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DEVELOPMENT OF ENERGY-SAVING VENTILATION SYSTEM FOR AGRICULTURAL BUILDINGS

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The article discusses the results of development of energy efficient ventilation system of sheepfold. The scheme of the experimental energy-efficient ventilation system of sheepfold is given. The differential equations of heat transfer for describing the temperature field in the soil around the duct of the ventilation system of the sheepfish are used. An example of calculation of dimensionless criteria at given initial and boundary conditions is shown. The values of the air temperature at the outlet of the channel and the value of the heat flux are determined. The results of the calculations are consistent with the test data using information and measuring system for remote recording of the thermal characteristics of ventilation systems.

***Keywords*:** ventilation system, sheepfold, ductwork, temperature field in the soil, heat transfer, heat flux.

Introduction

Rational using of fuel and energy resources is one of the global problems. One promising solution to this problem is the use of new energy-saving technologies, using renewable energy sources. The range of renewable energy on farms is quite broad: it is heating or cooling buildings, and drying of agricultural products, and desalination and water heating, and even autonomous power supply. The advantages of the energy sources are environmental friendliness and low cost of labor and funds for the operation of facilities for their use. The solution of the problem in the energy-saving ventilation systems of agricultural buildings is the effective use of low-grade soil heat. The ground surface layers of the Earth, actually is a heat accumulator of unlimited capacity, which thermal regime is formed by the action of solar radiation. Low-grade heat of the Earth can be used in agricultural buildings for heating, hot water, air-conditioning (air-cooling). There are a number of examples of the use of soil heat for heating and cooling of livestock buildings through underground air conduits and heat exchangers. They are allowed to save from 50 to 75% of the costs for heating and cooling the buildings. [1-4]. Studying these examples allowed to develop energy-saving ventilation system for sheep premises [5, 6].

1. Ventilation system

Functional block diagram of the ventilation system (Fig. 1) contains the intake shaft 1 and 2 provided with a fan motor 3 and water spray 4, exhaust shaft 5 with control valve 6 and air supply ducts 7.8 with control valves 9,outlets in air 10-ventilated room with a 11 -coil temperature of 12 linked via the intake 13 air shutter shaft 1 and placed in the soil below the freezing and the latter program controller 14 microclimate temperature sensors 16 , 17, 19 , 20 and 15 velocity , humidity 18 connected to the fan motor 3 control valve 6 2 9 exhaust shafts and air intakes to 7, 8 and 4, and the atomizer coil units 12 temperature.

The device contains two air-supply ducts 7, 8 to ensure continuity of supply of heated air into the room 11 during charging one of them. Assembly and manufacture of air handling unit is made from prefabricated modular elements, designed to suit the required volume of ventilation air and the type of agricultural premises. In a cold season the heavy gravity fresh air enters the intake shaft 1 and through air shutter 13 enters the outdoor air duct 7 contacts with the surface of the walls, is heated with the warmth of a soil and moves up , goes through 10 outlets in room 11, flowing temperature closer 12. Air shutter 13 threshold, which is located below the bottom of the duct 7, 8 does not allow exit easily of the heated air from the air in the intake shaft 1. Thereby it provides a strictly unilateral movement gravity flow of fresh air. Exit from the ventilated room of the exhaust air through the exhaust shaft 5 with a control valve 6, which is controlled by software regulator microclimate 14. Program controller 14 controls operation of the electric motor 3 of the fan 2 which supports the set speed of a self-flowing stream and adjusting valves 9, stitched air ducts 7, 8, providing the set threshold of temperature of a self-flowing stream, and also temperature closer.

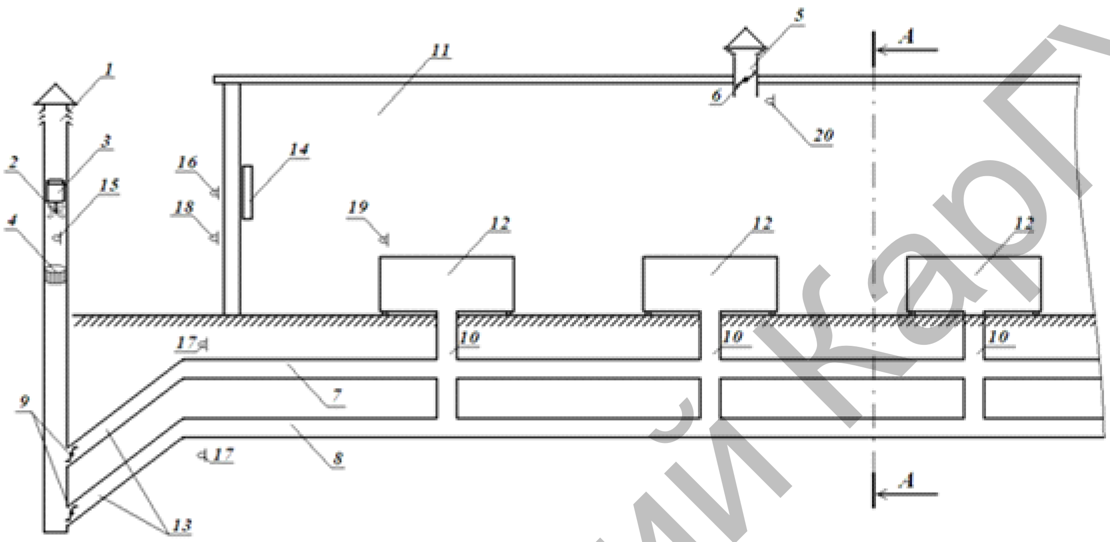

Fig.1. Scheme of ventilation device.

As the temperature of the walls of the duct 7 or soil mass reduces the intensity of heat removal and at a certain temperature the threshold exceeds a specified value. At this point, the temperature sensor signal ground 17 climate control 14 closes the control valve air supply duct 7 and opens the valve 8. An array of ground round duct 7 after a while restores its natural temperature, i.e. recharges, and the array of soil around the duct 8 is cooled, i.e. discharges. Upon reaching the ground temperature values are normalized by the sensor 17, the controller 14 closes the valve 9 microclimate supply duct 8 and 9 opens the valve duct 7. Thus, blowing ducts alternately operate in the mode of charging and discharging, provides normalized stable supply air temperature, i.e. stabilizing the temperature of the supply air. Enter the room heated inlet air temperature 12 wraps closer, increases its temperature to the rated value. Enable or disable the controller 14 performs closers microclimate by temperature sensor 19. 12 closers provide radiant and convective heat transfer in the process of creating a local microclimate. Valve 6 of exhaust shaft 5 regulates the exit of the exhaust air; its work is controlled by the regulator of microclimate 14 through the temperature sensor 20.

As the internal temperature rises gravity flow velocity decreases and at a certain temperature, the flow rate will be insufficient to provide the rated air. At this point, the signal sensor 16, the outdoor temperature sensor 15 and a flow rate regulator 14 connects the electric motor 3 microclimate fan 2.

In a warm season, heated fresh air by fan (2) is injected at the intake shaft (1) to the duct (7), from where (10) through off takes air enters the ventilated room. When passing through the air duct (7) the heated fresh air is cooled by transferring heat to ground through its walls. Ducts (7, 8) will also run in both the charging and discharging as during a cold season. Depending on the desired humidity parameters of ventilated fresh air moisturize with water through the gun (4). Sprayer (4) is operated by the regulator (14) of microclimate through the humidity sensor (18) outside air and provides the required humidity of supplied air. Under this scheme, designed and built experimental energy-saving ventilation system for the sheepfold and conducted production tests during the lambing.

Within the framework of the problem statement, an experimental energy-saving ventilation system for the sheep-dog was developed and constructed and production tests for the time of lambs litter were carried out and its calculations were performed.

2. Calculation parameters of sheepfold ventilation system

For designing the energy saving ventilation system, was viewed the differential equation of the temperature field of soil around the ductwork of ventilation system

$$\frac{\partial t}{\partial \tau} = a \left(\frac{\partial^2 t}{\partial R^2} + \frac{1}{R}\frac{\partial t}{\partial R} \right) \tag{1}$$

where a - temperature conductivity of the soil.

The boundary conditions for equation (1):

$$t = t_{soil} \quad at \quad \tau = 0; \qquad R \to \infty, \quad \tau \ge 0; \qquad -\lambda \frac{\partial t}{\partial R} = \alpha' \left[t(R_o, \tau) - t_{aver}(\tau) \right] = 0 \tag{2}$$

where λ is the temperature conductivity of the soil;

α - heat transfer coefficient of the channel walls**.**

The value of integral air temperature along the channel length with the total area of heat transfer *F:*

$$t_{aver}(\tau) = \frac{1}{F}\int_0^F t(x,\tau)dF \tag{3}$$

,

where $t\ (x,\ \tau)$-is local temperatures determined from the heat balance equation duct area *dF*:

$$cGdt = \alpha\left[t(R_o,\tau) - t(x,\tau)\right]dF \tag{4}$$

The solution of the equation (2) has the form:

$$\varphi_x = \frac{t(x,\tau) - t(R_o,\tau)}{t_0 - t(R_o,\tau)} = \exp\left(\frac{-\alpha F_x}{cG}\right) \tag{5}$$

,

where t (R_0, τ)- is the average temperature over the length of the channel walls at a given moment of time; *Fx* - the area of heat exchange of channel through section x.

The solution of the differential equation (5) allows calculate the thermal technical parameters of the energy-saving system [1, 2].

Let's calculate the thermal engineering parameters of the ventilation system at the following initial data:

$D_o = 0.22m$, $L = 12m$ - are the diameter and the length of the air duct;

$t_{soil} = +10^oC$ - is the initial uniform temperature of the soil;

$a_{soil} = 5.2\cdot 10^{-7} m^2/s$ - is the coefficient of soil temperature-conductivity;

$\lambda_{soil} = 1.3\ \ W/(m^2 \cdot {}^oC)$ - is the coefficient of thermal conductivity of the soil;

$\rho_{soil} = 1700\ \ kg/m^3$ and $c_{soil} = 1.47 kJ/(kg\cdot{}^oC)$ -are the density and the specific heat of soil;

$t_{out-air} = t_o = -16^oC$ - is the estimated ventilation or the temperature of the incoming outside air;

$t_{aver} = -5^oC$ - is the average temperature of the heating period;

$n = 198 days$ - is the duration of the heating season;

$\vartheta = 2m/s$ - is the speed of air flow;

$\nu_{air} = 12.42 \cdot 10^{-6} m^2/s$ - is the kinematic viscosity of air;
$\lambda_{air} = 0.0253 W/(m^2 {}^oC)$ - is the coefficient of kinematic heat conductivity of air;
$a_{air} = 17.44 \cdot 10^{-6} m^2/s$ - is the coefficient of kinematic air temperature-conductivity;
Then the Prandtl criterion equals $\Pr = \frac{\nu_{air}}{a_{air}} = \frac{12.42 \cdot 10^{-6}}{17.44 \cdot 10^{-6}} = 0.71$
It is possible to calculate the length of the air duct based on condition: $St^{/} = 2$.
We have from the next formula:

$L = \frac{R_0 \operatorname{Re} \Pr}{Nu}$ that $L = \frac{R_0 \cdot \operatorname{Re} \cdot \Pr}{Nu} = \frac{0.11 \cdot 35427 \cdot 0.71}{78.48} = 35.35m$

The maximum operating time of the air duct is determined from the next condition $Bi^{//}\sqrt{Fo} = 1$:

$Bi^{//} = Bi^{/} + 0.375$ and $Bi^{/} = \bar{\varphi} \cdot Bi$

$$\bar{\varphi} = \frac{1 - \exp(-St^{/})}{St^{/}} = \frac{1 - e^{-2}}{2} = 0.43$$

$$Bi = \frac{\alpha \cdot R_o}{\lambda_{soil}} = \frac{9.02 \cdot 0.11}{1.3} = 0.76$$

$$Bi^{/} = \bar{\varphi} \cdot Bi = 0.43 \cdot 0.76 = 0.33$$

$$Bi^{//} = Bi^{/} + 0.375 = 0.33 + 0.375 = 0.705$$

$$\tau = \frac{R_0^2}{(Bi^{//})^2 \cdot a_{гр}} = \frac{(0.11)^2}{(0.705)^2 \cdot 5.2 \cdot 10^{-7}} = 46817 = 13 hours$$

The air temperature at the outlet of the duct is equal to

$$t_L = t_0 + \bar{\varphi} St^{/} \cdot \theta_w \cdot (t_{soil} - t_0)$$

$$\varphi_L = \frac{t(L,t) - t_0}{t_{soil} - t_0} = \bar{\varphi} \cdot St^{/} \cdot \theta_w$$

$$\theta_w = 1 - \frac{Bi^{/}}{Bi^{//}} f_1(x),$$

Where

$$f_1(x) = 1 - \exp\left(Bi^{//}\sqrt{Fo}\right)^2 erfc\left(Bi^{//}\sqrt{Fo}\right) = 1 - \exp(1)^2 \cdot erfc(1) = 1 - 2.72 \cdot 0.157 = 0.572$$

$$\theta_w = 1 - \frac{Bi^{/}}{Bi^{//}} f_1(x) = 1 - \frac{0.33}{0.71} \cdot 0.57 = 0.73$$

$$\varphi_L = \bar{\varphi} \cdot St^{/} \cdot \theta_w = 0.43 \cdot 2 \cdot 0.73 = 0.63$$

$$t_L = t_0 + \bar{\varphi} St^{/} \cdot \theta_w \cdot (t_{soil} - t_0) = -16 + 0.63 \cdot (10 + 16) = +0.44^oC$$

The amount of heat removal in a time τ is equal:

$$\Delta Q = 2 \cdot Po^{/} \cdot c \cdot \rho \cdot V \cdot (t_{soil} - t_0) \cdot Bi^{/} \cdot Fo$$

$$Fo = \frac{a_{soil}\tau}{R_0^2} = \frac{5.2 \cdot 10^{-7} \cdot 46817}{0.11^2} = 2$$

$$Po^{/} = 1 - \frac{Bi^{/}}{Bi^{//}} f_3(x),$$

where

$$f_3(x) = 1 - \frac{2}{\sqrt{\pi} \cdot Bi^{//} \cdot \sqrt{Fo}} + \frac{f_1(x)}{\left(Bi^{//} \cdot \sqrt{Fo}\right)^2} = 1 - \frac{2}{\sqrt{3.14 \cdot 1}} + \frac{0.57}{1^2} = 0.44$$

$$Po^{/} = 1 - \frac{Bi^{/}}{Bi^{//}} f_3(x) = 1 - \frac{0.33}{0.705} \cdot 0.44 = 0.79$$

$$\Delta Q = 2 \cdot Po^{/} \cdot c \cdot \rho \cdot V \cdot (t_{soil} - t_0) \cdot Bi^{/} \cdot Fo = 2 \cdot 0.79 \cdot 1.47 \cdot 1700 \cdot 1.9 \cdot (10 + 16) \cdot 0.33 \cdot 2 = 129092 kJ$$

The average capacity of the air ventilation system is

$$P_{aver} = \frac{\Delta Q}{\tau} = \frac{129092}{46817} = 2.75 kW$$

The air duct feeding zone:

$$\overline{R_z} = 4\sqrt{Fo} + 1 = 4\sqrt{2} + 1 = 6.6, \quad R_z = R_0 \cdot \overline{R_z} = 0.11 \cdot 6.6 = 0.726 m$$

Then Stanton's criterion is equal:

$$St^{/} = \frac{Nu}{\mathrm{Re} \cdot \mathrm{Pr}} \times \frac{2L}{R_o}, \quad St^{/} = \frac{Nu}{\mathrm{Re} \cdot \mathrm{Pr}} \times \frac{2L}{R_o} = \frac{78.48}{35427 \cdot 0.712} \times \frac{2 \cdot 12}{0.11} = 0.68$$

The Bio criterion is equal:

$$Bi = \frac{\alpha \cdot R_o}{\lambda_{soil}} = \frac{9.02 \cdot 0.11}{1.3} = 0.76$$

$$Bi^{/} = \overline{\varphi} \cdot Bi; \quad \overline{\varphi} = \frac{1 - \exp(-St^{/})}{St^{/}} = \frac{1 - ext(-0{,}6788)}{0.68} = 0.73,$$

$$Bi^{/} = 0.73 \cdot 0.375 = 0.554, \quad Bi^{//} = Bi^{/} + 0.375 = 0.554 + 0.375 = 0.929$$

3. Discussion of results

The experimental energy saving ventilation system was built in the sheepfold for lambing in Almaty region. The registration of thermo technical parameters of ventilation system (temperature of the outer, inside air, soil and humidity external and internal air) was made using the information-measuring system [3, 4]. To transfer data to the computer modem operator is connected working in master mode after the signals are transmitted to the processing and visualization.

Underground heat exchangers - air conduits are made of corrugated plastic pipe of LLP "EPA Almaty" production. Pipes are made from high density polyethylene, the nominal inner diameter from 110 mm to 630 mm. GOST18599-2001. Pipes are produced with socket and muff joints. Specially designed outer surface of the pipe has a high ring stiffness and makes them more resistant to compressive loads (transport, soil water, frost and soil compaction), and elastic structure pipe protects them from damage when exposed to overload. As the material of high density polyethylene has: a high tensile strength, have higher thermal stability and is not subject to corrosion.

The pipe is produced in the segments of standard length of 6 m and 12 m and is designed for underground lying to a depth of 15 m. For registration of thermo technical parameters of ventilation system, that is temperature of the outer, inside air, soil and humidity external and internal air have been developed information-measuring system. During tests energy saving ventilation system during the winter period found that the room temperature of the sheepfold ranged from $+5.4^0$C to $+6.0^0$C, on average $+5.6^0$C, with the number of measurements n=72.

The relative humidity of the room of the sheepfold was in average 79.2%. The maximum and minimum value of relative humidity was respectively 93.4% and 64.1%. At the lowest outdoor temperature -18^0C (04.02.2014) supply air temperature reached 6^0C. Supply flow rate fluctuate depending on the outdoor temperature within 70-140 m^3/h. The maximum heat output of installation was 2.2 kW.

During tests energy saving ventilation system in summer found that the room temperature of sheepfold ranged from $+16.6^0$C to $+27.29^0$C on average $+22.3^0$C, with the number of measurements n = 820. The relative humidity of the room of sheepfold averaged 30.5%. Maximum and minimum value of relative humidity was respectively 58.88% and 10.37%. At the highest temperature of the outside air +33.4°C supply air temperature reached $+19.6^{\circ}$C and humidity increased from 12% to 23%. Air flow rate was 140m^3/h. The cooling capacity of the installation was 2.6 kW.

Conclusion

In times of testing energy saving ventilation system provided the required power saving mode and zootechnical parameters of the microclimate in the maternity ward of the sheepfold. Energy saving ventilation system has been adopted for economic use and recommended for implementation in the sheep farms.

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