Impact of a pump unit and geothermal pump use on soil condition

K P Orlov1*, V A Orlova2, S V Kupriyanov2 and Y N Bojkov2
1 National Research University of Technology (NITU) «MISiS», 4 Leningradsky Avenue, Moscow, 119049, Russia
2 Belgorod State Technological University named after V.G. Shukhov, 46 Kostyukova st., Belgorod, 308012, Russia

E-mail: orlov_kp@gmail.com

Abstract. The article considers the advantages of air heat pump use. Their positive impact on ecology compared to other types of similar pumps, in particular geothermal ones, is shown. The author aims to focus on the problems of gross interference with the soil structure. In the majority of sources, geothermal pumps are presented as environmentally friendly and recommended pumps. The task of the study is to prove analytically, as well as using general scientific methods, that these sources are wrong. The use of geothermal heat pumps causes damage to the environment, since well drilling in the vast majority of cases is followed by formation segregation, interstratal insulation violation, change in natural processes of water bodies self-purification, rate of mineralization flow, kinetics of microflora and fauna development and die-away. Significant areas of uninhabitable trees and plants are formed due to subsoil cooling and freezing. Various heat pump layouts were analyzed and conclusion on the most environmentally friendly integrated use of heat air pump and solar energy was made.

1. Introduction

The environment is of interest as a source of energy when its temperature level slightly differs from the temperature required by the consumer, which is specific to room heating. Indeed, depending on the season, indoor air temperatures and the temperature of an environmental source of energy differ by no more than 10-35°C. Environmental sources of energy for a heating pumping unit (hereinafter HPU) can involve soil, ground and surface waters, air, river water, well water, sea water.

With HPU, the existing environmental energy can be used, for room heating primarily. However, the efficient use of HPU involves consideration of appropriate operating conditions associated with the temperature pattern of energy sources.

To work with heat pumps, there is the need to study geology of a site where drilling or horizontal collector laying is expected. This issue is thoroughly discussed in the article written by the leading Alliance-Neva LLC engineer, K.P. Prunenko "Heat pump installation in Russia: operational experience" [1]. The companies that agree to develop budget for probe installation not having studied soil properties at a particular site of the customer should be cautiously dealt with.

In the 1980s, the European market also faced the problems of poor-quality installation and design of heat collection systems, but it has managed to overcome the increasing problems. Studies of soil
properties were carried out, maps were designed. The works which were carried out in Lund University, Sweden, by the expert Goran Hellstrom [2] are of a special interest.

Let us consider the types of heat sources for heat pumps.

Geothermal (using groundwater or top surface heat):

a) closed-type:
- horizontal – the collector is laid radially or wavyly in horizontal trenches below the soil frost zone (usually below 1.2 m and more). This method is the most cost-effective for residential buildings, provided that there is no shortage of land for the circuit;
- vertical – the collector is laid vertically in wells of 50 - 200 m in depth. This method is used when the land plot area either does not fit to lay the circuit horizontally, or there is a risk to damage the landscape [3.4];
- water - the collector is laid wavyly or radially in a reservoir (pond, lake, river) below the soil frost zone. Thus, it becomes the most cost-effective option, but there are restrictions on the minimum depth and water volume in the reservoir for a particular region;
- with direct heat exchange - unlike the previous types, there is no heat conductor (salt solution) in the external circuit. Here, the coolant supplied through copper tubes by the heat pump compressor is directly involved. Copper tubes are located vertically in 30m-long wells 80 mm in diameter, horizontally below the soil frost zone;

b) open-type: this system type uses water as a heat exchange liquid, pumping it directly through the geothermal heat pump system within an open cycle, which means that having flowed through the system water is fed back to the ground. This option can be implemented only if there is enough moderately clean water and provided that this approach to use groundwater is not prohibited by law.

2. Materials and methods

To write the article, general scientific, private and special methods were used to study technological phenomena and processes occurring in the field of geothermal pump drilling: retrospective, logical, analytical, system, structural, analysis and synthesis, deduction and induction, etc. The basic method used in the current research is a descriptive method involving observation, interpretation, comparison, generalization approaches. The study also used the methods of synchronous and diachronic scientific fact analysis.

To achieve the goal and test the hypothesis on the environmental damage caused by geothermal pumps, a general scientific method was used, including the literature analysis on the issue under research, generalization, comparison and systematization of empirical and theoretical data.

The influencing factors and major soil cover projected changes occurred during the well development were studied. The final-stage method of the study involved heat flow simulation. Visual methods were also used. Distribution of heat flows and temperatures in the source of energy for the jointly laid solar and heat pump collector is shown.

3. Results

Air heating system is a modern compact and environmentally friendly heating system that supplies hot water and heat to warm cottages by means of air heat use. Heating system that use waste heat (e.g. waste water pipeline heat, heat network pipeline) are also efficient. This option is most suitable for industrial facilities having waste heat sources (WHS) requiring recycling.
Table 1. Capacity of wastewater discharge, geothermal and low-temperature heat of Russian soils and reservoirs. Source: compiled by the author based on the source [3].

| Parameter                                      | Gross capacity | Technological capacity | Economic capacity | Production capacity |
|-----------------------------------------------|----------------|------------------------|-------------------|--------------------|
|                                               | Million tons of oil equivalent |                         |                   |                    |
| Totally across the Russian Federation, including: | Over 30000      | 12 058                 | 216.3             | 20.08              |
| - wastewater discharge                        | 40.8           | 19.1                   | 8.56              | 2.82               |
| - soil and reservoir heat                     | -              | 26.4                   | 13.22             | 4.36               |
| - power plant condenser cooling systems       | 142.4          | 37.4                   | 9.50              | 3.14               |
| - water recycling systems                     | 370.3          | 106.0                  | 20.0              | 6.60               |
| Geothermal heat                               | Over 30000     | 11869                  | 165               | 3.16               |

Ambient air as a heat source depends on daily and seasonal temperature fluctuations. Other sources of energy may be less responsive to these factors, or may even be irresponsive to them. Thus, the temperature level of the environmental energy depends on different external conditions affecting each other. When using HPU for heating, the environmental energy is not a primary goal for using, but high-temperature sources are focused instead to gain a high energy conversion coefficient due to the temperature difference between a heat source and HPU heat carrier.

Soil heat exchangers are a system of pipelines, either laid horizontally in the ground, or installed in vertical wells (U-shaped pipes that reduce the required soil surface by 10+20 times compared to horizontal ones). Non-freezing power fluid (water, calcium chloride, methanol, ethylene glycol (anti-freezing agent)) circulates through pipes made of copper, steel (or its alloys), polyethylene or polypropylene. The amount of heat supplied by HPU depends on certain conditions: solar radiation intensity, soil humidity, soil thermal and physical properties, laying depth, distance between pipes and heat exchanger temperature.

CT pipes are often laid in trenches during drainage work on the site allocated for construction, which increases harmful effects on the soil.

The drilling company shall be authorized in accordance with DVGW W 120 (for Germany, Austria and Switzerland) worksheet. Planning shall be carried out in cooperation with the customer. The drilling company shall develop a work plan in which all permits and restrictions are recorded.

The soil probe and its feeding and return lines are laid at a distance of not less than 70 cm from water supply and sewage pipes, as well as from other pipeline systems. When crossing feeding lines, the collection pipe shall be isolated in the intersection area. Soil probes are delivered to the construction site being assembled. To avoid the damage, probes should be handled with special care.

When planning a construction site, the following requirements shall be fulfilled:
- approximate aisle width for track-type drilling rig vehicles is not less than 1.5 m, 2.5 m for trucks;
- site size for small track-type drilling rig vehicles is not less than 6x5 m; 8x5 m for trucks;
- washing reservoir or basin, if required;
- 400V power supply;
- cold water supply;
- layout indicating electric cables, water supply and sewage pipes or other underground structures [5].
The required information can vary considerably depending on the needs of the drilling company and equipment type and, therefore, should be considered only as an estimated starting point. Theoretically, drilling operations are performed during the pipe laying stage. When working near buildings under construction, their protection from dirt should be ensured.

Radial clearance clogging between the geothermal probe and the well walls (Figure 1) is very important to ensure heat exchange between soils and the geothermal probe and to seal permeable water-bearing underground layers at different depths.

A prerequisite is to prevent groundwater (from a depth of 20 m, for example) from flowing into the water-bearing layer (60 m, for example). This situation poses a real threat to water supply based on extracting water from an underground source.

There is also a major risk of damage to glycol underground pipeline integrity [6].

4. Discussion
Impacts on soils and projected changes. The main types of man-made effects on soils during drilling are mechanical damage to the soil cover and chemical pollution. The greatest mechanical impact on soils is produced by construction work (construction of drilling platforms, their infrastructure and utility systems) and remediation (fertile soil layer removal, excavation backfilling, land planning, etc.).

They are followed by the fertile layer removal and pedoturbations (turnover of soil genetic horizon substrates), which worsens the ecological properties of soils disturbed in the landscape [8]. Soil chemical pollution is associated with the impact of vehicles, household waste, and potential hydrocarbon and drilling fluid spills, as well as leads to negative changes in physical, chemical, ion-exchange soil properties and their biological activity. Though in general, this is not an inevitable consequence of drilling operations. In addition, manifestation of this impact type varies considerably depending on the properties of certain soils. Factors and types of impacts, as well as the major projected changes in the soil cover during well development are given in Table 2.

Table 2. Influencing factors and major projected changes in the soil cover during well development for geothermal pump use. Source: made by the author [7].

| Influencing factors                                                                 | Impact types         | Projected changes                                      |
|-------------------------------------------------------------------------------------|----------------------|--------------------------------------------------------|
| preparatory works: logging, site cleanup, site planning, trench work, drainage trenching, site backfilling, utility system construction, etc. | Mechanical predominantly | bedding damage and destruction, linear and area deformations of surface soil layers, soil profile rearrangement, partial and complete soil cover destruction or removal, antecedent soil lodging |
construction and installation works: winch unit and other infrastructure facilities erection, foundation water isolation, construction unit mounting, mechanisms, etc.

| Mechanical predominantly | bedding damage and destruction, linear and area deformations of surface soil layers, soil profile compaction and restructuring, partial or complete soil cover destruction, chemical soil pollution |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| well drilling and testing: water and heat supply, layered mineral water (salt water) inflows are possible | Mechanical and chemical linear and area soil deformations, chemical soil pollution |

Heat pumps using air masses are considered to have great potential compared to systems operating on the soil surface layer heat and groundwater heat. This is due to the fact that the use of the latter is limited to the availability of land plots having the required properties, while the use of groundwater as a heat source is determined only by availability of their appropriate properties in acceptable proximity to the consumer. However, the risk to disturb the ecological groundwater balance should be eliminated, which may occur if there is a groundwater scarcity and it is simultaneously used to supply water to people [9].

Though, such pumps, despite being relatively environmentally friendly, are low-powered. The efficiency of heat supply using a solar and geothermal source decreases during the winter season due to the increase in heat load and the decrease in solar activity; in this time of year additional potential is required to be used.

The decision to improve the air heat pump efficiency during the heating period will involve combining an air pump and a solar collector. Since solar radiation does not generally reach the ground in winter (due to the clouded sky, short daylight hours), we will use a solar collector installed on the roof of the building, and the heat exchanger circuit will be laid together with the air circuit, thereby accumulating solar energy directly in the air throughout the year. To prevent heat loss, we will use a thermal insulation layer at the top of the circuit.

By means of the method of static heat flow simulation, we will determine the most efficient circuit arrangement using graphic examples of heat flow and temperature air distribution [10]. The ELCUT simulation examples show (Figure 2) [11] that the heat flow is directed upward towards the cold surface.

![Figure 2. Heat flow simulation. Source: made by the author.](image-url)
At the top of the graph, temperature of 0.6°C at the edge of a heat insulation layer is accepted, top circuit depth is at -1.5 m. The lower circuit boundary is at a depth of 2 m with a temperature of 1.3°C. Temperature of the heat exchanger operating from a solar collector is 15°C [12].

Having arranged the circuit in the way shown in Figure 1 (left side), it is clear that the cold circuit is affected by the regular influence of heat flow and temperature, providing equal air heating at the level of the circuits laying in a radius of 300-350 mm. Figure 2 (the middle part) with the upper heating circuit arrangement shows the heat flow “dips” and the temperature distribution throughout the circuit. Figure 1 with parallel heating circuit arrangement shows a chaotic distribution of heat flow and temperature, which results in heat loss. Thus, heat flow and temperature distribution in the source of heat combining solar and heat pump collectors is clearly shown.

5. Summary
The obtained results lead to the following conclusions:

- The integrated utilization option is the most efficient in terms of accumulating temperature in a certain range, since solar energy transfer to the source directly and using it as a heat accumulator makes it possible to smooth up the peak demand for heat supply;
- The use of geothermal heat pumps causes environmental damage, since in 96% of cases well drilling is followed by formation segregation, interstratal insulation violation, change in natural processes of water bodies self-purification, rate of mineralization flow, kinetics of microflora and fauna development and die-away. Significant areas of uninhabitable trees and plants are formed due to subsoil cooling and freezing. There is also a risk of glycol underground pipeline leakage;
- heat flow and temperature simulation when combining a heat air pump and a heat supply source (solar collector) circuits allows determining the optimal circuit arrangement. In addition, the search for materials more energy-intensive than sand is supposed to be extended in order to accumulate solar energy seasonally at a shallow depth.

6. References
[1] Prunenko K P 2013 Heat pump installation in Russia: operational experience S.O.K. 11
[2] Goran Hellstrom 1997 Residential Vertical Geothermal Heat Pump System Models: Calibration to Data, Jeff W. Thornton, Timothy P. McDowell, John A Shonder, Jan.
[3] Sherev Met E O, Seminenko A S, 2013. Heat pump application in centralized heat supply systems to improve heating network energy efficiency Modern knowledge-intensive technologies 8 54-57
[4] Bondar E.S., 2011, Heat pumps: design, choice, installation Plumbing, heating, air conditioning 4 62-37
[5] Reich 2011 Geothermal heat pumps (Plumbing, heating, air conditioning) 1 80-83
[6] Economics-Technology-Environment (Regional Energy Service Company) http://eco-t.eco.ru/pumps (date of the address: 19.07.2020)
[7] Solarsoul: data resource on the solar energy use and energy saving. Detailed information on renewable energy technologies http://solarsoul.net/vodyanoj-teplovoj-nasos (date of the address: 19.07.2020)
[8] Soil probes and water probes (ALTAL production portal) http://www.altalgroup.com/ghp.htm (date of the address: 22.07.2020)
[9] Manzhilevska S E 2019 Organizational and economic issues of environmental safety in construction Construction Materials and Products 2 (4) 73-78 https://doi.org/10.34031/2618-7183-2019-2-4-73-78
[10] Karpov D F 2019 Algorithm for complex diagnostics of the technical state of building structures based on the heat pattern analysis Construction Materials and Products 2 (2) 23 – 28 https://doi.org/10.34031/2618-7183-2019-2-2-23-28

[11] Geotherm: Geothermal heat pumps http://www.geotherm.com.ua/about/closedloop/heatbasket.html (date of the address: 22.07.2020)

[12] Thermal service: Spiral and vertical geoprobes - innovative soil heat collection technologies for heat pumps http://teplo-v-dome.net/spiralnye-vertikalnye-geozondy-novejshe-texnologii-sbora-tepla-grunta-dlya-teplovych-nasosov/ (date of the address: 23.07.2020)