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The cooling capacity of geothermal ventilation under the conditions of a temperate climate

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Abstract: The paper deals with innovative technologies for maintaining the microclimate in energy-efficient buildings through ventilation systems. A detailed analysis of scientific publications on studies of soil heat exchangers, in particular their efficiency and features of application in microclimate systems, has been carried out. A schematic diagram of an air conditioning system with a soil heat exchanger has been given. Analytical and graphical dependences for determining the cooling efficiency of air supply in a heat exchanger for the warm period of the year in temperate climates have been presented.

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

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Introduction

The technology of cooling or heating air supply by soil potential has been known since ancient times. In the current development of energy-efficient construction, the use of low-potential soil heat to reduce energy consumption of homes, both in cold and warm periods of the year, is becoming more common. State-of-the-art ventilation systems should not only provide a healthy indoor environment, but also have an energy-efficient effect. Among such systems there are geothermal ventilation systems. The peculiarity of their operation is that in the presence of a soil heat exchanger, the outside air that passes through it cools down during the warm season, and heats up in winter. This is due to the heat exchange of air with the soil through the wall of the heat exchanger, as the soil temperature stays constant at a certain depth during the year.

Analysis of scientific publications has shown that to understand the phenomena that take place in soil heat exchangers, special attention is paid to heat exchange processes. Thus, in particular, paper (Schasnyj & Smirnova, 2012) deals with the issues of development and prospects of applying heat pumps as the heat supply for buildings. Such energy-efficient systems are becoming increasingly popular in energy-efficient construction (Beniaidze & Kharaborska, 2018). They are becoming the subject of scientific research in order to improve and increase energy-efficiency. Thus, papers (Basok & Novitska, 2017; Basok et al., 2013; Dolinsky, 2013) consider the issues of developing conceptual foundations, projects, and techniques, which were tested on a full-scale model of a passive house. The schematic solutions for the heat supply of such a house using soil heat exchangers have been presented, as well as the results of numerical modelling of the heat exchange process for the proposed design of a “soil-to-air” heat exchanger. It has been established that such a system can heat the outside air by 2 to 8 degrees. Unfortunately, these studies contain no data to assess the efficiency of the heat exchanger during the warm period of the year.

The results of experimental studies to determine the temperature of the soil thickness and the air flow in the soil heat exchanger have been presented in paper (Sikora, 2010). The research was conducted throughout the year and was based on data from the weather station in Bielsko-Biala Aleksandrowice. Graphical dependences of temperature change over time have been presented.

Works (Dolgih & Kovyazin, 2016; Dolgih et al., 2014; Dolgikh, 2013) present the results of scientific studies of the performance indicators of a vertical soil heat exchanger on an experimental installation that was installed in the premises of a rabbit farm. The experiments were conducted during the warm season for loamy soil with a humidity of 7.4% and a density of 1800 kg/m^3. It has been found that the thermal efficiency of the soil heat exchanger is significantly influenced by the air temperature at the inlet to the heat exchanger. An increase in the soil temperature around the heat exchanger was observed during the experiment.

Many of the studies are devoted to researching the operation of heat supply systems for houses with soil heat exchangers that work together with heat pumps. In particular, paper (Kurpaska et al., 2006) presents the dependences for determining the main parameters of a heat exchanger, taking into account its depth of laying and length and heating efficiency of the heat pump. It has been noted that the amount of useful heat that can be obtained from the soil depends on the soil temperature, humidity and depth of the heat exchanger. For a heat supply system with heat pumps and soil heat exchangers of the “liquid-air” variety, the dependences of the COP coefficient change on the variable factors have been established, namely, the heating efficiency of the pump and the operating time of the system (Latała, 2011; Bezrodnyi & Oslovsky, 2018). Special attention was paid to the fact that a significant relationship between the COP coefficient and the temperature inside the object was not confirmed.

There are scientific works that present the characteristic features of the soil heat exchanger operation in a solar system (Vysochin & Gromova, 2013). The studies dealt with non-stationary heat exchange in a seasonal heat accumulator of a solar system with the soil heat exchanger. It has been noted that it is possible to increase the efficiency of the heat exchanger when working with the internal circulation of the coolant in the absence of insolation.

Currently, scientific research of soil heat exchangers remains important and relevant, as one of the main elements of energy-efficient house systems and such systems that use low-potential soil heat. The studies of such systems in the warm season, when the need for cold supply increases significantly, are of particular interest. This work is a continuation of previous studies of the efficiency of using soil heat exchangers (Zhelykh et al., 2015; Zhelykh et al., 2018a; Zhelykh et al., 2018b; Zhelykh, 2019). A schematic diagram of the geothermal ventilation system is shown in Figure 1.

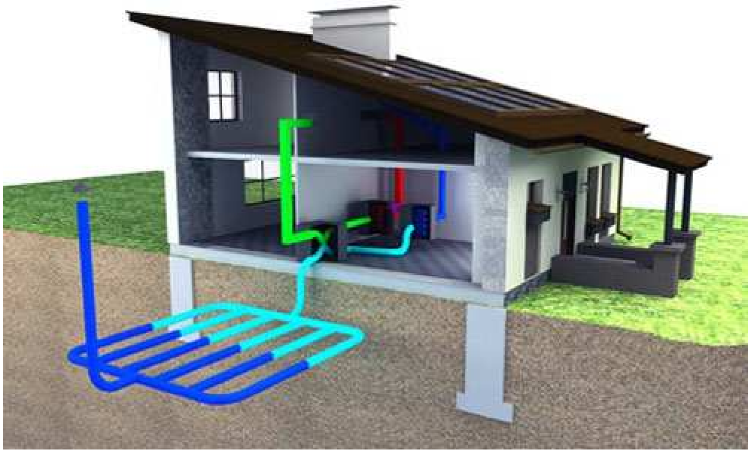

Fig. 1. General view of the geothermal ventilation system for a single-family house (https://rodovid.me/energy/zakopannaya-v-zemlyu-truba-pozvolyaet-ekonomit-na-obogreve-i-ohlazhdenii-doma.html)

The application of this principle of ventilation of energy-efficient homes is quite effective.

1. Purpose and scope of research

The purpose of these studies was to establish the level of cooling of the outdoor air during its movement through the pipelines of the soil heat exchanger. In the warm period of the year, the soil temperature is significantly lower than the ambient air temperature and depends on the thermophysical characteristics of the soil, in particular, the thermal conductivity. However, a characteristic feature is that at a certain depth, the soil temperature is constant throughout the year. At a depth below soil freezing, and for regions with temperate climates (Poland, Ukraine) it is 1-1.5 m. The temperature may be equal to the average annual ambient air temperature. Thus, for example, at a depth of 1.5 to 4.0 m, in summer, the soil temperature ranges from 10 to 12°C. When using soil heat exchangers, the air supply can be sufficiently cooled. The efficiency of the system itself will depend on how large the temperature difference is between the outside air and the soil. Therefore, in the off-season, i.e. in spring and autumn, it is not advisable to use the soil heat exchanger. In order to better transfer heat from the air to the soil, heat exchangers are usually made of polyvinyl chloride (PVC) or polypropylene pipes, which have a higher coefficient of thermal conductivity. In addition, the pipes of the soil heat exchanger have a special coating that prevents the reproduction of micro-organisms. The recommended length of pipelines is 35 to 50 m. The longer the pipeline, the more efficient the heat exchange, however, the aerodynamic drag increases. During the warm season, there is a risk of condensation. Therefore, it is important to lay the pipelines at an inclination of 2% with drainage at the bottom of the slope.

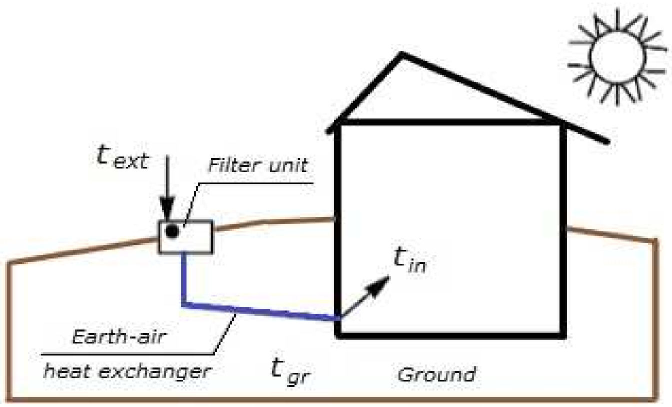

Fig. 2. Schematic of a ventilation system with a horizontal soil-to-air heat (Zhelykh, et al., 2015)

During the operation of the above ventilation system with the soil heat exchanger (Fig. 2) in the warm period of the year, the efficiency of supply air cooling has been evaluated. The heat that remains in the soil can be determined by:

$$Q = 0.278\, L \times c_p \times \rho \times \Delta t, \tag{1}$$

where:
Q – the amount of heat remaining in the soil, W,
L – air supply flow rate, m^3/s,
c_p – heat capacity of air, J/(kg×K), determined from the dependence:

$$c_p = 1003 + 0.027t, \tag{2}$$

where:
t – air temperature, °C,
ρ – air density, kg/m^3, to estimate the thermal potential of the soil, air density can be assumed to be $\rho = 1.2$ kg/m^3,
Δt – temperature difference, or increase in air temperature in the soil heat exchanger, °C:

$$\Delta t = t_{ext} - t_{in}, \tag{3}$$

where:
t_{ext} – outdoor temperature, °C,
t_{in} – air supply temperature, °C.

The amount of heat that will be utilized by the soil during the warm period of the year Q_{cool} (kWh) can be determined from the dependence:

$$Q_{cool} = N \times n \times Q, \tag{4}$$

where:
N – period of heat extraction by soil, $N = 80$ days,
n – time of heat extraction by soil, $n = 24$ h.

Thus, when using geothermal ventilation, it is possible to significantly reduce energy consumption for cooling the air supply in the soil heat exchanger. In general, we can write the equation (2) as follows:

$$Q_{cool} = 0.278N \times n \times L \times c_p \times (t_{ext} - t_{in}), \tag{5}$$

This dependence allows the estimation and analysis of the annual energy potential of the soil depending on the climatic conditions of operation of the geothermal ventilation system.

2. Research results

As a result of the analytical studies, we have obtained graphical dependences, which allow the estimation of the amount of heat that remains in the soil during the year for the operating conditions of geothermal ventilation systems in the warm period of the year (Fig. 3). The normalized flow rates of air supply in the pipelines of the geothermal heat exchanger were taken into account, in particular the speed was in the range of v = 2-5 m/s. In addition, the main technical characteristics for the studies were similar to the initial data in the studies conducted during the cold period of the year (Zhelykh, 2019), the diameter of the soil heat exchanger was 250 mm and only its horizontal section, which was sunk into the ground, was taken into account; the length of the heat exchanger l was equal to 150 m. The outdoor temperature was in the range of t_{out} = 20-30°C, while the soil temperature was taken for temperate climates in the warm period of the year t_{soil} = 5-15°C.

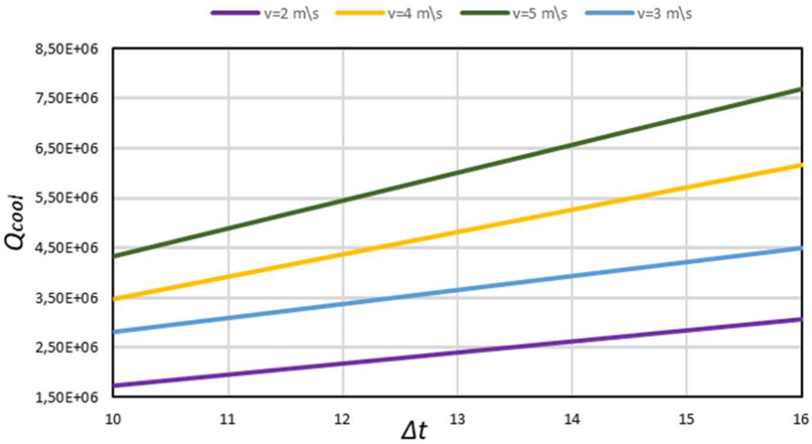

Fig. 3. Dependence of the amount of heat utilized by the soil Q_{cool}, Wh, in the warm period of the year on an increase in temperature Δt, °C, at different air speeds in the heat exchanger (*own research*)

In addition, for the above operating conditions, the results were obtained in the form of a graphical dependence of the air supply temperature on outdoor temperature conditions (Fig. 4). The figure shows that in the warm period of the year, it is possible to effectively use the thermal potential of the soil as an additional source of cooling of the outdoor air.

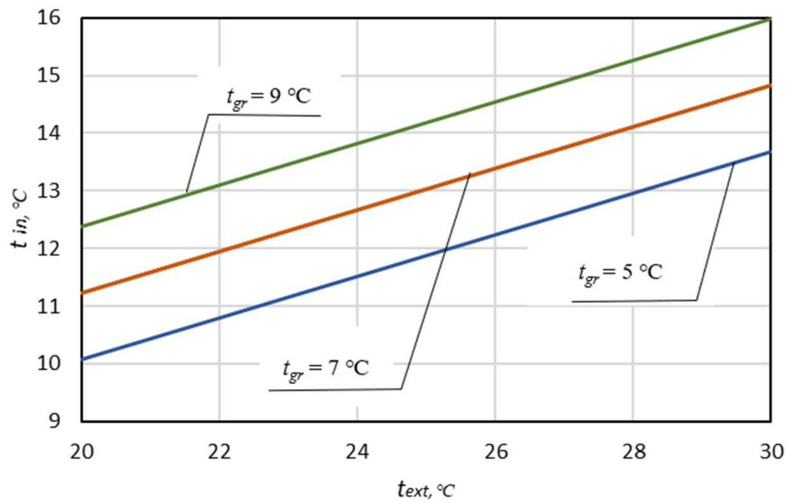

Fig. 4. Dependence of the air supply temperature t_{in}, °C, on the soil temperature t_{gr}, °C, and outdoor air t_{ext}, °C, for the warm period of the year (*own research*)

Conclusions

As a result of the conducted studies, based on the presented technique for determining energy potential of the soil in the warm period of the year for effective performance of geothermal ventilation, we have obtained graphical dependences of the temperature of pre-cooled air supply. In addition, in the range of outdoor air temperatures of t_{out} = 20-30°C for the warm season, we have managed to determine the amount of energy that was saved on cooling the air supply during the operation of the geothermal ventilation system. This value can average 5000 kWh during the warm period of the year. As a rule, this amount of energy is not enough to maintain the required temperature parameters, so the microclimate system should provide an additional method of cooling the air supply.

It should be noted that such technical solutions with the use of soil heat exchangers of geothermal ventilation significantly saves money when used to maintain the microclimate of the premises both during cold and warm seasons.

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