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Horizontal earth-air heat exchanger for preheating external air in the mechanical ventilation system

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Abstract

To save traditional energy sources in mechanical ventilation systems, it is advisable to use low-energy ground energy for preheating or cooling the outside air. Heat exchange between ground and outside air occurs in ground heat exchangers. Many factors influence the process of heat transfer between air in the heat exchanger and the ground, in particular geological and climatic parameters of the construction site, parameters of the ventilation air in the projected house, physical and geometric parameters of the heat exchanger tube. Part of the parameters when designing a ventilation system with earth-air heat exchangers couldn't be changed. The one of the factors, the change which directly affects the process of heat transfer between ground and air, is convective heat transfer coefficient from the internal surface of the heat exchanger tube. In this article the designs of a horizontal earth-air heat exchanger with heat pipes was proposed. The use of heat pipes in designs of a horizontal heat exchanger allows intensification of the process of heat exchange by turbulence of air flow inside the heat exchanger. Besides this, additionally heat transfer from the ground to the air is carried out at the expense of heat transfer in the heat pipe itself.

Key words: ventilation system, horizontal earth-air heat exchanger, heat transfer, heat pipe.

1 Introduction

The ventilation system is known to be designed to maintain permissible sanitary, hygienic and meteorological parameters in the premises. [1, 2, 3, 4] For this purpose fresh air is supplied to the premises, which, in the mechanical ventilation system, may be subjected to additional processing, such as purification, wetting or drying, heating or cooling, depending on the meteorological parameters of the outside air. So, in the cold period of the year in the climatic conditions of Ukraine, it is necessary to heat the outside air before it enters into the premises. To save traditional energy sources in mechanical ventilation systems, it is advisable to use low-energy ground energy for preheating or cooling the outside air. Heat exchange between ground and outside air occurs in earth-air heat exchangers, which, depending on laying in the array of ground, are vertical and horizontal. [5] In the ventilation systems horizontal earth-air heat exchangers are used, which, depending on the design, can be channel (tube), channel-free and membrane-free. [6] Due to the low heat transfer coefficient from ground to air in the heat exchanger, the main disadvantage of horizontal earth-air heat exchangers is the large area of their laying.

2 Aim of work

The aim of the work is to suggest the designs of a horizontal earth-air heat exchanger, which would allow increase the heat transfer from ground to air during the preheating of the inflow air in the mechanical ventilation system.

3 The analysis of existing research

At present, channel (tube) horizontal earth-air heat exchangers, which consist of successively or parallelly laid with a certain step of pipes, are most commonly used. The pipelines can be from steel, aluminum, concrete or plastic and different tube geometries. [7] The heat exchanger pipes are laid in the ground, at a depth that depends on the geological and climatic parameters of the construction site. The scheme of a ventilation system with a horizontal earth-air heat exchanger is shown on Fig. 1.

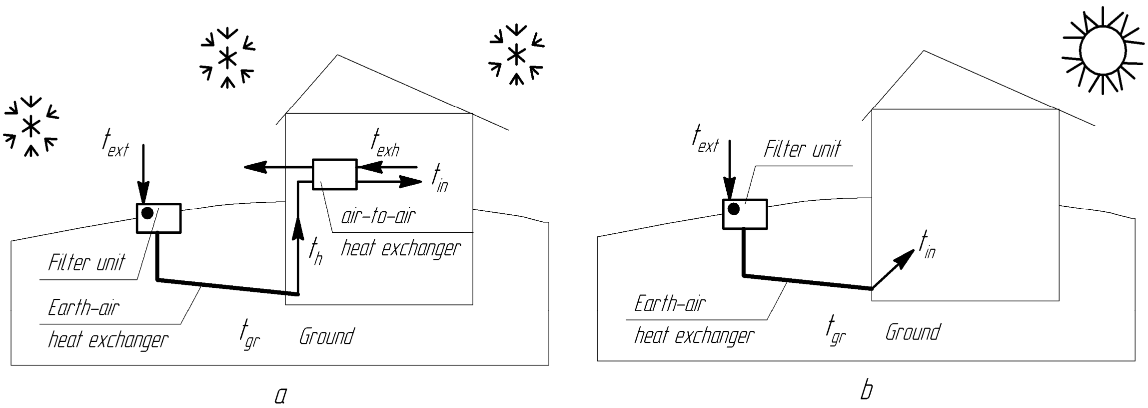

Figure 1: Scheme of ventilation system with a horizontal earth-air heat exchanger
a - cold period of the year, b - warm period of the year

In the cold season, the ground temperature is higher than the outside air temperature, which allows it to use its low-temperature heat to heating the outside air. In the cold season, the ventilation system will work as follows (Fig. 1a). The external cold air after the clearing unit enters to the horizontal ground heat exchanger, which, due to the heat of the ground, is heated. Preheated external air enters to the air-to-air heat exchanger, where it is additional heating by an exhaust air. After the air-to-air heat exchanger, the cleaned and heated air is fed into the premises.

The total heat transferred to the air when it flowing through of the horizontal earth-air heat exchanger tube, is determined by the formula [8]:

$$Q_p = n \cdot c_p \cdot (t_{out} - t_{in}) \quad (1)$$

where: Q_p – total heat transferred to the air (W) ; n – mass flow rate of air passing through the heat exchanger tube (kg/s); c_p – specific heat of air (J/(kg·K)); t_{out} – temperature of air at outlet of heat exchanger tube (°C); t_{in} – temperature of air at inlet of heat exchanger tube (°C).

The mass flow rate of air through of the horizontal heat exchanger tube defined as [8]:

$$n = \frac{\frac{\pi}{4} \cdot D^2 \cdot \rho \cdot v_a}{N_p} \tag{2}$$

where: D – internal diameter of the horizontal ground heat exchanger tube (m); ρ –air density (kg/m^3); v_a – air velocity in the heat exchanger tube (m/s); N_p – number of parallel heat exchanger tubes (–).

In the warm period of the year, the ground temperature is lower than the temperature of the outside air, so its excess heat can be given to the ground. During the warm period, the ventilation system will work as follows (Fig. 1b). The external hot air after the clearing unit enters to the horizontal earth-air heat exchanger. There, through the wall of the heat exchanger pipe, air gives its heat to the ground and cools down. After the earth-air heat exchanger, the cooled air can flow directly into the premises.

Many factors influence the process of heat transfer between air in the heat exchanger and the ground, in particular geological and climatic parameters of the construction site, necessary parameters of the ventilation air in the projected house, physical and geometric parameters of the heat exchanger tube. Some of parameters at designing a ventilation system with earth-air heat exchangers could not be changed. [6] These parameters include the thermophysical characteristics of the ground and the thermophysical properties of the outside air, since they are permanent for a specific construction site. The ground temperature is determined by the formula:

$$T_s = \overline{T_s} + A \cdot e^{-x\sqrt{\frac{\pi}{365a}}} \cdot sin\left(\frac{2\pi(t-t_o)}{365} - x\sqrt{\frac{\pi}{365a}} - \frac{\pi}{2}\right) \tag{3}$$

where: x - depth of ground (m); t - day of the year; $\overline{T_s}$ - annual average surface temperature of the soil taken equal an annual average outdoor air temperature for the selected region (°C); A - annual amplitude fluctuation of the surface temperature of the ground (°C); a - thermal diffusivity of the ground (m^2/s); t_o - time lag (in days) from a random initial date of the emergence of the minimum temperature in year.

As can be seen from (3), the ground temperature depends on the depth of laying of the heat exchanger, the day of the year, as well as the thermal and physical properties of the ground and outside air. Since it is not possible to change the coefficient of heat conductivity of the soil, ground density, specific heat capacity of the ground and the estimated external air temperature in the specific construction site, the temperature of the ground in a certain area varies only depending on the depth and day of the year.

The factors that could not change the heat transfer from ground to air include factors that depend on the design task. They include the air flow to be supplied to the building, and the air temperature at the outlet of the heat exchanger. These factors depend on the appointment of the building, the volume of its premises, the requirements for the parameters of ventilation air in these rooms and the operation conditions of the air-to-air heat exchanger. Consequently, they have precise values for the ventilation system of a particular building.

One of the factors, change of which directly influences on process of heat transfer between ground and air, is convective heat transfer coefficient from the internal surface of the heat exchanger tube:

$$\alpha_{in} = \frac{Nu \cdot \lambda_a}{d_{in}} \tag{4}$$

where: Nu - Nusselt number (-); λ_a – coefficient of thermal conductivity of air, which is transported to the heat exchanger, (W/(m·K)); d_{in} - internal diameter of the heat exchanger tube (m).

As it can be seen from formula (4), increase of Nusselt number and the coefficient of thermal conductivity and decrease of tube diameter results in to increase of coefficient of heat transfer from the wall of the heat exchanger to the air. Since the coefficient of thermal conductivity of the air in the temperature range that is characteristic of the operation of the soil heat exchanger does not change significantly, then to increase the coefficient of heat transfer, it is necessary to increase Nusselt number and reduce the diameter of the heat exchanger tube.

Nusselt number depends on many indicators, in particular, the method of inducing air movement (natural or forced convection), air velocity, flow regime (laminar or turbulent), as well as physical parameters of air (coefficient of dynamic viscosity, specific heat, density). These factors are taken into account with the help of dimensionless numbers of Reynolds Re, Grasgoff Gr and Prandtl Pr.

Nusselt number can be increased by turbulence of the air flow in the heat exchanger tube.

4 Main material

Increase Nusselt number by the air flowing in the tube of the ground horizontal heat exchanger can be by means of heat pipes that are additionally used in the construction of an earth-air heat exchanger.

The heat pipe is a sealed chamber of a round section, which is filled with a working fluid. The heat pipe consists of an evaporator, a transport section and a condenser. [9] The operation principle of the heat pipe is as follows. The working fluid moves in a sealed chamber and turns into a pair, then into a condensate. When the working fluid enters the evaporator of the heat pipe it is evaporated, it is accompanied by the absorption of a large amount of heat. After that, the steam of the working fluid through the transport section enters the condenser, where it condenses and gives the heat.

In the horizontal earth-air heat exchanger, the heat pipes are mounted in the wall of the tube, perpendicular to its surface with a certain step. [10] At that, half of the heat pipes are located on top of the heat exchanger, and the other half - from the bottom of the heat exchanger (Fig. 2). The upper heat pipes operate in the cold period of the year, for this the evaporator is outside the tube of the heat exchanger, and the condenser is inside the heat exchanger tube. The lower heat pipes operate in the warm period of the year, for this the evaporator is inside the tube of the heat exchanger, and the condenser is outside the heat exchanger tube.

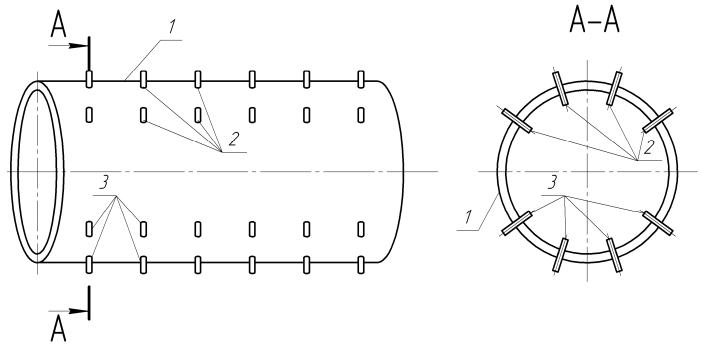

Figure 2: Appearance and section of the horizontal earth-air heat exchanger
1 – polypropylene tube, 2 – lower heat pipes, 3 – upper heat pipes

The operation principle of a horizontal earth-air heat exchanger with heat pipes in the cold period of the year is as follows. The exterior inflow air passing in a horizontal earth-air heat exchanger with heat pipes is heated by the wall of the heat exchanger polypropylene tube 1 and absorbs heat from the upper heat pipes 2 in the condensation zone, which are installed in the wall of the heat exchanger propylene pipe 1. Due to the existing protruding parts of the upper heat pipes 2 (condensation zones), inside the heat exchanger polypropylene pipe 1 there is a perturbation of the air flow, which allows further intensification of the heat exchange process between the heat exchanger inner surface and the outside inflow air. The preheated air in the horizontal earth-air heat exchanger with heat pipes is fed to the air-to-air heat exchanger for the second heating to the temperature and after that enters to the room. The bottom heat pipes 3 of the horizontal earth-air heat exchanger do not work during the cold period of the year.

At the warm period of the year, the exterior inflow air passing in a horizontal earth-air heat exchanger with heat pipes is cooled down by the walls of the polypropylene pipe 1 and the lower heat pipes 3 in the evaporation zone. The presence of protruding parts of the lower heat tubes 3 (evaporation zones) inside the horizontal earth-air heat exchanger causes disturbance of the air flow, which allows further intensification of the heat exchange process between the internal surface of the heat exchanger and the outside air. Pre-cooled air can be directly supplied to the ventilation system. The upper heat pipes 2 of the horizontal earth-air heat exchanger do not work during the warm period of the year.

The use of the proposed horizontal earth-air heat exchanger with heat pipes in mechanical ventilation systems can increase the convective heat transfer coefficient from the internal surface of the tube to the air in the heat exchanger.

5 Conclusion

The design of the horizontal earth-air heat exchanger with heat pipes is proposed, which allows increase the heat transfer from ground to air during the preliminary heating of external air in the mechanical ventilation system. Using of heat pipes in the designs of a horizontal heat exchanger allows intensification of the process of heat exchange by turbulence of air flow inside the heat exchanger. Besides this, additionally heat transfer from the ground to the air is carried out at the expense of heat transfer in the heat pipe itself.

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