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Research Article

The Impact of Ventilation System Type on the Microclimate of Boar's Pen and Their Clinical Triad Parameters

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Abstract: The purpose of the study was the impact of different types of ventilation systems in boar`s pen on the microclimate and their physiological parameters. The control group of boars was kept in a house with a transverse ventilation system, and the animals of the experimental group were kept in a geothermal air supply. It was found that, regardless of the season, transverse ventilation provides a significantly higher air velocity and relative humidity: in Winter - 0.15 m s^{-1} and 5.4%; in Spring - 0.35 m s^{-1} and 5.3%; in Summer - 0.41 m s^{-1} and 0.7%; in Autumn - 0.28 m s^{-1} and 8.1%. Maintaining a stable temperature by the normative values in the boar housing was due to geothermal ventilation, regardless of the season, especially the "basement effect" was observed in the summer months, where the air temperature was cooled to 4.5°C ($P < 0.001$), compared to the transverse ventilation system. Compared with the boars in-the experimental group, under the influence of the temperature increase in Summer, the boars in the control group increased significantly the respiratory rate to 50.9 ppm ($P < 0.001$) and heartbeat rate of 45.7 ppm ($P < 0.001$). An increase in rectal temperature in boars at elevated ambient temperature under both air ventilation systems was not found. The obtained results make it possible to introduce the use of cost-effective geothermal air supply technology in pig farms to harmonize the physiological parameters of boars to meet their biological needs, even in closed housing to improve their welfare.

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1. Introduction

According to the United Nations, as of November 15, 2022, the world's population reached 8 billion people, and the population growth forecasts from the same global organization are as follows: 8.5 billion in 2030, 9.7 billion in 2050, and 10.4 billion in 2100 (United Nations Department of Economic and Social Affairs, Population Division, 2022). Based on the above prerequisites, global population growth by 2050 will increase the food demand by about 60% (Mun et al., 2021). This will mean that livestock producers will need to spend more energy soon to increase the number of animals to meet the needs of a developing population and balance food and nutrition security (Ofuoku and Ekorhi-robinson, 2020; Wijaya et al., 2023). In addition, animal proteins belong to some foods with an amino acid composition similar to that of human proteins, so their digestibility in the human digestive system is 90-98%, which is the main reason why the world's population uses up to 25% of animal proteins (Mottet et al., 2017). For this reason, raising animals in enclosed spaces with regulated humidity, temperature, and other parameters, also known as livestock houses, is essential. According to Costantino et al. (2021), the outcome is that contemporary livestock complexes are highly automated systems for producing pork that run with the least amount of expenses, the highest level of technology, and the greatest possible production capacity to comply with legal needs for housing pigs from various technical groups.

These facts are contributing to a profound transformation of energy systems in livestock buildings, which are gradually shifting from fossil fuels to more sustainable and low-carbon energy sources such as photovoltaic, solar thermal, and geothermal energy (Kim et al., 2023). As noted by Krommweh et al. (2014), the use of renewable energy is an important alternative to fossil resources in the agricultural sector, particularly in pig production. At the same time, the use of alternative energy in pork production is necessary to reduce the industry's environmental impact, as well as to ensure the welfare of pigs to normalize the biological needs of pigs by keeping them at industrial complexes (Krommweh et al., 2014).

Energy has become increasingly important to agriculture from an economic and environmental standpoint throughout the past year, particularly amid the aggressor country's huge shelling of Ukraine's energy facilities. In light of this, renewable energy sources like geothermal energy are gradually replacing fossil fuels, as mandated by EU legislation.

The meteorological conditions of the southern region of Ukraine, in particular Zaporizhzhya region, are temperate continental with mild winters with little snow and particularly hot summers. In this regard, the temperature, humidity, and quality of the air pool in pig housing are important care parameters, and temperature control is crucial for pigs, as a slight change in internal temperature has a negative impact on behavior, health, growth, performance parameters and, as a result, welfare (Lacetera, 2019; Gody et al., 2020; Gourdine et al., 2021; Costantino et al., 2022). Even with complete feeding, obtaining high-grade protein from premium pork is unachievable without guaranteeing balanced microclimatic factors. In Ukraine, temperature fluctuations are quite pronounced throughout the year (Figure 1), and therefore there are still problems with the air temperature inside the pig housing.

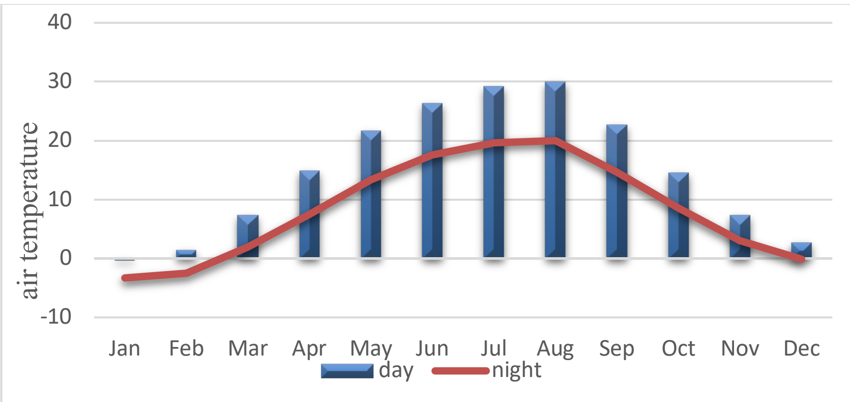

Figure 1. Day and night air temperature in the Zaporizhzhya region in 2021.

Source: data from the Ukrainian Hydrometeorological Center of the State Emergency Service of Ukraine as of 2021 in Zaporizhzhya region.

With changes in ambient temperature, the metabolism of pigs increases, which leads to a decrease in the efficiency of feed resources and an increase in the time to reach slaughter weight. Thus, the geothermal ventilation system is suggested as a way to enhance the pig housing's microclimate, boost the pigs' performance traits, avoid pig infections, and reduce the emission of noxious gases and odors during high or low ambient temperatures. Geothermal ventilation systems, in which the supply air travels via stones placed beneath the chamber and basement air supply ventilation systems. The temperature of the ground, which can reach up to 10 °C in the summer and 5 °C in the winter, causes the supply air to heat or cool in subterranean ducts or as it travels through the stones. Additionally, geothermal ventilation with stone cushions is used for the boars. Beneath the structure are three-meter-deep pits filled with slabs, and the floor is covered in broken stones. Thus, the cooled air passes through the trench, cools down to 12 °C, and then goes to the boars. As a result, the temperature does not rise above 24 °C indoors, even though it can be over 40 °C outside.

In connection with the above, the aim of the study was to investigate the effect of different types of ventilation systems on microclimate and physiological parameters in pig barns.

2. Material and Methods

2.1. Ethics

Regulations on the protection of animals and their comfort (Council Directives 2008/120 / EU, 2010/63/EU) and the Order of the Ukrainian Ministry of Economy governed the conditions for feeding, watering, housing, care, prevention, and treatment. Boars were handled in the tests in a way that complied fully with bioethical guidelines for the humane treatment of animals. October 28, 2021 (007/2021) saw the approval of the experimental protocol by the Bioethics Commission of the National University of Life and Environmental Sciences of Ukraine.

2.2. Experimental design

Experimental studies were carried out at the period of 2021, at the farm of Ukraine - Private Joint Stock Company “Plemzavod “Stepnoy” Zaporizhzhya region. A total of 18 boars of Large White, Landrace, and Duroc breeds were used in the experiment (Figure 2).

Figure 2. Breeds of boars kept on the farm.

Source: photo by the authors.

The average live weight of boars aged 24 months was: Large White - 325 kg, Landrace – 330 kg, Duroc - 326 kg. They were kept on litter in individual pens with an area of 7 m^2, on a concrete floor with thermal and moisture isolation. The boars of different breeds selected for the experiments were clinically healthy. The pig housing used forced transversal and geothermal ventilation with electronic control. Boars were fed individually with a pelleted complete feed «Eber» 2.8-3.0 kg of feed per head/day of nutritional value: a crude protein content of 202.630 g/kg and an exchange energy of 12.406

MJ/kg. The composition of 1 kg of granulated feed «Eber» produced by "Private Company "Alternative" Limited Liability Company contains the following ingredients (%): corn (20.000), wheat (18.355), wheat bran (25.000), soybean cake (22.645), sunflower meal (10.000), AminoMix Eber (4.000), (the certificate of quality according to the Technical Conditions of the State Standard of Ukraine 4508:2005). Feed was provided twice a day, at 8:00 a.m. and 4:00 p.m. The boars had constant access to drinking water from the nipples of watering devices.

Microclimate parameters during the keeping of boars corresponded to the Departmental Norms for Technological Design - Agro-Industrial Complex - 02.05 "Pig-breeding enterprises (complexes, farms, small farms)", 2005. The boars were divided into 2 groups of 9 heads each (3 heads of each breed). The control group of boars was kept in a house ventilated by a transverse ventilation system with wall air intake valves (1), exhaust wall fans (2), and an automated microclimate control system (3) (Figure 3). A computerized microclimate control system controlled the opening of the wall valves, which let air into the room, as well as the exhaust fans' speed.

1 2 3

Figure 3. Structural elements of transverse ventilation for keeping boars of the control group (Source: photo by the authors).

The design features of the ventilation system in the room where the boars of the experimental group were kept are the organization of air circulation by a geothermal system: air inflow from the environment is carried out through the air intake shaft (1), then the air flows through an underground tunnel-air duct (2), where it is additionally heated in winter or cooled in summer by soil energy before entering the room directly through the lower air racks (3), which are evenly located near the Exhaust fans of the shafts located on the ceiling extract air outside, and the functioning of the entire system is organized and controlled by a microclimate control device (4), Figure 4.

1 2 3 4

Figure 4. Structural elements of geothermal ventilation for keeping boars of the experimental group (Source: photo by the authors).

Both experimental groups of boars kept in houses with different ventilation systems had identical structures, were made of the same building materials, and were equally spatially located relative to the prevailing wind rose. The number of cages in both buildings was the same, with the same area, and a similar system of watering and feed transportation and distribution, manure removal was carried out by horizontal conveyors TSN-3 and remote conveyors on tractor trailers.

2.3. Measurement of microclimate parameters

The microclimate parameters were measured every month of the corresponding season of the year at the same time three times a day (at 7:00 am, 02:00 pm, and 10:00 pm). During the experiment in 2021, in both experimental groups of boars, indoor microclimate parameters were measured using certified devices: air temperature - pyrometer «Testo 810» manufacturer – «Testo AG» (Germany) with a range of non-contact surface temperature -30...+300 °C and an error of ±2 °C and air temperature - - 10...+50 °C with an error of ±0.5 °C; air velocity – thermo-anemometer «Testo 425» manufacturer – «Testo AG» (Germany) with a temperature measurement range: -20...+70 °C with an accuracy of ±0.5 °C, flow rate measurement range: 0...20 m $s^{-1}$and accuracy ±(0.03 m s^{-1}+ 5% of the measured value). Relative humidity was measured using a thermo-hygrometer «Testo 605» manufacturer – «Testo AG» (Germany) with a measuring range of 5-95% RH (±3.0% RH). The air content of ammonia (NH_3), hydrogen sulfide (H_2S) and carbon dioxide (CO_2) was measured using gas analyzer «DOZOR-SM» manufacturer – «SPE Orion» (Ukraine) with a measuring range for CO_2 of 0-10,000 ppm (±2,500 ppm), for NH_3 of 0-28.18 ppm (±7.05 ppm), and for H_2S of 0-21.12 ppm (±3.52 ppm). The equipment is certified in Ukraine and complies with DSTU 3377-96.

An electronic microclimate analyzer was used to record the dynamics of temperature swings in August, the hottest month of the summer. Throughout the course of the week, three independent sensors recorded variations in the microclimate's temperature every 60 minutes and stored the data on each sensor's internal electronic storage. Additionally, all sensor values were transferred to the central console via Wi-Fi switching to create a shared database. From there, a duplicate recording of the memory card was done. Three different locations were assessed for air temperature: 1. outdoors; 2. the boars' resting place, which is situated 25–30 cm above the ground; and 3. the standing area, which is situated 60–70 cm above the ground.

The degree of heat stress in pigs was determined by the temperature-humidity index (THI) developed by Thom (1959), which is a combination of two variables (air temperature and relative humidity) and allows for assessment of the need for cooling of animals and take the necessary measures to avoid heat stress. THI gradations: Suitable THI < 74; Mild: 74 ≤ THI < 78; Moderate: 78 ≤ THI < 82; Severe: THI ≥ 82.

2.4. Physiological data

Respiratory rate (RR) counted the number of uninterrupted flank movements (bpm) per minute (60 seconds) using a stopwatch. The heartbeat rate (HR) was measured in pigs using a portable veterinary pulse oximeter UT100V for pulse rate with a saturation interval of 25-350 bpm with an accuracy of ±2 bpm by fixing the device on the ears of the animal. The rectal temperature (RT) was measured using a digital thermometer inserted 50 mm into the rectum until the reading was constant.

2.5. Data analysis

Data were analyzed using Statistica 12.0 (StatSoft Inc., 2014, www.statsoft.com). Results are presented as mean ± standard deviation (X ± SD). The following significance levels were used for the study: $P < 0.05$, 0.01, and 0.001.

3. Results and Discussion

The analysis of the temperature in the boar housing in winter indicates a significant excess of its values in the room with geothermal ventilation by 3.6 °C ($P < 0.01$) (Table 1). It should be noted that the measurement of air velocity in a room with transverse ventilation in winter resulted in higher values of this microclimate parameter by 0.15 m s^{-1} ($P < 0.001$) and higher relative humidity by 5.4% ($P <$ 0.001).

The study of temperature changes in the spring made it possible to establish that the air temperature in the boar housing under the influence of the geothermal ventilation system was significantly higher by 2.5 °C ($P < 0.01$) than in the house with a transverse climate control system. Regarding the parameters of air velocity and relative humidity, the buildings with a transverse type of ventilation system had significantly higher values by 0.35 m s^{-1} ($P < 0.001$) and 5.3% ($P < 0.001$), respectively, than those with an underground type of air supply.

Because Summer ambient temperatures in the south of Ukraine have been and remain extremely high, with peak temperatures of 38.0 °C in the sun and average values of 29.9 °C, the air temperature in the boar housing also increases significantly with a transverse ventilation system - 28.9 °C, and with an underground tunnel type of air supply, its temperature was 24.4 °C, which is 4.5 °C significantly lower ($P < 0.001$). If there is a high ambient temperature, which in pigs exceeds the zone of their temperature neutrality, it becomes more difficult for animals to maintain temperature comfort due to their limited ability to sweat (Hörtenhuber et al., 2020; Lykhach et al., 2022; Hu et al., 2023).

Table 1. Microclimate parameters in a boar housing with different types of air ventilation systems throughout the season of the year, X ± SD

Parameter	Normative value	Season of the year			
		Winter	Spring	Summer	Autumn
Transverse ventilation					
Air temperature (AT)	17.0-19.0	15.6±0.74	16.3±0.56	28.9±0.48***	17.2±0.83
Relative humidity (RH)	40.0-65.0	63.6±0.52***	67.5±0.46***	43.4±0.34	70.5±0.39***
Air velocity (AV)	0.30-1.00	0.30±0.011***	0.45±0.008***	0.60±0.012***	0.45±0,010***
THI	< 74	59.6	60.7	75.8	62.1
Geothermal ventilation					
Air temperature (AT)	17.0-19.0	19.2±0.69**	18.8±0.49**	24.4±0,62	19.4±0,45*
Relative humidity (RH)	40.0-65.0	58.2±0.41	62.2±0.54	42.7±0,72	62.4±0,61
Air velocity (AV)	0.30-1.00	0.15±0.012	0.10±0.011	0.19±0.042	0.17±0.011
THI	< 74	64.5	64.2	70.2	65.0

Notes: Significant: * $P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$ (in comparison with the parameter of the different types of ventilation systems).
Source: author's measurement data and calculations.

As a livestock production and processing technologist, it is important to keep in mind that animals undergo heat stress when the air temperature in the boar-breeding room rises to +26 °C or higher. This stress directly impacts the primary reproductive function, the quality of the ejaculate produced by the boars, and causes morphological changes in the sperm (Forcada and Abecia, 2019; Gody et al., 2020; Gourdine et al., 2021; Kondracki et al., 2021). As a result, the quality of embryos decreases, embryonic mortality and abortions in the early stages of sow pregnancy are more common, and litter weight decreases (Mc Glone et al., 2019).

Therefore, the control of the microclimate in the housing allows to ensure the optimal temperature for boars, however, at extremely high external temperatures, which have been observed more and more often recently, it requires the use of an air-cooling system from the ground through underground shafts (channels), as in our case. Fixing the air velocity revealed a tendency to a significant excess of this value in the boar's housing with a transverse ventilation system relative to the same parameter with a geothermal ventilation system by 0.41 m s^{-1} ($P < 0.001$). It is noteworthy that throughout the Summer of the examined year, the relative humidity in boar housing with both ventilation systems ranged from 42.7 to 43.4%, meeting hygienic and sanitary norms. Regarding the Autumn period of the year, it should be noted that the temperature in the room at the boar's standing level with geothermal ventilation was recorded at 19.4 °C, which is within the norms of "VNTP-APK-02.05 - Pig enterprises (complexes, farms, small farms)", as well as the recommendations of PIC on the organization of the artificial insemination station. The temperature in the boar housing room with the transverse system in autumn was measured at 17.2 °C, which is significantly lower (P < 0.05) by 2.2 °C than ventilation with an air supply. The parameters of air velocity and relative humidity are higher by 0.28 m s^{-1} ($P < 0.001$) and 8.1% ($P < 0.001$), respectively, than those set for the transverse ventilation system.

Our research is consistent with the experiments conducted by Mykhalko et al. (2022), who found that a geothermal ventilation system normalizes the air temperature in pig farms, especially in Summer, reducing it by 3.9 °C (P < 0.01), which allows for maintaining thermal indifference in pigs at an appropriate level. However, these researchers compared different air ventilation systems in a farrowing shed, where the object of study was lactating sows and piglets.

In general, the TNI in the boar housing with both ventilation systems was in line with the norm and did not exceed 74. However, in the Summer the TNI in the boar housing was 75.8 with the transverse ventilation system, which clearly indicates the presence of a mild degree of heat stress in animals, which is a consequence of increased heart rate and respiratory rate compared to the norm. Niu et al. (2024), in the manuscript "Impacts of climate change-induced heat stress on pig productivity in China" measured the effect of heat stress on the production and output of the pig industry and found a significant negative relationship between the THI (a characterization of heat stress) and pig production. End up authors projecting the loss of production and output value of the pig industry under heat stress levels.

Both microclimate systems provided different gas compositions of the air in the boars' housing (Table 2). According to the legal requirements for the content of harmful gases in pig farms, the critical value of CO_2 is set at 2000 ppm. In our experiment, most often the level of carbon dioxide was below the critical value, depending on the ventilation flow rate and the outside air temperature. Thus, in a boar's housing under the influence of geothermal ventilation, the concentration of carbon dioxide in the air ranged from 1200 ppm (in Summer) to 2000 ppm, with $P < 0.001$ (in Winter). The latter value corresponded to the lowest ambient air temperature of 1.2 °C. Significant high concentrations of CO_2 in the air in the boar's housing were recorded with the geothermal microclimate system throughout the year, where the difference in Winter - 300 ppm ($P < 0.001$), in Spring - 200 ppm ($P < 0.001$) and in Autumn - 100 ppm ($P < 0.001$) compared to the same parameter of the transverse ventilation system. The results of our experiment are in line with the findings of Wenke et al. (2018), where the concentration of carbon dioxide in the air ranged from 1130 ppm (in Summer) to 4363 ppm (in Autumn) in a pig fattening room. According to Krommweh et al. (2014), Islam et al. (2016), and Mun et al. (2021), the geothermal air ventilation system has the resource capacity to reduce carbon dioxide and other harmful gases in pig housing. However, our experimental results do not coincide with the opinion of these authors and demonstrate that when using an underground air supply, the carbon dioxide content in the boar's housing was significantly higher in all seasons except Spring than in the transverse ventilation microclimate system, which is consistent with the reports of Mykhalko et al. (2022) in the lactating sow housing.

Table 2. Contents of gases content in boar housing throughout the year with various air ventilation systems, X ± SD

Parameter	**Normative value**	**Season of the year**			
		Winter	Spring	Summer	Autumn
Transverse ventilation					
CO_2, ppm	2000	1700±19.0	1400±12.2	1200±21.4	1900±16.1
NH_3, ppm	20.0	11.1±0.18	7.4±0.25	6.8±0.16	8.2±0.21
H_2S, ppm	10.0	1.2±0.06	1.5±0.12	1.8±0.21*	1.2±0.09
Geothermal ventilation					
CO_2, ppm	2000	2000±27.2***	1600±42.0***	1200±19.5	2000±16.6***
NH_3, ppm	20.0	12.4±0.34**	9.8±0.17***	7.4±0.24	8.7±0.21
H_2S, ppm	10.0	1.2±0.07	1.4±0.12	1.3±0.11	1.1±0.08

Notes: Significant: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$ (in comparison with the parameter of the different types of ventilation systems).
Source: author's measurement data and calculations.

According to Michiels et al. (2015), and Mun et al. (2021), ammonia and hydrogen sulfide are typical gaseous compounds in pig housing, which are produced by animals and, as a result of manure biotransformation, have a negative impact on the health of both pigs and staff by penetrating the respiratory system. The threshold limit for ammonia is 20.0 ppm. The ammonia concentrations measured during the experiment in the air of the boar's housing with geothermal ventilation were 7.4-12.4 ppm and with transverse ventilation - 6.8-11.1 ppm. With the underground air supply, the highest values of ammonia in the air for boars were recorded in Winter - 12.4 ppm ($P < 0.01$) and in Spring - 9.8 ppm ($P < 0.001$), compared to the transverse ventilation system. Forcada and Abecia (2019) found higher ammonia levels in the air with a valve ventilation system in a pig housing. According to Rong and Aarnink (2019) and Jo et al. (2020), ammonia content of 50 to 100 ppm causes pathologies in the tissues and organs of pigs, reducing their average daily weight gain by 10%. In our experimental case, the ammonia content in the air in the boar's housing, depending on both air ventilation systems, did not exceed the standard values in different seasons of the year.

Hydrogen sulfide concentrations of 50-100 ppm cause chronic and acute intoxication. According to Szabo (2018), people with toxicological effects of high doses of hydrogen sulfide in the air experience irritation of the mucous membranes of the respiratory system, visual analyzer, olfactory paralysis, loss of consciousness, pulmonary edema, and even death. Mykhalko et al. (2022) reported that higher temperatures in the pig housing and lower air velocity led to an increase in the concentration of hydrogen sulfide in the air. In our case, a similar significant increase in hydrogen sulfide content of 1.8 ppm ($P < 0.05$) was observed in Summer with the transverse ventilation system due to a higher air temperature for boars - 28.9 °C, compared to geothermal ventilation. It should be noted that in different seasons of the year, the hydrogen sulfide content did not exceed the standard values regardless of the air supply system.

In August, measured the oscillation of air temperature outside, in the area where boars lie at a level of 25-30 cm from the floor, in the standing area at a level of 60-70 cm from the floor, depending on the air supply system in the boar housing (Figure 5, Figure 6).

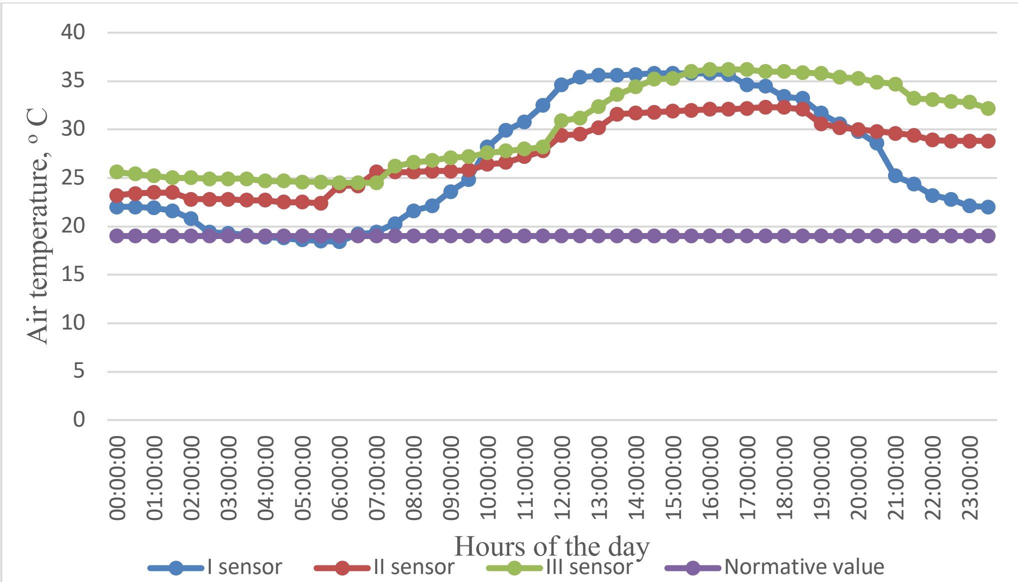

Figure 5. Oscillation of the air temperature of three sensors by transverse ventilation system in a boars housing in August (Notes: I sensor - air temperature outside; II sensor – air temperature area where boars lie at a level of 25-30 cm from the floor; III sensor - air temperature standing area boars at a level of 60-70 cm from the floor. Source: author's measurement data).

Observations show that from midnight to 6.00 am, the outside temperature steadily decreased from 22 °C to 18.4 °C, which is an obvious process at this time of year. Starting from 6.30 am, the outside temperature steadily increased from 19.2 °C to 35.8 °C by 2.30 pm. Then, the temperature remained unchanged at 35.8 °C until 4.00 pm. From 4.30 pm, the air temperature began to gradually and slowly decrease and by midnight its value stabilized.

However, the temperature parameters in the boar lying area at 25-30 cm from the floor and in the animal standing area at 60-70 cm from the floor differed depending on the type of climate control system in the boar housing.

August's average ambient air temperature was 26.7 °C at the time of measurement. With the transverse ventilation system, the average temperature in the boars' laying region was 27.5 °C, which is considerably ($P < 0.05$) 21.45% higher than the same parameter with the geothermal ventilation system. This area is located 25–30 cm from the floor.

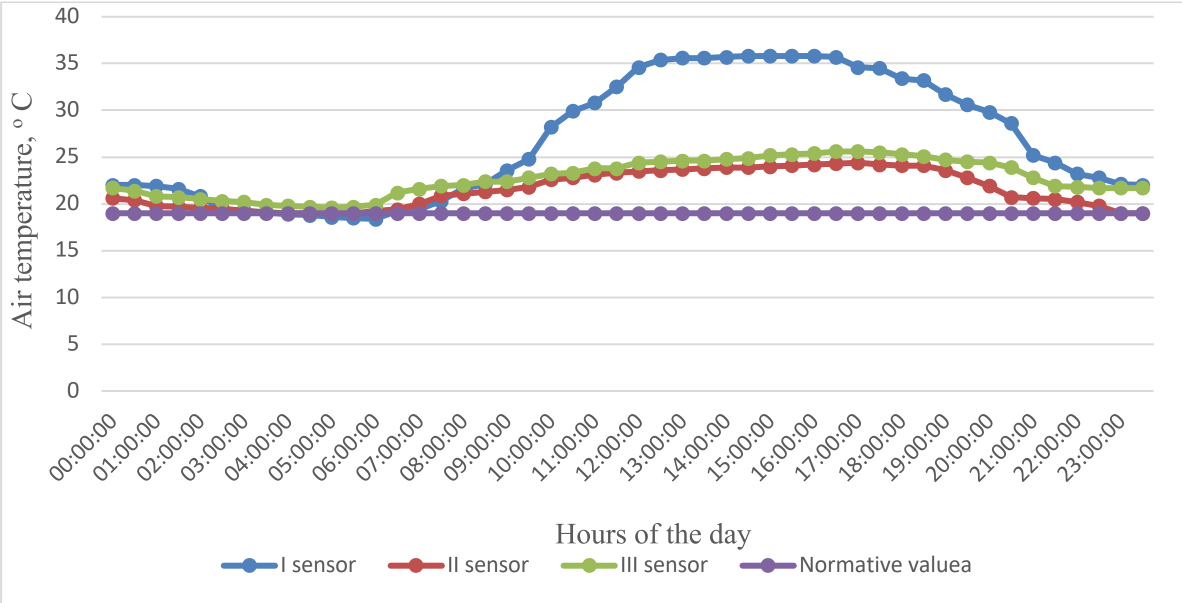

Figure 6. Oscillation of the air temperature of three sensors by a geothermal ventilation system in a boar housing in August (Notes: I sensor - air temperature outside; II sensor – air temperature area where boars lie at a level of 25-30 cm from the floor; III sensor - air temperature standing area boars at a level of 60-70 cm from the floor. Source: author's measurement data).

The temperature difference in terms of air cooling was in favor of geothermal ventilation in the boars' lying down area, as the air, having passed through the air ducts of the underground tunnel, lost 5.9°C of heat, which indicates the operation of the «basement effect» (Figure 7), which means that the underground cooling system copes with its main task.

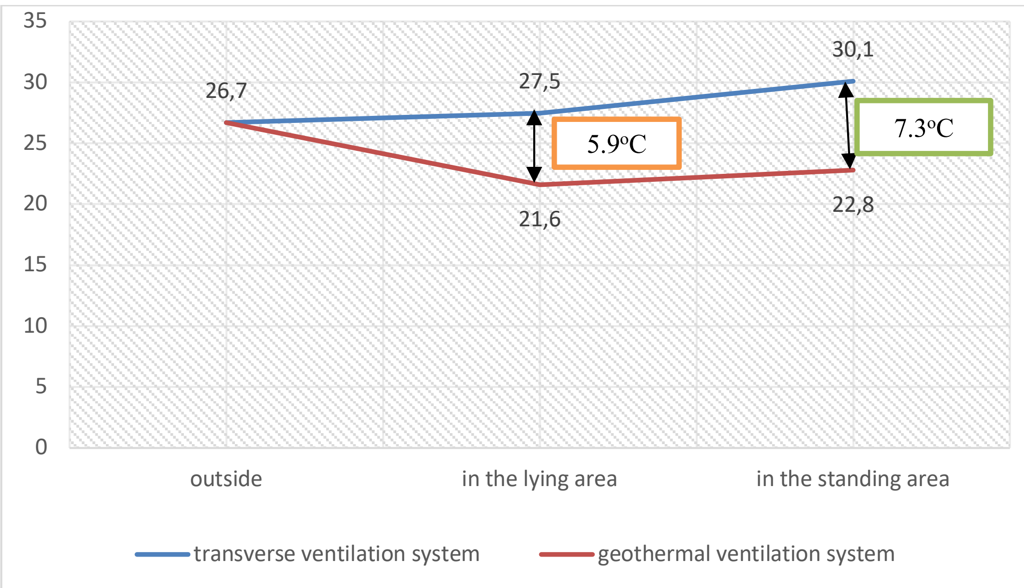

Figure 7. Temperature control in the boar housing (Notes: ↕ -the presence of the figure indicates the «basement effect»; ☐ ☐- air heat loss. Source: author's development).

In the area of boars standing at the level of 60-70 cm from the floor, the air temperature decreased by 7.3°C, or 24.25% (*P* <0.05) under geothermal ventilation, which again indicates the operation of the «basement effect». Instead, with the transverse air ventilation system, the average temperature at the level of boars' standing was recorded at 30.1 °C.

August's average ambient air temperature at the time of measurement was 26.7 °C. When using the transversal ventilation system, the average temperature in the boars' lying region, which is 25–30 cm from the floor, was 27.5 °C. This is considerably ($P < 0.05$) 21.45% higher than the same parameter when using the geothermal ventilation system.

The temperature factor influenced the physiological parameters of boars with different types of indoor ventilation systems (Table 3). As Ross et al. (2015) showed, the response of animals to heat stress begins with an increase in respiration rate, followed by a decrease in feed intake, leading to an increase in rectal temperature, an indicator of reduced productivity in pigs. Experimental results showed that under the influence of increased temperature, the respiratory rate of boars housing with transverse ventilation systems significantly increased the respiratory rate by 68.3% ($P < 0.001$) of boar pens with cooled air supply. Oliveira et. al (2024) reported that heat stress increased pigs' respiratory rate by 112%. It is worth noting that increased respiratory rate is the primary mechanism of heat dissipation in the pig body an effective physiological system for maintaining heat generation and transfer. On the other hand, pigs' typical respiratory rates range from 10.0 to 32.7 bpm, according to Lykhach et al. (2022). If the temperature difference between the boars' skin and the outside air decreases, heat transfer by convection becomes impossible. Then the mechanism of increasing the frequency of respiratory movements is activated to stabilize the body temperature, which becomes dangerous for the animals (Scriba-Janulis and Wechsler, 2021).

Table 3. Boars' clinical triad parameters based on the housing's ventilation system, X ± SD

Parameter	Type of ventilation		Normative value
	transverse	geothermal	
Heartbeats rate, bpm	$134.9 \pm 5.62^{***}$	89.2±4.25	80.0-100.0
Respiratory rate, bpm	$74.5 \pm 4.72^{***}$	23.6±3.29	10.0-35.0
Rectal temperature, ºC	39.2±2.44	38.6±1.78	38.0-39.0

Note: significant: $^{***}P < 0.001$ (in comparison with same parameter geothermal ventilation system);
Source: author's measurement data and calculations.

In terms of the heart rate parameter, boars housed in housing with transverse air ventilation as opposed to the geothermal system showed an increase in this signal by 45.7 bpm, or 33.88% ($P < 0.001$). The reason for this response is the direct activation of the hypothalamic thermal center, which triggers the cardiorespiratory system to try and evaporatively release heat through elevated heart rate and respiration (Rodrigo et al., 2018; Scriba-Janulis and Wechsler, 2021).

Measurements of rectal temperature in boars kept under different types of indoor ventilation systems did not reveal significant differences in the value of this indicator and were within the normative values, varying in the range of 38.0-39.2 °C. Thus, no increase in body temperature with an increase in ambient temperature was detected.

The results obtained from the experiment can be used to show schematically the effect of temperature under different ventilation systems used to maintain the metabolism of the boars (Figure 8).

The temperature zone in which the boars' metabolism is maintained at a constant level is called the thermoneutral zone, or comfort zone with warm and cool zones, in which animals maintain a constant body temperature through vasocontraction and vasodilation (Scriba-Janulis and Wechsler, 2021; Lykhach et al., 2023).

In the experiment conducted for boars, the thermoneutral zone was +17...+19 °C, which is consistent with the research Dekker, 2015. If the temperature reaches the lowest critical point (+5...0 °C), showed a drop in the body temperature of boars (hypothermia). Boars are more tolerant of low temperatures (Gourdine et al., 2021).

At ambient temperatures above +26 °C, boars reduce their movement, rest more time, and increase their body area to release heat from their skin. If the air temperature is above +30 °C, hyperthermia is observed, breathing becomes frequent, and appetite decreases up to the point of refusal to feed, end up leading to death (Lykhach et al., 2022).

The lower and upper temperatures of the thermoneutral zone are called critical temperatures. Therefore, when the air temperature is lower than the lower critical temperature, it is no longer possible to retain heat in the body by reducing heat transfer, muscle tremors are observed and animals are forced to increase the intensity of metabolism to produce heat. At air temperatures above the upper critical limit, there is an increase in heat transfer due to sweating and increased respiration (Dekker, 2015).

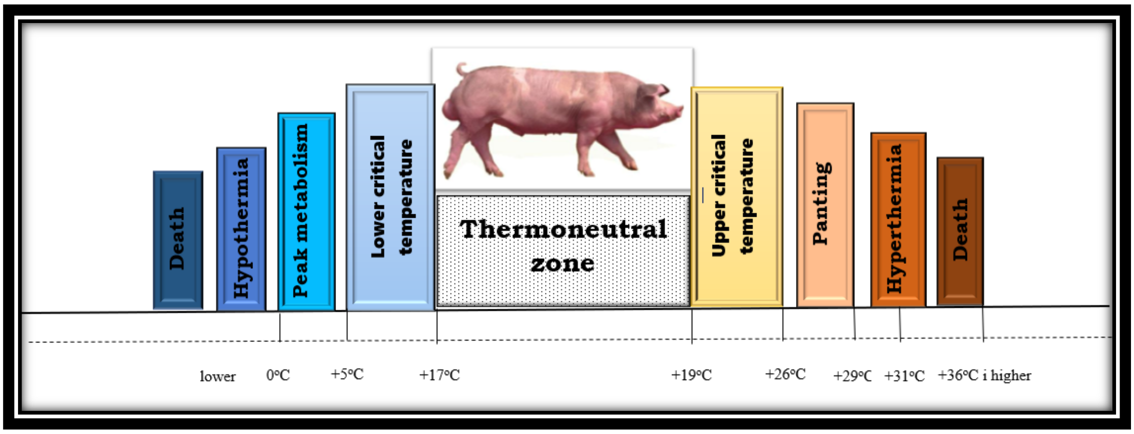

Figure 8. The effect of temperature under different ventilation systems used to maintain the metabolism of the boars (Notes: the lower critical temperature is the temperature of the environment with the lowest level of metabolism in boars at the lowest tension of heat transfer mechanisms, and the upper critical temperature is the temperature of the environment with a high level of metabolism in boars with reduced convection and increased heat transfer through the respiratory and circulatory systems with increased energy metabolism).

With energy prices on the rise both in Ukraine and globally, low-energy ventilation systems are becoming more profitable than ever. The economic efficiency of using different ventilation systems for boar housing is shown in Table 4.

Table 4. The economic analysis of using different ventilation systems for boar housing

Parameter	**Type of ventilation**		**+/- geothermal/ transverse**
	transverse	**geothermal**	
Average cost of a boar, UAH*	87300.00	87300.00	
EUR	2000.00	2000.00	
Average cost per day boar for 365 days of operation, excluding the cost of feeding, management and care, UAH*	239.20	239.20	
EUR	5.38	5.38	
Electricity consumption, kWh	10.00	2.50	
Electricity consumption for the day, kWh	240.00	60.00	-180.00
Electricity consumption for 365 days, kWh	87600.00	21900.00	-65700.00
Price of electricity consumption per 1 kWh, UAH*	6.00	6.00	
EUR	0.14	0.14	
Cost of electricity consumption per year, UAH*	525600.00	131400.00	-394200.00
EUR	11827.18	2956.80	-8870.38

Note: * - at average prices in the Ukraine in the first half of 2024.
Source: author's measurement data and calculations.

Based on the economic analysis, it was found that pig farms with a geothermal ventilation system will be able to save 394200.00 UAH (8870.38 EUR) in electricity consumption per year. Such a cost-saving technology in pig husbandry is extremely important for countries with hot climatic conditions and will reduce the heat load on animals through a geothermal cooling system and, as a result, improve boar welfare.

Conclusion

Monitoring of the microclimate in boar housing with the studied types of ventilation systems makes it possible to obtain significant information on the oscillation of air temperature and relative air humidity conditions during all seasons of the year. Based on the measurements and calculations, it was found that both the transverse ventilation and geothermal ventilation systems provide boars with microclimate parameters that meet biosecurity standards. The transverse ventilation system removes contaminated air from the room better, minimizing the negative impact of harmful gases on the physiological parameters of boars. However, the use of a transverse ventilation system did not ensure a comfortable temperature in the boar's housing and led to its exceeding 9.9°C in Summer. Therefore, the underground air supply ensures uniform air exchange, normalizing the temperature and air movement, providing standard humidity values at different times of the year, and copes well with the task of creating a satisfactory indoor microclimate for this technological group. In addition, the geothermal ventilation system provides a comfortable temperature for boars in Summer, which is particularly hot, thanks to the 'basement effect', which is confirmed by the normative values of the clinical triad parameters, and will save pork producers UAH 394200.00 (EUR 8870.38) in electricity consumption per year. Therefore, the study on the impact of ventilation systems on the microclimate of boar's housing and their physiological parameters is useful for pork farmers in developing strategies for sustainable practices that open up ways to ensure the comfort of boars and their welfare.

Ethical Statement

Ethical approval for this study was obtained from the Bioethics Commission of the National University of Life and Environmental Science of Ukraine (007/2021).

Conflict of Interest

The Authors declares that there are no conflicts of interest.

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Author Contributions

A. Deschenko, A. Lykhach, L. Lenkov participated in the design of study, performed the experiments and writing original manuscript. V. Lykhach, Y. Barkar, M. Shpetny assisted in performing the study, data arranging, and calculation. V. Lykhach and A. Lykhach critically revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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