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# The influence of ground heat exchanger installation on the efficiency of residential geothermal ventilation systems

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Abstract: Geothermal ventilation is used for preheating outdoor air in the cold season and pre-cooling it in the warm season using a mechanical ventilation system. It allows the building to save on traditional fuels when preheating or cooling outdoor supplied air by using low-potential soil heat. Air and soil exchange heat through the walls of the ground heat exchanger. Ground heat exchangers for geothermal ventilation can be installed in the ground according to a ring scheme, a Tichelmann scheme, or with a coil scheme. This article focuses on the geothermal ventilation system of a residential building using two methods of installing ground heat exchangers. The thermal energy performance of ground heat exchangers when laid in a coil format and in the Tichelmann scheme was compared. The operation of the variants was simulated using REHAU-GAHE software. As the calculation results showed, the thermal energy performance of the system for the two types of installation is approximately the same, since the program is set to maintain the minimum temperature at the outlet of the ground heat exchanger. For example, the amount of heat received per year for a ground heat exchanger installed in a coil format is 7310.22 kWh/year, and for a ground heat exchanger installed according to the Tichelmann scheme – 7430.35 kWh/year. As for the geometric dimensions, the results obtained are significantly different. Thus, for an installation depth of 2.5 m when installed in a coil format, the pipeline diameter was 500 mm and the length was 168 m, and when installed according to the Tichelmann scheme – the diameter was 250 mm and the length was 403 m.

Keywords: geothermal ventilation system, ground heat exchanger, low-potential ground energy, heat exchanger installation scheme, thermal energy



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## Introduction

At the moment, buildings and the built environment are responsible for about 37 % of global $CO_2$ emissions. One of the steps being used to achieve energy independence of the country and reduce greenhouse gas emissions is the introduction of alternative energy sources in the generation of thermal energy. In residential and public buildings, thermal energy is necessary for the functioning of heating, ventilation and hot water supply systems. According to estimates of the World Green Building Council, demand in buildings will double by 2050 (Ujma et al., 2025). Recommended alternative energy sources include: solar energy (Gorás et al., 2024; Savchenko & Lis, 2023), biomass energy (Savchenko et al., 2018; Timilsina et al., 2023; Zhelykh et al., 2016), waste heat (Ziemele et al., 2023; Zirne & Pakere, 2024), surface water energy (Abbiasov et al., 2025; Wang et al., 2021; Wang et al., 2025), and geothermal energy (Kljajić et al., 2020; Sun et al., 2021). Geothermal energy can be extracted from geothermal waters (Galantino et al., 2021; Savchenko et al., 2023) or directly from the ground.

The thermal regime of soil is formed under the influence of solar radiation and the flow of radiogenic heat from the Earth's interior (Savchenko et al., 2015). The soil up to a depth of 1.5 m is significantly affected by seasonal and daily changes in the intensity of solar radiation and the temperature of the outside air. At a depth of more than 15-20 m, the thermal regime of the soil depends on the thermal energy coming from the Earth's interior. Various types of ground heat exchangers are used to exploit low-potential ground heat. Vertical heat exchangers (geothermal probes) are mainly used in heating systems (Hagedorn et al., 2024; Woroniak, 2020). The most common type of geothermal probe consists of parallel polyethylene plastic pipes, two of which are connected at the lower end by a U-shaped base, the so-called U-probes. If two pairs of pipes are used, they are called double U-probes (Guz et al., 2024; Rudakov & Inkin, 2021). There are also coaxial probes, in which the movement of the coolant occurs in the inner pipe and in the annular space between the inner and outer pipes of the coaxial probe.

When designing ventilation systems, it is advisable to use low-potential ground energy for preheating the supply air in the cold season or for cooling it in the warm season (Nagy et al., 2024; Nedbaylo et al., 2024). Ventilation systems that use low--potential ground energy are called geothermal ventilation systems (Liu et al., 2023). Geothermal ventilation systems are actively integrated into energy-saving and passive house projects, and "green" construction. This is especially observed in European Union countries, where there are strict regulatory requirements for energy consumption. Currently, the implementation of geothermal ventilation systems is advisable to achieve energy independence, reduce the use of fossil fuels and decarbonize ventilation systems.

## 1. Analysis of existing research

The schematic diagram of a geothermal ventilation system is shown in Figure 1.

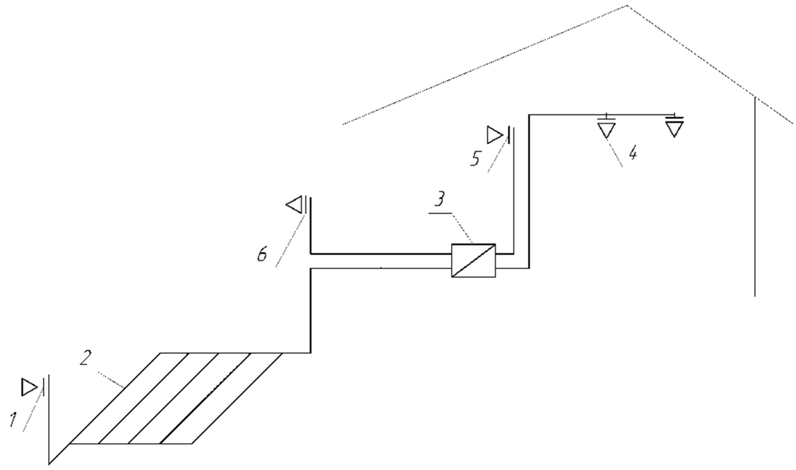


**Fig. 1.** Geothermal ventilation scheme: 1 – air intake unit, 2 – horizontal ground heat exchanger, 3 – recuperator, 4 – supply air, 5 – exhaust air, 6 – air exhaust unit (*own research*)

The geothermal ventilation system works as follows. Through the air intake unit, outside air enters the ground heat exchanger. The ground heat exchanger can be laid in the ground at a depth of 1.5 m - 3.5 m from the surface, where the ground temperature is approximately constant throughout the year and is equal to 5 °C - 10 °C. In the cold season, the ground temperature is higher than the outside air temperature, so the outside air is heated through the wall of the ground heat exchanger. The preheated air enters the recuperator, where it is heated up by the heat of the exhaust air. Next, the outside air enters the room through the supply pipelines to assimilate excess heat and moisture. In the warm season, the ground temperature is lower than the outside air temperature, so the outside air gives off its heat to the ground through the wall of the ground heat exchanger. The cooled air enters the heat exchanger, where it is further cooled, and then enters the room (Liu et al., 2023; Nedbaylo et al., 2024; Piotrowska-Woroniak, 2020).

The efficiency of the ground heat exchanger is influenced by the climatic parameters of the construction location: outdoor air temperature, outdoor air humidity, soil composition, temperature, thermal conductivity and density. In addition, the efficiency of the ground heat exchanger is influenced by design and installation solutions: diameter and length of the heat exchanger pipelines, pipeline material, heat exchanger installation scheme, etc. (Zeng et al., 2021).

Currently, the following installation methods for ground heat exchangers of a geothermal ventilation system are used: a ring scheme, the Tichelmann scheme and a coil format (Fig. 2) (Liu et al., 2023; Savchenko et al., 2015).

The ring scheme for ground heat exchangers is recommended for residential buildings with the required air exchange of between 120 $m^3/h$ - 250 $m^3/h$. With the ring format, it is advisable to install the ground heat exchanger around the foundations during the construction stage of the structure.

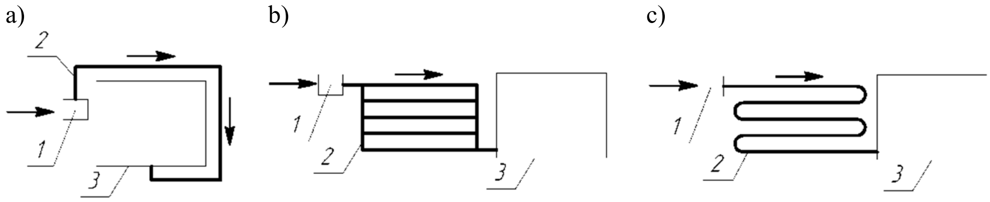


**Fig. 2.** Installation diagrams for ground heat exchangers for geothermal ventilation: a) ring scheme, b) the Tichelmann scheme, c) coil format, 1 – air intake unit, 2 – ground heat exchanger, 3 – house (*own research*)

For houses that require a larger amount of supply air, the pipelines are laid either according to the Tichelmann scheme or like a coil. The thermal capacity of the ground heat exchanger is selected from the condition of preventing the ventilation system recuperator from freezing during the cold season. The required supply air temperature at the inlet to the recuperator is ensured by selecting the number of pipes in the heat exchanger and their length. Land plots are required for laying ground heat exchangers according to the Tichelmann scheme or coil format.

## 2. Purpose of work

The purpose of the work is to compare the parameters of a ground heat exchanger in a geothermal ventilation system of a residential building in the Rivne region using a heat exchanger with both a coil installation and an installation according to the Tichelmann scheme.

## 3. Results

A numerical study of thermal and energy indicators of geothermal ventilation was carried out using the REHAU-GAHE v.1.0.8 software product from REHAU. The following data were taken as the initial data for the calculation. A residential building was designed for construction in the Rivne region (Ukraine), where the outdoor air temperature in the cold season, according to the state standards of Ukraine, is –21 °C, and in the warm season +31 °C. The total area of the premises of the house was 1746.9 m$^2$; the internal volume of the residential premises was 5627.97 m$^3$. The air exchange of the premises of the house was determined by calculations using available standards and norms, depending on the volume of the premises and the equipment installed in them. The total amount of supply air that must be supplied to the premises of the house was 1360 m$^3$/h. Ground heat exchangers were installed in soil of the "loam" type, which is typical for this area, with a thermal conductivity coefficient of 1.50 W/(m$^2$·K) and a thermal diffusivity coefficient of $1.25 \cdot 10^{-6}$ m$^2$/s.

As ground heat exchangers, Awadukt Thermo pipelines with an antimicrobial coating of silver particles were adopted. The ground heat exchanger was operated throughout the year. The following daily operating mode of the ventilation system was selected in the software product: from 00.00 to 07.00 – the ventilation system capacity was 50 % of the total capacity, from 07.00 to 12.00 – 100 %, from 12.00 to 18.00 – 50 %, from 18.00 to 24.00 – 100 %.

As a result of the calculations, the following data was obtained: the total length of the heat exchanger pipes, the amount of heat extracted from the ground in the cold period of the year (CPY), the amount of heat transferred to the ground in the warm period of the year (WPY), the minimum air temperature after the ground heat exchanger in CPY and TPY, the speed of air movement in the heat exchanger, pressure losses in the heat exchanger, reduction of $CO_2$ emissions during heating and cooling of the house.

The calculations were performed for two installation options, namely the coil format and the Tihelmann scheme. For each option, the heat energy indicators were determined for the following depths of pipelines: 1.5 m, 2.0 m, 2.5 m, 3.0 m, 3.5 m.

A feature of REHAU-GAHE v.1.0.8 is that it was developed for Poland, so the values of the outdoor air temperature are typical for Polish cities. The closest in terms of outdoor air temperature to the city of Rivne in Poland is the city of Suwalki with an outdoor temperature of –21.1 °C so it was chosen for the calculations. In addition, the calculation of the geothermal ventilation indicators was carried out for the coil format heat exchanger and the Tichelmann heat exchanger. Therefore, when calculating the indicators of geothermal ventilation with a ground heat exchanger, it was necessary to additionally indicate the number of its bends.

When modelling the operating modes of the coil ground heat exchanger, the following initial data were accepted: diameter of the ground heat exchanger 500 mm × 17 mm, distance between the heat exchanger pipes – 1 m.

The results of calculations of the thermal energy characteristics of the geothermal ventilation system in the CPY of a residential building in the Rivne region with a ground heat exchanger installed in a coil format are given in Table 1.

**Table 1.** Results of calculations of thermal energy indicators of a geothermal ventilation system in the CPY of a residential building in the Rivne region with a ground heat exchanger (GHE) installed using a coil format (*own research*)

| Depth of installation [m] | Minimum temperature at GHE inlet [°C] | Minimum temperature at GHE outlet [°C] | Pressure losses in GHE [Pa] | Air velocity in GHE [m/s] | Total pipes length [m] |
|---|---|---|---|---|---|
| 1.5 | –21.1 | –3.5 | 23.87 | 2.22 | 177 |
| 2.0 | –21.1 | –3.9 | 23.06 | 2.22 | 171 |
| 2.5 | –21.1 | –3.3 | 23.39 | 2.22 | 168 |
| 3.0 | –21.1 | –2.7 | 22.12 | 2.22 | 164 |
| 3.5 | –21.1 | –2.1 | 21.17 | 2.22 | 157 |

As seen from Table 1, with an increase in the depth of the heat exchanger installation, the total length of the heat exchanger decreases. Thus, with an increase in the depth by 2 m, namely from 1.5 m to 3.5 m, the length of the heat exchanger decreases by 20 m. The software calculated the length of the heat exchanger so that the minimum air temperature at the outlet from it was approximately –3 °C, provided that the recuperator did not freeze. Therefore, for different depths of the pipeline, the minimum temperature at the outlet from the ground heat exchanger was within –3 °C, but still, the greater the depth of the heat exchanger installation, the higher it was. Of the simulated options, the highest value of –2.1 °C corresponds to a heat exchanger installation depth of 3.5 m.

Accordingly, to Table 1, the closest value of minimum temperature at the outlet of the ground heat exchanger to –3 °C, namely –3.3 °C, had a heat exchanger 168 m long, which was installed at a depth of 2.5 m. The heat that came from the ground to the air in the heat exchanger was 7310.22 kWh/year, the heat that was transferred to the ground was 7446.92 kWh/year. The reduction in $CO_2$ emissions in the air heating mode when using such a heat exchanger was 1575.76 kg/year, and in the air cooling mode – 1122.36 kg/year.

When modelling the operating modes of a soil heat exchanger installed according to the Tichelmann scheme, the following initial data were additionally taken: the diameter of the heat exchanger pipe was 250 mm × 8.8 mm, the diameter of the collector pipe was 400 mm × 13.5 mm, the number of rows in the heat exchanger Dn 400/250 mm – 13 pcs.

The results of calculations of the thermal energy characteristics of the geothermal ventilation system in the CPY of a residential building in the Rivne region with a ground heat exchanger installed according to the Tichelmann scheme are given in Table 2.

**Table 2.** The results of calculations of the thermal energy characteristics of the geothermal ventilation system in the CPY of a residential building in the Rivne region with a GHE installed according to the Tichelmann scheme (*own research*)

| Depth of installation [m] | Minimum temperature at GHE inlet [°C] | Minimum temperature at GHE outlet [°C] | Pressure losses in the collector Dn 400/250 [Pa] | Pressure losses in the pipes Dn 250 mm of GHE [Pa] | Air velocity in the pipes Dn 250 mm of GHE [m/s] | Total pipes Dn 250 mm length [m] |
|---|---|---|---|---|---|---|
| 1.5 | –21.1 | –4.9 | 14.31 | 1.27 | 3.46 | 416 |
| 2.0 | –21.1 | –3.7 | 14.28 | 1.23 | 3.46 | 403 |
| 2.5 | –21.1 | –3.3 | 14.29 | 0.96 | 3.46 | 403 |
| 3.0 | –21.1 | –2.3 | 14.24 | 1.19 | 3.46 | 390 |
| 3.5 | –21.1 | –2.1 | 14.25 | 1.16 | 3.46 | 377 |

As can be seen from Table 2, with increasing depth of the heat exchanger, the total length of the heat exchanger decreases; with increasing depth from 1.5 m to 3.5 m, the length of the heat exchanger decreases by 39 m, which is approximately 10% of the total length of the heat exchanger. The closest value of the minimum temperature at the outlet of the ground heat exchanger to –3 °C, namely –3.3 °C, was found in a heat exchanger 403 m long, which was installed at a depth of 2.5 m. For such a depth the heat that comes from the ground to the air in the heat exchanger was 7210.3 kWh/year, the heat that was transferred to the ground was 7077.06 kWh/year. $CO_2$ emissions were reduced in the "air heating mode" by 1554.22 kg/year, and in the "air-cooling mode" – 1066.61 kg/year.

As shown by the simulation in REHAU-GAHE, there is one mandatory requirement for the calculation. The temperature at the outlet of the ground heat exchanger must be at least –3 °C, provided that the recuperator of the building ventilation system is protected. It is the amount of supply air and the minimum temperature at the outlet of the ground heat exchanger that are decisive for calculating the diameter and length of the ground heat exchanger tubes. As can be seen from the calculations, according to the value of the temperature at the outlet of the ground heat exchanger of –3.3 °C, a sufficient depth for laying pipelines, regardless of the scheme, is 2.5 m. For the two installation schemes, the heat and energy indicators are within similar limits. For example, the heat that flows from the ground to the air in the coil heat exchanger was 7310.22 kWh/year, and for the Tihelmann heat exchanger – 7210.3 kWh/year. The discrepancy between these values is 1.4 %. The same minor discrepancies are observed for other heat and energy indicators. Significant discrepancies are observed in the geometric indicators of the heat exchanger tubes. Thus, for an installation depth of 2.5 m, the program suggested choosing: when installed using a coil format – a pipeline with a diameter of 500 mm and a length of 168 m, and when installing according to the Tichelmann scheme – a diameter of 250 mm and a length of 403 m. This leads to the fact that despite the same thermal energy indicators for different installation schemes, the value of investment costs for the purchase and installation of ground heat exchangers differ significantly.

## Conclusions

This article is devoted to a numerical study of the thermal energy indicators of the geothermal ventilation of a residential building in the Rivne region (Ukraine). The study compared two installation methods for a ground heat exchanger, namely the coil and the Tichelmann scheme. Calculations were carried out using REHAU-GAHE v.1.0.8 from REHAU, and Awadukt Thermo pipelines with an antimicrobial coating of silver particles were used as ground heat exchangers. When modelling the operation of the ground heat exchangers using the REHAU-GAHE program, the amount of supply air and the minimum air temperature at the outlet of the ground heat exchanger were decisive. The amount of supply air should be determined for each house individually depending on the requirements for air exchange in the premises. The air temperature at the outlet of the ground heat exchanger must be at least –3 °C to prevent freezing of the heat exchanger of the building's ventilation system.

Studies have shown that a sufficient depth for laying pipes, regardless of the scheme, is 2.5 m, which corresponds to a temperature at the outlet of the ground heat exchanger of –3.3 °C. For the two installation schemes, the thermal energy indicators are within similar limits, and the geometric indicators of the pipelines differ significantly. Thus, for a depth of 2.5 m, the heat that flows from the ground to the air in the heat exchanger is 7310.22 kWh/year when laid like a coil and 7210.3 kWh/year for the Tichelmann installation scheme. For an installation depth of 2.5 m, the program selected the following geometric dimensions of the pipes: the coil installation has a diameter of 500 mm and a length of 168 m, and when the Tichelmann installation scheme – a diameter of 250 mm and a length of 403 m.

Therefore, despite the same thermal energy for both installation schemes, due to different geometric dimensions of the pipes, the value of investment costs for the purchase and installation of ground heat exchangers will differ significantly. Therefore, in subsequent studies it is advisable to consider an economic comparison of installing ground heat exchangers according to different installation formats.

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