaporator 5, water pump 12, module of purification with tanks 13, 14 and pump 15 for potable water supply of consumers 16.

3. Research method.

Flow rate of subsoil water [6]:

$$V_w = \frac{\pi \cdot (H_0^2 - h_0^2) \cdot k}{\ln(R/r_0)}, \text{ m}^3/\text{s} \quad (1)$$

where  $R=3000 \cdot (H_0 - h_0) \cdot k^{-1/2}$  – radius of funnel, m;  
 $k=10^{-5}, 0.5 \cdot 10^{-5}, 10^{-6}$  – filtration coefficient for sand, loam and clay accordingly, m/s;  
 $r_0=0.075, 0.15, 0.3$  – radius of borehole, m [7].

Heat power of the heat pump at subsoil water which is defined as [8]:

$$Q_0 = G_w \cdot C_p \cdot \Delta t, \quad (2)$$

where  $G_b = V_w \cdot \rho_w$ , kg/s;  
 $\rho_w$  – density, kg/m<sup>3</sup>;  
 $C_p$  – specific heat capacity, kJ/(kg·K);  
 $\Delta t$  – cooling of water in evaporator  
 $(\Delta t_w = t_w^{vx} - t_w^{vux} = 14 - 4 = 10 \text{ K})$ ;  
 $t_w^{vx}, t_w^{vux}$  – inlet and outlet temperature of water in evaporator.

4. Results and discussions

Results of numerical simulation (figure 2, 3) shows that flow rate of subsoil water is close to square-law dependence on pressure  $z=H_0-h_0$ , because of laminar mode of flow of subsoil water through the ground layer. Flow rate of subsoil water depends proportionally on filtration factor  $f$  but influence of borehole's radius  $r_0$  is negligible [7].

Figure 2 allow determining necessary depth of borehole  $H_0$  with the account of  $h_0$  and quantity of boreholes (at changes of borehole depth).

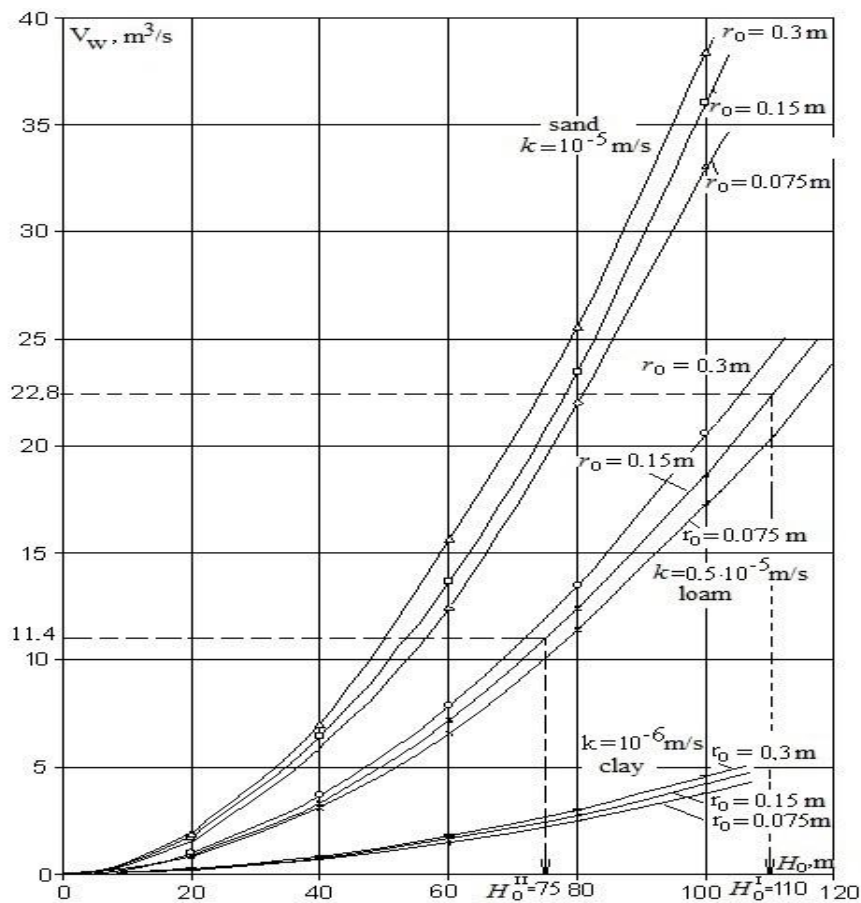


Figure 2. Flow rate and depth of borehole.

For heat pump evaporator having surface area of heat transfer  $F = 320 \text{ m}^2$ , having heat transfer coefficient

$k_f=0.5 \text{ kWh}/(\text{m}^2 \cdot \text{K})$  for temperature difference  $\Delta t = 6^\circ\text{C}$ , which corresponds to the heat flow density  $q=3 \text{ kW}/\text{m}^2$ .

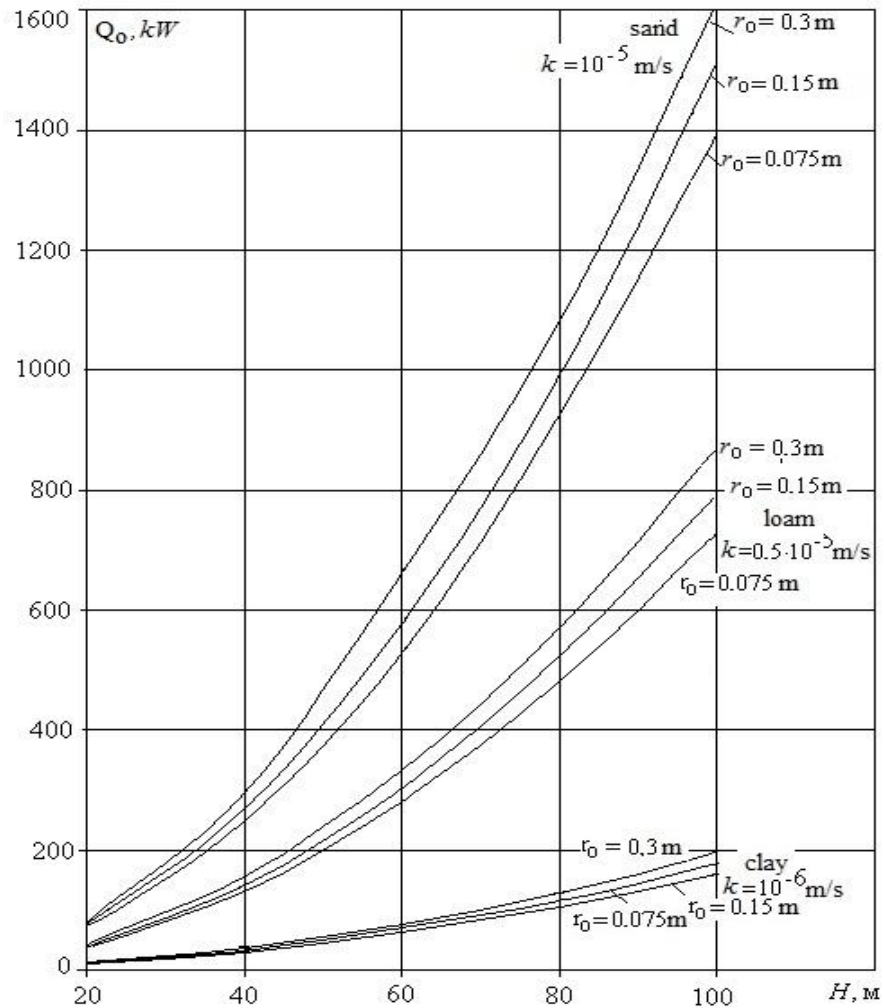


Figure 3. Heat power of the evaporator.

The heat power (figure 3) of the evaporator can be defined as:  $Q_0=q \cdot F=3 \cdot 320=960$  kW.

For the case of cooling of subsoil water in the evaporator of heat pump  $\Delta t_w=10^{\circ}\text{C}$  the required flow rate of subsoil water, with the account of equation (2), can be defined as:

$$G_w = \frac{Q_0}{C_p \cdot \Delta t} = \frac{960}{4.2 \cdot 10} = 22.8 \text{ kg/s.}$$

The temperature of the refrigerant boiling in the evaporator of heat pump can be estimated as [9]:

$$E = \frac{C_w (t_w^{vx} - t_w^{vux})}{C_{min} (t_w^{vx} - t_0)}, \quad (3)$$

where E – thermodynamic efficiency, which show the ratio of real flow of heat to maximum possible in the ideal heat exchanger.

In our case  $C_w = C_{min}$ , therefore:

$$E = \frac{t_w^{vx} - t_w^{vux}}{t_w^{vx} - t_0}, \quad (4)$$

From equation (4):

$$t_0 = t_w^{vx} - \frac{t_w^{vx} - t_w^{vux}}{E},$$

where  $E = 1 - \exp[-k_r F / (C_p \cdot G_w)]$  – for evaporator of the heat pump [10].

In order to estimate the cost-effectiveness of the installation the method of economic evaluation based on a comparison of cost of the traditional heat supply unit and traditional water supply unit was applied [11–13].

Results of numerical simulation shows that in case of three boreholes (for example, for loam) when the depth of each borehole is 60 m the flow rate of subsoil water equals  $G_w=7,6 \cdot 3=22,8$  kg/s (figure 2).

Temperature of boiling of refrigerant (R-142) equals 1,5°C;

temperature of condensation of refrigerant equals 70°C; temperature of hot water 65°C;

efficiency of compressor 0,85;

flow rate of refrigerant equals 7.3 kg/s;

COP=3,5;

heat capacity of condenser of heat pump equals 1350 kW;

electric capacity of electric motor for compressor equals  $N_k = 390$  kW;

heat capacity of heat pump evaporator equals 960 kW, capacity of 3 electric motors for subsoil water pump equals 16 kW.

While heat capacity of heat pump equals  $Q_h = 1350$  kW, the quantity of apartments which can be supplied by heat equals 450 (needs of one apartment approximately 3 kW) [14].

The total economic efficiency of heat and water supply system can be determine with the account of annual costs of heat supply system  $Z_h^y$  and water supply system  $Z_w^y$  (e.g.  $G_w = 22,8$  kg/s) [13]:

$$Z_h^y = C_h^y + K_h \cdot E_n$$

$$Z_w^y = C_w^y + K_w \cdot E_n$$

where  $C_h^y$ ,  $C_w^y$  – annual operating costs of heat and tap water production;

$K_h$ ,  $K_w$  – costs of the system (including costs of heat pump, boreholes with water pumps and water supply system with water treatment installation);

$E_n$  – normative amortization factor ( $E_n = 0.1$ ).

Annual operating costs for the generation of heat:

$$C_h^y = C_{el}^h \cdot N_{el}^h \cdot \tau_y + 12 \cdot n \cdot Z_n = 0.02 \cdot 420 \cdot 8760 + 12 \cdot 5 \cdot 200 = 74800$$

USD/year

where  $C_{el}^h$  – cost of 1 kWh;

$\tau_y = 8760$  – annual operating hours;

$n$  – number of persons serving the installation;

$Z_n$  – monthly salary per person;

$N_{el}^h$  – electric power for generation of heat.

$$N_{el}^h = N_k + N_{el} = 390 + 30 = 420 \text{ kW},$$

where  $N_k$  – electric capacity of electric motor of compressor;

$N_{el}$  – electric power of water pump.

Annual costs for heat generation, USD/year:

$$Z_h^y = C_h^y + K_h \cdot E_n = 74800 + 5 \cdot 10^5 \cdot 0.1 = 125 \cdot 10^3.$$

Specific costs for heat production:

$$z_h^{sp} = \frac{Z_h^y}{Q_h^y} = \frac{125 \cdot 10^3}{1350 \cdot 8760} = 1.05 \cdot 10^{-2}$$

USD/kWh=3USD/GJ.

Annual operating costs for the generation of pure water:

$$C_w^y = C_{el}^w \cdot N_{el}^w \cdot \tau_y + 12 \cdot n \cdot Z_n = 0.02 \cdot 30 \cdot 8760 + 12 \cdot 5 \cdot 200 = 17250$$

USD/year,

where  $N_{el}^w = 30$  kW – electric power for pumps of water treatment unit.

Annual costs for water supply system:

$$Z_w^y = C_w^y + K_w \cdot E_n = 17250 + 0,1 \cdot 10^5 = 272,5 \cdot 10^3$$

Specific costs for water provision in case of three boreholes:

$$z_w^{sp} = \frac{Z_w^y}{Q_w^y} = \frac{Z_w^y}{G_w \cdot \tau_y} = \frac{272,5 \cdot 10^3}{22,8 \cdot 3,6 \cdot 8760} = 0.038$$

USD/m<sup>3</sup>.

Annual cost savings for heat supply system based on our proposals, USD/year:

$$\Delta z_h^y = (z_{hs}^{sp} - z_h^{sp}) \cdot Q_h \cdot \tau_y = (5 - 3) \cdot 1350 \cdot 3,6 \cdot 8760 = 81 \cdot 10^3$$

where  $z_{hs}^{sp} = 5$  USD/MJ – costs of heat incoming from boiler.

Annual cost savings for water provision based on our proposals:

$$\Delta z_w^y = (z_{ws}^{sp} - z_w^{sp}) \cdot Q_h \cdot \tau_y = (0.1 - 0.038) \cdot 22,8 \cdot 3,6 \cdot 8760 = 45 \cdot 10^3 \text{ USD/year},$$

where  $z_{ws}^{sp} = 0.1$  USD/m<sup>3</sup> – costs of pure water.

Cost savings due to implementation of water provision system while  $T = 10$  years of operation:

$$\Delta z_w = \Delta z_w^y \cdot T = 45 \cdot 10^3 \cdot 10 = 450 \cdot 10^3 \text{ USD}.$$

Cost savings due to implementation of heat provision system while  $T = 10$  years of operation:

$$\Delta z_h = \Delta z_h^y \cdot T = 81 \cdot 10^3 \cdot 10 = 810 \cdot 10^3 \text{ USD}.$$

General cost savings due to implementation of installation of heat and potable water supply at base of heat pump while  $T = 10$  years of its operation can be defined as:

$$\Delta z = \Delta z_h + \Delta z_w = 810 \cdot 10^3 + 450 \cdot 10^3 = 1.26 \cdot 10^6 \text{ USD.}$$

## 5. Conclusions

Removal of subsoil waters from the surface of the ground with its subsequent use for water and heat supply reduces negative influence of subsoil waters circulating near to surface of the ground. Especially during autumn-winter period in the regions with high level of subsoil water a danger of flooding of the buildings becomes real and deficiency of energy for heating rises simultaneously. Heat pump installation with integrated purposes – water and heat supply – can compensate escalating annually deficiency of potable water for numerous regions having problems with water deficit and

allows solving the problem of substitution of traditional fuels.

Social effect of implementation of heat pump installation with integrated modes of work – preventing flooding of buildings during a high water period.

The results of numerical simulations shows technical and economic expediency of application of heat pump installation with integrated purposes. The general economy while 10 years equals 1,26·10<sup>6</sup> USD (including water provision – 0.45·10<sup>6</sup> USD, heating 0,81·10<sup>6</sup> USD).

The amount of specific investments into heat pump systems is largely determined by the applied technology and quantity of heat and water derived from the utilization of subsoil water. In general, the specific costs decrease with an increase in integrated capacity of system.

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