Functional redundancy of air exchange processes in technological premises for poultry keeping

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Abstract. The article focuses on the problem associated with emergency power outages at poultry farms. Poultry farming is one of the key branches of agriculture underlying the implementation of the country's food security doctrine. The trouble-free operation of the technological equipment of poultry workshops is an important and essential condition for improving the productivity and health of poultry. The article presents a method for calculating the multiplicity of air exchange, which makes it possible to determine the optimal parameters of natural ventilation to stabilize microclimatic conditions in a poultry shop in the event of an emergency in the power supply system. The analysis of infrared thermography of the poultry housing confirms the presence of thermally stressed zones and the unevenness of their distribution, which is a prerequisite for creating a model for leveling temperature fields to a physiologically comfortable level for poultry. The article proposes to consider the issue of introducing refrigeration units into the production cycle as a method of solving the issue of livestock safety if it is necessary to transfer the ventilation system to a free-convection mode. The arguments put forward in the article are focused on the impossibility of the bird's vital activity during the transitional and warm periods, even with a short-term shutdown of the ventilation system. The creation of a temperature difference will provide a backup air exchange for the period of repair work. The analysis of electricity consumption at a poultry enterprise by month allows us to put forward a proposal to redistribute part of it to the cold storage process. The preliminary calculations carried out confirm the sufficiency of the part of the electricity allocated for the implementation of air-conditioned air exchange, with the "tunnel" type ventilation used.

1 Introduction

Poultry farming is one of the key branches of agriculture in Russia, which plays a significant role in the country's economy, meets the needs of the population for food and supplies raw materials for related industries. In modern conditions, the poultry industry is considered as one of the dominant components of the country's food security system [1-20].

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At the same time, the productivity of poultry as a source of biological raw materials is determined by the level of comfort of the microclimatic conditions of its maintenance. Therefore, when developing projects of poultry workshops for energy-saturated biotechnical complexes, methods and technical solutions that implement optimal operating parameters of the environment in the technological space of industrial premises are always considered as fundamental prerequisites for the development of production [1, 16, 17].

2 Material and methods

Ventilation of poultry workshops, where the maintenance and processing cycle does not involve a walking period, is given special attention, since controlling the thin air and speed of air flow solves the problem of dustiness and gas contamination of the technological space. The atmospheric composition, which contributes to the best well-being and the implementation of redox processes in the body, should contain approximately 78% nitrogen, 21% oxygen, 0.03% carbon dioxide, 0.94% argon, as well as a small amount of impurities of helium, hydrogen, ozone and other gases. In poultry farms with poor ventilation and excessive stocking density that does not meet accepted standards; there is a lack of oxygen (O_2), which leads to a decrease in the activity of metabolic processes occurring in the bird's body. In addition, the work of the cardiovascular system is disrupted. For the same reason, the concentration of carbon dioxide (CO_2) can reach 0.7%, which is almost three times higher than the maximum permissible level for poultry. Long-term exposure to high concentrations of carbon dioxide leads to a decrease in appetite and poor digestibility of feed, as a result, the live weight of poultry is reduced by 15-20%.

With any of the technological options for poultry cultivation, including industrial, one has to deal with the process of decomposition of manure, litter, remnants of stale feed, etc. As a result, ammonia (NH_3) and hydrogen sulfide (H_2S) are formed. The effect of these gases on a living organism has been deeply studied. Cases of exposure to mucous membranes, upper respiratory tract and eyes have been recorded; damage to the nervous system, decreased body resistance have been observed; puberty is delayed in birds. Due to the violation of oxidative reactions in the blood, complete respiratory and cardiac arrest may occur [2, 18, 19].

It should be noted: ammonia is lighter than air, therefore it does not accumulate in the lower part of the technological room, but circulates with air flows throughout the entire volume of the poultry workshop, unlike carbon dioxide and hydrogen sulfide. These gases are heavier than air - they most often accumulate in cesspools and manure trenches, but they also move under the influence of the pressure of ventilation systems that provide air exchange with the environment. In accordance with the technological design standards of poultry enterprises, the maximum permissible concentration of ammonia is 10 mg/m^3 and hydrogen sulfide – 5 mg/m^3.

When modeling the geometric and infrastructural elements of poultry buildings, it is necessary to form a priori subsystems for atmospheric air purification, sewage drainage, and timely removal of droppings. And, if we are talking about a multicomponent approach to maintaining hygiene and veterinary and sanitary culture, then a specific emphasis in ensuring the vital activity of the biological livestock of farms and complexes must be placed on the productivity and manufacturability of ventilation systems, on the reliability of which the full cycle of productivity of farmed poultry depends. It is reliable that birds are more adapted to low temperatures than to high ones. An increase in a chicken's body temperature by 2-3°C compared to standard values will lead to the death of the individual. But even at low temperatures, their anomalies develop - metabolic processes in the body accelerate, feed consumption increases, egg production and egg weight decrease, the functioning of the heart and respiratory organs is disrupted, and the functioning of the nervous system malfunctions. Therefore, when designing ventilation systems for poultry farms, both the above factors and the fact that different types of poultry at different periods of growth require different temperature conditions are taken into account. Namely, the optimal temperature for keeping chickens is 18°C, turkeys – 16°C, waterfowl – 14°C. In addition, if the poultry farm is equipped with a room for raising chicks, then the temperature in such a room should be maintained at 28-31°C and decrease as the chicks grow older. This is an important technological element, indicating the complexity and ambiguity in the technical solution of ventilation issues in poultry workshops [2, 3,18].

Moreover, in terms of the relevance of designing specialized equipment for the formation of air flows during technological air exchange and for conditioning the internal working space of poultry shops, one cannot ignore the indicator of the level of air humidity, the relative humidity of which, in this case, should be within 75%. This condition can be ensured by supply and exhaust ventilation, but at an optimal air speed of 0.6 m/s in the spring-summer period and 0.3 m/s in the autumn-winter period. Otherwise, with increased air humidity, the content of dust, and, consequently, pathogens, in the surrounding space may approach a critical mass, inevitably leading to the death of the bird. But it should be added that the design calculation of ventilation air flow will not be correct without taking into account heat gain from animals, artificial lighting and solar radiation. Only with full consideration of harmful factors can one reliably determine the air exchange rate when ventilating a room, and this is the main prerequisite for designing the power characteristics of supply and exhaust systems - up to the creation of specially equipped rooms with emergency backup functions. Only with full consideration of harmful factors can one reliably determine the air exchange rate when ventilating a room, and this is the main prerequisite for designing the power characteristics of supply and exhaust systems - up to the creation of specially equipped rooms with emergency backup functions.

By analyzing the pattern of air flows that affect the thermal regime of a typical poultry keeping room (Fig. 1), we can identify the main design elements characteristic of the methodological approach to the design of air exchange systems.

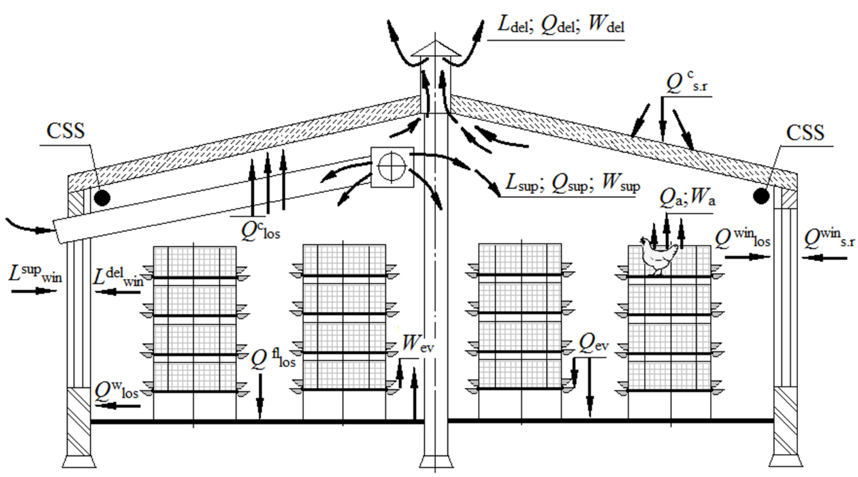


Fig. 1. Air exchange diagram providing thermal conditions: L_{del}, Q_{del}, W_{del} – the amount of air, heat and moisture removed from the room by the ventilation system; L_{sup}, Q_{sup}, W_{sup} – the amount of air, heat and moisture supplied to the room by the ventilation system; Q^{c}_{los}, Q^{w}_{los}, Q^{win}_{los}, Q^{fl}_{los} – heat loss through the ceiling, walls, windows and floor; Q_a, W_a – heat and moisture release by animals; Q_{ev}, W_{ev} – the amount of heat and moisture in the process of evaporation from open water and wetted surfaces; $Q^{win}_{s.r}$, $Q^{c}_{s.r}$ – heat input from solar radiation through windows and ceilings; L^{sup}_{win}, L^{del}_{win} – the amount of air entering or being removed through the windows; CSS – cold storage system.

Further synthesis of the algebraic transformations carried out into an algorithmic structure makes it possible to develop non-standard technical solutions already at the level of mathematical modeling without investing material costs in future full-scale objects [3, 4, 20].

As a rule, air exchange in a room is determined separately for warm, cold and transition periods at a density of exhaust and supply air of 1.2 kg/m^3. To determine the frequency of air exchange, it is necessary to take into account excess heat, moisture, harmful substances, as well as the specific flow rate of supply air. Knowing the overall dimensions of the poultry workshop, the number of individuals that are planned to be kept in it, and their main morphological characteristics, it is possible to reliably determine the optimal parameters of the air exchange regime for the planned premises. However, setting the problem of optimizing operating characteristics when modeling ventilated air flows involves the development of a special calculation and methodological algorithm that takes into account heat input from animals, heat input from artificial lighting, heat input from solar radiation, taking into account heat input from window openings. Thermal power N can serve as a criterion for the intensity of heat release (Fig. 2) [5, 6].

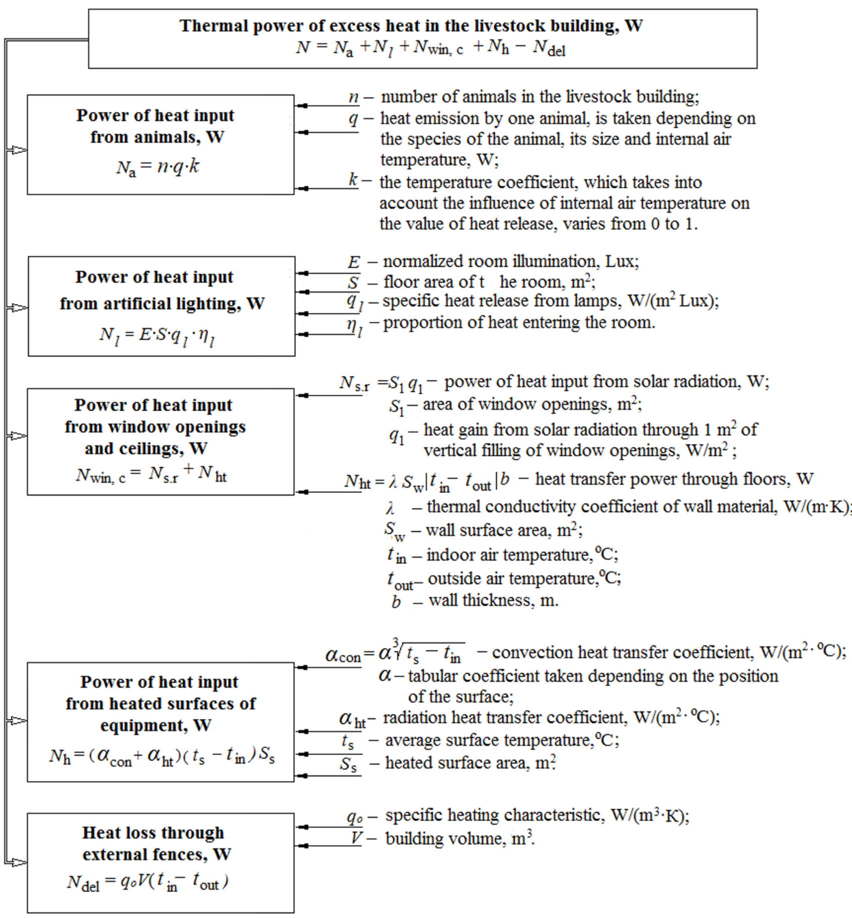


Fig. 2. The algorithm for calculating heat input in a livestock building.

When assessing the state of the microclimate in a room, the parameters of the air exchange regime will have to be calculated based on excess moisture. And, if in a poultry workshop the calculation of moisture release is made taking into account the drying of droppings, then when working with animals, the moisture supply to the holding area depends on their type, their activity and, of course, on the ambient temperature. A feature of this methodological approach is the need to take into account “latent” heat releases, based on the type and number of birds kept (Fig. 3).

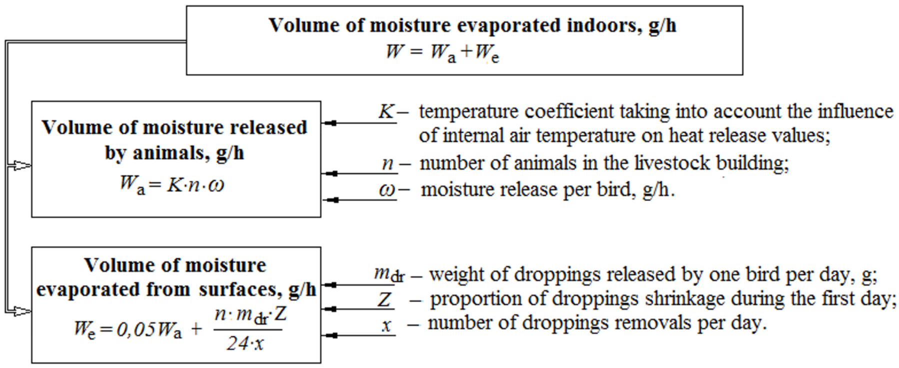


Fig. 3. Algorithm for calculating the volume of moisture generated in a livestock building.

As mentioned above, premises containing large numbers of poultry or other animals are typically filled with toxic gases - ammonia, hydrogen sulfide and carbon dioxide. Carbon dioxide poses a separate problem because it is a product of the emissions of serviced animals. It is based on carbon dioxide that the design scheme of air exchange is structured, aimed at ventilating air flows adequately to the mass of released harmful substances. But, if technologically the designer is forced to work in the integrated area of heat input - even minus the heat loss of the room, which is compensated by heat input from heating devices, then the calculation of air exchange when creating a model for the distribution of thermal fields will most likely be implemented based on the condition of removing water vapor, that is, from the condition of moisture release inside the room [7].

In principle, there is no contradiction here, since the larger of the two calculated ventilated air flow rates is accepted according to regulations. After this, the air flow per centner of live weight of the bird is established. In the case when the obtained value is less than the recommended air exchange rate for the cold period of the year [3], then the flow rate of ventilated air should be determined using the recommended air exchange indicator, focused on the total live weight in a specific volume of a livestock building.

However, it is necessary to take into account that the heat and humidity conditions of poultry premises during the transitional and warm periods are characterized by the presence of excess heat, since during these periods the technological heat gains exceed the heat losses of the premises. Calculation of air exchange during these periods of the year is made based on the conditions of simultaneous removal of excess heat and moisture. In this case, the theoretical model will be synthesized taking into account the thermal power of the total heat emission of all animals, the thermal power of heat emission from the lighting system, the thermal power of solar radiation. Only the thermal power of heat loss through external fences is not taken into account. It should be noted that, despite the calculation and methodological analogy with the information model (Fig. 4), in this case, when the transitional and warm periods are considered, we are talking about heat excesses that directly determine the value of thermal power and, accordingly, the state of the air during ventilation of building (Fig. 2) [8, 9].

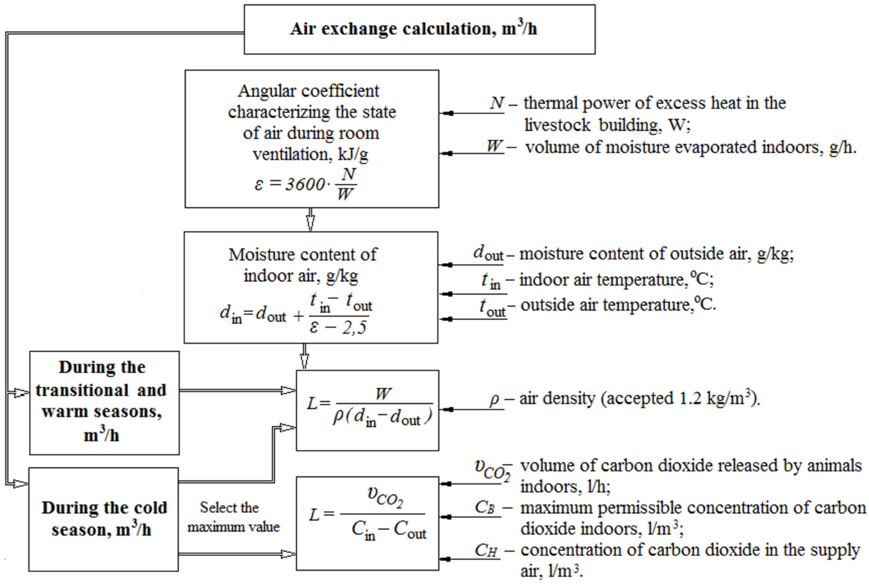


Fig. 4. Algorithm for calculating air exchange in livestock buildings.

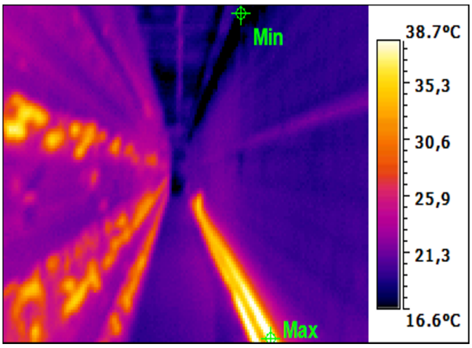
Ventilation air flow during transitional and warm periods is calculated taking into account the moisture content of indoor and outdoor air during the specified periods of the year, based on the condition that the moisture content of indoor air is determined at the maximum permissible relative humidity.

For the reliability of calculations, it is necessary to take the internal air temperature in the transition period of the year in accordance with the standards for keeping poultry (but not less than 15ºC), and in the warm period of the year - higher than the average temperature of the hottest month by no more than 5ºC (but not higher than 33ºC for poultry houses). At $\varepsilon \approx 2{,}5$ kJ/g, the temperature of the indoor air is assumed to be equal to the outdoor temperature.

3 Results and discussion

An assessment of the adequacy of the proposed theoretical provisions to the real thermal state of the poultry workshop was carried out at a local poultry farm through thermal imaging monitoring of the designated windowless technological facility with a total usable area of 1728 m^2, with a capacity of 71540 heads of laying hens. At the surveyed enterprise, all poultry workshops are equipped with mechanized cage batteries, central heating, water supply, sewerage and forced supply and exhaust ventilation. The microclimate in poultry shops is ensured by a complex of heating and ventilation units; is regulated automatically within specified limits, in accordance with veterinary standards.

Goal setting for thermal imaging control was determined based on the need to improve the ventilation system, taking into account extreme periods - failure of power supply equipment. During the transitional and warm periods, when there is a power outage, the risk of losing a significant number of poultry is extremely high, even in the event of a short-term emergency failure. Therefore, the upgraded ventilation systems must provide the physiologically necessary air exchange for the serviced livestock in a natural supply and exhaust mode, which does not allow the death of poultry for the period of time required for the restoration of electricity supply. We are talking about creating a design for a backup system, the implementation of which requires a reliable determination of thermal stress points and fields, as well as the dynamics of heat exchange and its logistics in terms of redistribution of air flows during their emergency transition to convection mode. In addition, objective information is required about partial and total heat losses, about hidden construction defects, and about the degree of resistance to heat transfer of enclosing structures. The relevance of these indicators is undoubted, especially when using modern cage batteries with a high density of poultry, creating broadband thermally stressed zones, which was confirmed by thermal imaging thermography inside the poultry workshop (Fig. 5).



infrared image

visual image

Background temperature	22,6°C
Max temperature	41,2°C
Min temperature	9,3°C

Fig. 5. Thermal imaging control of thermally stressed fields of a poultry workshop.

In this regard, the thermal image of the external and internal contours of the poultry keeping room was taken in the winter-spring season, when the uneven distribution of temperatures inside the poultry workshop is most pronounced. It turned out that the maximum temperature - (36...38 ° C) is observed in chickens located on the upper tiers of cages. While in the lower and middle tiers lower temperatures prevail. The heterogeneity of the distribution of poultry body temperature, first of all, indicates the need for work related to optimizing the distribution of heat sources - heating equipment in the technological space of the poultry house. At the same time, this kind of assessment of the thermal insulation qualities of the building envelope showed that the inevitable heat losses during the cold season represent an unformed model of heat-mass exchange in the system of convection flows at a power level adequate to the thermal gradient within the boundaries of the premises being examined. So, for example: the minimum temperature - (1...5°C) is recorded on the ventilation shafts, on the supply valves, near the doors and windows of the poultry house. The background temperature inside the poultry house has a difference in the range (14...30°C), which, according to known physical and mathematical dependencies, is easy to convert into the power characteristics of the air flows required for organizing heat exchange. When modeling the microclimatic zone for transitional and warm periods, it is necessary to take into account the ambient temperature, but as preliminary calculations have shown, for effective convection air exchange, the temperature range in the technological space must have a negative level. That is, in order to ensure air exchange through supply and exhaust ventilation without forced movement of the air mass, which is extremely necessary in the event of an emergency shutdown of the power supply to a poultry farm, it will be necessary to create sources of low-potential energy in advance. This means the accumulation of cold in zones along the route coordinates of air flows, which will not only enhance convective heat transfer, but also provide design power and timing indicators - depending on the degree of destruction of the power supply system. This means the accumulation of cold in zones along the route coordinates of air flows, which will not only enhance convective heat transfer, but also provide design power and timing indicators - depending on the degree of damage to the power supply system. There is no issue with the technical implementation of creating low-potential temperature zones with the modern range of refrigeration equipment. The problem is finding an electricity resource for the refrigeration process. The solution to this problem is of an applied production-territorial nature and can only be implemented as a result of a thorough analysis of the entire technological chain for the sufficiency of energy supply for each functional link [10, 11].

The cost analysis of the surveyed poultry workshop showed that with an annual electricity consumption of 127988 kWh for the operation of the ventilation system, only in 2023 the cost of the enterprise for its purchase amounted to 806324 rubles. Of interest in the aspect of innovation is the distribution of electricity consumption by ventilation systems by months of the calendar year (Fig. 6).

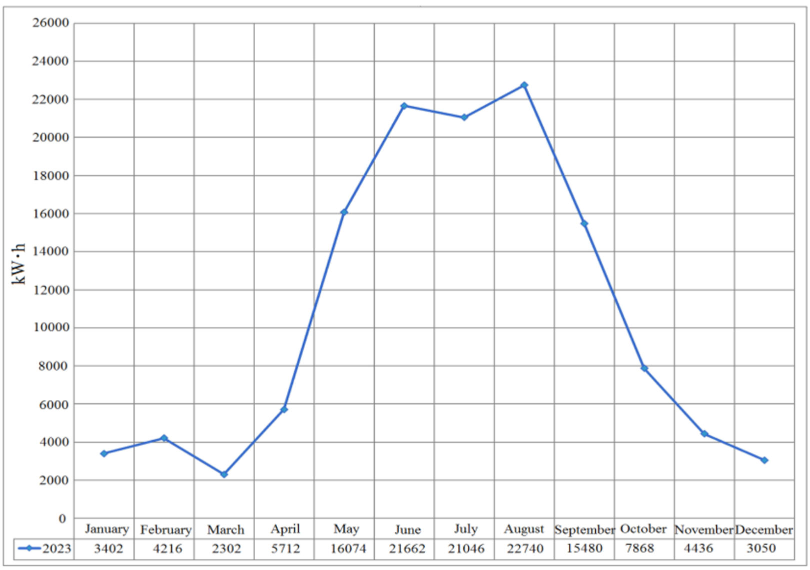


Fig. 6. The schedule of electricity consumption by month.

It can be noted that the minimum consumption was 2302 kWh in March, and the maximum was 22740 kWh in August, but more important is the fact of the concentration of energy activity - that is, the greatest electricity consumption and, adequate to it, material costs occur in the warm period of the year when tunnel ventilation is used. The question of how much electricity is really needed for the rational operation of the enterprise requires a reliable analysis. But for this, an optimal model of air exchange in the poultry shop is needed, which assumes both the energy supply of an active ventilation mode and the implementation of backup technological functions: in this design version, we are talking about the use of refrigeration equipment in order to ensure convective movement of air mass. Only in this case it is possible to create a natural ventilation system that allows you to save poultry during periods of emergency power outage, or, which is also important, temporarily switch to natural ventilation mode in a targeted manner to carry out the necessary operational and preventive measures for electronic climate control systems [12, 13].

 https://doi.org/10.1051/bioconf/202413007006

It is known that air exchange, as a physical and technical process, is a partial or complete replacement of air saturated with harmful emissions with clean and fresh air, most often atmospheric. And as mentioned above, it is required to calculate the flow rate of air supplied or removed during ventilation of premises separately for cold, transitional and warm periods of the year. Based on these conditions, an analysis was carried out, which showed that the necessary multiplicity of air exchange can be provided with less energy consumed. The excess part, when converted into power indicators, is sufficient for the introduction of a cold storage system into the technological cycle, which will set the convection movement of cold air in case of an emergency power outage (Fig. 7).

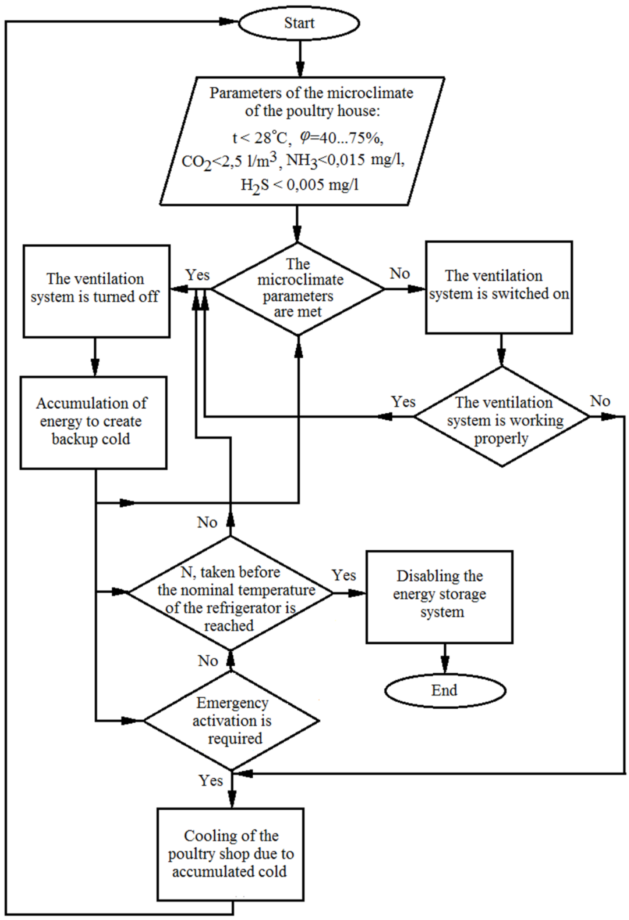


Fig. 7. Block diagram of a ventilation system with a backup air exchange function in case of an emergency power outage.

The effect of natural defrosting accumulated by ice refrigerating plants will allow preserving the number of chickens for the period of time required to carry out work on the resumption of electricity supply and prevent the death of poultry [14, 15].

An example of calculating a ventilation system that provides the necessary air exchange in the warm season (Fig. 8).

Calculation of the ventilation system of the poultry shop for 71540 heads of chickens. The dimensions in the plan are 96×18 m, the height of the outer walls is 4 m, the average height of the room is 5,205 m, the glazing coefficient is 0.25. A bird of average weight of 1.7 kg, contained in cell batteries with a planting density of 430.7 cm^2/head.

The average outdoor air parameters in the study area, according to data for 2023, amounted to t_{out} =29°C, φ_{out} =53% in the warmest period of the year. The parameters of the microclimate inside the poultry shop in the warm season were t_{in} < 33 °C, φ_{in}=40...75%.

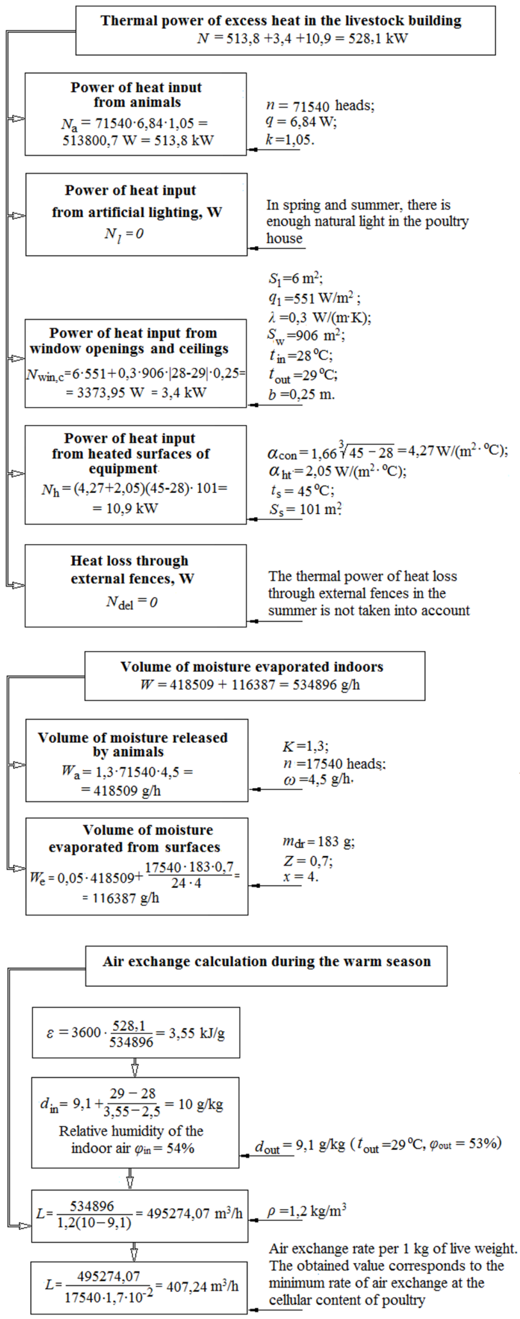


Fig. 8. Air exchange calculation during the warm season.

4 Conclusions

A thorough analysis and accurate calculation of the parameters of the backup ventilation system showed that:

1. The necessary multiplicity of air exchange, which allows ensuring the required parameters of the microclimate, can be provided with less energy consumed.
2. The excess part of the energy, when converted into power indicators, is sufficient for the introduction of a cold storage system into the technological cycle, which will set the convection movement of cold air in case of an emergency power outage.
3. It is possible to ensure a smooth operation of production, eliminate the risks associated with power outages and increase the profitability of production.

This result can be achieved only with the professional design of backup ventilation.

References

1. V.A. Rotova, E.M. Asmankin, Yu.A. Ushakov, et al., *On the issue of updating ventilation systems of the "natural" type and the historical aspect of the expediency of their implementation in agriculture. National* priorities for the development of the agro-industrial complex: Materials of the national scientific and practical conference with international participation, Orenburg, November 17 (2023). Orenburg: OOO "Printing house "Agency Press", 24-30 (2023)
2. V.N. Bogoslovsky, V.P. Shcheglov, Heating and ventilation. Textbook for the specialty "Water supply and sewerage" of universities (Stroyizdat, Moscow, 1970).
3. A.G. Tsubanov, Heat supply, heating and ventilation of livestock facilities (Harvest, Minsk, 1987)
4. A.A. Velichkov, A.P. Kozlovtsev, V.A. Shakhov, et al., *Microclimate and air quality control systems on pig farms.* Izvestia Orenburg State Agrarian University OSAU. **2(106)**, 148-154 (2024)
5. P. Ivanov, E. Asmankin, Yu. Ushakov, et al., *Spherical storage facilities as an energy-saving innovation in small business forms.* International Scientific Forestry Forum 2023: Forest Ecosystems as Global Resource of the Biosphere: Calls, Threats, Solutions (Forestry Forum 2023), Voronezh, Russian Federation, October 23–25.Vol. 93, 03008 (2023). Les Ulis, 2024
6. L.M. Obeidat, J.R. Jones, D.M. Mahaftha, et al., *Optimizing indoor air quality and energy efficiency in multifamily residences: Advanced passive pipe system parametrics study.* International Journal of Environmental Science and Technology (2024).
7. Zh. Zhao, *Analyzing the influence of architectural form on building sustainability - the case of Qingdao Liyuan.* New ideas of the new century: materials of the international scientific conference Institute of Architecture and Design Pacific National University. **Vol. 2,** 314-320 (2024)
8. T.N. Ilyina, M.S. Kolesnikov, I.V. Kryukov, et al., *On the methods of ensuring air exchange in the workshops of livestock complexes.* Bulletin of BSTU named after V.G. Shukhov. **3**, 46-55 (2023)
9. K.P. Zubarev, M.R. Timofeeva, *Calculation of infiltration in the organization of natural ventilation in a building.* Components of Scientific and Technological Progress. **2(80)**. 22-28 (2023)
10. Sh. Medani, *Factors of formation of a stable environment in a hot climate.* Components of Scientific and Technological Progress. **3(81)**, 32-36 (2023)

11. K. Zubarev, M. Timofeeva, *Special aspects of calculation of infiltration in residential and public buildings*. E3S Web of Conferences: Ural Environmental Science Forum "Sustainable Development of Industrial Region" (UESF-2023), Chelyabinsk, April 25–28. Vol. 389, 06001 (2023). Chelyabinsk: EDP Sciences, 2023
12. A.A. Prokopyev, R.R. Khasanshin, Engineering systems of buildings and structures. Heat and gas supply and ventilation (Kazan National Research Technological University, Kazan 2023)
13. F. Bre, Ju.M. Gimenez, A cloud-based platform to predict wind pressure coefficients on buildings. Building Simulation. **Vol. 15,** n. 8, 1507-1525 (2022)
14. E.V. Sazonov, Ventilation: theoretical foundations of calculation. 2nd ed. cor. and exp. (Youright Publishing House, Moscow, 2022)
15. A.V. Putko, Heat and gas supply and ventilation : a methodological guide to the study of the discipline (Far Eastern State Transport University, Khabarovsk, 2017)
16. E. Neifeld, E. Asmankin, Yu. Ushakov, E3S Web of Conferences **458**, 08020 (2023)
17. M. Chkalova, V. Pavlidis, Engineering for Rural Development **20**, 843-848 (2021)
18. E. V. Neifeld, E. M. Asmankin, Yu. A. Ushakov, P. A. Ivanov, I. Yu. Kargaev, M. B. Fomin, Siberian Herald of Agricultural Sciense **54(1),** 107-117 (2024)
19. V. Pavlidis, M. Chkalova, Ways to increase the efficiency of industrial production of combined feed **1206(1),** 012045 (2023)
20. P. Ivanov, E. Asmankin, Yu. Ushakov, BIO Web of Conferences **67**, 02022 (2023)