Ventilation processes in premises: productivity and optimization

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Abstract. An effective ventilation system is an important element in creating a comfortable and safe working environment, which directly impacts employee health and productivity. In this regard, the article examines the organizational and economic aspects of managing labor productivity through the optimization of ventilation processes in premises. Various types of ventilation systems are explored, along with their influence on labor productivity and organizational measures aimed at improving working conditions. Recommendations for managing and optimizing ventilation processes to enhance employee efficiency are proposed. The study substantiates the necessity of ventilating the air environment in industrial premises and presents a methodology for its implementation through the use of natural ventilation devices. Furthermore, it emphasizes that the proper choice of ventilation system can significantly reduce heating and air conditioning costs, which is particularly relevant in today's economic realities. The importance of regular monitoring of ventilation system conditions is highlighted to ensure timely identification and resolution of potential issues, thereby maintaining optimal working conditions throughout the entire working period. It is argued that the implementation of modern technologies in ventilation systems can provide a competitive advantage for companies by attracting and retaining qualified specialists.

1 Introduction

Modern working conditions require employers to create a safe and productive working environment. Ventilation plays a key role in this process, as it ensures the required level of air quality, which in turn affects employee health and productivity. Contaminated air can lead to decreased performance, increased illnesses and poorer overall health of employees. Therefore, optimization of ventilation processes becomes the most important task of labor productivity management [1-10].

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2 Materials and methods

According to the Harvard School of Public Health, improving workplace ventilation reduces the risk of respiratory disease by 30%. Meanwhile, a 10% increase in ventilation levels leads to an 8% increase in productivity and a 20% decrease in errors, and a 10% decrease in air pollution levels leads to a 20% decrease in the incidence of chronic lung disease, supporting the need for air quality control. This analysis, as well as several other studies, emphasize the importance of quality ventilation for workers' health, as it directly affects their productivity [3,4,8,9,10].

In addition, according to a study conducted by the European Journal of Public Health, poor air quality is associated with an increase in asthma and other respiratory disease exacerbations. An increase in PM2.5 concentration is associated with a 30% increase in asthma symptoms [9]. In turn, the study Environmental and Health Impacts of Air Pollution: A Review [7], found that improving ventilation in homes reduces the risk of respiratory tract infections by 25%. This emphasizes the need to invest in ventilation systems to ensure a healthy environment. According to a study in the Journal of Thoracic Disease, people living in homes with poor ventilation and high humidity have a 41% higher risk of developing respiratory disease. This emphasizes the importance of quality housing construction and ventilation systems [1].

The above data, in our opinion, indicate the need to invest in quality ventilation systems, as they not only contribute to the improvement of employee health, but also lead to economic benefits for organizations. Investment in ventilation can be considered as a strategic decision to improve the overall performance of a company. Improved indoor air quality contributes to reduced fatigue and increased concentration of workers, which directly affects their productivity. In addition, a reduction in errors and illnesses results in lower health care costs and higher employee morale. Thus, creating a comfortable working environment through quality ventilation systems is not only a matter of employee health, but also an important economic factor [2]. In a highly competitive market, organizations must strive to optimize their costs and increase productivity, which makes investments in ventilation worthwhile.

Ventilation systems can be classified into natural, mechanical and combined ventilation systems [2,5,6]. Each of these systems has its own advantages and disadvantages.

1. Natural ventilation utilizes natural air flows such as wind and convection to provide indoor air exchange, thus reducing energy costs. However, the effectiveness of this method depends on external climatic conditions such as temperature, humidity and wind speed, which may limit its use in certain regions. In environments with high air pollution, such as industrial areas, natural ventilation may not provide the necessary level of air purification, which can negatively affect the health of workers. In such cases, it is therefore advisable to consider combined or mechanical ventilation systems, which can more effectively control air quality and provide comfortable working conditions.

2. Mechanical ventilation uses fan and filter systems to actively manage air quality to effectively remove pollutants and maintain optimum temperature and humidity levels. In manufacturing environments where heat and harmful gases are released, such a system becomes vital to ensure worker safety and health. Filters can be configured to remove specific pollutants such as dust, smoke or chemical vapors, contributing to a cleaner and safer work environment. In addition, mechanical ventilation allows for precise control of the volume of air supplied and exhausted, helping to reduce energy costs and improve the overall energy efficiency of the building.

3. Combined ventilation combines elements of natural and mechanical ventilation, allowing the system to be adapted to different operating conditions. This approach provides greater flexibility in air quality management, allowing the benefits of both methods to be

effectively utilized. For example, in low pollution environments, natural ventilation can be relied upon, whereas in high pollution situations, the mechanical system can be activated to clean the air. In addition, combined systems can be equipped with automated controllers that adjust airflow based on current conditions, significantly improving overall energy efficiency and reducing operating costs.

The design of effective ventilation systems should take into account the specifics of each workplace. It is important to analyze the needs of employees and working conditions to select the optimal type of system. Sanitary and other regulatory requirements should be taken into account during the design phase. It is also important to train employees on the proper use of ventilation systems and inform them about the importance of clean air, as this helps to increase their involvement in maintaining a comfortable working environment and helps to create a culture of responsibility for the health of colleagues. Continuous monitoring of air quality is also important. Regular air quality monitoring allows problems to be quickly identified and corrective action to be taken. Installing sensors to monitor air pollution levels, temperature and humidity will help maintain optimal working conditions. Establishing a feedback system where employees can report air quality problems helps to improve working conditions. This allows for prompt responses to problems and improves the working environment.

The cost-effectiveness of optimizing ventilation processes is extremely important, as it can significantly reduce operating costs for heating and air conditioning. The introduction of modern technologies, such as heat recovery systems, can reduce energy costs by up to 30-75%, making production more economical. In addition, quality ventilation contributes to improved worker health, resulting in a 25% reduction in sick days and a significant increase in labor productivity. Thus, investments in optimizing ventilation systems not only ensure comfortable working conditions, but also have a positive impact on the company's financial results.

So, investing in optimizing ventilation processes can lead to significant economic benefits for organizations. Improved air quality contributes to lower levels of illness among employees, leading to lower medical costs and improved overall productivity. In order to assess the cost-effectiveness of implementing new ventilation systems, it is necessary to consider indicators such as reduced employee illness, increased productivity and reduced costs of disease management. This will help to justify the need to invest in modernization of ventilation systems.

It should be noted that the direct impact on labor safety has a direct impact on the state of the air environment of workplaces, which contains harmful substances, dust, various gases. The level of danger to the human body from these substances is different. It depends on their quantitative content per 1 m^3 of air and toxicity of the substances themselves. In industrial premises, the air is polluted with dust, vapors, products of vital activity and technological processes. Here such harmful substances as ammonia, hydrogen sulfide and other harmful gases are spread. The content of these substances in the air affects the respiratory organs, digestion, skin, mucous membranes and can cause diseases of varying severity, which with further exposure to these substances on the body can turn into chronic inflammatory processes. Due to the presence of such a large number of factors that have a negative impact on the state of the air environment of workplaces, we have studied in detail the principle of ventilation of the room by natural method, as the most common, affordable and effective in modern economic conditions.

In natural ventilation we can use pipes of different cross-sections, with the help of which we remove polluted air from the room. Let us place them in such a way that the lower part of the pipe is inside the room, while the upper part goes outside and protrudes above the roof ridge. Clean air can enter the room by means of slits in the window and door openings, and in addition, air inlets in the lower part of the walls can be included in the design (Figure 1) for more intensive air exchange.

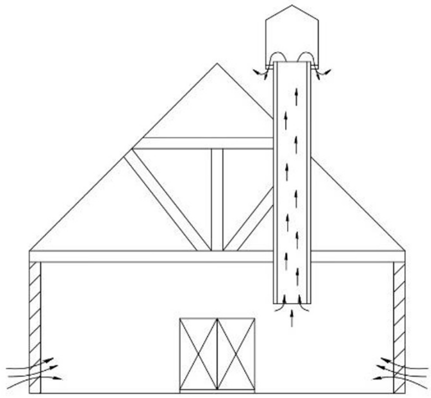

Fig. 1. Schematic diagram of natural ventilation of premises.

In order to ventilate the air environment with the help of an exhaust pipe, it is necessary to have a pressure difference at its ends, which arises due to the difference in the density of the air outside and inside the room. The pressure difference is found by the following formula (1):

$$\Delta H = h(\gamma_{out} - \gamma_{in}), \quad (1)$$

where ΔH – pressure difference, kG/m^2; h – height of the ventilation pipe, which is open at both ends, m; γ_{out} – weight of 1 m_3 of air at outdoor temperature; γ_{in} - weight of 1 m^3 of air at indoor temperature.

The density of outdoor and indoor air at a known temperature can be established as follows:

$$\gamma_{out} = \frac{1{,}293}{1+\alpha\, t_{out}}\ kg/m^3;$$

$$\gamma_{in} = \frac{1{,}293}{1+\alpha\, t_{in}}\ kg/m^3,$$

where α is the coefficient of volumetric expansion of gases $= \frac{1}{273}$; number 1,293 – air density at $t = 0°$.

To find the air velocity in the exhaust pipes we use the formula (2):

$$v = \sqrt{\frac{2g\Delta H}{\gamma_{out}}}\ \text{,m/sec}, \quad (2)$$

where g is the acceleration of free fall m/sec^2.

Taking into account the shape of the pipes and the material of which they are made, the velocity of air moving through them will change due to the resistance provided. This velocity is called the actual velocity and is found by the formula (3):

$$v = 0{,}5 \cdot 4{,}427\sqrt{\frac{\Delta H}{\gamma_{out}}}\ m/sec. \quad (3)$$

The total cross-section of exhaust pipes can be found from the air velocity and ventilation capacity (4):

$$\Sigma F = \frac{L}{3600\,v}\ m^2. \quad (4)$$

Consider the example: in the industrial room for keeping pigs, located in the Krasnodar region, there are 45 fattening sows with a live weight of 100 kg, 25 - 200 kg and 30 - 300 kg. To remove carbonic acid produced by fattening pigs, natural ventilation is used to remove it. Using the method described above, we will calculate the number of exhaust pipes required for ventilation. In order to find the total amount of carbon dioxide that is emitted by all animals during one hour, we use the data from the graph (Figure 2).

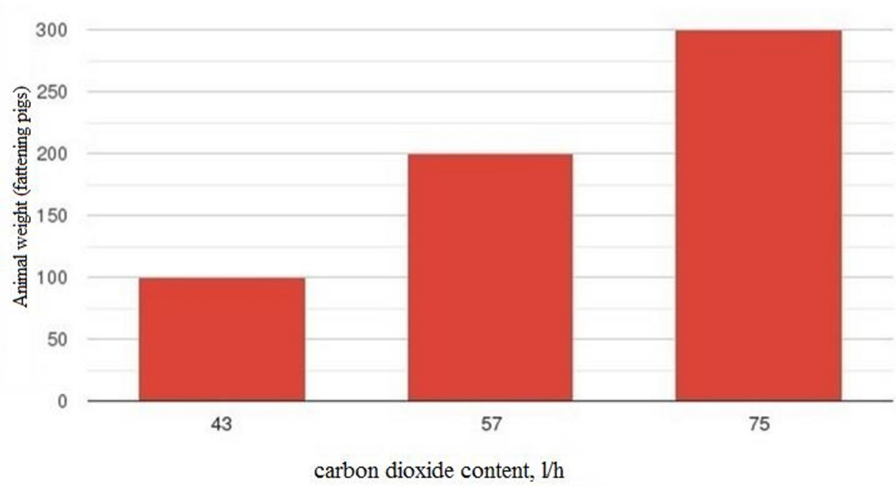

Fig. 2. Dependence of the amount of carbon dioxide emitted of animal weight.

$$P = 45 \cdot 43 + 25 \cdot 57 + 30 \cdot 75 = 5610\ l/h.$$

The ventilation capacity should be:

$$L = \frac{P}{P_1 - P_0} = \frac{5610}{2{,}5 - 0{,}3} = 2550\ m^3/h.$$

The length of the pipes that we can use for the pig house construction is $l = 4.2\ m$. Temperature inside the pig barn is +10°C. The outside air temperature is determined by the graph shown in Figure 3. For Krasnodar region in winter months, when the pig barn is closed, it is equal to +0.2°C (January).

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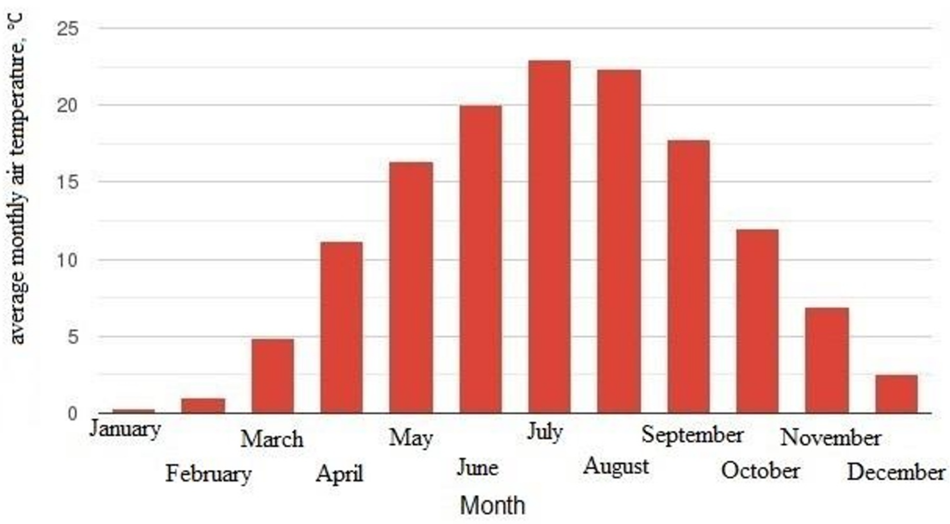

Fig. 3. Dependence of average monthly air temperature in Krasnodar Krai by month.

We calculate the pressure difference in the duct by formula (1), using the data from the graph shown in Figure 4.

$$\Delta H = 4.2(1.292 - 1.247) = 0.2 \ kg/m^2.$$

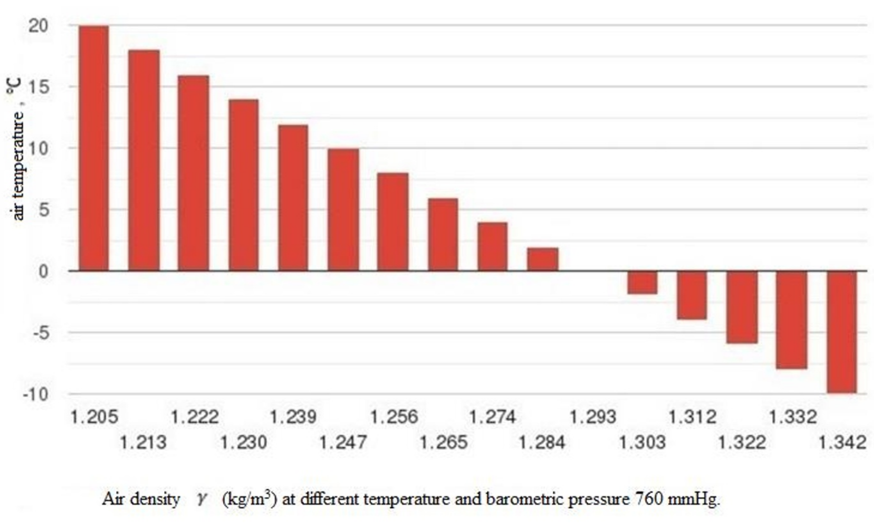

Fig. 4. Dependence of air density on air temperature at barometric pressure of 760 mm Hg.

Calculation of the actual air velocity is carried out by formula (3):

$$v = 0.5 \cdot 4.427\sqrt{\frac{0.2}{1.292}} = 0.871 \ m/sec$$

In order to find the total cross-section of all pipes, we use the formula (4):

$$\Sigma F = \frac{2550}{3600 \cdot 0.871} = 0.813\ m^2.$$

Based on the calculated data, we conclude that for normal ventilation of this room, it is necessary to install ten ventilation pipes with a cross-section: $0.3 \times 0.3 = 0.09$ m^2. The total cross-section is 0.90 m^2. Deflectors are installed on top of the ventilation pipes. By blowing them with the wind flow, the air extraction from the room is enhanced. In order to exclude obstacles that slow down the air flow, the deflectors are installed above the roof ridge. It should be taken into account that there are different types of deflectors, which differ in their design.

3 Conclusions

Thus, evaluating in general the necessity of ventilation of the air environment of industrial premises on the basis of the presented methodology, as well as the possibilities and prospects of increasing the effectiveness of the use of labor resources in modern companies by optimizing the ventilation processes, we can draw the following conclusion. The use of natural ventilation devices makes it possible to significantly reduce the level of air pollution, which directly contributes to the reduction of worker morbidity. This, in turn, leads to an increase in labor productivity, as employees are less tired and better concentrate on their objectives. In addition, optimizing ventilation processes can reduce heating and air conditioning costs, making it possible to reallocate funds to other important aspects of management. Regular monitoring of ventilation system health ensures that problems are identified in a timely manner. This helps to reduce equipment downtime. As a result, effective management of ventilation systems becomes one of the key factors in improving the quality of labor utilization and overall production effectiveness.

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