A method to minimize the intake of exhaust air in a climate control system in livestock premises

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Abstract. This paper presents a method of aerodynamic separation of supply-exhaust airflows in a supply and exhaust climate control unit for livestock facilities in order to minimize back suction. The air removed from livestock buildings contains a large amount of moisture, carbon dioxide, ammonia, hydrogen sulfide and other harmful gases and in mine units, the outlet and inlet openings are located close enough, which is why exhaust air can be sucked together with the supply air. The paper presents a set of measures to minimize back suction. In particular, the distance between the supply and exhaust openings is substantiated. Moreover, it was proposed to give an additional velocity to the exhaust air due to the energy of natural traction. In order to solve this problem, a nozzle with a convergence angle of 45° was installed at the outlet of the unit. The effectiveness of the proposed solution was tested experimentally and it was found that when the inlet and outlet openings were located at a distance of more than 0.5 m, as well as when the exhaust jet was given a velocity of 3 m/s, the amount of back suction did not exceed 5%.

1. Introduction
The effective management of livestock enterprises is impossible without strict compliance with sanitary requirements. First, this concerns the microclimate, which has a significant impact on the health and productivity of animals. For example, the deviation of the microclimate parameters from the required indicators leads to a decrease in animal weight gain by 20-30%, the life expectancy of the breeding stock by 15-20%, the resource of technological equipment by 10-50%, etc. [1-7].

During the organization of supply and exhaust ventilation, it is important to separate the supply and exhaust airflows, which is a serious task under the conditions of high concentration of production. This task is especially important for supply and exhaust ventilation systems of mine systems [1-7].

The purpose of the research is to minimize the intake of exhaust air in the supply and exhaust ventilation unit for livestock premises.

2. Materials and methods
Figure 1 shows the diagrams of the suction and exhaust plumes indicating the principal character of the distribution of the flow velocity of the supply and exhaust air. Obviously, the proportion of suction largely depends on the distance between the inlet and outlet openings, the size of the suction plume and the outlet velocity of exhaust air.
Placing the exhaust pipe outside the suction plume, we eliminate the suction of exhaust air. With distance from the suction opening, the air velocity will decrease and the dimensions of the suction plume can be outlined with a velocity of up to 0.2 m/s, since it is practically impossible to reliably measure lower velocity in production conditions. Consequently, with a fixed capacity of the unit, the dimensions of the suction plume will be finite.

Obviously, the more kinetic energy the exhaust air jet has, the further it will move away from the supply port.

During the operation of air handling units, it is necessary to strike a balance of performance. However, natural draft makes a significant difference, which contributes to the increase in the performance of exhaust system.

Installing a pipe at the outlet, we increase the velocity of the exhaust airflow, balance the performance of the supply and exhaust systems.

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\begin{align*}
\Delta p_{\text{exh}} - \Delta p_{\text{nat}} + \Delta p_{\text{pipe}} & \approx \Delta p_{\text{sup}}, \\
\Delta p_{\text{nat}} & = (\zeta_{\text{pipe}} + \zeta_{\text{out}}) \frac{\bar{\rho} \cdot v_{\text{out}}^2}{2}, \\
v_{\text{exh}} & = f(\alpha; \zeta_{\text{pipe}}, \zeta_{\text{out}} \ldots) \rightarrow \text{max},
\end{align*}
\]

where: \(\Delta p_{\text{sup}}, \Delta p_{\text{exh}}, \Delta p_{\text{pipe}}\) – air resistance of the supply air, exhaust system and pipe, Pa; \(\Delta p_{\text{nat}}\) – natural draft, Pa; \(\zeta_{\text{pipe}}, \zeta_{\text{exh}}\) – coefficient of local resistance of the pipe and the outlet of the free drowned jet; \(v_{\text{out}}\) – air velocity at the outlet of the pipe, m/s; \(\alpha\) – angle at the tip of the pipe, degree.

Let us draw the dependence of the zone of influence of the suction plume on the velocity at the entrance to the inlet opening. If the flow rate is constant, this characteristic depends only on the area of the inlet port (Figure 2).
The calculation results show that when the distance between the inlet and outlet is more than 1 m, the suction is insignificant, and at a distance of more than 0.5 m, the ratio of the sides of the suction opening ceases to have a significant effect on the proportion of suction.

Despite the differences in forms, reducers obey some general laws. In particular, the dependence of the coefficient of local resistances on the convergence angle is traced, which is a saddle-type curve, the optimum for most transitions is in the range from 30° to 50° (Figure 3). The resistance can be reduced to losses along the length in the case of small Reynolds numbers and the use of reducers with curvilinear generators and small convergence angles.

The convergence angle of 45° is the most attractive from both energy and technological points of view. With a resistance of 5±1 Pa, the air velocity at the outlet is 2.5-3.0 m/s. The experimental studies were carried out on a laboratory setup (Figure 4). In order to describe it, the prototype unit 9 is made of acrylic glass. Fans 13 and 12 respectively perform the supply and exhaust mechanically.
Figure 4. Laboratory setup No. 1 (a - general view; b - diagram): 1-controller display 5; 2-thermohygrometer; 3- thermo-hygrometer sensor 2; 4 - fan velocity regulator 16; 5 - fan velocity regulator 12; 6 – fan switch 13; 7 – vane anemometer-thermometer; 8 – differential manometer; 9-prototype; 10-inlet port; 11-outlet pipe, 12-supply fan; 13 – exhaust fan; 14– probe of anemometer-thermometer 7; 15 – valve; 16 - fans; 17-inlet pipe

Fans 16 are connected via a pulse-width modulator (PWM) 4, which allows flexible regulation of the fan velocity. In order to reduce aerodynamic drag, the unit is equipped with a smooth inlet pipe 17. The control of the temperature and relative humidity of the ambient air is recorded by thermohygrometer 2, sensor 3 of which is located on the dashboard.

Flow-pressure characteristics are measured by an anemometer-thermometer 7 with a probe 14 and a differential manometer 8. Probe 14 is installed in the aerodynamic system coaxially through the valve 15.

3. Findings

Figure 5 shows the propagation of the exhaust airflow without and with a pipe. It is found that at a velocity of 1 m/s, the flow forms an angle at the apex of 21°, the boundaries are poorly defined and the influence of the convective component is pronounced. The average range is 4.2 calibers and at a distance of three calibers, the jet is extinguished.

During the use of the pipe, the jet velocity at the outlet was 3.5 m/s (Figure 5 b), the jet angle was 2.5-3 °, the air jet had clear boundaries. The average range was 10.4 calibers; the increase in range was 76% taking into account the reduction in the caliber of the outlet.

Figure 6 shows the results of the research on the proportion of suction of the exhaust air to the supply air. The calculated value of the Fisher criterion was 15.7, which was less than the tabulated one (19.2) i.e. the model was adequate. According to these results, at the outlet velocity of more than 3 m/s, the mass fraction of suction did not exceed 5%.
Conclusion

During the course of the research, it was found that in mine climatic plants, suction of the exhaust air together with the supply air is possible. Due to natural draft with equal aerodynamic characteristics, the exhaust system turns out to be more efficient, which negatively affects the efficiency of heat recovery and the operation of the microclimate system in general. In order to compensate the imbalance and dilution of the exhaust and supply airflows, the exhaust pipe is installed - a pipe that...
increases the air velocity at the outlet of the unit to 3-3.5 m/s and provides the increase in the range of the exhaust air jet by 76% due to the energy of natural draft. Such a measure, in conjunction with the dilution of the supply and exhaust ports at a distance of at least 0.5-1 m allows reducing the amount of suction of the exhaust air together with the supply air to the values not exceeding 5%.

References

[1] Ershova I A, Vasilyev A, Samarin G, Tikhomirov D, Normov D, Ruzhyev V and Ershov M 2019 Development of the experimental heat exchanger for obtaining energy from phasetransition water-ice International Transaction Journal of Engineering, Management and Applied Sciences and Technologies 11(1) 1

[2] Gulevsky V A, Ryazantsev A A, Nikulichev A A and Menzhulova A S 2018 Mathematical modelling of processes of heat and mass transfer in channels of water evaporating coolers Journal of Physics: Conference Series 1015 32-52

[3] Shatsky V P, Gulevsky V A and Chesnokov A S 2012 Joint modelling of heat and mass transfer and aerodynamic processes in evaporative water coolers Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture 3(15) 26-32

[4] Shatsky V P, Vysotskaya Zh V and Gulevsky V A 2009 To the question about work of water-evaporating coolers Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture 3-4 (3-4) 46-51

[5] Tikhomirov D A, Dudin S N, Trunov S S, Rastimeshin S A, Tikhomirov A V and Kuzmichev A V 2019 Combined electric accumulation unit for air heating Revista de la Universidad del Zulia 10(27) 168-183

[6] Tikhomirov D A, Trunov S S, Kuzmichev A V, Rastimeshin S A and Shepovalova O V 2020 Energy-efficient thermoelectric unit for microclimate control on cattlebreeding premises Energy Reports 6(S6) 293-305

[7] Tikhomirov D A, Vasilyev A N, Budnikov D and Vasilyev A A 2019 Energy-saving automated system for microclimate in agricultural premises with utilization of ventilation air Wireless Networks 1-8