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Thermal efficiency of geothermal ventilation under conditions of temperate climate

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Abstract: The article deals with modern energy-efficient systems for providing the microclimate of energy-saving buildings, consisting of geothermal ventilation with ground heat exchangers. The results of modern scientific research in this field are described. A schematic diagram of a geothermal ventilation system based on Rehau equipment is presented and a system of balance equations for the heat exchanger process in a ground heat exchanger is made, as well as analytical and graphical dependencies for determining the heat exchanger thermal efficiency for temperate climate conditions.

Keywords: geothermal ventilation, soil heat exchanger, energy-efficient buildings

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Introduction

Global warming, caused by the ever-increasing level of pollution in the atmosphere, reservoirs, and soil. The constant rise of morbidity, due in particular, to the pathogenic microorganisms of the planet, is in no small proportion the result of irresponsible human activity. Encouragingly, humanity is turning to the use of alternative energy sources, therefore, not only reducing environmental pollution but also reducing the problem of organic fuel deficiency. After all, renewable energy is not only safe, environmentally friendly, and inexhaustible but also economically viable.

One way of providing heat and maintaining the necessary microclimate of energy-efficient buildings is the use of geothermal ventilation systems, which use the energy potential of the soil. Such systems are becoming increasingly popular within alternative energy technology. The principle of geothermal ventilation is

that the outside air enters the ground heat exchanger, and is heated by the ground. In the colder periods of the year heating is provided and during the warmer months the air is cooled. This is due to the constant temperature of the soil at a certain depth throughout the year. After the heating/cooling process, the air from the heat exchanger enters the ventilation system.

The results of experimental studies into geothermal ventilation systems are presented in (Rensevich & Pariewa, 2015). It has been found that the thermal capacity of a geothermal ventilation system increases with increasing airflow and the temperature difference at the inlet and outlet of the heat exchanger. Unfortunately, the authors did not carry out studies that take into account the different thermophysical properties of the soil. The results are solely for vertical ground heat exchangers.

In (Kovyazin, 2018; Koviazin, 2018), the results of a numerical experiment are presented. This experiment obtained the temperature field of the cooling air and soil mass for soils of different thermal conductivity. The dependences of the heat capacity on the separately located soil heat exchanger during the time of operation and the thermal conductivity have been established. The results are quite useful in assessing the feasibility of operating geothermal ventilation systems for different soil types. Unfortunately, the work does not show how the temperature of the air supply, after the heat exchanger, changes depending on the different temperature conditions of the soil.

Works (Basok et al., 2019; Dolgikh & Kovyazin, 2016; Dolgikh & Kovyazin, 2015) are devoted to presenting the results of experimental studies into heat exchange processes during the passage of atmospheric air into the air-to-ground heat exchanger. The studies were conducted during the warm season.

At the same time, a large amplitude of oscillations of ambient air temperature was observed. The graph of air temperature change at the inlet and outlet of the air-to-ground heat exchanger is presented. The technique of conducting experimental research for geothermal ventilation systems with vertical ground heat exchangers in order to maintain the microclimate of livestock premises is presented. Experiment planning methods were used to minimize the number of experiments. During the experiments, the characteristics of the soil, in particular its amplitude of temperature fluctuations, were not taken into account. The results were obtained for the depth of the air-ground heat exchanger and its diameter.

Much of the literature is devoted to the research of ground heat exchangers for heat pump installations for low-temperature water heating. For example, paper (Bezrodnyi & Pritula, 2017) determines the optimal operating conditions of soil heat exchangers that would provide a minimum amount of energy costs for heat production. Attention was drawn to the fact that the characteristics of such heat exchangers depend mainly on the type of soil and less on the temperature conditions of the heat pump operation.

At present, the study of air-ground heat exchangers, as an integral part of a promising alternative energy source system i.e. soil energy, remains relevant. At the same time, considerable attention should be paid in considering the thermophysical characteristics of different soil types to allow the effective use of such

systems. Such scientific work has been carried out previously in (Basok et al., 2008; Zhelykh et al., 2015; Zhelykh et al., 2018) as a continuation of previous research.

The laying of a geothermal ventilation ground heat exchanger from Rehau is shown in Figure 1.

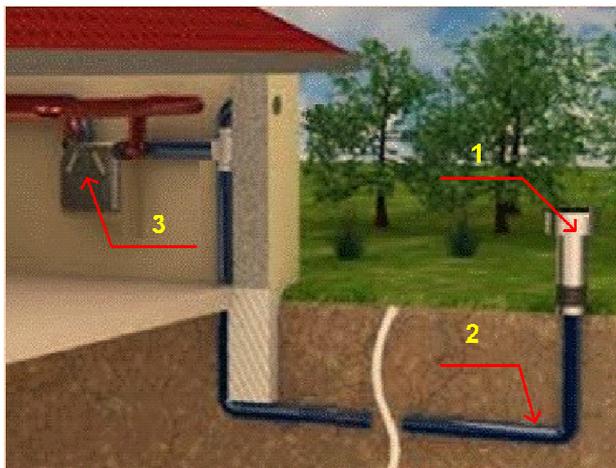


Fig. 1. The arrangement of a geothermal ventilation ground heat exchanger (<https://domteplo.ru>): 1 - exhaust air intake; 2 - ground heat exchanger; 3 - heat exchanger-recuperator

The geothermal ventilation system shown in the figure is effective enough for residential energy-saving homes.

1. Objective and scope of the research

The purpose of these studies was to determine the efficiency of the ground heat exchanger from a geothermal ventilation system at different soil temperatures and ambient air temperatures during the cold season. Soil temperature depends directly on the soil's thermophysical characteristics and the intensity of solar radiation on the soil surface. Radiant solar energy is a source of heat for soils with different properties. On average, the Earth's surface receives $8.15 \text{ J}/^\circ\text{C}$ per 1 cm^2 per minute. Most of the heat is reflected off the Earth's surface, some of it is dissipated into the atmosphere by vegetation, and the remaining small part enters the soil due to its thermal conductivity. Soil absorption depends on their humidity. Sandy soils have less moisture, so heat up and give off heat faster than others. For dry soils the mass capacity is in the range of 0.15 to $0.29 \text{ J}/(\text{kg}\cdot^\circ\text{C})$. Soil heat capacity is affected by hygroscopicity, i.e. the ability to absorb moisture, in particular, the hydrophilicity of colloids, the content of silt particles and the nature of organic matter. Wet soil has a higher thermal conductivity than dry soil.

Mineral-enriched soils produce the best heat. The higher the homogeneous soil mass, the greater the thermal conductivity. For example, large sand particles are

heated 2-2.5 times faster than dust. Soil thermal conductivity is also significantly dependent on density, the higher the porosity, the lower the thermal conductivity. The soil heat absorption phenomena forms its thermal regime. It is determined by a set of phenomena related to absorption, heat emission and is characterized by a temperature gradient at different depths and at different times of the year. The highest amplitudes of temperature fluctuations are observed in the upper soil layers, with minimal changes at depths of 3-5 and below.

This article is devoted to the research and justification of the possibility of using ground heat exchangers for geothermal ventilation in conditions with temperate climates and to establish analytical dependencies of the air supply temperature from the external climatic conditions. In the case of laying the ground heat exchanger (Fig. 2), an analysis was made of the heat exchange between the air supply moving in the heat exchanger and the ground.

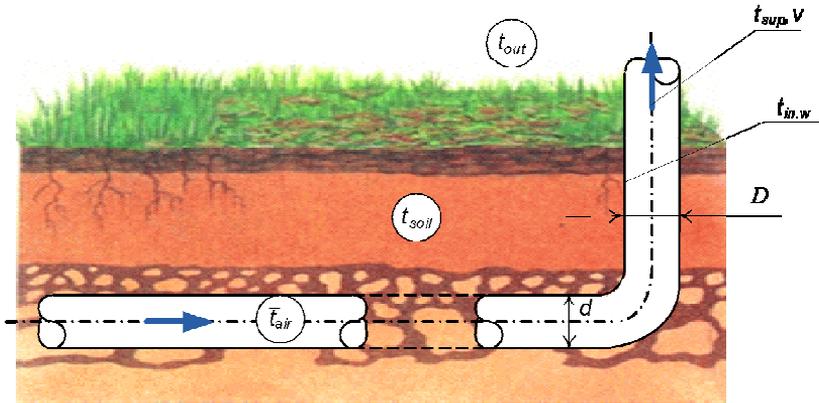


Fig. 2. The layout of the ground heat exchanger in a geothermal ventilation system (www.shutterstock): d - the inner diameter of the soil heat exchanger [m]; D - outer diameter of the soil heat exchanger [m]; V - outer diameter of the soil heat exchanger [m/s]; $t_{in.w}$ - the temperature of the inner surface of the wall of the soil heat exchanger [°C]; t_{sup} - air supply temperature at the outlet of the heat exchanger [°C]; \bar{t}_{air} - air supply temperature in the soil heat exchanger [°C]; t_{soil} - soil temperature [°C]

The result is a system of balanced equations for this process, which looks like:

$$\begin{cases} Q = \alpha \pi d l (t_{in.w} - \bar{t}_{air}) \\ Q = L \rho c (t_{sup} - t_{out}) \end{cases} \quad (1)$$

where:

α - coefficient of heat transfer from the inner surface of the wall of the ground heat exchanger to the supply air $\left[\frac{W}{m^2 K} \right]$;

l - length of the ground heat exchanger [m];

L - the flow of intake air $\left[\frac{m^3}{s} \right]$;

ρ - the density of the air supply $\left[\frac{\text{kg}}{\text{m}^3}\right]$;

c - the heat capacity of the air supply $\left[\frac{\text{J}}{\text{kg}\cdot\text{K}}\right]$.

The average flow temperature of the inlet air moving in the ground heat exchanger can be determined from the following:

$$\overline{t_{air}} = \frac{t_{out} + t_{sup}}{2} \quad (2)$$

This way, the balance of thermal energy will take the form:

$$\alpha \pi d l (t_{in.w} - t_{air}) = L \rho c (t_{sup} - t_{out}) \quad (3)$$

the mode of movement of air in the heat exchanger is turbulent.

The following simplifications have been adopted to solve this balanced equation:

- the mode of movement of air in the heat exchanger is turbulent;
- the temperature of the inner surface of the heat exchanger wall is equal to the soil temperature;
- the direct area of the heat exchanger is taken into account;
- the mode of heat transfer from the soil to the airflow in the heat exchanger is stationary.

The main factor in the process of heat exchange, which allows us to make a qualitative and quantitative assessment of the intake air heating is the coefficient of heat transfer α . For tubes of circular diameter d , one can determine from the dependence:

$$\alpha = \frac{Nu \lambda}{d} \quad (4)$$

where:

d - internal diameter of the heat exchanger [m];

λ - air thermal conductivity [W/(m K)];

Nu - Nusselt number.

For turbulent motion and straight sections of pipelines, the Nusselt criterion can be written:

$$Nu = 0.021 Re^{0.8} Pr^{0.43} \left(\frac{Pr}{Pr_{in.w}}\right)^{0.25} \varepsilon_l \quad (5)$$

depending on this, the Reynolds criterion is determined - $Re = \frac{v d}{\nu}$; Prandtl criterion for diatomic gases which is air can be taken - $Pr = 0.72$; ε_l - a correction factor that takes into account the effect of pipe length when $l/d \geq 50$, then $\varepsilon_l = 1$.

Thus, after data substitution and simplification, we get:

$$Nu = \frac{91 V^{\frac{4}{5}} d^{\frac{4}{5}}}{5000 \nu^{\frac{4}{5}}} \quad (6)$$

Substituting dependence (4) into dependence (2) we obtain:

$$\alpha = \frac{91 \lambda V^{\frac{4}{5}} d^{\frac{4}{5}}}{5000 d \nu^{\frac{4}{5}}} \quad (7)$$

Expressing the velocity V of the airflow in the soil heat exchanger due to the volumetric airflow L , we obtain an empirical dependence with respect to the dimensions:

$$\alpha = \frac{69 \lambda \left(\frac{L}{d^2}\right)^{\frac{4}{5}}}{1250 \pi^{\frac{4}{5}} d^{\frac{4}{5}} \nu^{\frac{4}{5}}} \quad (8)$$

Substituting this dependence into the equation of balance for thermal energy (3), it is possible to obtain the function of the intake air temperature t_{sup} on various factors. These processes were modeled in MathCAD.

2. Results of the research

As a result of analytical studies, the function f_L (9) was obtained, making it possible to analyze significant factors influencing the temperature of the supply air t_{sup} .

$$fL(t_{sup}, t_{out}) \rightarrow \frac{69\pi^{\frac{1}{5}} \lambda d^{\frac{4}{5}} l \left(\frac{L}{d^2}\right)^{\frac{4}{5}} (t_{soil} - t_{sup})}{1250 \nu^{\frac{4}{5}}} - L \rho c (t_{sup} - t_{out}) \quad (9)$$

As a result, graphical dependences (Fig. 3) of the intake air temperature were obtained t_{sup} on the outside air temperature t_{out} and soil temperature t_{soil} . The diameter of the soil heat exchanger was 250 mm and takes into account only its horizontal section which is buried into the ground; the velocity of the airflow in the heat exchanger V was within 2 m/s; the length of the heat exchanger l was equal to 150 m. The ambient air temperature was in the range $t_{out} = -20-0^{\circ}\text{C}$, the temperature of the soil was assumed for a temperate climate in the cold season $t_{soil} = 0-15^{\circ}\text{C}$.

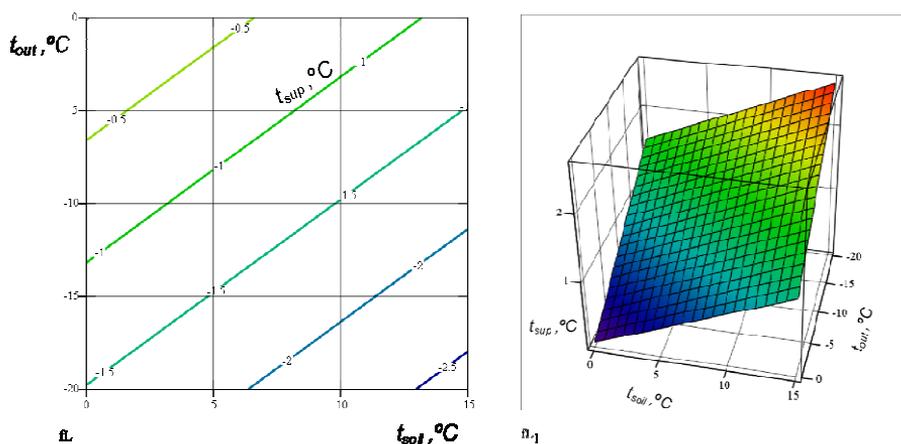


Fig. 3. Dependence of intake air temperature t_{sup} [°C] of ambient air temperature t_{out} [°C] and soil temperature, t_{soil} [°C] (own research)

In this situation, other influential factors were considered constant and unchanged.

Conclusions

As a result, of the conducted research, on the basis of composite heat balance for airflow in a ground heat exchanger of a geothermal ventilation system and the obtained graphical dependencies, we determined the influence of certain factors on the airflow in a heat exchanger. For example, when moving outside air with a temperature equal to $t_{out} = -15^{\circ}\text{C}$ through a heat exchanger that is in soil with a temperature $t_{soil} = 5^{\circ}\text{C}$, the outside air is heated to $t_{sup} = -1.5^{\circ}\text{C}$.

It should be noted that as the ambient air temperature decreases and the air velocity is steady in the ground heat exchanger, the air supply temperature also decreases. In this case, the use of additional heat in the heat exchanger of the ventilation unit is required.

This reaffirms the feasibility of such systems in regions with temperate climates. Since the preheating of cold, outside air significantly reduces the consumption of traditional energy sources in heaters and increases the efficiency of ventilation systems.

Further studies will be carried out on the feasibility of using such systems in the warm season for pre-cooling in an external ventilation air-ground heat exchanger.

Bibliography

Basok, B., Nedbailo, O., Tkachenko, M. & Bozhko I. (2019) *Use of air - soil heat exchangers in the geothermal ventilation system*, XX International Research and Practice Conference *Refurbishable Energy and Energy Efficiency in XXI Century*, Section 5. Kyiv, Geothermal Energy, 541-546.

- Basok, B., Vorobyov, L., Mikhailik, V. & Lunina, A. (2008) *Thermophysical properties of natural soil*. Prom. Heat Engineering, 30, 4, 77-85.
- Bezrodnyi, M. & Pritula, N. (2017) *Optimal characteristics of ground heat exchangers for heat pump systems*. Bulletin of NTU „KPI”. Series: Energy and Thermal Engineering and equipment. Kharkiv: NTU „KPI”, 8 (1230), 41-49.
- Dolgikh, D. & Kovyazin, J. (2016) *Methodology of experimental research works of air soil heat exchanger*, Materials 4th Scientific and Technical Conference *Technical progress in livestock and feed production*, December 14-20, 2015 Glevakha, 49-53.
- Dolgikh, D. & Kovyazin, J. (2015) *Methodology of experimental research geothermal ventilation functions*, Materials 4th Scientific and Technical Conference *Technical progress in livestock and feed production*, December 8-26, 2015 Glevakha, 23-26.
- <https://domteplo.ru/blog/gruntovyy-teploobmennik-awadukt-thermo/>.
- <https://www.shutterstock.com/ru/search/similar/483557674>
- Kovyazin, O. (2018) *Study of functioning of heat exchanger in soils with different thermal diffusivity*. Geophysical Journal, 40, 2, 164-170.
- Koviazin, O. (2018) *Substantiating the diameter of the liner pipe of the earth heat exchanger and providing the air supply to it*. Vestnik KPI Kharkov. Power and Heating Engineering Processes and Equipments, 12(1288), 71-74.
- Rensevich, E. & Pariewa, O. (2015) *Study of geothermal ventilation system*. SBTSATU. 8. 2., S. 7.
- Zhelykh, V., Savchenko, O. & Pashkevych, V. (2015) *The geothermal ventilation of passive house*, Construction of Optimized Energy Potential, 2(16), 145-150.
- Zhelykh, V., Savchenko, O. & Pashkevych, V. (2018) *The expedient depth of laying of a horizontal tube earth-air heat exchanger of geothermal ventilation*, Scientific and Technical Journal. Energy-efficiency in Civil Engineering and Architecture, Issue 10, 54-61.

Sprawność cieplna wentylacji geotermalnej w warunkach klimatu umiarkowanego

Streszczenie: Artykuł dotyczy nowoczesnych energooszczędnych systemów zapewniających właściwe warunki mikroklimatu budynków energooszczędnych, składających się z wentylacji geotermalnej z gruntowymi wymiennikami ciepła. Opisano wyniki współczesnych badań naukowych w tej dziedzinie. Przedstawiono schemat ideowy geotermicznego systemu wentylacji opartego na sprzęcie Rehau oraz układ równań bilansowych dla procesu wymiany ciepła w gruntowym wymienniku ciepła, a także zależności analityczne i graficzne do wyznaczania wydajności termicznego wymiennika ciepła w umiarkowanych warunkach klimatycznych.

Słowa kluczowe: wentylacja geotermiczna, gruntowy wymiennik ciepła, budynki energooszczędne